Vol. 60 • No. 11

November 2017

Microwave Journal.com

Coexistence

horizon house®

Founded in 1958

BETTER COMMUNICATION SOLUTIONS

MECA Products & Equipment

MECA Electronics designs and manufactures an extensive line of RF/Microwave Equipment and components with industry leading performance including Public Safety, D.A.S. Equipment, Low PIM Products, supports 5G & Millimeter-Wave, Power Dividers & Combiners, Directional & Hybrid Couplers, Fixed & Variable Attenuators, RF Terminations, Circulators/Isolators, DC Blocks & Bias Tees, Adapters & Jumpers. Models available in industry common connector styles: N, SMA, 2.92mm, TNC, BNC, 7/16, 4.1/9.5 & 4.3/10.0 DIN as well as QMA, Reverse Polarity SMA, TNC and various mounting solutions.

Since 1961 MECA Electronics (Microwave Equipment & Components of America) has served the RF/Microwave industry with equipment and passive components covering Hz to 50 GHz. MECA is a privately held ISO9001:2008 Certified, global designer and manufacturer for the communications industry with products manufactured in the United States of America. We stock products so that you do not need to.

5G

Products in STOCK when you need them!

Buy RF Online

RFPartsOnDemand.com

Public Safety
Homeland Security

Satcom, mmWave
& Military

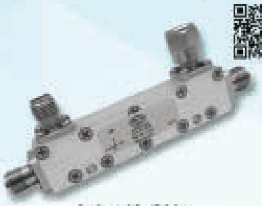
Aeronautical/Space
Transportation

AMER, EMEA
D.A.S

Attenuators/Terminations

Up to 40 GHz
SMA, 2.4, 2.92, QMA, N, TNC, BNC, RPSMA, RPTNC, 4.1/9.5, 4.3/10.0 & 7/16 Up to 150 watts

Directional Couplers



0.4 - 40 GHz
SMA & 2.92
MIL-DTL-15370 Available

Circulators/Isolators

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

Bias Tee´s & DC Blocks

Up to 6 & 18 GHz
SMA, 2.4, 2.92, QMA, N, TNC, RP-TNC & 7/16 DIN

Equipment & Enclosures

Integrated Assemblies, NEMA Enclosures IP67/68 & EN 50155

Power Divider/Combiners

5 MHz - 40 GHz
SMA, 2.4, 2.92, QMA, N, TNC, BNC, RPTNC 4.1/9.5 & 7/16
MIL-DTL-23971 Available

Low PIM Attenuators

50 & 100 Watt
6, 10, 20, & 30 dB
N, 4.1/9.5 / 4.3/10.0 & 7/16 DIN
IP67/68

Low PIM Terminations

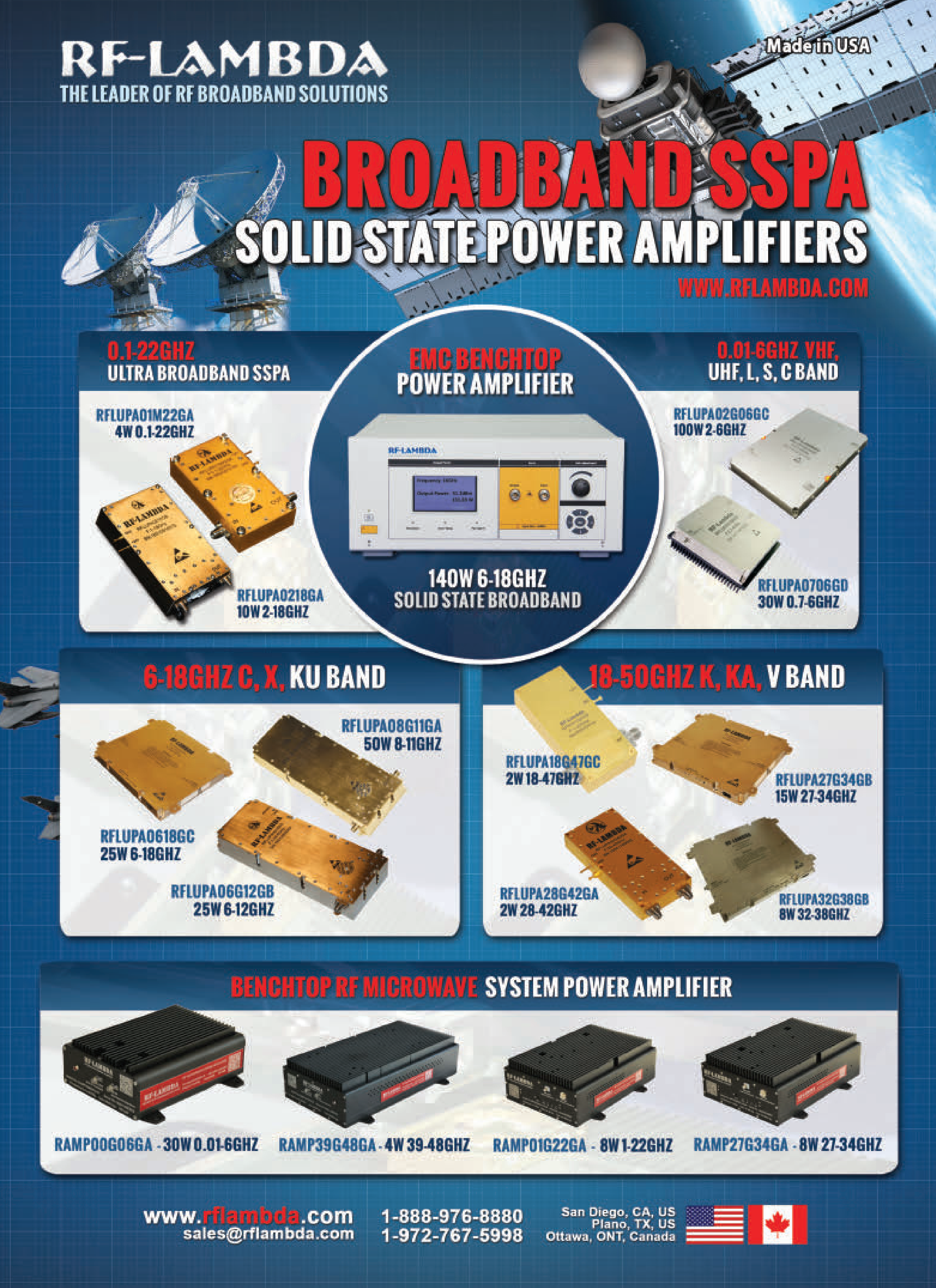
380 MHz - 2.7 GHz
10 watts - 250 watts N, 4.1/9.5, 4.3/10.0 & 7/16 DIN, IP67/68

MECA Electronics, Inc.
Microwave Equipment & Components of America
The Professional's Choice for RF/Microwave Passive Components
459 E. Main St., Denville, NJ 07834
Tel: 973-625-0661 Fax: 973-625-9277
Sales@e-MECA.com

e-MECA.com
Since 1961

iBwave


MCL B 744
ADP-2-10
MCL B 744
ADP-2-10
MCL B 744
ADP-2-10
MCL
GBA-12


RF-LAMBDA
THE LEADER OF RF BROADBAND SOLUTIONS
Made in USA
BROADBAND SSPA
SOLID STATE POWER AMPLIFIERS
WWW.RFLAMBDA.COM
0.1-22GHZ
ULTRA BROADBAND SSPA
RFLUPA01M22GA
4W 0.1-22GHZ
RFLUPA0218GA
10W 2-18GHZ
EMC BENCHTOP
POWER AMPLIFIER
140W 6-18GHZ
SOLID STATE BROADBAND
0.01-6GHZ VHF,
UHF, L, S, C BAND
RFLUPA02G06GC
100W 2-6GHZ
RFLUPA0706GD
30W 0.7-6GHZ
6-18GHZ C, X, KU BAND
RFLUPA08G11GA
50W 8-11GHZ
RFLUPA0618GC
25W 6-18GHZ
RFLUPA06G12GB
25W 6-12GHZ
18-50GHZ K, KA, V BAND
RFLUPA18G47GC
2W 18-47GHZ
RFLUPA27G34GB
15W 27-34GHZ
RFLUPA28G42GA
2W 28-42GHZ
RFLUPA32G38GB
8W 32-38GHZ
BENCHTOP RF MICROWAVE SYSTEM POWER AMPLIFIER
RAMP00G06GA - 30W 0.01-6GHZ
RAMP39G48GA - 4W 39-48GHZ
RAMP01G22GA - 8W 1-22GHZ
RAMP27G34GA - 8W 27-34GHZ
www.rflambda.com
sales@rflambda.com
1-888-976-8880
1-972-767-5998
San Diego, CA, US
Plano, TX, US
Ottawa, ONT, Canada


mpG
K&L MICROWAVE
A DOVER COMPANY
SUPPORTING OUR WARFIGHTERS SINCE 1971
Phase Matched Filters
High-Power Lowpass Filters
PIN Diode Switches
Multiplexers
• Filters DC to 94 GHz
• Bandpass
• Bandreject
• Lowpass
• Highpass
• Switched Filter Banks
• Tunable Filters
• Filter/LNA Assemblies
• Rugged Designs for Harsh Military Environments
• In-House MIL-SPEC Environmental Testing
• Multiplexers
• Non-Contiguous
• Contiguous
• Overlapping Bands
Microwave Products Group
K&L MICROWAVE
BSC
POLE ZERO
Dow-Key Microwave
ENABLING COMMUNICATION AND SIGNAL CONTROL
www.klmicrowave.com • www.klfilterwizard.com • 410-749-2424 • sales@klmicrowave.com •

api technologies corp.

Inmet & Weinschel

RF & Microwave Coaxial Component Solutions

DEFENSE • COMMERCIAL • INDUSTRIAL • SPACE

Attenuators and Terminations

DC to 50 GHz, power handling up to 1000W
Available with various connector options and Low PIM.

Bias Tees, DC Blocks and Power Dividers

Up to 50 GHz
Including broadband and high current bias tees, high voltage and broadband dc blocks and resistive or Wilkinson power dividers.

Gain Equalizers and Phase Shifters

DC to 40 GHz
Fixed and adjustable gain equalizers and manually adjustable phase shifters.

Adapters, Connectors and Accessories

DC to 65 GHz
Adapters with various connector configurations, Planar Crown® and Planar Blindmate® connector systems, dust caps, opens, shorts, open/short/loads and impedance matching pads.

API Technologies designs and manufactures high performance systems, subsystems, modules, and components for technically demanding RF, microwave, millimeter wave, electromagnetic, power, and security applications. API products are used by global defense, industrial, and commercial customers in the areas of commercial aerospace, wireless communications, medical, oil and gas, electronic warfare, C4ISR, missile defense, harsh environments, satellites, and space.

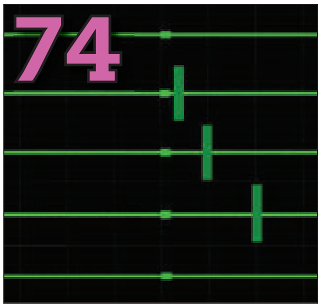
API Technologies is proud to offer Inmet and Weinschel brand components.

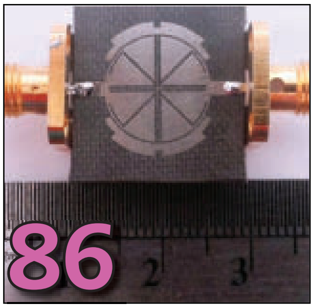
www.inmet.apitech.com | www.weinschel.apitech.com

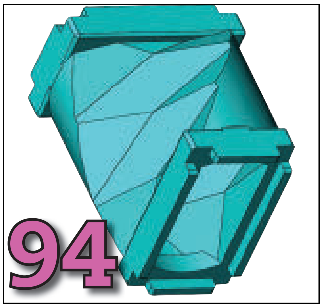
Microwave Journal

November 2017
Vol. 60 • No. 11
Government and
Military Electronics
mwjournal.com

CONTENTS







Cover Feature

Perspective

Technical Features

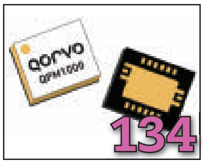
Special Reports

60 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@omeda.com. Subscription information: (847) 291-5216. 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

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) 291-5216
e-mail: mwj@omeda.com

BPA WORLDWIDE

www.mwjournal.com

Printed in the USA

INTRODUCING THE WORLD'S FIRST ULTRAPORTABLE FAMILY OF mmWAVE SPECTRUM ANALYZERS TO 110GHz.

Now taking it to the extreme just got easier. The footprint for up to 110 GHz measurements is now a whole lot smaller, and so is the price tag. Anritsu introduces a new family of 9 kHz to 110 GHz direct-connect solutions which offer superior dynamic range in the mmWave bands and in a form factor that fits in your pocket! Nothing on the market comes close.

ANRITSU MS2760A SPECTRUM MASTER

mmWAVE
Test and measurement for Automotive Radar, Satellite, 5G, WiGig and more

ULTRAPORTABLE
Benchtop power from a smartphone-sized instrument that fits in your pocket

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

Anritsu

1-800-ANRITSU
WWW.ANRITSU.COM/TEST-MEASUREMENT

Microwave Journal Online

Visit us @ mwjournal.com

E LEARNING CENTER

Interference-Free Designer of Electronic Devices
Sponsored by: ANSYS, Inc. 11/7

The Impact of Final Plated Finishes on Insertion Loss for High Frequency PCB's
Sponsored by: Rogers and Sonnet Software 11/9

Advanced Spectrum Measurements for Modern Radios
Sponsored by: National Instruments 11/14

EM and Harmonic Balance Simulation of a 200 W L-Band Push-Pull GaN Power Amplifier
Sponsored by: National Instruments/AWR 11/15

5G: Ready or Not, Here it Comes
Sponsored by: National Instruments 11/28

Improved Antenna Pattern Accuracy of a Benchtop Real-Time Measurement Solution with Upcoming Extensions to X-Band, Ku-Band and mmWave
Sponsored by: EMSCAN 11/29

Web Survey

What technology do you want to learn about?

Look for our multiple choice survey online at mwjournal.com

September Survey
Which of these concept cars was the first to feature radar?

BMW Lovos (11%)

Cadillac Cyclone XP-74 (68%)

Flintstone Flash (11%)

Lightning McQueen (0%)

Volkswagen ID Buzz (11%)

Executive Interview

Bill Callahan, General Manager of **Times Microwave**, discusses the focus of this longstanding cable and connector company and the market opportunities he sees.

WHITE PAPERS

ims — 5ZG: Where High Power and High Frequency Join Forces

NATIONAL INSTRUMENTS — Decoding 5G New Radio: The Latest on 3GPP and ITU Standards

KEYSIGHT TECHNOLOGIES

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

COM

DECEMBER MARK YOUR CALENDAR

11/28-12/1

ARFTG

Boulder, CO

90th ARFTG Microwave Measurement Symposium

www.arftg.org

4-6

IEDM 63rd International Electron Devices Meeting

San Francisco, Calif.

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

www.ieee-iedm.org

5

WEBINAR

Signal Integrity Journal

The 3 Necessary Evils: Discover and Solve PI, SI and EMI Issues Affecting Designs

Sponsored by:

ROHDE&SCHWARZ

6

WEBINAR

Sponsored by:

NATIONAL INSTRUMENTS

6-7

esc EMBEDDED SYSTEMS CONFERENCE '17

San Jose, Calif.

ESC's program provides 23+ hours of expert-led, hands-on technical education. Learn the latest strategies and techniques for turning concepts into competitive products straight from industry experts during a range of engaging formats. ESC Silicon Valley provides access to a comprehensive showcase of industry suppliers and technical education.

www.escsiliconvalley.com/conference

7

WEBINAR

Sponsored by:

KEYSIGHT TECHNOLOGIES

10

Call for Papers

ICMIM

The 4th annual IEEE International Conference on Microwaves for Intelligent Mobility (ICMIM) will be held in Munich, Germany. The conference covers all key enabling technologies for intelligent mobility, including components, circuits and systems, from decimeter to mmWaves. Potential applications may address automated land, sea and airborne vehicles, automotive radar and other sensing techniques, navigation and localization, mobile communications, driver assistance and OTA testing.

https://icmim-ieee.org/

11-13

IMaRC

Ahmedabad, India

IMaRC has become the premier RF and microwave engineering conference in India. IMaRC 2017 will create a platform which will be shared by researchers, academia, space scientists, professional organizations, government organizations, RF and microwave industry from various parts of the globe.

www.imarc-ieee.org

FOR DETAILS, VISIT MWJOURNAL.COM/EVENTS

Coming**Events**

CALL FOR PAPERS

NIWeek 2018
November 17, 2017

EDI CON China 2018
November 30, 2017

ICMIM 2018
December 10, 2017

RFIC 2018
January 12, 2018

IEEE EMC + SIPI 2018
January 12, 2018

2018 Symposia on VLSI Technology and Circuits
January 29, 2018

mwjournal.com

NOVEMBER

IEEE COMCAS 2017
November 13–15, 2017 • Tel Aviv, Israel
www.comcas.org

IEEE APMC 2017
November 13–16, 2017 • Kuala Lumpur, Malaysia
www.apmc2017.org

90th ARFTG Conference
November 28–Dec. 1, 2017 • Boulder, Colo.
www.arftg.org/index.php

DECEMBER

IEDM 2017
December 4–6, 2017 • San Francisco, Calif.
www.ieee-iedm.org

ESC Silicon Valley
December 6–7, 2017 • San Jose, Calif.
www.escsiliconvalley.com/conference

IEEE IMaRC
December 11–13, 2017 • Ahmedabad, India
www.imarc-ieee.org

JANUARY 2018

CES 2018
January 9–12, 2018 • Las Vegas, Nev.
www.ces.tech

Radio and Wireless Week
January 14–17, 2018 • Anaheim, Calif.
www.radiowirelessweek.org

DesignCon
January 30–Feb. 1, 2018 • Santa Clara, Calif.
www.designcon.com

FEBRUARY 2018

EMV 2018
February 20–22, 2018 • Duesseldorf, Germany
www.mesago.de/en/EMV/For_visitors/Welcome/index.htm

Military Radar Summit
February 26–28, 2018 • Washington, D.C.
www.militaryradarsummit.com

Mobile World Congress 2018
February 26–March 1, 2018 • Barcelona, Spain
www.mobileworldcongress.com

MARCH 2018

IWCE 2018
March 5–9, 2018 • Orlando, Fla.
www.iwceexpo.com/iwce18/Public/Enter.aspx

GOMACTech-18
March 12–15, 2018 • Miami, Fla.
www.gomactech.net

SATELLITE 2018
March 12–15, 2018 • Washington, D.C.
http://2018.satshow.com/

EDI CON China 2018
March 20–22, 2018 • Beijing, China
www.ediconchina.com

Microwave & RF 2018
March 21–22, 2018 • Paris, France
www.microwave-rf.com

APRIL 2018

WAMICON 2018
April 9–10, 2018 • Sand Key, Fla.
www.wamicon.org

ICMIM 2018
April 16–18, 2018 • Munich, Germany
https://icmim-ieee.org/

ExpoElectronica 2018
April 17–19, 2018 • Moscow, Russia
www.expoelectronica.ru

AUVSI Xponential 2018
April 30–May 3, 2018 • Denver, Colo.
www.xponential.org/

From IC to Array - Anokiwave Enables your 5G System

Our Growing IC Family now Covers all Major 5G Bands

AWMF-0135 Quad Core IC for 24-27 GHz
AWMF-0108 Quad Core IC for 27-29.5 GHz
AWMF-0123/5 Quad Core ICs for 37-40 GHz

IC family supports low cost hybrid beam forming
for multi-antenna arrays with high energy efficiency
and low latency beam steering™

Active Antenna Solutions for Low Latency Beam Steering™

Coexistence of LTE and Radar Systems

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

Due to the proliferation of wireless communications systems using LTE, LTE-A and soon to be 5G, the number of assigned frequency bands between 400 MHz and 6 GHz has dramatically increased. In 2011, the 3GPP standards association had defined 11 bands; now there are over 55 assignments for worldwide deployment. Of particular concern is the use of wireless services and the coexistence of UHF, L-, S- and C-Band radars and geolocation services (see ***Tables 1*** and ***2***). While the topic of coexistence in not new, this article focuses on unresolved issues and the potential impact to sensitive radar receivers, demonstrating a proposed methodology for the assessment of cooperative radar receivers.

DEFINING COEXISTENCE

Numerous studies and ITU-R recommendations have focused on the impact of the radar transmission on the receiver in wireless communications systems. These studies have resulted in measurement procedures and recommended practices for the prediction of mitigation distances between the systems. This has been enabled by an accepted methodology to measure the power of the radar (ITU-R M1177-4)[1] and the 3GPP Technical and Test Specifications[2,3] to test the minimum acceptable performance of the wireless base station and user equipment. The receivers in radar and wireless communications have approximately the same sensitivity, -115 dBm. By means of the 3GPP standards, base station receivers are designed to physically coexist on the same antenna tower, a few feet apart with minimal frequency separation. Since the power of the radar can be orders of magnitude higher than the typical 40 W base station carrier signal, it would seem to make sense to just focus on the impact of the radar transmission on the “victim” wireless base station receiver.

However, the performance of radar receivers is not subject to international or commercially assessed requirements, and the lack of standard performance profiles limits the availability of data demonstrating the impact on the radar receiver from the transmission of a wireless communications system. While not the focus of this article, it should be noted that the recent Radio Equipment Directive in the European Union, RED Article 3.2, now requires the radio receivers of global navigation satellite systems (GNSS) to be tested for interference from terrestrial broadcast systems. Per EN 303 413, minimum performance requirements for GNSS receivers will enable the licensing of wireless communications systems in bands adjacent to services like GPS.

COAXIAL AND WAVEGUIDE SWITCHES

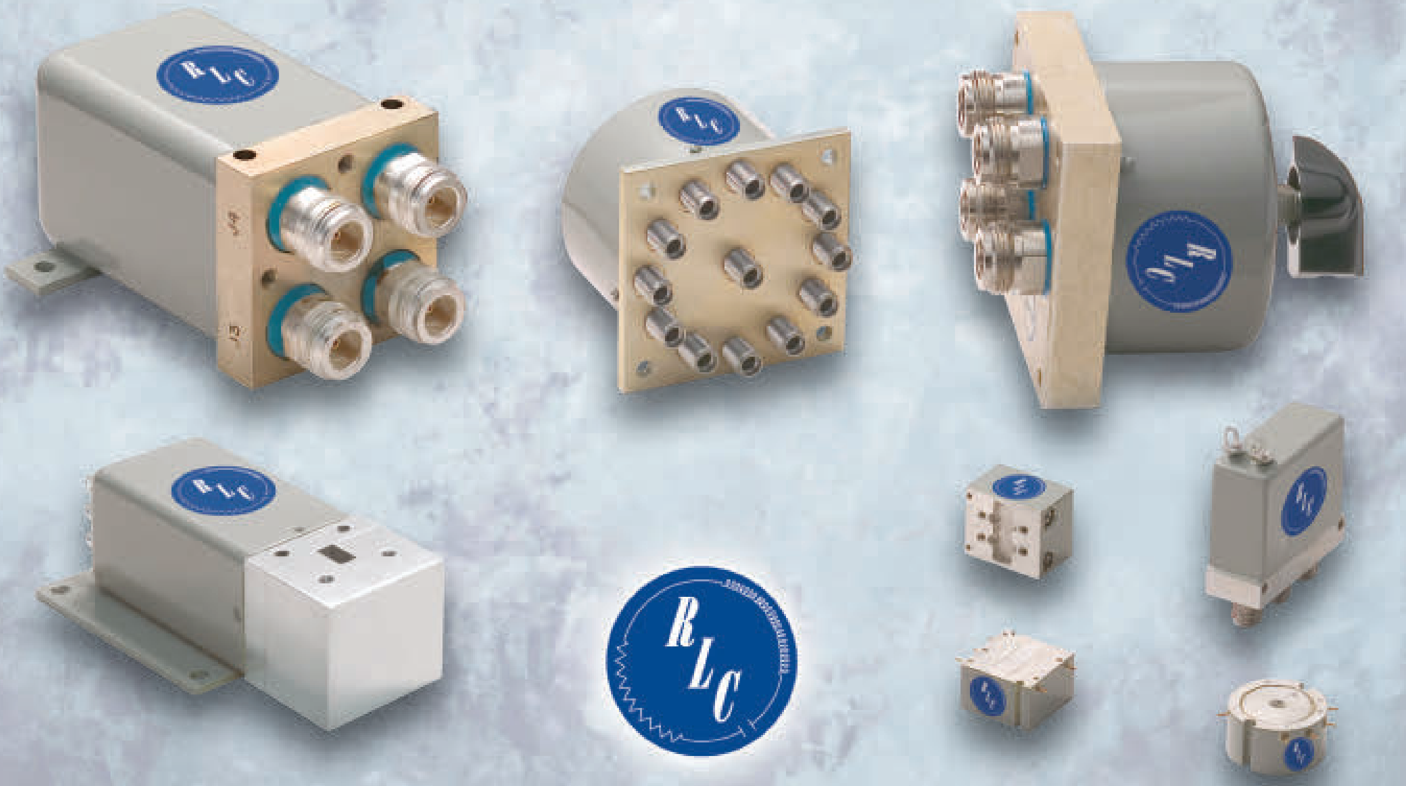
RLC has the exact solution you're looking for.

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

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

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

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



RLC ELECTRONICS, INC.

83 Radio Circle, Mount Kisco, New York 10549 • Tel: 914.241.1334 • Fax: 914.241.1753
E-mail: sales@rlcelectronics.com • www.rlcelectronics.com

ISO 9001:2000 CERTIFIED

VISA MasterCard

RLC is your complete microwave component source...
Switches, Filters, Power Dividers, Terminations, Attenuators, DC Blocks, Bias Tees & Detectors.

TABLE 1

LTE BANDS CLOSE TO RADAR AND GEOLOCATION SERVICES

Band	Name	Downlink (MHz)			Bandwidth	Uplink (MHz)			Duplex Spacing
		Low	Middle	High	DL/UL (MHz)	Low	Middle	High	(MHz)
FDD									
7	2600	2620	**2655**	2690	70	2500	**2535**	2570	120
21	1500 Upper	1495.9	**1503.4**	1510.9	15	1447.9	**1455.4**	1462.9	48
22	3500	3510	**3550**	3590	80	3410	**3450**	3490	100
24	1600 L-Band	1525	**1542**	1559	34	1626.5	**1643.5**	1660.5	–101.5
32	1500 L-Band	1452	**1474**	1496	44	Downlink Only			
69	2500	2570	**2595**	2620	50	Downlink Only			
252	Unlicensed NII-1	5150	**5200**	5250	100	Downlink Only			
255	Unlicensed NII-3	5725	**5787.5**	5850	125	Downlink Only			
TDD									
38	TD 2600	2570	**2595**	2620	50				
41	TD 2500	2496	**2593**	2690	194				
42	TD 3500	3400	**3500**	3600	200				
43	TD 3700	3600	**3700**	3800	200				
46	TD Unlicensed	5150	**5537.5**	5925	775				
47	TD V2X	5855	**5890**	5925	70				
48	TD 3600	3550	**3625**	3700	150				

This should serve as a proof point that the lack of standards on radar receivers will not prevent sovereign nationals from licensing spectrum in bands adjacent to radar infrastructure.

The few standards on commercial radar receiver performance have tended to focus on the issues of coexistence and interoperability with similar systems. Clearly, there are important examples, such as automotive radar and even maritime radar interoperability, to prevent undesired performance from two radars working in close proximity. The IEC 62388 international standard "Maritime navigation and radiocommunication equipment and systems" defines such test methods and performance requirements for commercial S-Band and X-Band systems. Referring to ***Figure 1***, when one considers the coexistence of the wireless systems in the frequency bands shown in Table 1 (Bands 7 and 69) with the target radar systems from Table 2 (S-Band air traffic control (ATC) radar), test cases have not been defined nor are there performance standards required for the radar systems. Further, the radar systems have pre-dated the existence of the wireless communications standards by many decades.

TABLE 2

POPULAR RADAR AND GEOLOCATION FREQUENCY BANDS

	Frequency Range (GHz)	Example
L-Band	1 to 2 (NATO)	Global Positioning System Carriers Centered at 1176.45 MHz (L5), 1227.60 MHz (L2), 1381.05 MHz (L3), 1575.42 MHz (L1)
S-Band	2 to 4	ATC, Maritime, Weather Radar: 2.7 to 3.1 GHz ASR: 3.1 to 3.5 GHz
C-Band	4 to 8	Magnetron/Klystron Radar: 5.25 to 5.35 GHz Single Object Tracking Radar (SOTR): 5.45 to 5.825 GHz

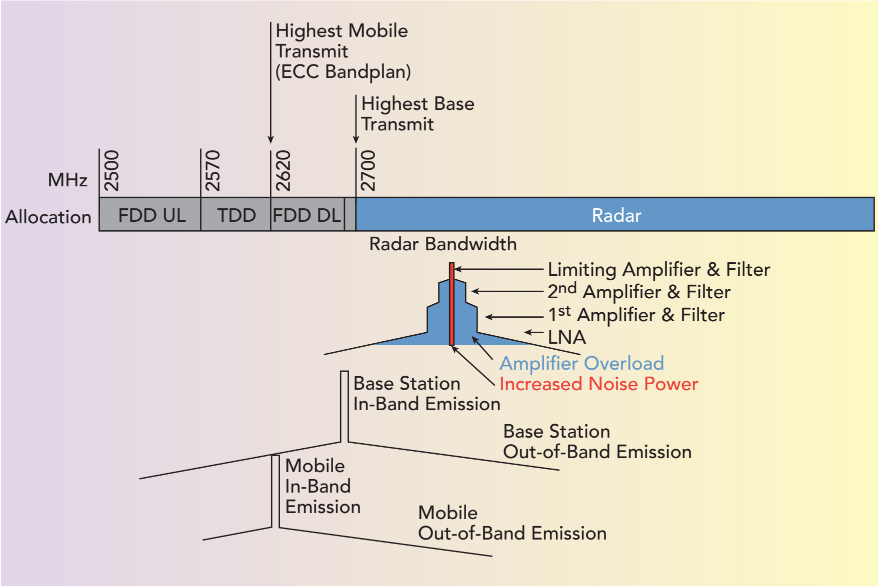
The measure of the radar's immunity to interference is defined as the frequency dependent rejection (FDR).[4,5] The FDR is determined by the receiver IF selectivity and is a function of the performance of the low noise amplifier (LNA) and noise power through the downconversion, filtering and signal processing. In a radar receiver, the two main interference parameters influencing the receiver sensitivity are blocking and selectivity. Blocking is the measure of gain compression at the front-end LNA due to a strong signal forcing the LNA into nonlinear compression. The selectivity is the measure of the increase in noise introduced into the receiver front-end while not in nonlinear compression, that will reduce the signal-to-noise ratio (SNR) of the receiver.

In the interest of developing a standard method to assess the coexistence of radar and wireless communications systems, a CW tone can be used to represent the blocking signal. The CW source should have the ability to generate high-power with low phase noise and low harmonics, so the unintentional artifacts of the signal generator do not influence the test results.

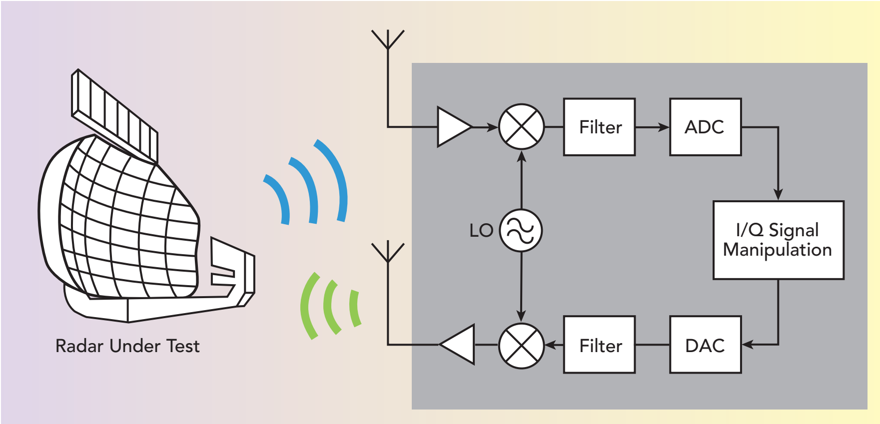
For a selectivity test, a noise signal is required. Since the challenge of coexistence in this case is primarily the mix of cellular and radar signals, the noise-like signal used to assess selectivity performance can be an LTE test model signal.[2,3] To study the performance of the radar receiver in the presence of an LTE network, a standard method of assessing the FDR performance of the radar blocking and selectivity behavior needs to be defined. A cooperative radar system is a radar whose service duty will not be impaired while performing the testing assessment. During the test, the radar can be in a decommissioned state, on a test range under emulated conditions or otherwise operating. While it is not expected to be in service during the test, the radar should be fully functioning to allow observation of performance.

ASSESSMENT METHODOLOGY

The functional performance of a cooperative radar should be assessed over-the-air (OTA) or in a test chamber, important to assure that all the components of the radar performance, including the antenna and LNA, are part of the system. Where allowed by law, OTA testing in situ provides the most realistic results. While the most common tool for assessing the functional performance of a radar is a single dihedral corner reflector or an array of reflectors at fixed locations, this method is not as ideal as test tools that provide a number of scaled amplitude, delayed echoes. Common tools with the ability to regenerate scaled echoes in an OTA RF environment include the use of digital radio frequency memory (DRFM) or radar echo generators (REG), as shown in ***Figure 2***. Utilizing digital delay taps,



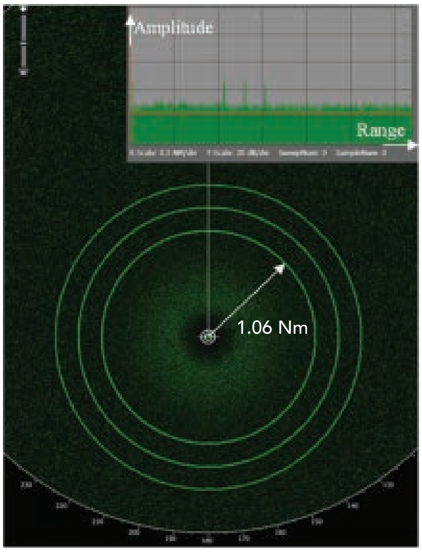
▲ **Fig. 1** Spectrum components from wireless communications and ATC radar receiver.



▲ **Fig. 2** Radar echo generator.

these tools have the advantage of a controlled delivery of a series of radar echoes that represent the transmitted radar signal delayed in time and at various attenuation levels, representing radar cross sections. This is important for assessing basic radar receiver capabilities such as delay time (range), signal amplitude (resolution) and even the Doppler rate of an echo. In a test lab, while it is common practice to test functioning radars with fiber optic delay lines (FODL) or coaxial delay lines (CDL), these may not have the flexibility to create multiple targets at different delays and attenuation levels. Further, these may bypass the critical RF components such as the antenna and LNA, which can skew the results.

The test method and results in this article use the REG as the desired tool, constructed from commercially available test equipment with metrology grade instruments.[6,7] With the added functionality, the REG can also create the additional RF interference signals required for testing, including CW, LTE or even arbitrary waveform signals. The baseline performance level for a selected mode of operation can be set with a REG to approximate a range of echo returns reliably detected on the radar system. The level and number of returns will depend on the quantitative thoroughness desired by the assessment. The baseline performance of the radar should provide a user interface that represents the actual operation expected by the end-user.

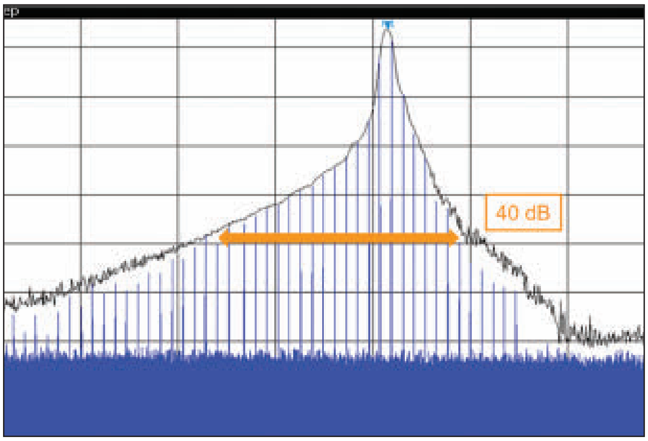


▲ **Fig. 3** Example radar PPI and range scope displays showing cascading echoes.

In the example shown in ***Figure 3***, three echo returns are shown in the user interface. For this demonstration, the REG is connected to an RF input port during scan mode, so the radar echo appears as concentric circles on the user display. While the levels of the echo returns are not enumerated in the user interface, a development mode interface of amplitude versus range is shown in the upper right corner of the figure. As the interference signals are introduced, the radar receiver will become impaired due to LNA compression (blocking) or increased noise into the IF (selectivity), and the number of echoes seen by the user will decrease. This is the method to determine the susceptibility of the radar.

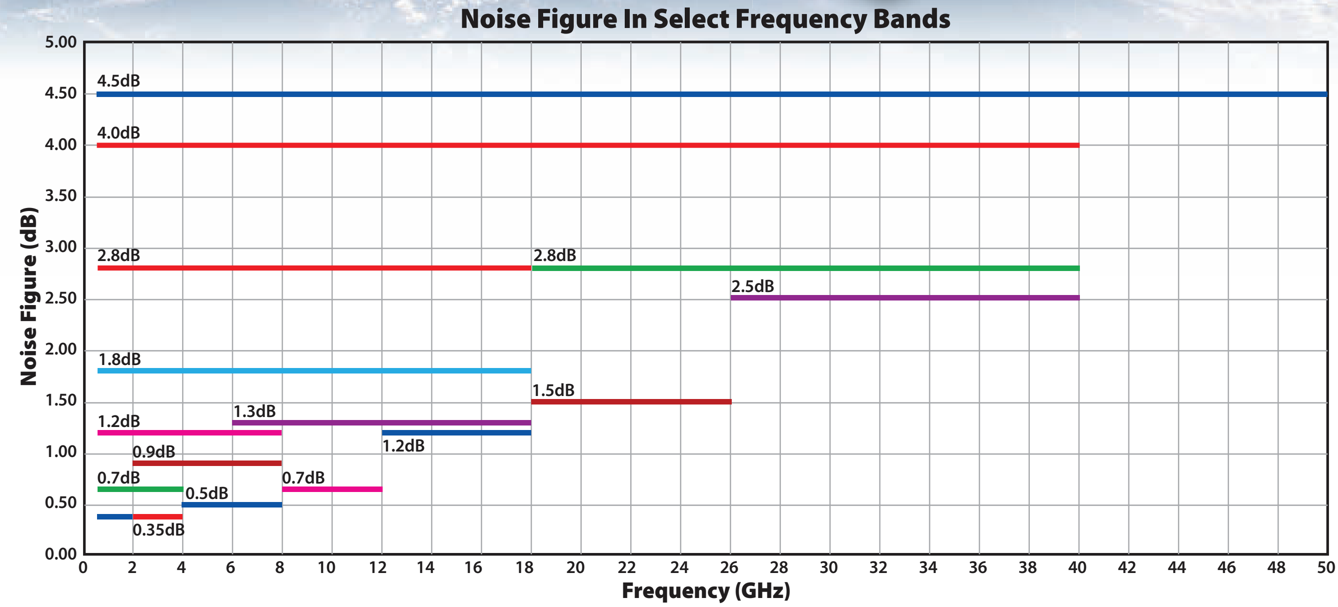
Some important considerations for the process and procedure for testing radar susceptibility are:

Occupied Channel—Using ITU-R M.1177-4,[1] it is necessary to determine the bandwidth of the occupied signal using the approximate 40 dB spectrum (e.g., ~10 MHz). The occupied channel can vary depending on the mode of operation (i.e., PPI rate) and tuning frequency. The example in ***Figure 4*** shows the asymmetric per-



▲ **Fig. 4** Asymmetric spectrum of a radar near the upper limit of its tuning range.

Has Amplifier Performance or Delivery Stalled Your Program?



B&Z TECHNOLOGIES
Innovating to Excel

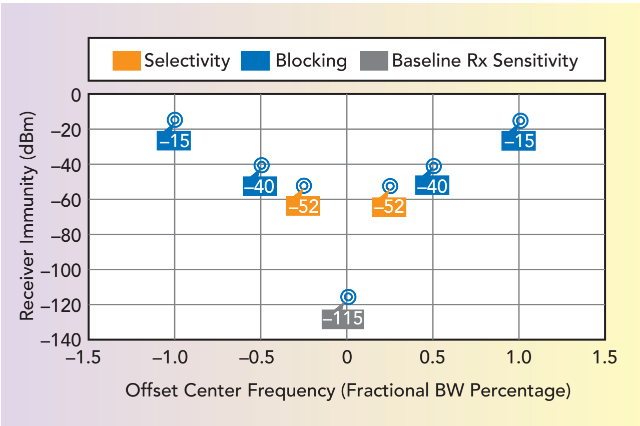
www.bnztech.com

formance of the transmit mask of a radar at the upper end of its tuning range. While the performance results are assessed against the fractional bandwidth of the carrier frequency, translating the occupied channel to fractional bandwidth contributes to important guidelines on the policy.

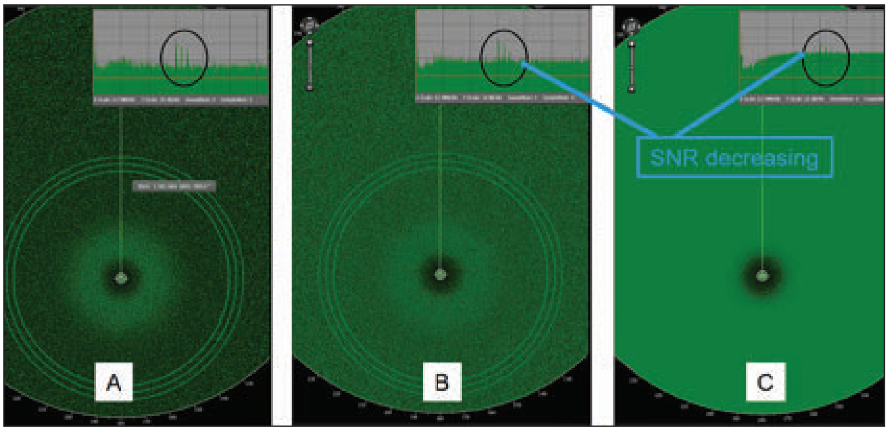
For example, in 3GPP, a 500 MHz system with an LTE signal having an occupied channel of 5 MHz has a signal that occupies 1 percent of the fractional bandwidth. Per the 3GPP standard, the expected blocking performance at a 20 MHz offset is 100 dB, representing 4 percent of the fractional bandwidth offset. The same 5 MHz communications system operating at 5 GHz occupies 0.1 percent fractional bandwidth. While 3GPP requires the same blocking performance at a 20 MHz offset, filter requirements and system receiver performance will now require 100 dB blocking performance at 0.4 percent fractional bandwidth offset. ***Figure 5*** shows the representative selectivity and blocking performance of an LTE base station receiver at a 2 GHz nominal center frequency.

FDR—The FDR is the measure of the rejection of an unwanted emission produced by the receiver's selectivity. There are a couple of important parameters of the FDR: the on-tune rejection (OTR) and the off-frequency rejection (OFR). Within the OFR, there are components OFR_{inband} and $OFR_{outband}$. These OFR components categorize the performance within the full tuning and operating range of the radar.

The OTR reflects the tuned center frequency occupied channel testing. Some radars have the ability to reject non-coherent and CW interference signals. Testing the OTR will help to separate the RF performance of the radar front-end and the reference performance gain of the digital signal processor (DSP) in the radar. The OFR will have different performance, based on the cascaded filter and amplifier receiver chain, as referenced in Figure 3. Therefore, it is necessary to provide enough test points to determine the behavior of the receiver considering these elements. These terms separate into OFR_{inband} and $OFR_{outband}$ to distinguish how these assessments might be determined.



▲ **Fig. 5 Representative performance of a 3GPP base station receiver at 2 GHz.**



▲ **Fig. 6 Radar selectivity with increasing interference, from (a) to (c), at a fixed frequency offset.**


NATIONAL INSTRUMENTS
SMART DEVICES REQUIRE
SMARTER
AUTOMATED TEST SYSTEMS
The old approach to automated test isn't scaling, but you already knew that. Look at your balance sheet. To test smart devices, you need a smarter test system built on a platform of NI PXI, LabVIEW, and TestStand. More than 35,000 companies deploy NI technology to lower their cost of test. What are you waiting for?
Prepare for the future at ni.com/smarter-test.
©2017 National Instruments. All rights reserved. LabVIEW, National Instruments, NI, ni.com, and NI TestStand are trademarks of National Instruments. Other product and company names listed are trademarks or trade names of their respective companies. 29911

RESULTS

Examining the test methodology, the performance of a maritime radar provides a test case for this assessment. The results for selectivity demonstrate the frequency and amplitude offsets of the radar's FDR. Again, for the purposes of demonstration, the REG is connected directly to the RF input port, while the radar is set to scan mode. ***Figure 6a*** represents the baseline performance with three cascading echoes delayed in time and near the sensitivity of the radar. The SNR may be rather subjective if the echoes represented just a blip on the screen; therefore, as in the prior example, the REG is connected directly to the RF input port. In ***Figures 6b*** and ***6c***, an interference signal is coupled to the radar echo return, offset in frequency and increasing in amplitude. The decreasing SNR due to the interference signal appears as increasing the baseline noise. In Figure 6c, while the echoes in the development mode of the radar amplitude versus time display are still visible, a user would need to adjust the noise level of the radar to be able to discern any objects on the display.

To provide a reference of the radar's FDR, a set of tests was conducted to plot the selectivity versus offset frequency at a fixed amplitude of -50 dBm (see ***Figure 7***) and the selectivity versus amplitude at a fixed frequency offset (see ***Figure 8***). The results are expressed in fractional bandwidth offset from the center frequency and the interference level relative to the receiver sensitivity. While typical radars have a receiver sensitivity between -90 to -120 dBm, the actual receiver sensitivity of the radar used in this test is proprietary. With coupling losses accounted for, the level of the interference signal was -50 dBm at the receiver input port. Without disclosing the additional coupling loss to the radar receiver, this represents a level approximately 50 dB above the input sensitivity. Three targets at range bins 270, 287 and 302 are shown in the "reference" measurement, where no interference was present. This shows that even at a modest interference level of -50 dBm at the receiver input, with a frequency offset between 2 to 3 percent fractional bandwidth, the echoes will not have enough SNR to be detected by the radar.

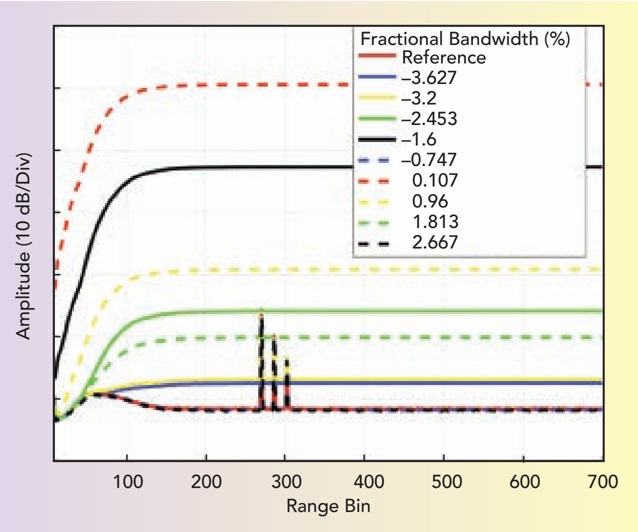


Fig. 7 Selectivity vs. offset frequency with –50 dBm amplitude.

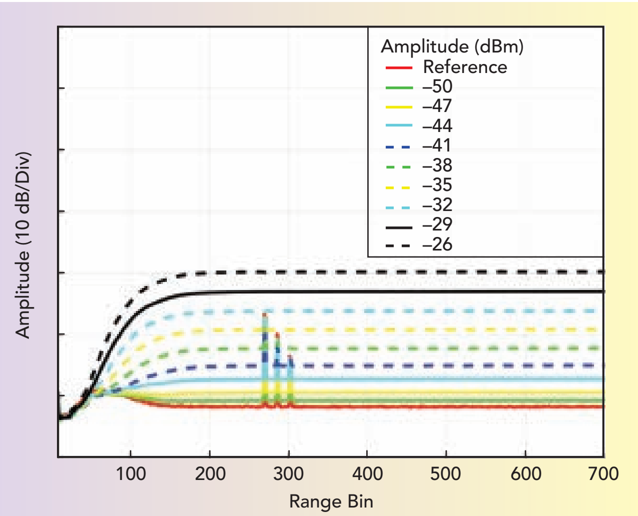


Fig. 8 Selectivity vs. amplitude with a fixed frequency offset (–3.733 percent fractional bandwidth).

Comparing these results to the standard performance of a wireless base station (see Figure 5), the base station can reject a +63 dB signal at a fractional bandwidth of 0.25 percent. It is clear that the selectivity of the radar has a much greater sensitivity at a much greater frequency offset. This affects the frequency allocation guard band between the radar and wireless services.

Using the values in Figure 7 and calculating a free space loss, the potential impact on a victim radar can be assessed. Assuming a cellular base station power in band 41 (see Table 1) at 40 W (+46 dBm), the cellular base station would have a free space attenuation of approximately -116 dB at a distance of 6 km. A possible band 41 downlink signal at 2690 MHz represents a -0.37 percent offset for a radar with a center frequency of 2.7 GHz. Knowing the FDR behavior of the victim radar, a 3 percent fractional bandwidth would dictate the radar should not be operated at a frequency below 2780 MHz at this 6 km distance.

The test of selectivity versus amplitude provides guidance on the physical separation distance allowed for coexistence at a defined offset frequency. Due to the performance of the selectivity versus frequency, the test for selectivity versus amplitude uses a large frequency offset (-3.733 percent fractional bandwidth). Figure 8 shows the results when the selectivity power is increased from -50 to -26 dBm at the radar receiver port. While these values do not directly relate to the absolute sensitivity, the relative performance is roughly +50 and +74 dB above the receiver's sensitivity.

Since the performance of the radar receiver and the wireless base station receiver are very similar, comparing the results with Figure 5 reinforces the need to have additional frequency guard band or stronger guidelines on the mitigation distances for mobile services.

CONCLUSION

The LTE base station and other fixed communications systems are designed for co-siting and coexistence, and substantial focus on blocking and selectivity immunity in the base station receiver has been specified by the 3GPP. When the transmit mask of the LTE base station (ACLR) and the receiver performance are compared, there is relative reciprocity in the out-of-band emissions and the block and selectivity performance.

The performance of the radar transmit mask and the radar receiver FDR curves demonstrate a substantial difference in performance for out-of-band signal behavior. While the radar emission mask shows a sharp and substantial roll-off in out-of-channel emissions (see Figure 4), the radar receiver used in this study clearly has an FDR that would make it highly susceptible to interference from a wireless network at a close-in frequency. It is clear that mitigation distances for frequency and separation distances for radar and radio systems need to consider the impact to the radar receiver. A standard methodology and approach will enable a baseline performance measurement, so these issues can get the necessary attention to determine appropriate guidelines for frequency allocations.■

References

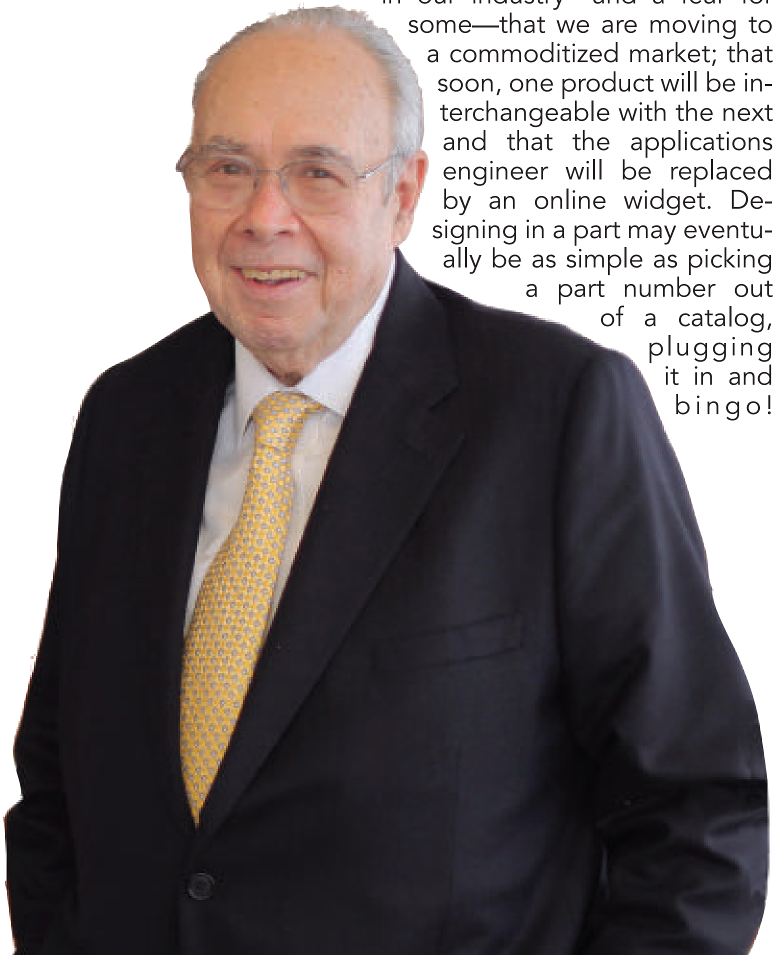
1. ITU-R Recommendation M.1177-4, *Techniques for Measurement of Unwanted Emissions of Radar Systems*, Switzerland, 2004.
2. 3GPP TS 25.141 V14.1.0, "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Base Station (BS) Conformance Testing (FDD), (Release 14)," *Test Specification*, Valbonne, France, December 2016.
3. 3GPP TS 25.104 V14.1.0, "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Base Station (BS) Radio Transmission and Reception (FDD), (Release 14)," *Technical Specification*, Valbonne, France, December 2016.
4. ITU-R Recommendation M.1461, *Procedures for Determineing the Potential for Interference Between Radars Operation in the Radiodetermination Service and Systems in Other Services*, Switzerland, 2000.
5. ITU-R Recommendation SM.337-6, *Frequency and Distance Separations*, Switzerland, 2008.
6. S. Heuel, "Real-Time Radar Target Generator," *Application Note 1MA256_0e*, Rohde & Schwarz, Germany, November 2014.
7. K. Shibli and S. Heuel, "Radar Echo Generator," *Application Note 1MA283_0e*, Rohde & Schwarz, Germany, August 2016.


Mini-Circuits
ZX60-83LN+
PMA3-83LN+
from $154.95 (qty. 1-9)
Rugged connectorized package
0.75 x 0.74 x 0.46"
from $11.95 (qty. 20)
3x3 mm MMIC

INVITED PAPER

Creating Value in the RF Supply Chain

Harvey Kaylie
Mini-Circuits, Brooklyn, N.Y.



Whether you have been in the RF and microwave world for five years or 50 years, we have seen the industry change at a continuously accelerating pace. We have watched consolidation on a historic scale, where brand names in the 70s, 80s and even 90s, like Watkins Johnson, Avantek, Anzac, RHG disappeared, leaving fewer suppliers in the RF space than we have seen in a long time. As this evolution takes place, there is an undercurrent in our industry—and a fear for some—that we are moving to a commoditized market; that soon, one product will be interchangeable with the next and that the applications engineer will be replaced by an online widget. Designing in a part may eventually be as simple as picking a part number out of a catalog, plugging it in and bingo! It works. In this future, you do not have to think anymore.

And if that is the direction we are headed, how will we, as an industry, define value? Is value something different now than it was five, 10 or even 50 years ago? If it is not a function of performance, and we define it solely in terms of price and delivery time, is the RF market any different from digital markets, where repeatable performance and interchangeability are givens? These are questions on many people's minds, and I would like to offer my perspective on what value means in the RF and microwave industry today.

COTTAGE INDUSTRY TO CONSUMER MARKET

I started working as a junior RF engineer in 1957, about 60 years ago. At that time, the RF market was a cottage industry. In the post-World War II, pre-Vietnam era, the military market was the main driver, in terms of demand for quantity and consistency of products. RF applications were really limited to military communications, radar, broadcast—and that was about it. There were a few large OEMs like GE, RCA, Westinghouse; then, there was a fringe of smaller, specialized companies like Airborne Instrument Labs, Sperry Gyroscope, Cardion and Wheeler Labs.

At that time, the component-level supply base was a cadre of tiny companies mostly garage shops. They were founder/owner companies established around one product or maybe a small product line in a few cases. They all had niche specialties. One person was the

owner, the chief designer and the applications engineer, and products evolved through regular, direct communication with customers. These were very tight-knit relationships: customer-supplier teams, where customers worked closely with their preferred suppliers, and suppliers specialized in specific customers' needs. "Commodity" was not even in the vocabulary. We were inventors, creators, pioneers, even artists, creating innovative solutions to specific customer challenges.

Fast forward 50 years. The markets for RF technology have ballooned. The number of applications has grown from just a few in the post-World-War-II period to the order of hundreds, maybe even thousands today. In 1985, Martin Cooper and Motorola released the world's first cell phone. That was an inflection point in the growth of the industry. Around that time, Mini-Circuits was supplying Motorola with 200 units a week for their cell phone; today, the weekly volume for cellular handsets is well into the millions of units. The popularity of applications created through cellular, Wi-Fi, eventually IoT and all the consumer RF devices and services those technologies enabled, drove massive demand for volume and pressure on price. In that landscape and in the transition leading up to it, the cottage industry of suppliers was no longer equal to the demand, so the industry had to evolve. Suppliers had to adapt to achieve performance, quality and competitive pricing at the scale these new markets demanded, and most adapted through consolidation.

The surge in demand brought about an evolution in quality standards, in terms of sigma. Quality has always been and remains inseparable from the definition of value: customers expect performance that meets their system requirements with a high degree of repeatability between units and the assurance that parts will not fail through the operating life of the system they are designed into. But as the industry has grown, suppliers have innovated design tools, processing techniques, ESD safeguards, measurement methods and statistical approaches to achieve quality at an astounding level of precision. As a result, the standards for product quality are higher now than they have ever been. At the birth of the industry, 1000 failures per million was considered exceptional, whereas today it is not unusual to have a requirement for 10 failures per million—or less.

Finally, products have evolved from a diverse universe of single-function components to highly integrated, digital-type solutions aiming toward total plug-and-play compatibility, where one part is a form, fit and function drop-in replacement for another part, and where hardware is secondary to the software and firmware that wraps around it. Where, dare I say, the tight-knit, specialized customer-supplier team seems, on the surface, to have diminishing relevance.

Does this new paradigm work? In some ways, it seems hard to deny.

EWA

. . . enabling a more secure future

40 Years of Excellence

1977 – 2017

www.EWA.com

COMMODITIZATION: NEW PARADIGM OR MISGUIDED PERCEPTION?

Today, giant companies like Apple, Samsung and their peers dominate the consumption of RF products. They shape the RF market and the RF supply chain. Because the trend in this volume market is gravitating toward ever more integrated, more repeatable solutions, the popular viewpoint has emerged that the market for RF products is becoming commoditized. With that viewpoint comes a parallel argument that RF application support is unnecessary for a true, fully integrated system-on-a-chip solution. Pick a catalog part, plug it in and it works. Performance is a guarantee. Value, they might say, comes down to competitive price, fast delivery and superior logistics and distribution.

In this new world of highly integrated, super cost-sensitive solutions, a few, very large suppliers are fully dedicated to supporting those high-volume applications. However, while these suppliers are offering fully integrated system-on-chip solutions, the prediction of a true plug-and-play commodity paradigm has yet to be fulfilled. In fact, these suppliers have entire teams of engineers embedded with their customers to help them integrate products, to understand and anticipate customers' future trajectories and to make sure that their own product development is meeting the demand of those customers a year or two in advance. So, while there is a perception that system-on-chip solutions are virtual commodity items, or they are headed that way, those suppliers still extend heavy resources to maintain close collaboration with their customers at the engineering level.

While most of the headlines in the RF/microwave market are focused on these volume markets, there is still a substantial market for RF solutions that are not supported by these high-volume, application-specific circuits and suppliers. The challenge today is that there are not many suppliers left who provide the breadth of product and application support that these smaller, more specialized customers need.

At Mini-Circuits, we are deeply committed to serving this segment of the market, and despite the consolidation and the ostensible shift toward commoditization, we have found that the paradigm is still very well rooted in a prevalent and powerful need for applications engineering, partnerships with the customer at the technical level and direct involvement in the customer's design process. The value that the little garage shops provided still exists and is very much warranted. We saw the need for this kind of support years ago, and that is what pushed us to hire more application engineers. Even though our applications engineering team has more than quadrupled in the last five years, we are still finding more demand for engineer-to-engineer application support. That is our validation that the industry still needs and values this kind of technical partnership.

The need for dedicated technical partnership is further validated when you consider the inherent challenges of replacing or second sourcing a component in an existing system architecture. Whether you take a Mini-Circuits mixer or a Skyworks front-end chip, nothing is perfectly fungible. Even though the end products may be commoditized in the consumer mass market, when the latest iPhone comes out, Apple does not say they can buy from either supplier A or supplier B. They make a commitment to one supplier, and they organize their development around that supplier's solution.

In the RF world, you cannot simply replace a part and expect it to work. That is the reality of the complex, three-dimensional electromagnetic world we live in. Take an example as simple as a capacitor. Replacing a Johansen capacitor with an AVX capacitor in a 10 GHz matching circuit and expecting no change in performance would be naïve. Whether we are talking about the simplest circuit element or the most integrated chipset solution, at 5 GHz or at 50 GHz, parasitics and unexpected results are still important factors in selecting the right component. And because of that, the value of technical collaboration between supplier and customer is undeniable.

VALUE: A CONSTANT IN A CHANGING INDUSTRY

This leads me to reconsider the prediction of a commodity market and the marginalization of the engineer-to-engineer relationship. Even at the most competitive, consumer-driven edge of our market, that is not what is really happening, and it is simplistic to expect that it ever will. Even though the industry may have evolved into two camps of suppliers, one serving the high-volume consumer wireless customers and the other dedicated to the diverse array of smaller, more specialized applications, is value defined differently in these two segments of the market?

Of course, we need to remain technically competitive and cost competitive while offering competitive lead times. We need world class product quality and reliability to meet increasingly demanding system requirements. These "commodity elements" are prerequisite to meeting market demand. But in all cases, the ultimate decisions are based upon communication between engineers at the customer and the supplier. The RF portion of the analog world still requires an intimacy between the design engineer and the supplier to achieve the expected results and to optimize system performance.

Through the course of industry history, the suppliers that successfully adapted and thrived were those who were able to transition to scale and improve upon the level of quality and engineering support that led to their initial success. They either adapted through consolidation to serve the biggest customers, with focused and intensive

engineering support, or they did what Mini-Circuits did and proliferated broad-based application support for many, diverse customers.

Those touch points may be organized differently to best serve the needs of particular customers or customer groups, but the value we're creating was, is and remains, in its essence, the same. It is in the close relationship between the supplier and the customer solving problems and achieving mutual success. The real value lies in the engineer-to-engineer collaboration at both the mega-volume level and the mini-volume level. Companies that have failed to preserve that value have been lost to history, and those that discount it now will leave a void between themselves and their customers.

There is no denying the profound transformation the industry has undergone in the last 50 to 60 years. We have evolved from a cottage industry to a ubiquitous element in the fabric of almost every society on Earth. The demand for wireless connectivity will continue to grow, the technology will continue to advance at an accelerating rate and I have no doubt that Mini-Circuits and other RF and microwave suppliers will continue adapting to bring greater value to customers.

But that does not mean the core value proposition has changed. The perceived shift toward commoditization in the RF market is just that, a perception. The RF world is distinct from other parts of the digital world, in that customers will always rely on their suppliers to some degree to develop solutions and integrate them to optimize system performance, regardless of how repeatable performance becomes. And suppliers will always look to their customers to guide their own development efforts. The moment we dismiss that collaborative relationship, the customer-supplier team, is the moment we lose sight of the meaning of value. And history has shown how that goes.

As for the future of our industry, although there is a trend toward commoditization at the high-volume, subscriber level, as there needs to be, the opportunities for RF engineers to blaze new paths through creative innovation and collaboration will remain vital to the evolution of the technology and ongoing growth of the industry.

In 1957, we were at the early stage of the commercialization of radio technology. Like artists, we were creating something where before there was nothing, out of little more than our knowledge, experience and passion, painting the picture of what the industry would eventually become. And while maybe the canvas has changed, I feel the same creative energy and spirit of invention today, creating new solutions for my customers with the tools I have from my education, knowledge and experience, the partnership of my peers in the field and the passion to keep solving problems and creating value.■

win SEMICONDUCTORS | Compound Semiconductor Solutions from RF to Lightwave™

WIN. Because not everyone can do this.

A wider selection of technologies
Scalable manufacturing for any application

WIN Semiconductors delivers technology solutions that cover applications from DC to 100GHz and beyond. As the innovation leader in compound semiconductors, WIN serves a wide range of rapidly growing markets with unmatched manufacturing scale and unique capabilities to help design engineers solve problems - fast.

- Leadership in compound semiconductor manufacturing
- Three production locations
- Over 1,000,000 ft^2 manufacturing space
- Flexible wafer production for consumer and specialty markets
- Wide array of value-added services

Technology platforms

- GaAs HBT for mobile PA and 802.11ac
- Highly integrated pHEMT
- Gallium Nitride
- Optical devices
- PIN diode MMICs
- High power passives for 28V and 50V operation

With an expansive technology portfolio, rapid turn times, and unrivaled manufacturing scale, WIN enables market leading products with a seamless move to high volume production.

How can WIN help you today?

Contact WIN today, and see how we can help you reduce size, improve performance and reach the next level of innovation.

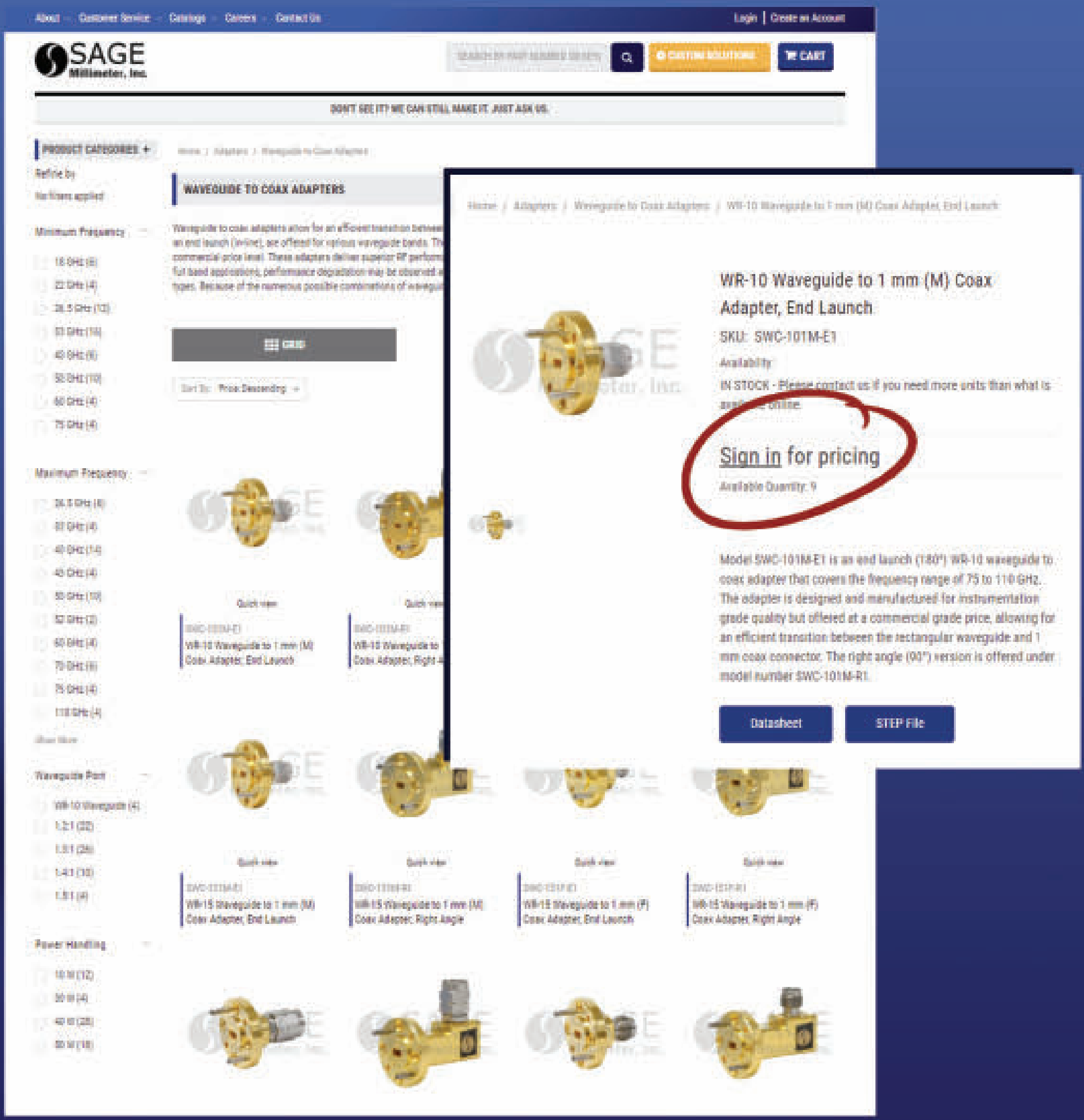
With technology, manufacturing scale and support services unmatched in the industry, you'll see why partnering with us is a win-win.

North America: ieliashevich@use.winfoundry.com
Europe: harryq@use.winfoundry.com

winfoundry.com/contactus
info@winfoundry.com

VIEW PRICING, LEADTIME, AND INVENTORY

NEW SAGE WEBSITE



WWW.SAGEMILLIMETER.COM/STOCKROOM

Over 1,000 millimeterwave components off-the-shelf, in stock, and ready to ship guaranteed in only 1-3 days.

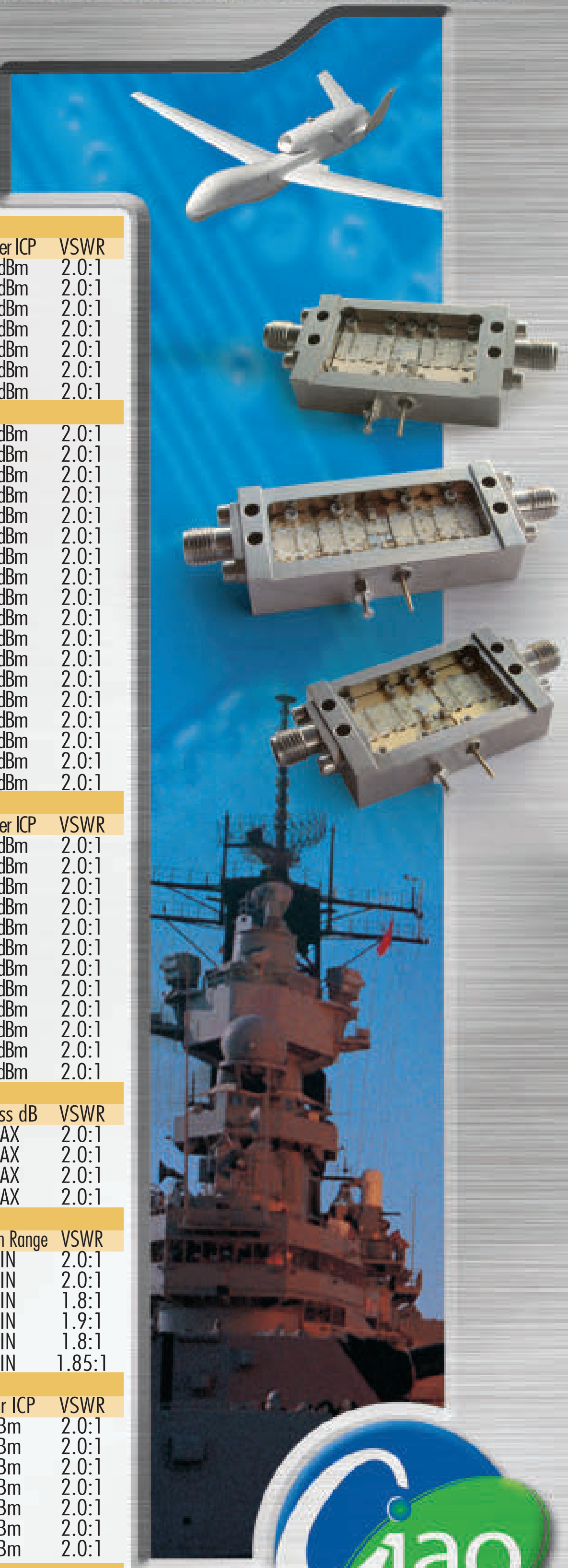
SAGE
STOCKROOM

RF Amplifiers and Sub-Assemblies for Every Application

Delivery from Stock to 2 Weeks ARO from the catalog or built to your specifications!

- Competitive Pricing & Fast Delivery
- Military Reliability & Qualification
- Various Options: Temperature Compensation, Input Limiter Protection, Detectors/TTL & More
- Unconditionally Stable (100% tested)

ISO 9001:2000 and AS9100B CERTIFIED



OCTAVE BAND LOW NOISE AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2110	0.5-1.0	28	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2111	0.4 - 0.5	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA01-2113	0.8 - 1.0	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3117	1.2 - 1.6	25	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3111	2.2 - 2.4	30	0.6 MAX, 0.45 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3116	2.7 - 2.9	29	0.7 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA34-2110	3.7 - 4.2	28	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA56-3110	5.4 - 5.9	40	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA78-4110	7.25 - 7.75	32	1.2 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA910-3110	9.0 - 10.6	25	1.4 MAX, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA1315-3110	13.75 - 15.4	25	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3114	1.35 - 1.85	30	4.0 MAX, 3.0 TYP	+33 MIN	+41 dBm	2.0:1
CA34-6116	3.1 - 3.5	40	4.5 MAX, 3.5 TYP	+35 MIN	+43 dBm	2.0:1
CA56-5114	5.9 - 6.4	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6115	8.0 - 12.0	30	4.5 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6116	8.0 - 12.0	30	5.0 MAX, 4.0 TYP	+33 MIN	+41 dBm	2.0:1
CA1213-7110	12.2 - 13.25	28	6.0 MAX, 5.5 TYP	+33 MIN	+42 dBm	2.0:1
CA1415-7110	14.0 - 15.0	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA1722-4110	17.0 - 22.0	25	3.5 MAX, 2.8 TYP	+21 MIN	+31 dBm	2.0:1

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA0102-3111	0.1-2.0	28	1.6 Max, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA0106-3111	0.1-6.0	28	1.9 Max, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-3110	0.1-8.0	26	2.2 Max, 1.8 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-4112	0.1-8.0	32	3.0 MAX, 1.8 TYP	+22 MIN	+32 dBm	2.0:1
CA02-3112	0.5-2.0	36	4.5 MAX, 2.5 TYP	+30 MIN	+40 dBm	2.0:1
CA26-3110	2.0-6.0	26	2.0 MAX, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA26-4114	2.0-6.0	22	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA618-4112	6.0-18.0	25	5.0 MAX, 3.5 TYP	+23 MIN	+33 dBm	2.0:1
CA618-6114	6.0-18.0	35	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA218-4116	2.0-18.0	30	3.5 MAX, 2.8 TYP	+10 MIN	+20 dBm	2.0:1
CA218-4110	2.0-18.0	30	5.0 MAX, 3.5 TYP	+20 MIN	+30 dBm	2.0:1
CA218-4112	2.0-18.0	29	5.0 MAX, 3.5 TYP	+24 MIN	+34 dBm	2.0:1

LIMITING AMPLIFIERS

Model No.	Freq (GHz)	Input Dynamic Range	Output Power Range Psat	Power Flatness dB	VSWR
CLA24-4001	2.0 - 4.0	-28 to +10 dBm	+7 to +11 dBm	+/- 1.5 MAX	2.0:1
CLA26-8001	2.0 - 6.0	-50 to +20 dBm	+14 to +18 dBm	+/- 1.5 MAX	2.0:1
CLA712-5001	7.0 - 12.4	-21 to +10 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1
CLA618-1201	6.0 - 18.0	-50 to +20 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	Gain Attenuation Range	VSWR
CA001-2511A	0.025-0.150	21	5.0 MAX, 3.5 TYP	+12 MIN	30 dB MIN	2.0:1
CA05-3110A	0.5-5.5	23	2.5 MAX, 1.5 TYP	+18 MIN	20 dB MIN	2.0:1
CA56-3110A	5.85-6.425	28	2.5 MAX, 1.5 TYP	+16 MIN	22 dB MIN	1.8:1
CA612-4110A	6.0-12.0	24	2.5 MAX, 1.5 TYP	+12 MIN	15 dB MIN	1.9:1
CA1315-4110A	13.75-15.4	25	2.2 MAX, 1.6 TYP	+16 MIN	20 dB MIN	1.8:1
CA1518-4110A	15.0-18.0	30	3.0 MAX, 2.0 TYP	+18 MIN	20 dB MIN	1.85:1

LOW FREQUENCY AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure dB	Power-out @ P1-dB	3rd Order ICP	VSWR
CA001-2110	0.01-0.10	18	4.0 MAX, 2.2 TYP	+10 MIN	+20 dBm	2.0:1
CA001-2211	0.04-0.15	24	3.5 MAX, 2.2 TYP	+13 MIN	+23 dBm	2.0:1
CA001-2215	0.04-0.15	23	4.0 MAX, 2.2 TYP	+23 MIN	+33 dBm	2.0:1
CA001-3113	0.01-1.0	28	4.0 MAX, 2.8 TYP	+17 MIN	+27 dBm	2.0:1
CA002-3114	0.01-2.0	27	4.0 MAX, 2.8 TYP	+20 MIN	+30 dBm	2.0:1
CA003-3116	0.01-3.0	18	4.0 MAX, 2.8 TYP	+25 MIN	+35 dBm	2.0:1
CA004-3112	0.01-4.0	32	4.0 MAX, 2.8 TYP	+15 MIN	+25 dBm	2.0:1

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

Visit our web site at **www.ciaowireless.com** for our complete product offering.

Ciao wireless

Ciao Wireless, Inc. 4000 Via Pescador, Camarillo, CA 93012

Tel (805) 389-3224 Fax (805) 389-3629 sales@ciaowireless.com

New Radar Sensor Provides Clear Vision in Any Weather

DARPA's Video Synthetic Aperture Radar (ViSAR) program recently completed flight tests, successfully demonstrating a new sensor that can capture real-time video through clouds.

The ViSAR program, which began in 2013, has been developing an Extremely High Frequency (EHF) targeting sensor to operate through clouds as effectively as current electro-optical and infrared (EO/IR) sensors operate in clear weather. The program's goal is to develop a cloud-penetrating EHF sensor in a moveable gimbal that could be mounted on a variety of aerial platforms to provide high-resolution, full-motion video for engaging moving ground targets in all weather conditions—cloudy or clear.

"The recent flight tests of the ViSAR sensor marked a major program milestone toward our goal, proving that we can take uninterrupted live video of targets on the ground even when flying through or above clouds," said Bruce Wallace, program manager in DARPA's Strategic Technology Office. "The EO/IR sensors on board the test aircraft went blank whenever clouds obscured the view, but the synthetic aperture radar tracked ground objects continuously throughout the flight."

Wallace noted that cloud-penetrating radar—such as from space or other operational systems—has existed in other formats, but there has not been a synthetic aperture sensor, which can fit in a standard EO/IR sensor gimbal on aircraft and maintain frame rates fast enough to track maneuvering targets on the ground. The recent ViSAR tests took place on a modified DC-3 aircraft that flew at low and medium altitudes, allowing researchers to collect and compare data from the ViSAR, EO and IR sensors mounted on standard sensor gimbals.

"Refining the ViSAR sensor's visualization software to provide operators a representation they're used to seeing is the next step in the program," said Wallace. "We don't want operators in the back of an aircraft to need special radar training to interpret the sensor's data—we are working to make the visual interface as easy to interpret as existing EO/IR sensor displays."

Source: DARPA

The ViSAR program has demonstrated and continues to push technology innovations in four technical areas: compact flyable EHF-band exciters and receivers; compact flyable EHF-band medium-power amplifier; EHF-band scene simulation; and advanced algorithms for EHF-band operation.

The next phase of the ViSAR program is to integrate the sensor into an aircraft that includes a complete battle management system, capable of real-time target engagement.

Global Defense Spending Momentum Will Provide $77B Industry Opportunity

Force modernization will be one of the primary factors underpinning growth in global defense spending, driven by unprecedented developments in autonomous systems, missile, space and cyber-electronic warfare and other technologies. Strategy Analytics forecasts the global defense budget will grow to $2.41 trillion in 2026, with the opportunities available to industry growing at a CAGR of 3.5 percent to reach $771 billion.

Asif Anwar, director of the Advanced Defense Systems (ADS) service notes, "Our analysis reveals a number of common drivers that recur within and across the different regions that will provide the impetus for industry growth. These include combating the increasing menace of cyber threats—with both defensive and offensive capabilities; maritime surveillance and border protection in the face of evolving threats especially from unmanned systems; increasing mission envelopes with advanced radar, long range missile, unmanned systems and space-based capabilities."

Strategy Analytics' 2017 global defense analysis is based on an assessment of 95 countries that spent a minimum of $500 million on their annual defense in 2016. Strategy Analytics' outlook for global defense spending is based on baseline information from Stockholm International Peace Research Institute (SIPRI).

"Global defense spending stabilized in 2016 following a dip in 2015, and this growth is forecast to continue in 2017 to reach $1.75 trillion. A renewed emphasis on growing defense spending in the U.S., bar the limitations of a continuing resolution, coupled with a changing economic environment in China, will mean that defense spending in the Asia-Pacific (APAC) region is unlikely to surpass North American spend levels through 2026. However, APAC defense spending will maintain the strongest growth trajectory, with a 5.4 percent CAGR, almost double the defense spending growth rate projected for North America."

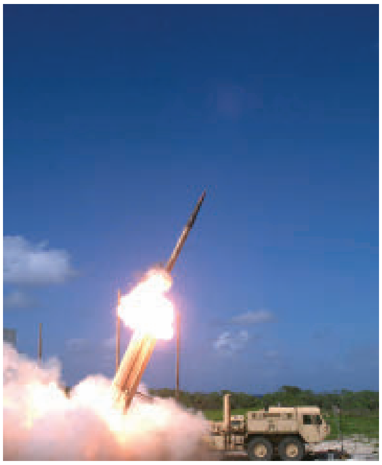
For More Information Visit mwjournal.com for more defense news.

Air Defense System Market Worth $45.19 Billion by 2024

The changing nature of modern warfare is one of the most important factors driving the demand for air defense systems across the globe. The nature of warfare has changed over the years with various technological advancements taking place in the defense sector, resulting in increased defense expenditure across the globe. The changing nature of aerial warfare across the globe has led to the acquisition of advanced air defense systems by various countries.

Based on platform, the naval segment of the air defense system market is projected to grow at the highest CAGR. The naval air defense capability of a ship is crucial for its survival, requiring complete protection against all types of projected and known air threats.

Based on range, the long range air defense (LRAD) system segment is estimated to account for the largest share of the market in 2017. Increase in attack threats from intercontinental ballistic missiles across the globe is fueling this growth. Based on type, therefore, the missile defense system segment is projected to lead the air defense system market over the forecast period. This is attributed to increased investments by countries such as the U.S., China, Iran, India, Russia, North Korea and France for the development of advanced missile defense systems.



Source: AD Reports

The Asia Pacific region is projected to lead the air defense systems market, growing at the highest CAGR from 2017 to 2024. Rising incidences of insurgencies, territorial disputes, terrorism and unrest between neighboring nations, along with increased defense spending by emerging economies of the Asia Pacific region are the factors fueling this growth.

The ecosystem includes manufacturers of air defense systems such as Saab AB (Sweden), Israel Aerospace Industries Ltd. (Israel), Raytheon Company (U.S.), Thales Group (France), Lockheed Martin Corporation (U.S.), Hanwa Corporation (South Korea) and BAE Systems PLC (U.K.), among others.

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
REACTEL, INC.
• 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.
RoHS Compliant
@reacteljim

Funding to Give the Connected Car Real IMPACT in Europe

IMPACT Accelerator has launched the first call of IMPACT Connected Car, a new programme led by FundingBox and ISDI. IMPACT Connected Car is funded by the European Commission, under the INNOSUP Initiative. It builds on the legacy and expertise of the IMPACT Accelerator, which invested over €7 million in 78 start-ups from 2014 to 2017.

By 2020, 220 million cars are expected to be connected, representing a €141 billion business opportunity. With a fund of €2.1 million, IMPACT Connected Car will help small to medium enterprises (SME) and start-ups to capture this business opportunity. It will identify companies that will lead the creation of new value link-chains in the Connected Car OpenSpace, with vehicle, infrastructure and device interactions as well as consumer and business services.

The current open call will be receiving applications from connected car start-ups and SMEs until 10 January 2018. During this period numerous information days will be organised across Europe, as well as online, in order to give applicants a deeper understanding of the programme and the application process. By March 2018, the best 13 companies will be selected to enter the three-stage smartization programme, upon the completion of which they will receive up to €60,000 equity free funding. Top performing start-ups will have the opportunity to receive additional private funding of up to €200,000 from participating venture capital funds.

As in other IMPACT programmes, funding will go hand-in-hand with a high-performance training programme in which renowned experts and international entrepreneurs will deliver practical classes across Connected Car Hubs and partners facilities. In addition, entrepreneurs will have access to an international network of more than 100 recognized mentors, founders and investors who are experts in both the digital sector and in the automotive industry.

New Agreement Strengthens U.K. Space Sector

Two leading scientific institutions from the U.K. have joined forces to strengthen their support for the nation's rapidly-growing multi-billion pound space sector. The Science and Technology Facilities Council (STFC) and the National Physical Laboratory (NPL) have signed an agreement to bring together their expertise in measuring and testing instruments for satellites.

Dr. Brian Bowsher, CEO of STFC, said: "We are delighted to be working with such a centre of excellence as the NPL in furthering the advancement of satellite calibration. By sharing our expertise and building on those strengths, we are putting the U.K. on the map as a global leader in satellite testing."

The agreement sets out the opportunities for collaboration between NPL, the U.K.'s National Measurement Institute, and STFC's RAL Space, home to the U.K. Centre for Calibration of Satellite Instrumentation. The Centre combines the strengths of industry and academia, and RAL Space scientists and engineers are currently playing a crucial role in the calibration of the Sea and Land Surface Temperature Radiometer (SLSTR) on the ESA/EU Sentinel-3 mission.

Dr. Thompson, CEO of NPL, said: "The explosion of data from satellite based instrumentation is transforming every sector and promises great economic and social benefits. Good measurement is vital in delivering these, from creating new instrumentation and calibration technology to improve the accuracy of data collection, to providing traceability and standards to ensure data can be used and applied with confidence. By working more closely with STFC, we can further support the U.K. space industry in taking a world-leading role in satellite technology and services, and accelerating the impact they will have."

Dr. Brian Bowsher (L), CEO of STFC, signed the agreement alongside Dr. Peter Thompson, CEO of NPL. (Credit: RAL Space/NPL)

LG U+, Huawei Demonstrate 5G Dual-Connectivity Technology

LG U+ and Huawei have completed "Dual-Connectivity" technology verification during a 5G field test in Seoul, Korea. The verification was conducted through cooperation between two base stations at a LG U+ 5G test base in Seoul, and it was confirmed that the downlink data from both the 3.5 and the 28 GHz base stations combined to provide a rate of around 20 Gbps.

Dual-connectivity is a technique that allows multiple base stations to transmit data simultaneously or alternately to a user so that they can seamlessly commu-

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

nicate with other users when moving between base stations. As well as being suitable for use between 5G 3.5 and 28 GHz base stations, the technology can also be used between 4G and 5G base stations.

Previously, LG U+ used a laboratory environment to verify the technology between 4G base stations. This time LG U+ and Huawei successfully completed the verification between 5G base stations, and also set up a foundation for future 4G to 5G Dual-Connectivity in a 4G to 5G heterogeneous network. The partners will continue to carry out 5G technical cooperation and verification, to meet the arrival of the commercial launch of 5G.

Kim Dae Hee, managing director of LG U+ 5G Strategy, said, "By demonstrating Dual-Connectivity technology, which will play a key role in multi-operation of 4G and 5G wireless base stations, we will develop various next-generation technologies to provide a 5G service."

ETSI Adopts CCC's MirrorLink Technical Specification

The Car Connectivity Consortium (CCC) and the European Telecommunications Standards Institute (ETSI) announced the publication of the MirrorLink® Specification, as an ETSI Technical Specification—the TS 103 544 series. Developed by the CCC, MirrorLink is an open standard for smartphone-car connectivity that allows smartphone apps to be projected on car In-Vehicle Infotainment (IVI) systems.

"MirrorLink's ability to safely connect smart phones to vehicle displays makes it a compelling addition to ETSI's portfolio," said Niels Peter Anderson, ETSI ITS chairman. "We have released the MirrorLink specification through our ETSI Publicly Available Specifications process, which enables specifications from industry bodies to benefit from the increased recognition and visibility of an ETSI Technical Specification."

The CCC developed MirrorLink in collaboration with cross-industry stakeholders including car OEM, tier-1 suppliers, phone manufacturers and app developers. MirrorLink gives smart devices a robust and streamlined, wired and wireless mechanism for presenting apps on IVI systems. Consumers have access to smartphone apps in a responsible way, while conforming to industry guidelines to minimize driver distraction by using voice, touch and rotary knob inputs. MirrorLink is already deployed in hundreds of millions of smart phones and millions of vehicles.

TEST CABLES *up to 40 GHz!*

Reliability You Can Trust... *from* $68.95 ea. (qty.1-9)

Why do 10,000 customers trust Mini-Circuits test cables? Because they simply don't fail! Our test cables have been performance qualified to 20,000 flexures* and come backed by our 6-month product guarantee**, so you can be confident you're getting rugged construction, reliability, and repeatable performance you can depend on. Whether you're performing production test, burn-in, over-temperature testing, hi-rel testing – you name it – chances are there's a Mini-Circuits test cable for your application in stock, ready for immediate shipment. Order some for your test setup at minicircuits.com today, and you'll quickly find that consistent long-term performance, less retesting and fewer false rejects really add up to bottom-line savings, test after test!

Model Family	Capabilities	Freq. (GHz)	Connectors†
KBL	Precision measurement, including phase, through 40 GHz	DC-40	2.92mm
CBL-75+	Precision 75Ω measurement for CATV and DOCSIS® 3.1	DC-18	N, F
CBL	All-purpose workhorse cables for highly-reliable, precision 50Ω measurement through 18 GHz	DC-18	SMA, N
APC	Crush resistant armored cable construction for production floors where heavy machinery is used	DC-18	N
ULC	Ultra-flexible construction, highly popular for lab and production test where tight bends are needed	DC-18	SMA, N
FLC	Flexible construction and wideband coverage for point to point radios, SatCom Systems through K-Band, and more!	DC-26	SMA, N
NEW! SLC	Super-flexible spaghetti cables with 0.047" diameter and 0.25" bend radius, ideal for enviromental test chambers.	DC-18	SMA
VNAC (M to F)	Precision VNA cables for test and measurement equipment through 40 GHz	DC-40	2.92mm

* All models except VNAC-2R1-K+

** Mini-Circuits will repair or replace your test cable at its option if the connector attachment fails within six months of shipment. This guarantee excludes cable or connector interface damage from misuse or abuse.

† Various connector options available upon request.

Contact apps@minicircuits.com to discuss your special requirements.

Mini-Circuits®

Enterprise Wearables Forecasted to Reach 118 Million Shipments in 2022

ABI Research forecasts that enterprise wearable shipments will reach over 118 million in 2022, increasing from just over 38 million in 2017, a CAGR of 25 percent. The enterprise wearables market is continuing to see stronger growth than the consumer market, which has shipment numbers increasing at a lower CAGR of 13 percent. Healthcare devices, wearable cameras and wearable scanners will account for 73 percent of enterprise wearable shipments in 2022. Innovative companies are leading the charge, such as Royole with flexible components, Waverly with real-time translation and Axon (previously Taser) with wearable cameras.

"Despite currently having lower shipment numbers, enterprise wearables are growing at a much stronger rate than consumer devices," says Stephanie Lawrence, research analyst at ABI Research. "These devices provide users across all industry verticals with hands-free access to information and communication, enabling them to become more productive."

> Enterprise wearables are growing at a much stronger rate than consumer devices.

Healthcare devices are the dominant enterprise wearable device type due to the significant benefits that they provide within the healthcare industry, such as the ability to remotely monitor many patients' vitals at one time. The devices account for 30 percent of enterprise wearable device shipments, as the healthcare industry vertical requires a large number of the devices for the continuously growing number of patients.

Wearable cameras and scanners are other dominant device types. Wearable cameras are particularly strong in the government and military industry vertical which accounts for 26 percent of the device shipments. This is mostly due to the devices' ability to record information, for example, police officer activity, which can then be used as indisputable evidence. Wearable scanners account for 37 percent of the shipments. Wearable scanners aid workers, particularly those in warehouses and manufacturing, by granting the ability to scan barcodes while they work and improving productivity as they do not have to pick up and put down a separate device.

"Enterprise wearable device usage is continuously on the rise because more and more companies are understanding the benefits of deploying the devices to specific tasked workers," concludes Lawrence. "Return on Investment potential is continually shown, and key performance indicators are proving positive. This will continue to cause enterprise wearable shipments to rise at a higher rate than consumer wearable shipments, where the devices productivity improvement benefits do not have the same impact."

Start-Ups are the Rising Stars of 5G

Mobile networks are evolving in an end-to-end way to address the challenges and opportunities facing the mobile network operators (MNO). The next three to four years will witness mobile networks evolve in a way that is more transformational than was the shift to IP in mobile networks.

"Traditionally operators have deployed a handful of infrastructure vendors in their networks, especially in the core network. Stagnating average revenue per user and increasing network traffic are driving operators to be more cost-effective and innovative in network performance and operations management and network upgrades. The end-to-end digital transformation toward virtualized and software defined networks is creating the opportunity for operators to open their highly proprietary networks and vendor ecosystem to include innovative start-ups," says Prayerna Raina, senior analyst at ABI Research.

As the industry progresses toward the standardization and the launch of 5G in the 2019-2020 timeframe, operators need to address some key network performance and traffic management issues now. Technology trends that address these challenges today and also lay the groundwork for 5G in future include: the application of virtualization and software-defined networking technologies to mobile networks; the evolution of the mobile edge to improve customer quality of experience (QoE) and the creation of monetization opportunities for the operator; the growing need for an effective self-organizing network (SON) solution; and the use of Big Data analytics to leverage granular network data to enhance network performance. Athonet, CellWize, CellMining, AirHop Communications, Core Network Dynamics, Blue Danube, Vasona Networks are a few examples of the start-ups that are poised to challenge the status-quo in the telecom industry.

> Opportunities created by the end-to-end digital transformation toward virtualized and software defined networks.

"The telco start-ups are challenging the incumbents in every way. From the flexibility of the solution to value-added services and a strong R&D focus, these companies are not just innovative, but also reflect an understanding of telco operators' operational models as well as revenue and network performance challenges. With strong financial backing and active engagement with major partners in their ecosystem, these start-ups have proven their ability to meet operator requirements in tests and field deployments," concludes Raina.

System Integrators Quickly Becoming the IoT Gatekeepers

Enterprises that are looking to address the challenges of building end-to-end Internet of Things (IoT) solutions are increasingly turning to System Integrators (SI) as partners to take on leading, client-facing roles to implement these solutions. ABI Research forecasts that IoT system integration and consulting revenues will grow past $35.7 billion in 2022 from just under $17 billion in 2017 at a CAGR of 16.1 percent. SI specialists address the challenges the IoT poses due to their vast experience integrating legacy systems into end-to-end solutions, their knowledge of the IoT landscape and players in the market and their existing relationships with enterprises and end-users.

"The core responsibility of a system integrator is to fill the gap between solution providers and targeted market verticals," says Ryan Harbison, research analyst at ABI Research. "As such, SIs have a deep knowledge not only of enterprise pain points and issues, but also of specific applications and the business as a whole."

SIs are becoming essential partners in many IoT partner program ecosystems due to their expertise in integrating IoT solutions across specific vertical markets and regions. SIs range from global system integrators (GSI) and consultancies like Accenture, Deloitte and PricewaterhouseCoopers to IT service system integrators like IBM and HP. GSIs like Accenture have stayed ahead of the curve in IoT primarily by addressing client demand for connected solutions and by understanding the value behind enterprise digital transformation and technology convergence. Technology services providers such as Altimetrik and Leverege have delivered value to their clients by offering extensive knowledge and expertise within particular vertical market segments.

"End-users are less concerned with the features of a various device or software platform and are more concerned with how their IoT solutions work as a whole to truly become a system of systems," concludes Harbison. "Enterprises looking to develop IoT solutions may not contact hardware or software vendors and instead rely on the advice of a SI to navigate the marketplace to find solution components that deliver a full solution. Moving forward, it's crucial for software and hardware providers to develop deep relationships with a range of SIs that provide vertical-specific solutions to end-users."

Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Northrop Grumman Corp. and **Orbital ATK Inc.** announced they have entered into a definitive agreement under which Northrop Grumman will acquire Orbital ATK for approximately $7.8 billion in cash, plus the assumption of $1.4 billion in net debt. Orbital ATK shareholders will receive all-cash consideration of $134.50 per share. The agreement has been approved unanimously by the boards of directors of both companies. The transaction is expected to close in the first half of 2018 and is subject to customary closing conditions, including regulatory and Orbital ATK shareholder approval.

PowerSphyr Inc. announced that it has successfully completed its acquisition of original design manufacturer, **Gill Electronics**. Based in Grand Rapids, Mich., Gill Electronics is led by wireless power industry veterans and is a member of the board of the AirFuel™ Alliance. Gill Electronics is one of the only manufacturers of resonant magnetic systems to have deployed both AirFuel™ and FCC-approved products into the commercial infrastructure market. The combined organization will now be the world's leading wireless solutions provider offering advanced near field and far field solutions in a wide range of applications and industries and has built the first product to bridge the Qi and AirFuel™ Resonant standards.

AVX Corp. announced that it has completed the acquisition of the previously announced acquisition of the **Transportation, Sensing and Control (TS&C) division of TT Electronics, PLC**, a U.K. company, for approximately £118.8 million (approximately $156 million) in cash, subject to customary post-closing adjustments based on the actual net debt and actual working capital of the target companies. The purchase comprises TS&C's manufacturing subsidiaries located in Austria, China, Germany, India, Mexico, Romania, South Korea, the U.K. and the U.S., including R&D, manufacturing and sales office locations.

Tetra Tech Inc. announced that it has acquired **Glumac**, a leader in sustainable infrastructure design. The company has more than 300 employees and incorporates innovative sustainable technologies and solutions into each of its designs, including the design and engineering of Leadership in Energy and Environmental Design (LEED) standard and Net-Zero infrastructure.

Vance Street Capital LLC announced the acquisition of two manufacturing facilities and related operations located in Wall Township, N.J. from **W. L. Gore & Associates** forming a new company named **Fermatex Vascular Technologies LLC**. Gore associates working at these facilities will transfer employment to the new company. The Wall Township operation—originally known as Adam Spence Corp.—was part of the Medical Products Division of Gore, a global materials science company dedicated to transforming industries and improving lives. The acquired facilities design and manufacture high pressure braided tubing and extrusions, and assembly/molding for the medical industry.

COLLABORATIONS

Keysight Technologies Inc. announced the collaboration with **Bluetest** on the successful creation of a narrowband-Internet of Things (NB-IoT) over-the-air (OTA) solution for use in Bluetest Reverberation Test Systems (bluetest.se/products/chambers). The solution, used by one of Japan's top operator customers, demonstrates the market leading position of both companies in NB-IoT test. NB-IoT technology uses existing cellular network infrastructure to deliver excellent coverage and reliable connectivity. This approach is becoming adopted by major worldwide operators. The OTA test is critical for operators to qualify the interoperability and compliance of their NB-IoT devices.

Qorvo announced that it has entered into a channel partnership with **Veterans Trading Company (VTC) LLC**. VTC provides a full suite of customized, end-to-end supply chain services and solutions, including supplier managed inventory and point-of-use management; procurement support; and maintenance, repair and operations support. The company has been recognized with industry awards, and has forged strategic partnerships with several prominent aerospace business organizations, including Lockheed Martin, Boeing and BAE System. VTC was named a Top 10 Service-Disabled Veteran-Owned Small Business in the U.S.

Undersea warfare experts at two of the nation's largest defense contractors are designing prototype extra-large unmanned underwater vehicles (UUV) with the potential to undertake long-endurance missions to deploy sensors or other UUVs. Officials of the **U.S. Naval Sea Systems Command** in Washington awarded contracts last week to the **Lockheed Martin Rotary and Mission Systems** segment in Riviera Beach, Fla., and to the **Boeing Defense, Space & Security** segment in Huntington Beach, Calif., to design the Orca Extra Large Unmanned Undersea Vehicle (XLUUV) system.

ZTE announced that Lixin Cheng, CEO of ZTE Mobile, spoke at the **U.S.-China Summit** during Mobile World Congress Americas (MWCA) 2017. Lixin Cheng shared ZTE's successful experience working in the U.S. and China on 5G, and provided an outlook of the future of collaboration through innovation which is expected to benefit not only China and the U.S., but the world as a whole. In the Internet industry, China has 771 million Internet users, of which 695 million are mobile Internet users. By comparison, the U.S. has 286 million Internet

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

users, including 225 million mobile Internet users. This huge amount of consumer demand in the telecommunication and Internet services requires further collaboration between both countries.

Arrow Electronics Inc. and **Cypress Semiconductor Corp.** announced the Titanium board, a technology ecosystem designed to enable developers to create products using Wi-Fi®, Bluetooth® Low Energy (BLE), cellular and LPWAN technologies, while taking advantage of Cypress' low-power edge. The new Titanium board is designed to the Linaro 96Boards IoT edition specification, and features Cypress' new PSoC® six microcontroller (MCU) with dual-core processing and BLE 5.0. With power provided by the Cypress EZ-PD™CCG3 USB-C controller, Titanium also provides developers with advanced sensing capabilities featuring Bosch Sensortec's new BME680 integrated environmental sensor for measurement of gas, humidity, temperature and pressure.

SparkCognition has announced a new engagement with the **British Army**, providing collaborative thought leadership on the role of artificial intelligence (AI) in future warfare. Specifically, the AI company's defense team will consult with the British Army on the role of machine learning in military applications and contribute to research on future military planning. This partnership focuses on how operations can be streamlined using AI technologies today. Ranked #20 on the 2017 CNBC Disruptor 50 list, SparkCognition has established itself as an AI technology leader. The company has business-critical cognitive enterprise solutions in place for customers in energy, oil and gas, manufacturing, finance, aerospace, defense, telecommunications and security.

ACHIEVEMENTS

Belden Inc. received two Innovators Awards this year from Cabling Installation & Maintenance: a Gold award for its 4K UHD Media Cables and a Silver award for its Fiber-Express Enterprise Closet X Patch Panel System. The Cabling Installation & Maintenance 2017 Innovators Awards program reviews and recognizes the most innovative applications of cabling and communications technology products and systems within the structured cabling industry. Platinum, Gold and Silver Honorees were announced at BICSI's 2017 Fall Conference on September 25, 2017. Criteria used in the Innovators Awards ranking included: innovation, value to the user, sustainability, meeting a defined need, collaboration and impact.

Ampleon, a leading manufacturer of LDMOS and GaN RF power products acknowledged their RF focused distributor, **RFMW Ltd.** with an award for Distribution Partner of the Year at RFMW's Global Sales Meeting in Las Vegas, Nev.

nanoPrecision Products has announced that it has received AS9100D/ISO 9001:2015 certifications from

the independent certifying body, Perry Johnson. The AS9100D and ISO 9001:2015 certifications confirm that the company's quality system meets all quality and safety requirements specific to the aerospace industry. nanoPrecision Products' agility in moving to this new, more robust set of certifications makes it one of the first companies serving the aerospace industry to qualify under the new standards. Achieving these new certifications at this time provides nanoPrecision Products with readiness to serve aerospace and technology-driven companies with its breakthrough products in 2017 and beyond. Both certifications are required for securing major contracts from companies in each sector.

Teledyne Technologies Inc. announced that Teledyne Brown Engineering's Multi-User System for Earth Sensing (MUSES) aboard the International Space Station (ISS) has achieved full operating capability (FOC). MUSES was developed as part of a cooperative agreement with NASA to create opportunities for both government and commercial applications such as imaging, technology demonstration and space qualification payloads supporting research, scientific studies and humanitarian efforts. MUSES provides a precision-pointing environment on the ISS for earth-viewing instruments, such as high-resolution digital cameras and hyperspectral imagers. It can accommodate up to four payloads simultaneously and offers the ability to robotically change, upgrade and service those instruments.

Avnet announced it has been awarded a 2016 Total Cost of Ownership (TCOO™) Supplier Award from Celestica, a leader in design, manufacturing and supply chain solutions for the world's most innovative companies. Celestica's awards program recognizes suppliers that provide the best TCOO performance to Celestica and support the company's overall business objectives. Celestica's TCOO Supplier Awards program evaluates and recognizes the top performers in Celestica's global network of over 4,000 suppliers. Celestica's TCOO system is focused on evaluating supplier performance by measuring the total cost to produce, deliver and support products and services beyond the supplier invoice price.

CONTRACTS

The Raytheon Co. racked up orders worth more than half a billion dollars to build radio-controlled anti-tank missiles for the militaries of Lebanon, Jordan, Morocco, Saudi Arabia, Thailand and Bahrain. Officials of the **Army Contracting Command at Redstone Arsenal**, Ala., announced a $300.1 million contract and a $292.4 million order to the Raytheon Missile Systems segment in Tucson, Ariz., to build the Tube-Launched, Optically-Tracked, Wireless-Guided (TOW) munition—better-known as the TOW missile. These new orders follows a $31.5 million TOW missile order on September 15 for the U.S. Army and for the military forces of Saudi Arabia

and Lebanon. Thursday's orders collectively are worth $592.6 million.

Harris Corp. has received a $260 million order to develop an integrated tactical communications network as part of an Asia-Pacific country's modernization program. The order was received in the first quarter of fiscal 2018. The integrated network solution will include tactical radios, network planning, monitoring and routing software, and other systems and technology from Harris and partnering companies. The solution will feature Harris' Falcon III® AN/PRC-158 multi-channel manpack radios and vehicular amplifiers and provide voice and data services to tactical forces for line-of-sight and beyond-line-of-sight applications.

PCX Aerostructures LLC recently received two indefinite-delivery/indefinite-quantity (IDIQ) contract awards from the **U.S. Department of Defense (DoD)** for production as well as overhaul and repair of Boeing AH-64 Apache helicopter components over a five-year period. As a major supporter of the Apache helicopter program for over 30 years, PCX will manufacture new main rotorheads for the U.S. Army on a contract with a total value of $72.3 million. The longtime aerospace manufacturing company, known globally for its advanced precision machining and complex assembly capabilities, has also secured a U.S. Army contract for Apache main rotorhead overhaul and repair services valued at $63.9 million.

Telos® Corp. announced it has been awarded a two-year, $34 million contract to modernize the Base Information Transport Infrastructure (BITI) Wireless Local Area Networks (WLAN) for the **U.S. Air Force**. The work will be completed under a Network Centric Solutions-2 Small Business task order at all worldwide active duty bases and specified Guard and Reserve bases. At each BITI Wireless location, Telos will replace the current network access control (NAC) appliances and upgrade the WLAN components and operating systems. The NAC and WLAN components will be integrated into the Hanscom Collaboration & Innovation Center to support a full cybersecurity certification and accreditation effort.

Allied Motion Technologies Inc. announced that it received a $6.8 million order for motors and other related products to control azimuth and elevation on a defense application. Revenue will be equally spread out over a three-year period at an estimated average of $2.2 million to $2.3 million per year. Production is expected to start in the latter part of the 2017 fourth quarter and be at full production levels within the first quarter of 2018.

Mercury Systems Inc. announced it received a $5.3 million follow-on order from a leading defense prime contractor for high-performance GPS Selective Availability Anti-Spoofing Modules (SAASM) for a precision guided munitions program. The order was booked in

the company's fiscal 2018 first quarter and is expected to be shipped over the next several quarters. The company's industry-leading portfolio of commercial microelectronics include SWaP-optimized and highly ruggedized components and modules tailored to defense industry requirements. By leveraging a heritage of precision engineering expertise, these compact solutions deliver highly differentiated performance without sacrificing affordability or security.

Humacyte announced that the company has received a Broad Agency Announcement (BAA) contract award of $3.4 million from the **U.S. Department of Defense (DoD)**. The funding will help support the addition of clinical sites for Humacyte's Phase II vascular trauma trial in the U.S. The trial is being conducted to study Humacyte's investigational human acellular vessel (HAV), or HUMACYL®, to treat patients with traumatic vascular injuries from violent civilian or military events, such as automobile crashes, industrial accidents or injuries of war.

Defence and security company **Saab** has signed a contract for delivery of the Giraffe 1X surface radar system, but due to a confidentiality arrangement with the customer, no further details can be revealed. Giraffe 1X is a flexible and agile 3D active electronically scanned array (AESA) radar, featuring the latest in radar technology, including GaN circuits. Compact and lightweight with what is claimed to be unparalleled performance, Giraffe 1X is suited for changing needs and mobile forces. The complete radar is portable and can be transported on a vehicle the size of a pickup truck.

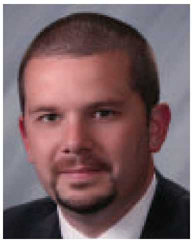
The Antenna Systems Division of Communications & Power Industries (CPI) has been awarded a multi-year contract to provide hundreds of advanced antenna products for a novel satellite system that will provide global coverage. The CPI Antenna Systems Division will design and manufacture Ka-Band satellite gateway and telemetry, tracking and control (TT&C) antennas to support the system. These antennas will combine the proven Ka-Band technology of CPI Antenna Systems Division's ASC Signal product line with the high-precision tracking system of its Malibu product line, providing state-of-the-art technology that demonstrates the breadth and depth of CPI Antenna System Division's portfolio of antenna products.

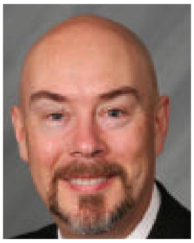
PEOPLE

▲ *Gregg Lowe*

Cree Inc. announced the appointment of **Gregg Lowe** as the new president and chief executive officer succeeding Chuck Swoboda. Lowe brings significant semiconductor experience to Cree, serving as president and CEO of Freescale Semiconductor from 2012 until 2015, when it was acquired by NXP. Prior to leading Freescale, he spent 28 years in vari-

ous roles at Texas Instruments (TI), including leading TI's analog semiconductor business. One of Cree's businesses is Wolfspeed, which comprises SiC and GaN materials and devices for RF and power electronics. From his tenure at Freescale, Lowe has some experience with RF power applications, as Freescale led the industry in LDMOS, particularly for wireless infrastructure.

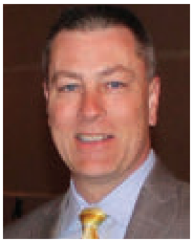

▲ *Brian Reid*


▲ *Rick Short*

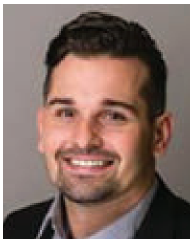

▲ *Dawn Roller*


▲ *Bill Jackson*

Indium Corp. has expanded the responsibilities of its global leadership team with the promotion of several top executives. **Brian Reid** serves as vice president of Global Operations, **Rick Short** is now corporate associate vice president and senior director of Marketing Communications, **Dawn Roller** has been named associate vice president of Human Resources and **Bill Jackson** has been appointed senior director and general manager of the Compounds Business Unit and Korean Operations.


▲ *Mark Perhacs*

3D Glass Solutions Inc. announced the appointment of **Mark Perhacs** as director of Sales and Marketing. Perhacs joins 3DGS with more than 25 years of sales and marketing experience and with an extensive background in RF and microwave technology markets. As a member of the Publisher's Council for the *Microwave Product Digest* publication, Perhacs also serves as an advisor for RF and microwave design and application engineers. In this new position, Perhacs will oversee all of the company's sales and marketing functions, reporting directly to Jeb Flemming, president and CEO.


▲ *Jeremy Wischmeyer*

Southwest Antennas has announced that **Jeremy Wischmeyer** has joined SWA as their new inside sales manager. Most recently serving as operations manager of Green Volt Energy, a renewable energy solutions provider in Southern California, Wischmeyer brings extensive customer service and technical skills to their team in support of the company's diverse customer base and markets.


EuMW 201
A PRIME YEAR FOR A PRIME EVENT
We Are Qorvo
KEYSIGHT TECHNOLOGIES


testing
Platinum Sponsor:
KEYSIGHT
TECHNOLOGIES
17 Exhibition
ANALOG
DEVICES
1000+ WAYS TO DRIVE RF AND MICROWAVE PERFORMANCE
Interactive Session
Wolfspeed
A CREE COMPANY
Delivering the broadest, most field-tested and fully commercialized GaN RF device portfolio and foundry services.
Experience The
Wolfspeed Difference

INVITED PAPER

Digitizer-Based Measurement Trade-Offs for Electronic Attack Systems

Brad Frieden
Keysight Technologies Inc., Santa Rosa, Calif.

A pilot's ability to maneuver out of harm's way depends on the seconds that elapse between detection, identification of an enemy missile's radar signal and the jamming response from the aircraft's electronic attack (EA) system. A designer's confidence in the integrity of that EA system is based, in part, on the ability to capture related RF signals using measurement equipment with sufficient dynamic range, instantaneous bandwidth and capture time to validate the radar/jammer signal interaction. These tests are often performed in a lab environment. This article describes digitizer capture methods, including raw and digital down-conversion (DDC), comparing the key trade-offs for making essential validation measurements: dynamic range, bandwidth and capture time.

One basic jamming technique is called range gate pull off (RGPO). The idea is that an EA system aboard an aircraft reacts to the received radar tracking pulses by creating and sending jamming pulses back to the radar. The goal is to deceive the radar and cause it to break range tracking, so it is unable to launch a surface-to-air missile (SAM). Or, if a missile is launched, the goal is to cause the radar to break range tracking in such a way that the missile veers off its target and is unable to harm the war fighter and aircraft. With RGPO, large jammer pulses are first placed "on top" of the radar skin return pulses at the radar receiver; then, the jammer pulses "walk away" from the radar skin return pulses, causing the radar range gates to follow the jammer pulses instead of the real radar reflection. Finally, the jammer pulses vanish, causing the radar to lose the range of the target (see ***Figure 1***).

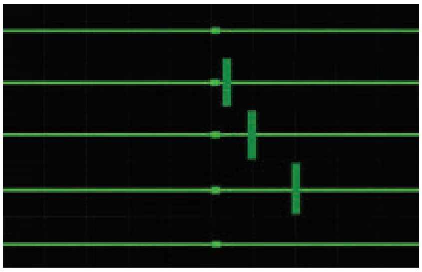


Fig. 1 In range gate pull off, large jammer pulses move away from the smaller radar reflection signal and then vanish.

When designing a radar RGPO jamming system, several SAM radar parameters must be understood for the EA to be effective. These include:

- FM chirp of the particular modulation width
- Carrier frequency and whether it hops
- Pulse repetition interval (PRI) and whether it dithers
- Pulse width
- Transmit power
- Antenna boresight gain.

While the missile's travel time and distance to a possible target vary across scenarios, these are also important to consider. A reasonable example is that a missile could take approximately 20 s to reach a target 10 km distant.

An important step when designing RGPO jamming systems is considering the expected radar skin return signal at the radar receiver. The jammer is then designed to create signals 6 to 20 dB larger in amplitude. The open literature describes the derivation and use of the radar range equation and calculations of skin return power levels. Several factors are part of the calculation, and simple equations have been developed for easy calculation of the power level in dBm.[1]

$S = -103 + ERP_r - 40\log(R) - 20\log(F) + 40\log(\sigma) + G$

where

S = Skin return power at the radar receiver in dBm

ERP_r = radar effective radiated power toward the target

R = range from the radar to the target in km

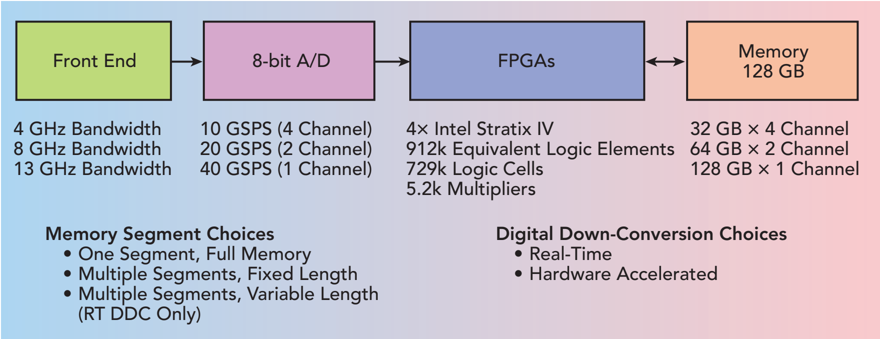
F = radar transmitting frequency in MHz

σ = radar cross section of the target in m^2

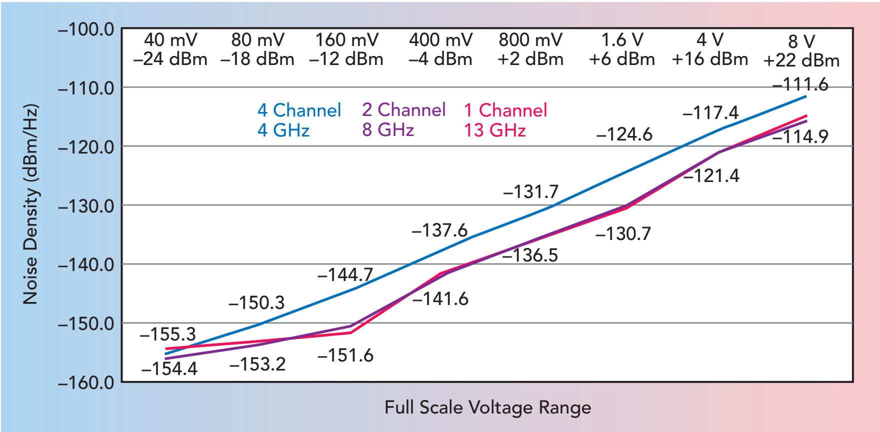
G = main beam boresight gain of the radar antenna in dB

The formula contains a constant, -103, which combines various conversion factors, allowing inputs for the variables to be in the most convenient units.

As an example, consider the return signal level from a target 10 km from the radar, with the radar's carrier frequency at 3 GHz. Typical values found in the open literature are used for the other factors or derived from related information found in the literature. Calculations based on a range of typical values yield power levels from around -45 to -65 dBm at the SAM tracking radar receiver. Jammer pulses would be designed to be up to 20 dB stronger at the radar receiver; with the skin return pulses at -65 dBm, the jammer pulses would need to be at -45 dBm.



▲ **Fig. 2** Wideband 8-bit digitizer technology.

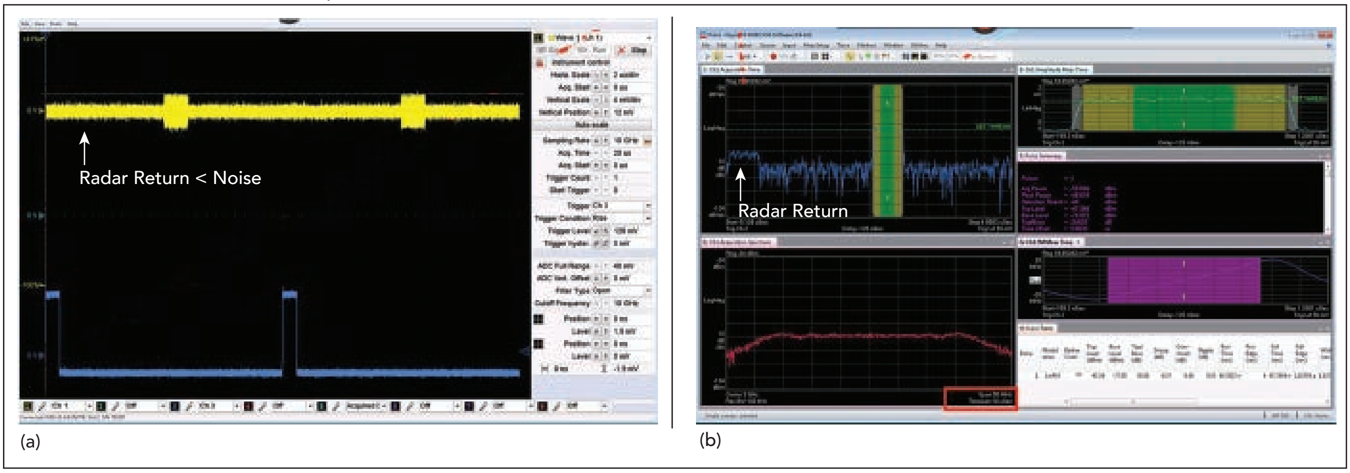


▲ **Fig. 3** Noise density for 4, 8 and 13 GHz bandwidth digitizers.

USING A DIGITIZER

Can a digitizer be used to measure the signals to validate a jammer? The answer is "it depends." Answering the question requires evaluating the trade-offs among bandwidth, sensitivity and the target time during which the pulses need to be captured. For this example, in addition to having a 3 GHz carrier, assume the radar and jamming signals have a 40 MHz wide FM chirp modulation, with a 1 μsec pulse width and 10 kHz PRI. It is helpful to observe a handful of RGPO jamming cycles, where the jamming pulses walk the radar range gates away from the real radar reflection pulses. Each RGPO cycle lasts around 10 s, so it is important to capture, observe and analyze the radar skin return and jammer pulses for about 60 s.

Modulation bandwidth, pulse width, PRI and total pulse capture time are factors that determine whether a digitizer can measure such pulses for EA validation. The digitizer technology, shown in ***Figure 2***, can achieve the bandwidths, sample rates and FPGA processing power for signal processing like



▲ **Fig. 4** With 4 GHz digitizer bandwidth, noise obscures the radar skin return (a). Using digital down-conversion to reduce the bandwidth to 50 MHz, both the radar skin return and jammer pulses are visible (b).

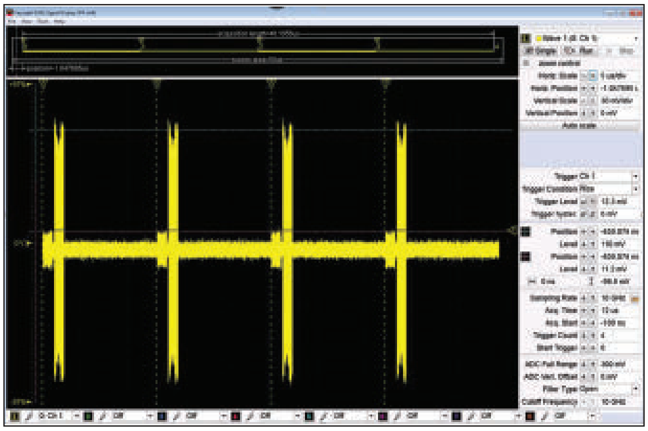


Fig. 5 Raw 10 GSPS capture with 12 µsec wide segments and 4 GHz digitizer bandwidth.

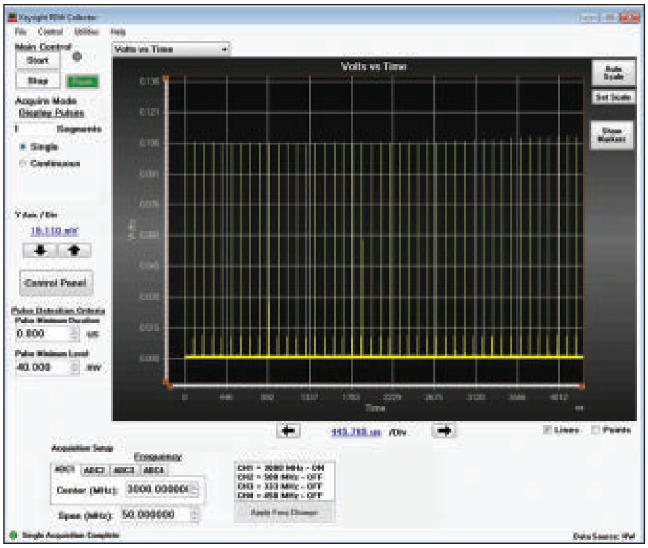


Fig. 6 Single segment capture using real-time DDC with a 50 MHz span.

DDC, which will be instrumental in achieving the desired 60 s pulse capture period. Another key digitizer capability is noise density and the sensitivity possible when using various digitizer models and capture modes. When operated at full bandwidth, each digitizer model has a certain rms noise level for each sensitivity setting. These rms noise levels can be converted into power levels in dBm, then scaled to a 1 Hz measurement bandwidth using the following calculation:

Noise density (dBm/Hz)= 20log $((V_{rms} * 2.83V_{pp}/V_{rms})/0.632V_{pp})$ – 10log(Full Bandwidth)

This is handy, since 1 Hz measurement bandwidth noise density values can easily be converted into noise levels for any desired measurement bandwidth. The noise density for three digitizer models is shown in ***Figure 3***.

In the example where the radar and jammer pulses have a 3 GHz carrier and are 40 MHz wide, a 4 GHz model digitizer can be used to sample the signals. Since both radar and jamming pulses need to be measured, the sensitivity must allow the input range to be larger than the -45 dBm jammer pulse level, to prevent the jammer pulses from being clipped. That allows the highest sensitivity of 40 mV full scale to be used with its corresponding -155.3 dBm/Hz noise density. Calculating the noise that would be present if the full 4 GHz bandwidth was used:

Noise dBm (Measurement Bandwidth Span) = Noise Density + 10log(Measurement Bandwidth Span)

For the example, at 40 mV full scale using a 4 GHz system at full bandwidth:

Noise dBm (@ 4 GHz Span) =
-155.3 dBm + 10log(4×10^9) =
-155.3 dBm + 96 dB = -59.3 dBm.

So, at a full 4 GHz bandwidth, the noise would be greater than the -65 dBm radar reflection pulse. This is where DDC comes into play. The signals only had a 40 MHz FM chirp spectral width, so DDC can be used to reduce the measurement span to something slightly wider than the signals. 50 MHz would work well. Considering the noise level in a 50 MHz measurement bandwidth at

8 mV full scale and using a 4 GHz system:

Noise dBm (@ 50 MHz span) =
-155.3 dBm + 10log(0.05 × 10^9) =
-155.3 dBm + 76.9 dB = -78.3 dBm

Theoretically, the noise would now be less than the -65 dBm radar skin return.

A measurement can prove this. Radar skin return and jammer signals can be emulated using an arbitrary waveform generator driving the wideband I/Q inputs of a vector signal generator, with measurements at the full 4 GHz bandwidth and then with a 50 MHz span (see ***Figure 4***).

HOW MUCH DATA?

After showing that a digitizer can be used to measure the signals necessary to validate a jammer, the next question is whether every radar and jammer pulse can be captured over the 60 s period. Again, the answer is "it depends." The 4 GHz bandwidth digitizer running at 10 GSPS and with 30 GB of memory available for capture equates to only 3 s of capture time. Two ways to increase the time over which pulses are captured are using segmented memory and DDC.

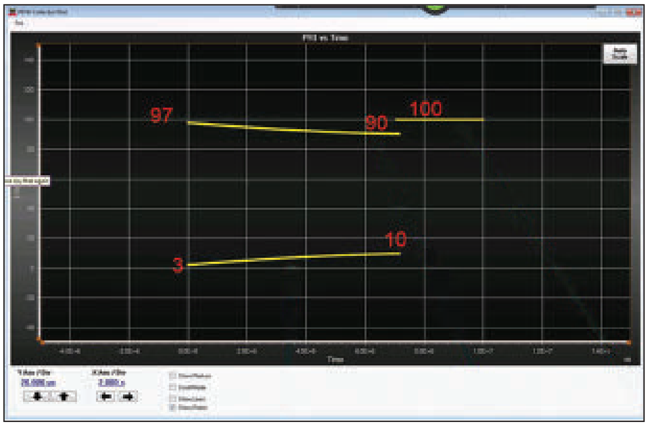
The RGPO example uses jammer pulses that walk away from radar reflection pulses for about a 10 μs period, then vanish for a few seconds until the radar gains range lock again. Then the jammer starts walking jammer pulses away from the radar reflection pulses. By using a capture mode called segmented memory, where capture begins with a trigger event and samples are captured for a fixed period, it is possible to capture the radar and jammer pulses as they interact. Capture is then turned off during the long period where no pulses are present during the 100 μs PRI. With a raw 10 GSPS capture and 100 ps sample point spacing, where 15/16 of the on-board 32 GB memory is available, the time that the digitizer can capture pulses is calculated as follows:

segments = (30 GB/10 GSPS)/
(12 μs/segment) = 250k segments

Time = 250k segments × 100 μs PRI
= 25 s

Over a 25 s period, one could see a couple RGPO cycles, but not the desired 60 s of engagement. There is also the issue of the high noise level using the full 4 GHz of bandwidth. ***Figure 5*** shows a capture using segmented memory and 12 μs segments, but with much larger input signals than previously calculated for the radar reflection and jammer pulses. With the signal levels expected at the radar receiver, the digitizer noise would have obscured the small radar reflection signals.

A feature called real-time DDC can narrow the span to both reduce noise and greatly utilize the memory by storing the I and Q data with a much lower sample rate than the original 10 GSPS voltage point samples. Using 50 MHz of instantaneous bandwidth to capture the 40 MHz wide signals, the 10 GSPS captured data is processed immedi-



▲ **Fig. 7** **Proper RGPO radar to jammer pulse timing relationships plotted and verified.**

ately by the FPGAs into 62.5 MSPS I and 62.5 MSPS Q data (125 MSPS total), resulting in 16 ns spaced I and Q sample pairs. The capture time is calculated as follows, knowing that with real-time DDC, one half of the digitizer on-board memory is available for I/Q samples:

Continuous capture = ((1/2)*(32 × 10^9 samples))/125 × 10^6 samples/s = 128 s

Figure 6 shows a single 400 ms segment of a 50 MHz wide real-time DDC capture.

Newer radars are using wider chirp bandwidths. If the radar has a 450 MHz wide chirp, and the measurement span is increased to accommodate this, then the capture time will scale by the ratio of the 50 and 450 MHz bandwidths, or roughly 10:1. So pulses will only be captured over a 13 s period. By using real-time DDC plus segmented memory, capturing RF pulses over the desired 60 s period would be possible with up to 488 MHz instantaneous bandwidth, limited primarily by FPGA processing power. In fact, pulses could be captured over a 100 s period:

segments = (½ * 32 GB/1.25 GSPS)/(12 µs/segment) = 12.8 s/(12 µs/segment) ≥ 1M segments

With a 100 µs radar PRI, the total time over which pulses are captured is

1M segments * 100 µs/segment = 100 s

But nothing comes for free. At this wider 488 MHz measurement bandwidth, it may again become difficult to pull weak -65 dBm radar reflection pulses out of the higher noise level.

A measurement of radar reflection and jammer pulses is shown in ***Figure 7***, where every radar/jammer pulse pair is placed into 12 µs long segments over a 10 s period, and PRI timing relationships are calculated and plotted to verify RGPO operation over that time. The number of segments is set to 100,000 to capture every pulse over a 10 s period (100,000 × 100 µs PRI = 10 s). A logical graph of the PRI calculations is shown, with a resultant PRI curve that changes from 3 to 10 µs in the bottom trace, as the jammer pulses pull away from the radar pulses. Then a fixed 100 µs PRI is seen once the jammer pulses disappear and only the radar pulses are present. This 10 s capture period began slightly after the radar and jammer pulses had already separated by a few µs.

The real-time DDC mode has the further advantage that data can be streamed to an external RAID array, only limiting the time capture by the size of RAID array. In cases where input signals go beyond the DC to 4 GHz input range of the four channel digitizer model, DDC is still possible on 8 and 13 GHz bandwidth models using hardware-accelerated DDC. For applications where a DDC measurement is needed with greater than the 488 MHz instantaneous bandwidth offered with real-time DDC, hardware-accelerated DDC is an option. Hardware-accelerated DDC can be used with 4, 8 and 13 GHz bandwidth digitizers and offers higher measurement bandwidth span settings, up to 1.9, 3.9 and 7.8 GHz, respectively. Hardware-accelerated DDC can also be used to speed up DDC processing when using vector signal analyzer software. But hardware-accelerated DDC has a drawback: it cannot be streamed to RAID, limiting the capture of I/Q samples to the digitizer's on-board memory.

TABLE 1

EXAMPLES AND TRADE-OFFS

Capture Mode (DC to 4 GHz Input Range)	Example Instantaneous Bandwidth	# Segments, Chosen Segment Length	On-Board Capture Time (s)	Use with VSA / PDW Collector	Noise Level (dBm)	Stream to RAID
Raw	4 GHz (Max)	1 Fixed, Max Memory	3	Yes/No	-59.3	Raw 1.25 GSPS Volt Sample Points, 500 MHz Bandwidth
Raw	4 GHz (Max)	Many, Fixed 12 µs	25	Yes/No	-59.3	Raw 1.25 GSPS Volt Sample Points, 500 MHz Bandwidth
RT DDC	50 MHz	1 Fixed, Max Memory	128	No/Yes	-78.3	Can Tune to Center Frequency and Select Up to 488 MHz Span, Stream 1.28 GSPS I/Q Pairs
RT DDC	488 MHz (Max)	1 Fixed, Max Memory	13	No/Yes	-68.4	Can Tune to Center Frequency and Select Up to 488 MHz Span, Stream 1.28 GSPS I/Q Pairs
RT DDC	488 MHz (Max)	Many, Fixed 12 µs	100	No/Yes	-68.4	Can Tune to Center Frequency and Select Up to 488 MHz Span, Stream 1.28 GSPS I/Q Pairs
Hardware-Accelerated DDC*	50 MHz	1 Fixed, Max Memory	128	Yes/Yes	-78.3	No
Hardware-Accelerated DDC*	1 GHz	Many, Fixed 12 µs	50	Yes/Yes	-65.3	No

*DC to 8 GHz and DC to 13 GHz input frequency ranges on 2 and 1 channel models

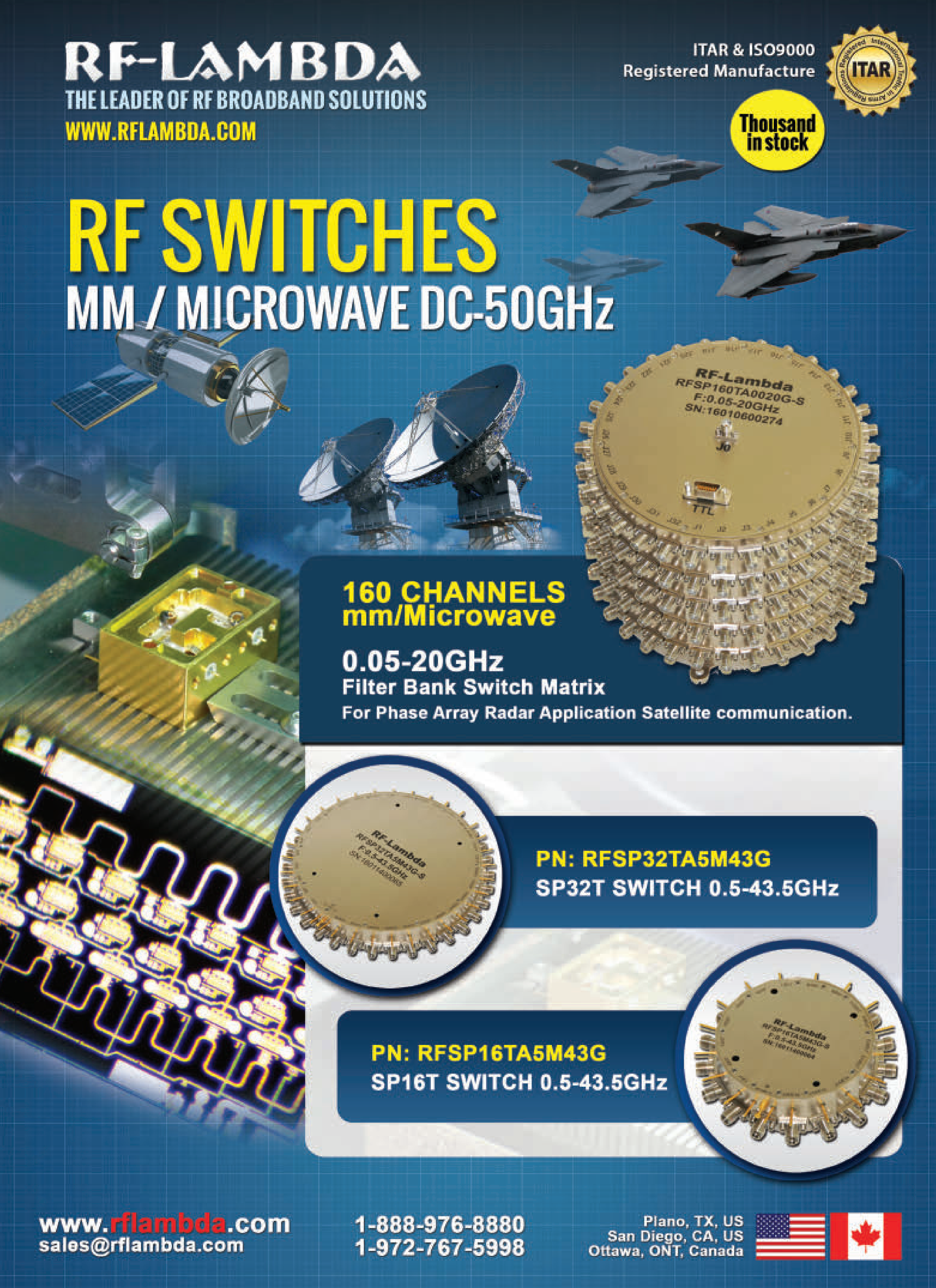
SUMMARY

We have seen how several tools are valuable for the EA designer who desires to make measurements on radar and jammer signals and the interaction of those signals during an RGPO engagement. RGPO is just one example of a jamming methodology. There are many types of radar electronic protection and EA methods that drive decisions related to the trade-offs discussed for system validation measurements.

Wideband 8-bit digitizers can be valuable in the collection of radar and jammer pulses for system validation, as well as measuring a host of other electronic warfare signals. Trade-offs are between measurement bandwidth and the total time radar and jammer pulses can be captured. These trade-offs affect the noise present in the measurements, which determines whether small signals like radar reflection pulses can be captured and analyzed. ***Table 1*** summarizes the examples and the trade-offs discussed. A combination of DDC and segmented memory is important for these measurements, which are often performed in a controlled lab environment.■

Reference

1. David L. Adamy, "EW 104: Electronic Warfare Against a New Generation of Threats," *Artech House Publishers*, 2015, pp. 60.


RF-LAMBDA
THE LEADER OF RF BROADBAND SOLUTIONS
WWW.RFLAMBDA.COM
ITAR & ISO9000
Registered Manufacture
ITAR
Thousand in stock
RF SWITCHES
MM / MICROWAVE DC-50GHz
RF-Lambda
RFSP160TA0020G-S
F:0.05-20GHz
SN:16010600274
J0
TTL
160 CHANNELS
mm/Microwave
0.05-20GHz
Filter Bank Switch Matrix
For Phase Array Radar Application Satellite communication.
RF-Lambda
PN: RFSP32TA5M43G
SP32T SWITCH 0.5-43.5GHz
RF-Lambda
PN: RFSP16TA5M43G
SP16T SWITCH 0.5-43.5GHz
www.rflambda.com
sales@rflambda.com
1-888-976-8880
1-972-767-5998
Plano, TX, US
San Diego, CA, US
Ottawa, ONT, Canada

Compact Microstrip Lowpass Filter with Wide Stopband and Sharp Roll-Off

Shiva Khani and Mohsen Hayati
Islamic Azad University, Kermanshah, Iran

A novel microstrip lowpass filter (LPF) composed of high impedance transmission lines loaded by radial split-ring resonators and radial patch resonators is compact in size and exhibits a wide stopband, sharp roll-off and low insertion loss. The demonstrated filter has a -3 dB cutoff frequency of f_c = 1.77 GHz with a roll-off rate of 121.4 dB/GHz. Its stopband is from 1.91 to 16 GHz with attenuation greater than 20 dB.

Microstrip LPFs have found wide application in microwave communication systems for suppression of spurious signals and unwanted high frequency harmonics. Various structures have been designed in recent years to achieve good characteristics, such as compact size, sharp roll-off, wide stopband and low insertion loss. Hayati and Moghadam[1] used modified circular resonant patches and folded lines for obtaining a wide stopband, but their structure is large and the cutoff is gradual. Velidi and Sanyal[2] report on a microstrip LPF with a wide stopband and high roll-off rate, but it is also large. Another wide stopband LPF uses triangular patch resonators, radial patch resonators and meander transmission lines,[3] but its roll-off is not sharp and has low stopband attenuation. Karimi et al.[4] describe a microstrip LPF with a wide stopband and sharp cutoff frequency, however, it is large and has high loss in the passband. A microstrip LPF with a radial resonator, triangular patch and open stub, introduced by Hayati et al.,[5] has a high roll-off rate, but the stopband is narrow. A compact microstrip lowpass filter with a quasi elliptic response, by Wang et al.,[6] exhibits a wide stopband, but its roll-off is not sharp and has low suppression. A LPF based on a resonator with slow-wave effects[7] has a wide stopband and high roll-off rate but is large. A microstrip LPF using a tapered microstrip resonator cell[8] has low insertion loss, but its roll-off is not sharp and it is also large. A microstrip LPF based on stepped-impedance resonators using semicircular structures to reduce its size[9] is still relatively large, with a narrow stopband. The use of a defected ground structure (DGS)[10,11] improves stopband characteristics but increases the total filter size and creates radiation losses.

In this work, a novel microstrip LPF with compact size using high impedance transmission lines loaded by radial split-ring resonators and radial patch resonators provides a wide stopband, sharp roll-off and low in-band insertion loss.


SKYWORKS®
Enabling the Internet of Things
RF Solutions for a Connected World
Automotive
Smart Home
Industrial
M2M
Medical
Mobile
Smart Energy
Wearables
For more information about Skyworks' portfolio of IoT connectivity solutions,
please visit www.skyworksinc.com/IoT
sales@skyworksinc.com | USA: 781-376-3000 | Asia: 886-2-2735 0399 | Europe: 33 (0)1 43548540 | NASDAQ: SWKS

LPF DESIGN

The filter comprises three types of resonators. ***Figure 1a*** shows the layout of resonator 1, which consists of high impedance transmission lines loaded by radial split-ring resonators. Its simulated frequency response is shown in ***Figure 1b***. Resonator 1 generates one transmission zero at 2.25 GHz with 43 dB of attenuation, which provides for a relatively narrow stopband with low attenuation. Optimal dimensions are L_1 = 10.5 mm, L_2 = 0.08 mm, L_3 = 0.74 mm, W_1 = 5.96 mm, W_2 = 1.6 mm, r_1 = 6 mm, r_2= 6.7 mm, r_3 = 7.4 mm, t_1 = 88 degrees and t_2 = 120 degrees. The transmission zero can be controlled with L_2 and t_2. By increasing the value of L_2 from 0.08 to 0.32 mm, the transmission zero is shifted to the right, as shown in ***Figure 2a***. By increasing t_2 from 60 degrees to 120 degrees, the transmission zero is shifted to the left (see ***Figure 2b***).

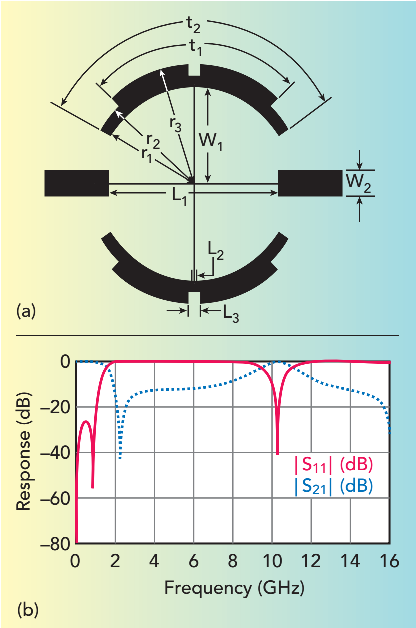


Fig. 1 Resonator 1 layout (a) and simulated frequency response (b).

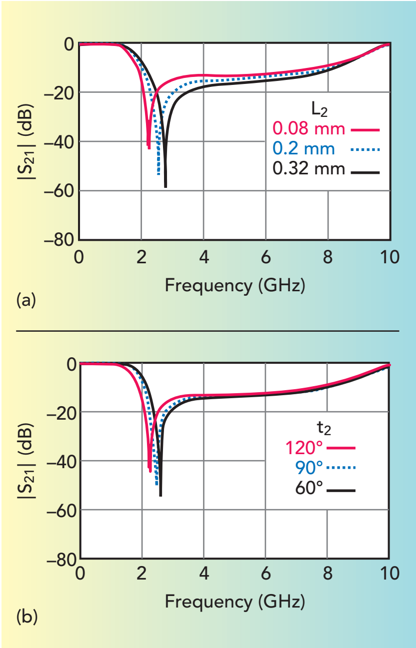


Fig. 2 Impact of resonator 1 L_2 (a) and t_2 (b) on $|S_{21}|$.

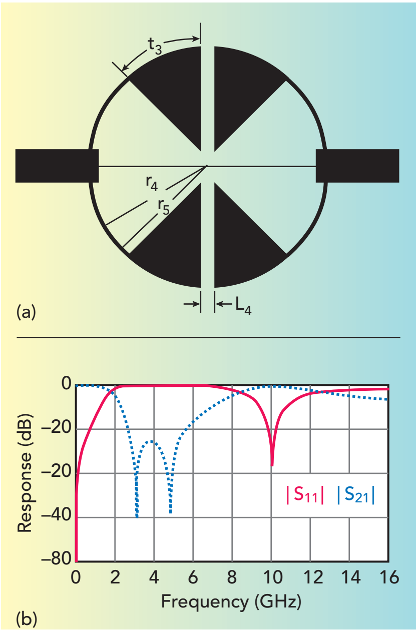


Fig. 3 Resonator 2 layout (a) and simulated frequency response (b).

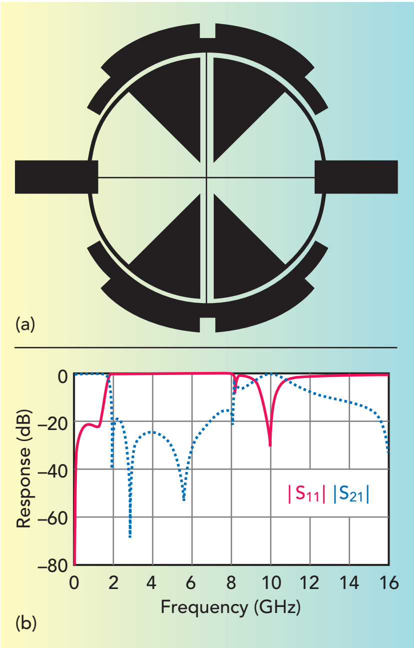


Fig. 4 Layout of combined resonators 1 and 2 (a) and simulated frequency response (b).

Resonator 2 along with its simulated frequency response is shown in ***Figure 3***. Its dimensions are L_4 = 0.68 mm, r_4 = 5.6 mm, r_5 = 5.8 mm and t_3 = 45 degrees. As shown in Figure 3b, resonator 2 generates two transmission zeros located at 3 and 4.8 GHz, with attenuation levels of 60 and 59 dB, respectively. The cutoff is not sharp and the stopband is narrow. ***Figure 4*** shows the combination of resonators 1 and 2 and the resulting frequency response. This structure has good attenuation in the stopband and a sharp transition; however, the stopband bandwidth is still relatively narrow. To suppress unwanted harmonics at high frequencies, a suppression cell is needed.

Resonator 3 (see ***Figure 5***) acts as the suppression cell to enhance the stopband bandwidth at high frequencies. Its dimensions are W_3 = 0.792 mm, W_4 = 0.08 mm, W_5 = 0.3 mm, r_6 = 5 mm and t_4 = 45 degrees. By adding resonator 3, the final filter structure is formed (see ***Figure 6a***). ***Figure 6b*** shows the simulated frequency response. The -3 dB cutoff frequency is around 1.77 GHz. The stopband region extends from 1.91 to 16 GHz with attenuation greater than 20 dB across the band. Maximum insertion loss and minimum return loss in the passband are 0.16 and 14.35 dB, respectively.

SIMULATED VS. MEASURED

The filter was fabricated on an RT/Duroid 5880 substrate with dielectric constant of 2.2, thickness of 20 mils and loss tangent of 0.0009. The circuit was simulated using Keysight's Advanced Design System (ADS) and measured with an HP8757A network analyzer. ***Figure 7a*** shows the final filter and ***Figure 7b*** compares measurements with simulation, showing close agreement.

Table 1 compares the performance of the proposed filter with other reported LPFs, using the following definitions:

The roll-off rate is

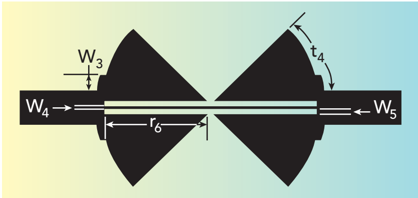
$$\xi = \frac{\alpha_{max} - \alpha_{min}}{f_s - f_c}\left(dB/GHz\right) \quad (1)$$

where α_{max} is the 20 dB attenuation point, α_{min} the 3 dB attenuation point, f_s the -20 dB stopband frequency and f_c the -3 dB cutoff frequency.

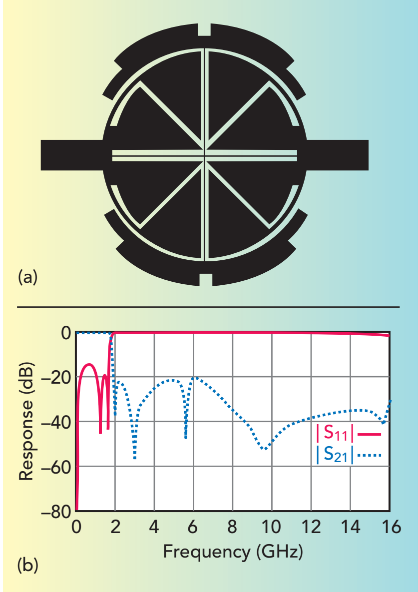
The relative stopband bandwidth (RSB) is

$$RSB = \frac{stopband(-20\ dB)}{stopband\ center\ frequency} \quad (2)$$

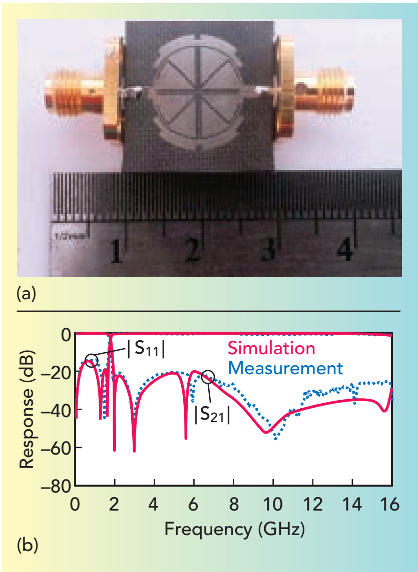
The suppression factor (SF) is based on the stopband suppression. A higher degree of suppres-



▲ **Fig. 5** Resonator 3 layout.



▲ **Fig. 6** Final filter layout (a) and simulated frequency response (b).



▲ **Fig. 7** Fabricated LPF (a) and simulated vs. measured performance (b).

TABLE 1
LOWPASS FILTER COMPARISONS

Ref.	f_c (GHz)	ζ(dB/GHz)	NCS(λg^2)	SF	RSB	AF	FOM
1-a	4.23	40.5	0.03000	2	1.630	1	4 400
1-b	4.26	70.8	0.05180	2.62	1.510	1	5 407
3	1	30.9	0.01010	1.5	1.760	1	8 076
5	4.24	130.7	0.01400	2	1.260	1	23 526
6	1.18	36.3	0.00624	1.5	1.323	1	11 543
7	2.4	92.5	0.03721	3	1.355	1	10 106
8	1.58	41.46	0.02933	2	1.676	1	4 792
This Work	**1.77**	**121.4**	**0.00943**	**2**	**1.598**	**1**	**41 122**

sion equates to a greater SF. If, for example, the stopband bandwidth requirement calls for 20 dB attenuation, then the SF is 2.

The normalized circuit size (NCS) is

$$NCS = \frac{\text{physical size (length} \times \text{width)}}{\lambda_g^2} \quad (3)$$

where λg is the guided wavelength at the -3 dB cutoff frequency.

The architecture factor is known as the circuit complexity factor, which is 1 or 2, for a 2D or 3D structure, respectively.

Finally, the figure-of-merit (FOM) is the overall index

$$FOM = \frac{RSB \times \xi \times SF}{AF \times NCS} \quad (4)$$

Table 1 shows the proposed filter exhibits a much higher FOM than the other reported designs.

CONCLUSION

A novel microstrip LPF consists of high impedance transmission lines loaded by radial split-ring resonators and radial patch resonators. The filter has a 1.77 GHz cutoff frequency with desirable features such as compact size, wide stopband, sharp roll-off and low insertion loss, resulting in a high FOM compared to other LPFs.■

References

1. M. Hayati and P. Karami Moghadam, "Compact Microstrip Lowpass Filter with Ultra-Wide Stopband Using a Modified Circular Resonator," *Microwave Journal*, Vol. 58, No. 4, April 2015, pp. 152–158.
2. V. K. Velidi and S. Sanyal, "Sharp Roll-Off Lowpass Filter with Wide Stopband Using Stub-Loaded Coupled-Line Hairpin Unit," *IEEE Microwave and Wireless Components Letters*, Vol. 21, No. 6, June 2011, pp. 301–303.
3. J. Wang, H. Cui and G. Zhang, "Design of Compact Microstrip Lowpass Filter with Ultra-Wide Stopband," *Electronics Letters*, Vol. 48, No. 14, July 2012, pp. 854–856.
4. G. Karimi, A. Lalbakhsh and H. Siahkamari, "Design of Sharp Roll-Off Lowpass Filter with Ultra Wide Stopband," *IEEE Microwave and Wireless Components Letters*, Vol. 23, No. 6, June 2013, pp. 303–305.
5. M. Hayati, S. Naderi and F. Jafari, "Compact Microstrip Lowpass Filter with Sharp Roll-Off Using Radial Resonator," *Electronics Letters*, Vol. 50, No. 10, May 2014, pp. 761–762.
6. J. Wang, L. J. Xu, S. Zhao, Y. X. Guo and W. Wu, "Compact Quasi-Elliptic Microstrip Lowpass Filter with Wide Stopband," *Electronics Letters*, Vol. 46, No. 20, September 2010, pp. 1384–1385.
7. J. L. Li, S. W. Qu and Q. Xue, "Compact Microstrip Lowpass Filter with Sharp Roll-Off and Wide Stop-Band," *Electronics Letters*, Vol. 45, No. 2, January 2009, pp. 110–111.
8. Y. Yousefzadeh and M. Hayati, "Compact Lowpass Filter with Wide Stopband Using a Tapered Microstrip Resonator Cell," *Microwave Journal*, Vol. 55, No. 3, March 2012, pp. 122–128.
9. L. Wang, H. C. Yang and Y. Li, "Design of Compact Microstrip Low-Pass Filter with Ultra-Wide Stopband Using SIRs," *Progress In Electromagnetics Research Letters*, Vol. 18, January 2010, pp. 179–186.
10. Y. Yang, Y. He and L. Sun, "Design of a Novel Compact Lowpass Filter with Defected Ground Structure and Open Stubs," *IEEE International Symposium on Radio-Frequency Integration Technology*, August 2014, pp. 1–3.
11. S. H. Fu, C. M. Tong, X. M. Li and K. Shen, "A Compact Ultra-Wide Stopband, Low Insertion Loss, and Sharp Cutoff Low-Pass Filter," *Microwave and Optical Technology Letters*, Vol. 52, No. 3, March 2010, pp. 568–570.

Shiva Khani *received her B.Sc. degree in electrical engineering from Razi University, Kermanshah, Iran, in 2011 and her M.Sc. degree in electrical engineering from Kermanshah Science and Research Branch, Islamic Azad University, Kermanshah, Iran, in 2014. Her research interests include the analysis and design of microstrip filters and antennas.*

Mohsen Hayati *received his B.E. in electronics and communication engineering from Nagarjuna University, India in 1985 and his M.E. and Ph.D. degrees in electronics engineering from Delhi University, Delhi, India, in 1987 and 1992, respectively. He is currently a professor in the Electrical Engineering Department, Kermanshah Branch, Islamic Azad University, Kermanshah, Iran. His research interests include microwave and mmWave devices and circuits.*

INVITED PAPER

3D Additive Manufacturing Meets the Microwave Industry

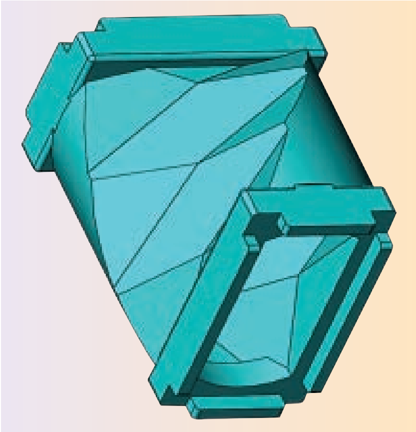
Tom McWalters
Microwave Development Labs, Needham Heights, Mass.

Three-dimensional (3D) printing provides a means of producing RF/microwave passive components and component parts as an alternative approach to traditional "subtractive" manufacturing methods, in which materials are trimmed down to a desired shape or form. 3D printers work with different materials to create parts layer by layer, under the guidance of a computer and a computer-aided design (CAD) file. While 3D printing is still improving in choice and quality of materials, it has already shown its value in the creation of challenging prototypes and limited production runs where fast turnaround times are needed.

Additive manufacturing (AM), also known as 3D printing, is a computer-assisted method of producing passive RF/microwave components. It is a departure from traditional subtractive methods, in which parts are formed by removing materials using processes such as drilling and milling. With AM, 3D components are created by adding materials using printers under computer control, adding layer upon layer of different materials to form the final product. AM methods provide precision and repeatability not often achieved with subtractive manufacturing processes.

In the manner that a two-dimensional (2D) printer can generate a physical representation of a computer document file, a 3D printer can manufacture a physical part from a CAD file. For passive RF/microwave components such as waveguide tees, in which dimensional tolerances must be met for acceptable electrical performance, computer simulation programs predict the performance based on mechanical dimensions, construction materials and other inputs. A 3D printer makes it possible to generate physical components using the same dimensions, achieving performance levels that are typically within ±1 percent of the simulated parameters. Files for driving a 3D printer as part of an AM process can be produced through synthesis, using a CAD program, or by making a 3D digital copy of an existing component, using a 3D scanner. The instructions for creating a part with a 3D printer can also be stored as an additive manufacturing file (ADF).

Demand is growing for passive components at mmWave frequencies, driven by the use of frequencies through 80 GHz for applications such as automotive safety systems and 5G wireless communications networks. Waveguide components for these higher frequencies require precise mechanical construction with dimensions held to tight tolerances. AM processes provide the means to



▲ **Fig. 1 With the MJM method, a 3D printer fabricates waveguide components, such as waveguide tees, by printing with two different materials, one layer at a time.**

fabricate prototypes and small production runs with highly repeatable performance.

AM production can be likened to the creation of a circuit laminate by adding metal films to dielectric layers, except that AM processes rely on different types of printers to create the material layers, using powders or other starting material formats. Various AM processes have been used to manufacture RF/microwave components, including stereolithography (SL), laser sintering, multijet modeling (MJM) and laser beam melting (LBM). For several years, MJM and LBM have been used successfully at Microwave Development Laboratories (MDL) to produce custom prototypes and small production runs of RF/microwave waveguide components.

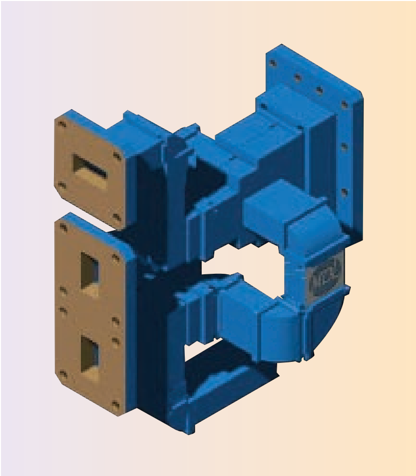
MULTIJET MODELING

The MJM AM method has proven to be an effective technique for producing repeatable and low loss E-plane and H-plane waveguide tees at microwave and mmWave frequencies (see ***Figure 1***). The MJM printer prints two different materials, one layer at a time, and then uses a very accurate knife to shave each layer flat. Two types of wax are used as the materials: a build wax, which forms the desired part, and a support wax, which helps maintain the shape of the desired part. The support wax is later dissolved in a hot bath to remove it from the part formed by the build wax (see ***Figure 2***). Within the 3D printer, the two waxes are heated and flowed through nanojets to form the support and build structures. These liquefied waxes, typically acrylic photopolymer materials, are then immediately hardened and cured with ultraviolet (UV) light. The support wax has a lower melting temperature than the build wax, allowing it to be removed in a hot bath, at a temperature that will not affect the build wax.

▲ **Fig. 2 Two different materials used in the MJM process: build wax and support wax. The support wax is removed in a hot bath.**

▲ **Fig. 3 Low VSWR waveguide twists produced by the MJM process.**

With the MJM method, the waxes formed in the printer are sent to a metal foundry for casting in metal—typically aluminum—to produce the actual waveguide components, using a technique named the "lost wax" process, since both of the waxes used to create such fine-featured components disappear in the process of forming the metal parts. The lost wax process is essentially an investment casting technique where the remaining wax serves as a mold for metal injected into, forming the cast metal parts. The MJM method and the lost wax technique enable metal parts to be formed to a tolerance of ±0.002 in or better. Working closely with the foundry or having an internal capability helps maintain the necessary quality control for the parts produced with the MJM process. MDL owns its own metal-working foundry and can fabricate precision metal parts from aluminum, beryllium and other metals.

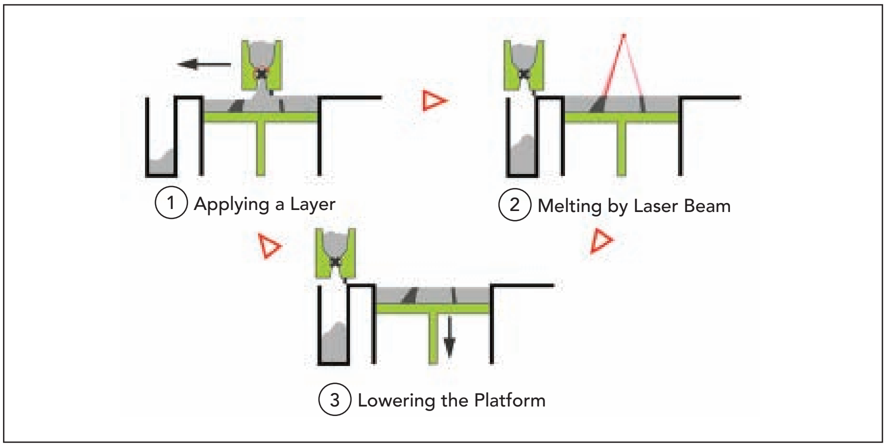


▲ **Fig. 4** **High performance monopulse comparator produced with the MJM process.**

The MJM method is capable of producing high definition waveguide components for applications well into the mmWave range. It is particularly useful for building components that may be at the limits of what a CAD program can define, such as experimental and highly custom components. As an example, standard waveguide components are defined by their frequency ranges, such as WR42 rectangular waveguide, which covers 18 to 26.5 GHz. Normally, a broadband application such as 18 to 40 GHz would require two waveguide sizes: WR42 and WR28, the latter covering 26.5 to 40 GHz. However, if a computer design and simulation program can create the models for a custom waveguide component that covers both bands, the MJM method can turn those wax results into a custom metal waveguide.

For most 3D printing techniques, the dimensional limits on parts produced by the printer are not how small they can be but how large—no larger than the working area of the printer. The real limit on the performance levels that can be achieved with AM methods such as MJM is not in a manufacturing process based on a 3D printer, but on the materials used for the manufacturing process. The build and support waxes can be formed and held to extremely tight tolerances, and these tolerances are then translated to the foundry, which is tasked with matching those dimensions in metal. It is the surface roughness of the metals, such as aluminum or stainless steel, used to cast the metal parts that contributes significantly to the performance of a 3D printed component, such as a waveguide tee or bend. Excessive surface roughness results in insertion loss and VSWR higher than modeled with the CAD tools. For amplitude and phase sensitive applications such as radar, surface roughness can also cause amplitude and phase variations higher than predicted. Metal surface roughness is one of the major factors in performance discrepancies between the simulated and measured performance for AM-produced components.

In addition to E-plane and H-plane waveguide tees, the MJM AM method has produced waveguide twists with extremely low VSWR (see ***Figure 3***) and components such as monopulse comparators for an antenna feed network, where tight phase and amplitude control are required



▲ **Fig. 5** **The LBM process uses a precision laser to melt metal particles and form multiple thin metal layers to create a precision part or component.**

(see ***Figure 4***). Since monopulse comparators are typically designed and built to meet specific polarization requirements, such as for horizontal, vertical or circular polarization, use of the MJM AM method makes it possible to work with an optimized CAD file to quickly produce a design prototype meeting a customer's requirements.

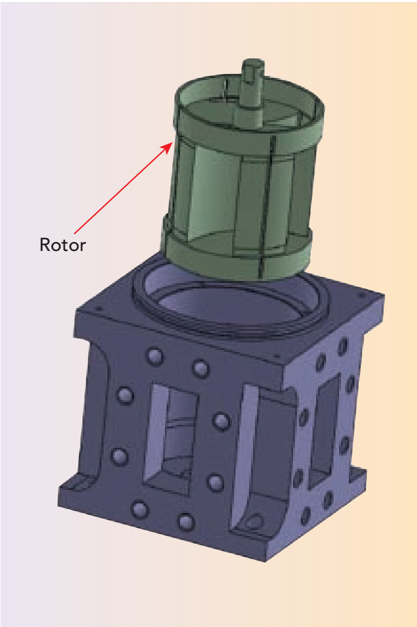
LASER BEAM MELTING

LBM is the second AM process used by MDL for producing high frequency components. The design process of both approaches is similar, working with 3D CAD data and a 3D printer to build a part or component one layer at a time. But the LBM process works with a different type of printer, a more complex and expensive 3D printer that works directly with metal, rather than wax, to form prototype components or small production runs. In LBM, a precision laser in the 3D printer is focused on the powdered form of a metal, heating the metal particles to selectively build up thin metal layers. Once a single layer is completed, the printer's base plate is lowered to provide the spacing required for the next metal layer. The process is repeated, building layer upon layer, until a part is complete (see ***Figure 5***).

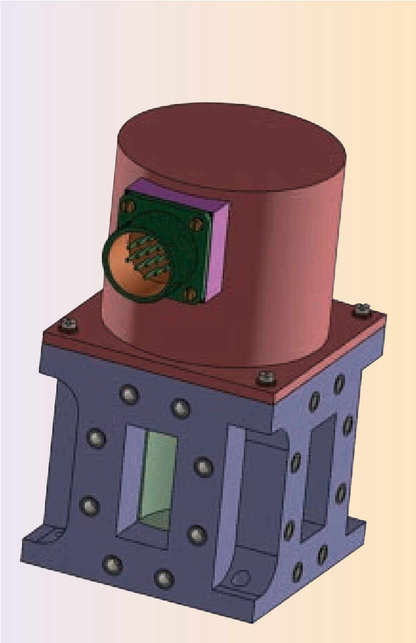
An LBM 3D printer is a significant investment compared to an MJM 3D printer—more than $500,000 compared to about $50,000. Because of this, MDL works with an outside supplier for LBM-produced components. The LBM process has been developed for specific materials that can be processed in powdered form in a 3D printer. For MDL's supplier, these materials include various forms of aluminum, stainless steel, cobalt chrome, copper alloy and titanium. However, they do not yet include a "brazeable" aluminum, the material formed using the MDM 3D printer and MDL's internal foundry.

Components manufactured by the LBM process can be created from a CAD file in the shortest time, for rapid assembly of a prototype. LBM-manufactured components can be welded and reworked using standard machining and processing methods, including milling and drilling, to enhance dimensional tolerances when necessary. Because of the extremely tight tolerances with LBM 3D printing methods, this AM approach is used for components where the dimensional tolerances are critical, such as rotors for waveguide switches (see ***Figure 6***).

Rotary waveguide switches produced with the LBM method have delivered excellent reliability with



▲ **Fig. 6** **Precision rotor used in a high-reliability waveguide rotary switch.**



▲ **Fig. 7** **WR187 rotary switch assembled with components fabricated with the LBM process.**

long operating lifetimes, such as the 3.95 to 5.85 GHz WR187 rotary switch shown in ***Figure 7***. Over this frequency range, the switch has almost negligible insertion loss, 0.10 dB maximum, and maximum VSWR of 1.10:1. The isolation of this switch is 60 dB minimum and it has an RF power rating of 1400 kW. The rotors for waveguide switches such as these, produced by the LBM process, have been laboratory tested for more than 10 million switching operations with minimal degradation in electrical performance.

SUMMARY

AM 3D printing approaches offer lower costs (except for LBM 3D printers), greater design flexibility (using CAD files) and increased production efficiency (with fast turnaround times) compared to traditional subtractive manufacturing methods.

Because 3D printing creates components by building multiple layers of materials, one might wonder if such a process is capable of producing components and parts with isotropic properties. It has been found that material consistency is a function of the choice of AM process. For the LBM process, the metals (mostly aluminum) produced by the 3D printer are consistent in the x, y and z axes, and the LBM layering has been found to produce metal parts with durability and consistency. Because a single part can be fabricated from multiple metal alloys, 3D printing allows material characteristics to be tailored for specific performance requirements in a way not possible with metal casting.

Work continues on improving 3D printers and, especially, on the materials used in AM, since the choice of technique depends on the available materials. Experience at MDL has shown the use of an AM approach such as MJM can eliminate the expenses associated with casting tools, as well as the lead times to build tooling for a particular component. The performance levels of the components manufactured by both the MJM and LBM processes speak well for both processes for RF/microwave component manufacturing.■

INVITED PAPER

Novel Wideband Frequency Selective Surface Filters with Fractal Elements

Ed Liang
MCV Microwave, San Diego, Calif.

T. K. Wu
FSS & Antenna Consulting, Rancho Palos Verdes, Calif.

High performance frequency selective surface (FSS) filters have a myriad of applications in the field of 5G wireless communication and antenna/radome systems. The most common FSS is a two-dimensional (2D) periodic array of thin conducting or aperture (also termed slot) elements etched on a flat or curved dielectric structure. This type of structure usually exhibits frequency filtering characteristics similar to the frequency filters in traditional RF circuits. In this article, resonant frequency stability in a bandstop filter over varying incident angles and polarizations is demonstrated in a miniature fractal patch element FSS. In addition, to meet the wide passband demand of 5G wireless communication systems, a fractal slot element FSS is designed and demonstrated to have more than 30 percent bandwidth with an insertion loss less than 0.5 dB. The filter's bandwidth is constant as the incident angle increases up to 60 degrees for both TE and TM polarizations.

The main themes of 5G wireless communication include a rapid growth of connectivity for a large number of devices and a huge increase in mobile data rates. Networks are required to support 1000x higher data volume per area, 10 to 100x more connected devices in real-time, and 10 to 100x higher data rates.[1] To meet these demands, industry research is focused in areas such as increased spectrum, improved efficiency and high-reliability communication links. To deal with stringent spectrum requirements, spatial filters are usually required. The design of multi-band spatial filters or FSS filters can be very challenging due to requirements for stable filtering performance with changes in incident angle and polarization.

PRIOR WORK

The most common FSS is a 2D periodic array of either thin conducting or aperture (slot) elements etched on a flat or curved dielectric structure.[2-5] Various FSSs with cross dipole patch elements have been used in multi-band communication systems;[6,7] however, the transmission performance changes drastically as the incident angle is steered from normal to 40 degrees. Thus, a large stop-to-passband ratio or band separation ratio is required to minimize RF losses. This is evident in a stop-to-passband ratio of 7:1 for a single screen FSS[6] or 4:1 for a double screen FSS.[7] Although the miniature fractal patch element FSS reported by Wu for dual band operation[8] exhibits frequency stability with varying incident angles and polarizations at its first resonant frequency, it is unstable at the second resonant frequency occurring closer to the grating lobe region.[9,10]

Much of the work for stabilizing FSS resonant frequencies has been through the use of cross or hexagonal loop slot elements[4,11] and complementary type miniature element FSSs (MEFSS)[12-15] for bandpass radome applications. Although stability of the passband

Modelithics®
World's Best RF & Microwave Simulation Models

&

ANSYS®

ACCELERATE

Your High Frequency Designs with

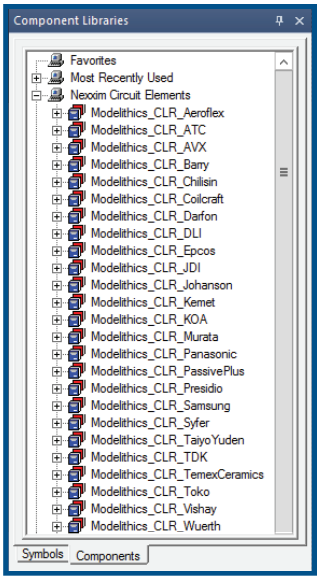
The Modelithics® COMPLETE+3D Library™

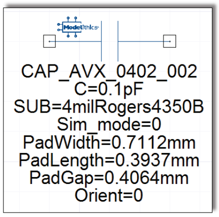
of Scalable, Parasitic Simulation Models and

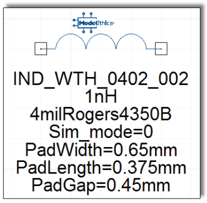
ANSYS® HFSS™

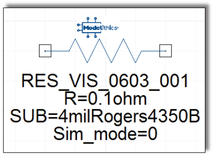
The Industry Standard Electromagnetic Field Simulation Software

Microwave Global Models™ for ANSYS HFSS EM Co-simulation



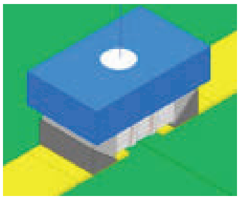




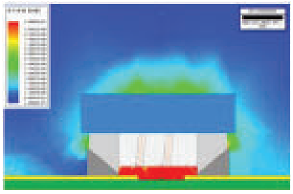


- Substrate scaling
- Part value scaling
- Statistical analysis
- Seamless EM co-simulation
- Over 275 models for commercially available components from **over 25 popular vendors**

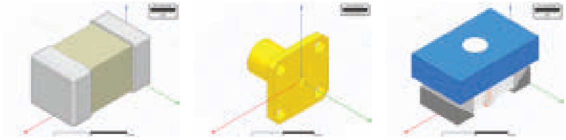
INTRODUCING 3D GEOMETRY MODELS*



3D Model



H-Field Visualization



- Substrate independent
- Measurement validated
- Full wave 3D EM simulation

*Sample 3D Geometry model library included in v17.3

Request a FREE 30-Day Trial

www.Modelithics.com/MVP/ANSYS

Modelithics®
Vendor Partner

center frequency can be achieved over various incident angles and polarizations,[15] bandwidth is generally decreased for TE polarization or increased for TM polarization. To mitigate this, designs proposed by Munk[4], Schneider and McCaan[11] have been used.

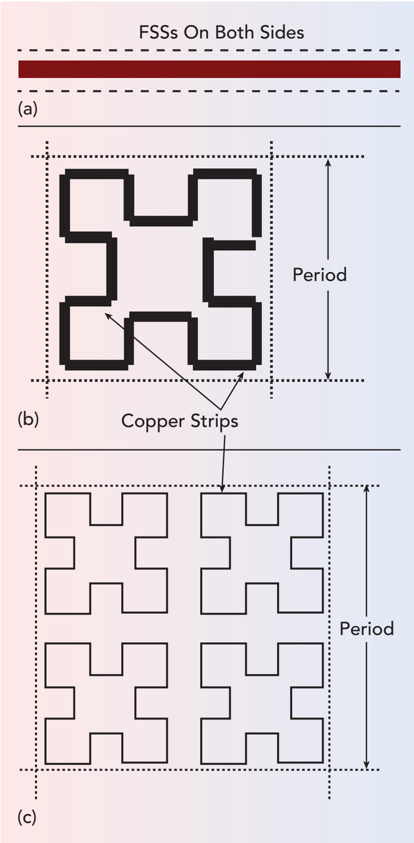
FRACTAL FSS FILTER DESIGNS

The design and analyses of the patch and slot FSS filters described in this article are based on an accurate integral equation formulation (IEF) combined with the method of moments (MOM).[2,16-19] This analytical approach is also known as the full wave analysis technique. The accuracy of this numerical approach has been verified by many comparisons with measured data.[2]

Fractal Patch Element FSS

These designs specifically address modern, multi-band wireless local area networks (WLAN), i.e., Wi-Fi systems, that generally operate in both the 2.4 and 5 GHz bands and are used to cover indoor environments such as hospitals, high-rise buildings and offices. Noise induced by unwanted outside electromagnetic interference (EMI) may cause life-support instruments to malfunction, endangering patients' lives. To reduce or eliminate interference from nearby Wi-Fi systems, the Wi-Fi signals must be confined within specific physical areas. A traditional miniature fractal patch element FSS for a Wi-Fi system may exhibit a stable first resonant frequency at 2.4 GHz at various incident angles and polarizations; however, the second resonant frequency in the 5 GHz band is generally not stable, making it difficult to block Wi-Fi signals in both bands. A similar problem is observed in a Wi-Fi FSS design using multi-ring elements.[20] Two innovative FSS designs aimed at improving the stability of the second resonant frequency are shown in ***Figures 1*** and ***3***.

The first (see Figure 1) is realized by etching a two screen fractal



▲ **Fig. 1** A two screen fractal FSS with fractal patch elements: side (a), top (b) and bottom (c) views.

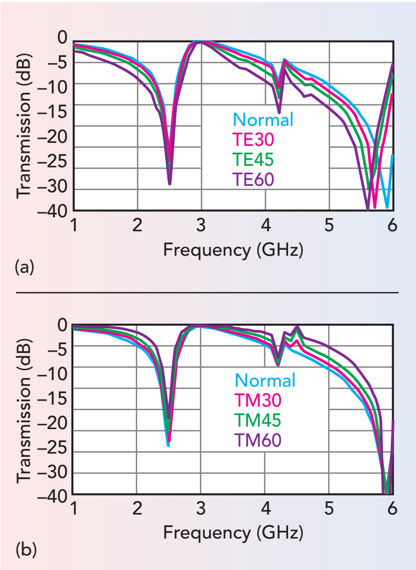

DELTA
Electronics Mfg. Corp.
Interconnect Solutions
Create
Collaborate
Connect
ARROW
Aerospace & Defense
A.E. Petsche Co.
SMP & SMPM
High Performance
Connectors to 65 GHz
"Fully customizable cost
effective solutions"
Distributed by A.E. Petsche Co.
A Delta Channel Partner
contactAEP@aepetsche.com
www.aepetsche.com
(844) AEP-7600
(844) 237-7600

FSS on both sides of a thin dielectric substrate. Note the top FSS screen's unit cell has one fractal loop patch element, while the bottom FSS screen's unit cell has four, i.e., 2 × 2 fractal loop patch elements. These two screens have the same period, and their unit cells must be aligned exactly with each other. Transmission performance is shown in ***Figure 2*** for a Duroid 6006 substrate with a dielectric constant of six. As the incident angle changes from normal to 60 degrees, the FSS provides at least 18 dB attenuation at both 2.45 and 5.8 GHz for both TE and TM polarizations.

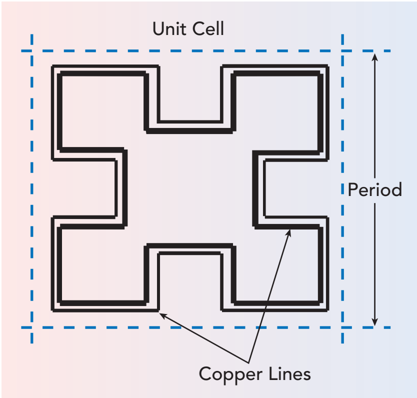
The second design (see Figure 3) is a single FSS screen with two, concentric fractal loop (or double fractal) patch elements sandwiched between two dielectric slabs, with a dielectric constant of 2.2 and thickness of 3 mm. The period of the unit cell is 2 cm. Transmission performance is shown in ***Figure 4***. At 2.45 and 5.2 GHz, at least 18 dB of attenuation is obtained for both TE and TM polarizations over incident angles varying from normal to 60 degrees. This is a considerable improvement with respect to previously published work.[20] There is also no difficult alignment required, as in the first design, making it more suitable for fabrication and mass production.

Fractal Slot Element FSS

Contrary to patch element FSSs, cross or hexagonal loop slot element FSSs are usually implemented to provide a passband with fast roll-off skirts for 5G wireless communication or antenna/radome applications. Multiple dielectric slabs are needed to stabilize the bandwidth of the passband, and two or more FSS screens are needed for a flatter



▲ **Fig. 2** Transmission performance of the FSS filter of Figure 1: TE (a) and TM (b) polarizations.

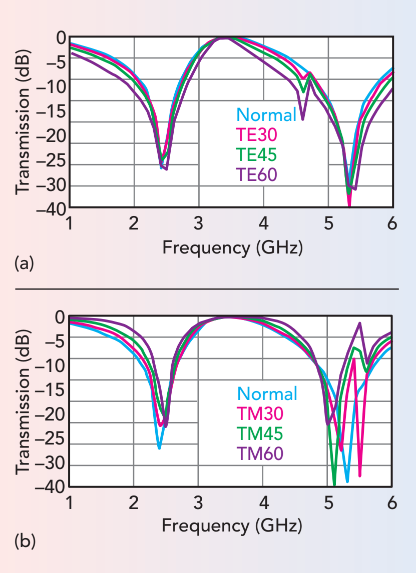


▲ **Fig. 3** Unit cell configuration of a double fractal element FSS.

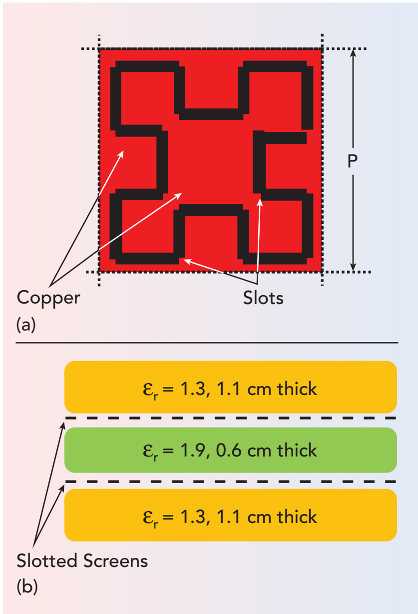
passband and sharper roll-off.[4,11] To provide wider bandwidth, we introduce a novel FSS design with fractal loop slots, as illustrated in ***Figure 5***. ***Figure 6*** shows the simulated transmission performance. The 0.5 dB passband bandwidth is about 34 percent, which is greater than previously published designs[4,11] for both TE and TM polarizations, as well as incident angles varying from normal to 60 degrees. One can further sharpen the roll-off skirts by adding another slotted screen.

CONCLUSION

Novel FSS filters with miniature fractal patch elements have been designed for 5G multi-band wireless communications, while a fractal slot element FSS was designed and demonstrated to have greater than 30 percent bandwidth with an insertion loss less than 0.5 dB for wideband antenna/radomes. Both patch and slot FSSs exhibit angular stability and polarization independent features as the incident angle is varied from normal to 60 degrees. They are low volume, lightweight and can be easily fabricated with conventional printed circuit board techniques. These designs may also be scaled to THz and infrared frequency bands. There are a myriad of applications in advanced communication and radar systems to be further explored.■



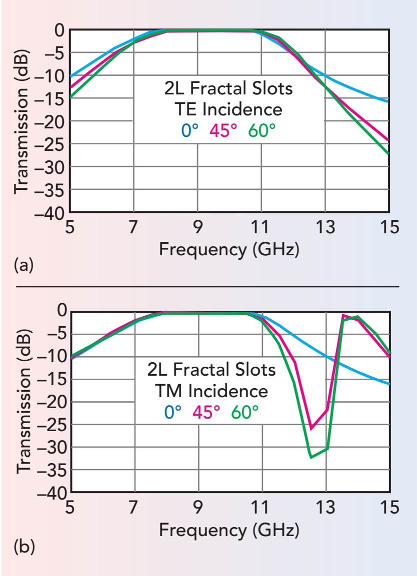
▲ **Fig. 4 Transmission performance of the double fractal FSS of Figure 3: TE (a) and TM (b) polarizations.**



▲ **Fig. 5 Configuration of a two screen fractal slot element FSS: unit cell (a) and cross section (b).**

References

1. B. Bangerter, S. Talwar, R. Arefi and K. Stewart, "Networks and Devices for the 5G Era," *IEEE Communications Magazine*, Vol. 52, No. 2, February 2014, pp. 90–96.
2. T. K. Wu, (ed.), Frequency Selective Surface and Grid Arrays, *Wiley*, N.Y., 1995.
3. J. C. Vardaxoglou, Frequency Selective Surfaces: Analysis and Design, *Research Studies Press*, Taunton, England, 1997.
4. B. Munk, Frequency Selective Surfaces, *Wiley*, N.Y., 2000.
5. B. Munk, Finite Antenna Arrays and FSS, *Wiley*, N.Y., 2003.
6. V. D. Agrawal and W. A. Imbriale, "Design of a Dichroic Cassegrain Subreflector," *IEEE Transactions on Antennas and Propagation*, Vol. 27, No. 4, July 1979, pp. 466–473.
7. G. Schennum, "Frequency-Selective Surface for Multiple Frequency Antennas," *Microwave Journal*, Vol. 16, pp. 55–57, 1973.
8. T. K. Wu, "Improved Dual Band FSS Performance with Fractal Elements," *Microwave and Optical Technology Letters*, Vol. 54, No. 3, March 2012, pp. 833–635.
9. T. K. Wu, "Improved THz/Infrared Frequency Selective Surface with Minkowski Fractal Elements," *International Conference on Wireless Information Technology and Systems (ICWITS) and Applied Computational Electromagnetics (ACES)*, March 2016.
10. T. K. Wu, "Single-Layer FSS for Wi-Fi Applications," *IEEE International Symposium on Antennas and Propagation* and *USNC-URSI Radio Science Meeting*, July 2017.
11. S. W. Schneider and J. F. McCaan, "Frequency Selective Surfaces," Chap. 56, J. Volakis, (ed.), *Antenna Engineering Handbook*, 4th ed., McGraw-Hill, N.Y. 2014.
12. K. Sarabandi and N. Behdad, "A Frequency Selective Surface with Miniaturized Elements," *IEEE Transactions on Antennas and Propagation*, Vol. 55, No. 5, May 2007, pp. 1239–1245.
13. X. D. Hu, X. L. Zhou, L. S. Wu, L. Zhou and W. Y. Yin, "A Miniaturized Dual-Band FSS with Closed Loop and its Complementary Pattern," *IEEE Antennas and Wireless Propagation Letters*, Vol. 8, December 2009, pp.1374–1377.
14. M. Al-Joumayly and N. Behdad, "A Generalized Method for Synthesizing Low-Profile Band-Pass Frequency Selective Surfaces with Non-Resonant Constituting Elements," *IEEE Transactions on Antennas and Propagation*, Vol. 58, No. 12, December 2010, pp. 4033–4041.
15. H. Li, C. Yang, Q. Cao and Y. Wang "An Ultrathin Bandpass Frequency Selective Surface with Miniaturized Element," *IEEE Antennas and Wireless Propagation Letters*, Vol. 16, June 2016, pp. 341–344.
16. C. C. Chen, "Scattering by a Two-Dimensional Periodic Array of Conducting Plates," *IEEE Transactions on Antennas and Propagation*, Vol. 18, No. 5, September 1970, pp. 660–665.
17. S. W. Lee, "Scattering by Dielectric-Loaded Screen," *IEEE Transactions on Antennas and Propagation*, Vol. 19, No. 5, September 1971, pp. 656–665.
18. C. C. Chen, "Transmission of Microwave Through Perforated Flat Plates of Finite Thickness," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 21, No. 1, January 1973, pp. 1–6.
19. R. Mittra, C. Chan and T. Cwik, "Techniques for Analyzing Frequency Selective Surfaces–a Review," *IEEE Proceedings*, Vol. 76, No. 12, December 1988, pp. 1593–1615.
20. D. Ferreira, I. Cuiñas, R. F. S. Caldeirinha and T. R. Fernandes, "Dual-Band Single Layer Quarter Ring FSS for Wi-Fi Applications," *IET Microwaves, Antennas and Propagation*, Vol. 10, No. 4, March 2016, pp.435–441.



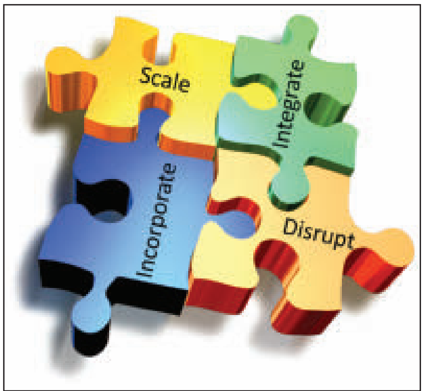
▲ Fig. 6 Transmission performance of the fractal slot element FSS of Figure 5: TE (a) and TM (b) polarizations.

INVITED PAPER

Countering the UAS Challenge

Asif Anwar
Strategy Analytics, Boston, Mass.

The success of unmanned aerial systems (UAS) in providing real-time information to military commanders has contributed to both mission effectiveness and protecting personnel. The expansion of commerical UAS could bring about disruptive uses, intentional or not, as well as their use in asymmetric warfare. Combating these potential threats will require a new front in electromagnetic spectrum operations. As a starting point, we can address some of the key issues that will define both the utilization and countering of drones, in terms of some of the broader issues that need to be addressed across both defense and commercial applications. The ability to manage spectrum within current and next generation networks requires an understanding of bandwidth optimization, latency and the underlying economics, underpinned by the use of more complex modulation, phased arrays and other approaches designed to increase spectral efficiencies, which will enable UAS use and provide strategies to monitor and counteract the use of drones.



▲ **Fig. 1 Strategies to address the counter-UAS opportunity in the civilian sector.**

The RF payloads, ground systems and jamming and monitoring capabilities of counter-UAS systems need to be optimized from the antenna to baseband, and this requires an understanding of which technologies span the RF front-end to the digital backend. Monitoring of the environment will evolve beyond fixed or portable systems to include handheld units constrained by size, weight and power (SWaP) to optimize battery life, which in turn requires an understanding of advances across baseband and application processes, displays, memory and other components. Ultimately, this will push semiconductor requirements toward higher frequencies and broadband performance of the RF front-end, with the range of technologies offering trade-offs in monolithic or modular integration. Digital processing requirements will also increase, and this will come with the expectation that there is no compromise on power consumption—ideally, power consumption decreases.

The potential market for counter-UAS platforms requires understanding where the system demand is presently on the growth curve and how forthcoming opportunities are best addressed. As military system suppliers attempt to migrate their experience in the defense sector to address the counter-UAS opportunity in the civilian sector, they will need to implement four primary strategies (see ***Figure 1***):

- Scale—achieved through either consolidation or manufacturing strategies that include partnerships, to enable full solution sets for counter-UAS solutions.

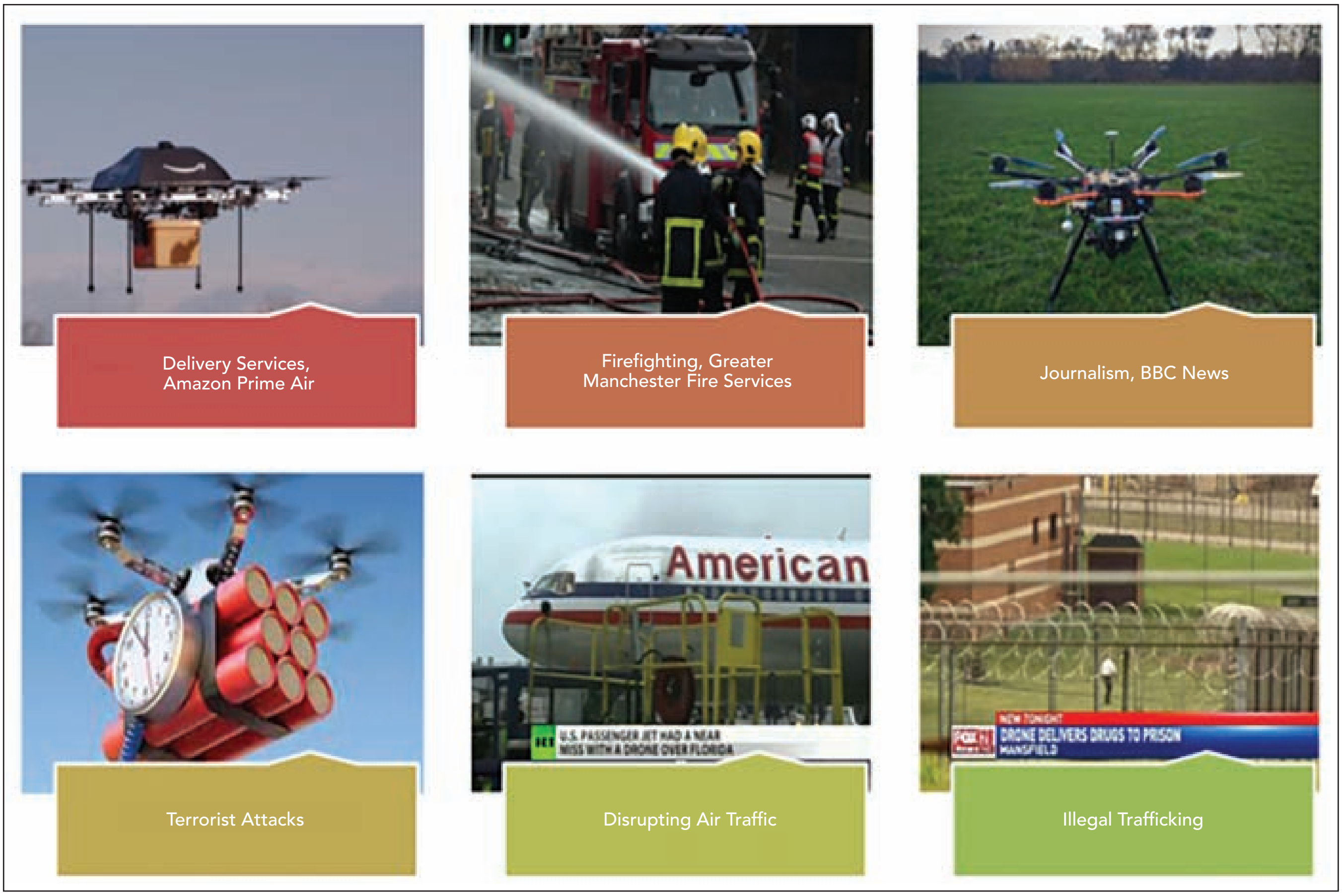
- Integrate and incorporate—to bring together technologies and subsystems that provide integrated solutions, to meet the needs of the end market, which may also involve moving up the supply chain. Companies will need to provide value-add capabilities, such as providing spectrum management alongside the necessary software and graphical user interfaces to optimize the experience for the end-user.
- Disrupt—either through the use of emerging technologies or exploring how best to bring experience from other sectors, in this case the military counter-UAS experience, into the civilian sector.

MILITARY UAS PLATFORMS

The use of UAS platforms is an example of how differentiation on the battlefield is central to military strategy, borne out by technologies developed for standoff, force projection and force multiplication through stealth. Asymmetric theaters such as Iraq and Afghanistan drove the demand for intelligence, which provided the initial opening for UAS platform use. What is clear is that technology remains the differentiator for both conventional and asymmetric conflicts, as well as the growing trends for scenarios that combine elements for hybrid situations. Understanding and being able to operate in these environments opened the door for UAS platforms, while maintaining a strong emphasis on solutions that are also cost effective. Size, weight and range define the different categories of UAS platforms (i.e., micro, mini, tactical, MALE, HALE), initially to provide additional layers of surveillance capability.

As UAS use has proliferated, the mission envelope for these platforms has expanded to incorporate other capabilities, and they have become integrated into the conventional manned fleets for special mission requirements such as airborne ground surveillance and airborne surveillance and reconnaissance. Some of the more prolific UAS examples include the Predator, Reaper, Hermes and ScanEagle platforms. Despite this growing proliferation, UAS platforms will be used to augment rather than replace manned platforms in the area of intelligence, surveillance and reconnaissance (ISR), where there are no payload size constraints limiting performance, and human-in-the-loop expertise can be leveraged to contextualize the data being gathered for conversion into actionable intelligence.

Use of these platforms is also starting to grow in other areas, such as maritime patrol, and these added mission envelopes have expanded the payloads to incorporate radar capabilities that augment electro-optic (EO) and infrared (IR). UAS platforms also form an integral part of the integrated net-centric communications environment, providing layered communications capabilities that extend beyond line-of-sight (BLOS) communication, providing tactical support to front-line troops as well as "reach back" to the strategic command. Expansion into electronic warfare (EW) is also being explored. An early representative example is the U.S. Army



▲ **Fig. 2** Good and bad uses for commercial drones.

Gray Eagle-based Project NERO, which uses a Raytheon electronic attack payload as part of the U.S. Army's Networked Electronic Warfare, Remotely Operated (NERO) system to provide BLOS jamming to support ground troop operations. Another example is the MQ-9 Reaper platform, which has been used to incorporate a Northrop Grumman electronic attack payload for use by the U.S. Marine Corps (USMC), with subsequent work exploring the ability to integrate the platform into the USMC C2 network, to enable control of the aircraft's EW payload. Beyond the expansion of mission envelopes for existing platforms, we are also seeing the development of new platforms designed to meet specific roles, such as combat (UCAV) and aerial refueling.

CIVILIAN USE—GOOD AND BAD

UAS platform use in civilian airspace is gaining ground as regulatory authorities implement strategies that allow their use for a wide range of non-military applications, applications that legitimately use drones, including deliveries, emergency services, journalism, traffic/parking management and asset inspection. Conversely, these same uses can be illegal or harmful (see ***Figure 2***). For example, delivery services translate to trafficking drugs and other illicit goods across borders and into prisons. Drones can also be used to perform industrial espionage or disrupt operations at critical infrastructure. The ability to carry payloads presents another avenue for terrorists to deliver lethal effects. Other examples include disruption of air traffic, e.g. near misses, and drones gaining proximity to high profile individuals. So while the use of drones in civilian airspace undoubtedly has benefits, there is a market for solutions that can effectively bring drones down without compromising safety.

COUNTERING UAS CHALLENGES

The typical commercial UAS platform has at least two radio links: the uplink is used for the remote control of the drone, and the downlink provides telemetry data and/or receive video. The typical frequencies used for drone operations are in the ISM bands (2.4 or 5.8 GHz), at UHF (433 MHz) or HF (27, 35 or 72 MHz). Presently, the ISM frequencies are the dominant frequencies used for the uplink and downlink. The 2.4 GHz band is primarily used for the uplink using frequency hopping spread spectrum (FHSS), direct sequence spread spectrum, Wi-Fi or Bluetooth. Both the 2.4 GHz and 5.8 GHz bands are used for the downlink, with video downlinks typically streamed in an MPEG format. The typical effective radiated power for the ISM uplink is around 100 mW, compared to 10 mW for UHF uplinks.

An effective counter-UAS system needs to effectively manage four tasks:

- Monitoring the spectrum
- Finding the signal
- Finding the threat
- Neutralizing the threat.

Monitoring the spectrum is the first step in an effective counter-UAS strategy. A key challenge for monitoring the spectrum is identifying the Wi-Fi, Bluetooth, Internet of Things (IoT), microwave ovens and other signals that comprise the cluttered spectra in a commercial environment. A wideband receiver is a key component to effectively monitor the spectrum, and it should have at least 20 MHz bandwidth. The receiver needs to be accompanied by software that can handle several functions: banded searches and setting a noise floor that accounts for the existing environment, then monitoring for signals that emerge above this threshold. Other desirable aspects of this monitoring equipment include: detecting FHSS signals, automatically detecting and classifying the signals of interest, reliably separating the signals, offering no false alarms and recording the activity, to support legal proceedings.

Once identified, the next step is accurately finding the signal of interest. Two primary techniques are used, direction finding (DF) and time difference of arrival (TDOA). Both have advantages and disadvantages; the final choice comes down to customer preference and cost. DF-

▲ Fig. 3 Hensoldt Xpeller Counter-UAV solution.

▲ Fig. 4 Anti-UAV Defence System.

based systems have faster processing, as they use a single receiver. However, the receiver is complex; with this complexity comes added cost and limited mobility, since the receiver is typically placed in a specific location. The TDOA-based approach uses multiple receivers and can, potentially, provide greater accuracy. However, accuracy depends on effective placement of the receivers within the area of interest. Other potential limitations of TDOA receivers include handling small band signals and significantly slower processing, since the information from the receivers must be collated and transmitted for processing at a central location.

Beyond the RF spectrum, the counter-UAS system needs to sense the threat using a combination of radar, EO-IR, acoustic and other sensors to detect, track, locate, verify and identify the drone that is potentially encroaching into a sensitive area.

The final stage is neutralizing the threat. From an RF perspective, jamming can be applied to disrupt the remote control link between the operator and the drone. This can either force the drone to land or return to the operator. Where a drone is following a predefined route based upon waypoints defined by a global navigation satellite system (GNSS) signal, RF jamming can be applied to disrupt the signal to bring the drone down or cause it to revert to default programming that takes it back to the operator. Another option is using a high-power electromagnetic (HPEM) pulse to neutralize all the electronic systems, which will force the drone into an uncontrolled descent. This approach raises the question of responsibility for a drone crash, an issue further complicated if the drone is carrying an explosive payload. Other interesting approaches to neutralizing drones include lasers, conventional guns, nets and birds of prey.

COUNTER-UAS SOLUTIONS

A growing number of counter-UAS solutions are being offered in the marketplace. The following examples, no means exhaustive, represent the different business strategy approaches:

- In-house capabilities
- Partnerships that combine the capabilities of multiple companies.

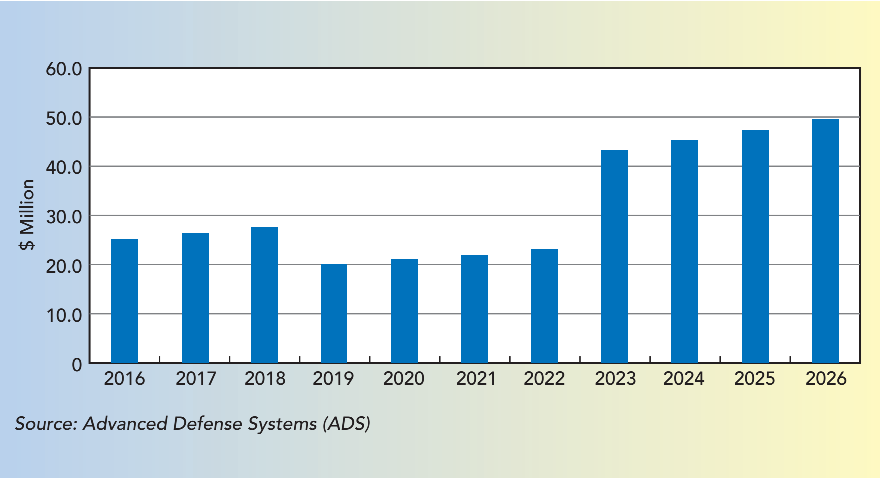
The Hensoldt Xpeller counter-UAS solution (see ***Figure 3***) is an example of the former, i.e., combining the radar, camera and jamming elements from different branches

and subsidiaries of the Hensoldt organization. The radar is based on the company's Spexer 500, a 4 W, X-Band active electronic scanned array (AESA) FMCW radar. It has detection ranges up to 4 km and can handle targets with a 0.2 m^2 radar cross section (RCS). The radar is coupled with the NightOwl ZM-ER thermal and color camera. The RF jammer from GEW Technologies covers 20 MHz to 6 GHz and has configurations that offer both directional and omnidirectional antennas and output power from 10 to 400 W.

Hensoldt is also partnering with companies for technologies not available in-house. So the Xpeller solutions can be configured to include the Discovair acoustic sensor from Squarehead Technology AS and close-in RF detectors from myDefence. Hensoldt has possibly realized that shoehorning systems originally designed for military applications may not be optimal, exemplified by their acquisition of U.K.-based Kelvin Hughes. Hensoldt cited the ability to target cost-sensitive markets as one of the motivations behind the acquisition. Kelvin Hughes offers capabilities around their GaN-based X-Band pulse Doppler SharpEye radar and command and control software that allows the integration of multiple radar and camera sensors into a comprehensive display.

Another example of adapting solutions developed for the military sector is the Rafael Drone Dome system, which adapts the company's existing Dome family of solutions designed for ground-based aerial defense to counter drones. In this case, Rafael is essentially the systems integrator, combining a range of systems from industry partners. RADA provides an S-Band RPS-42 GaN-based AESA radar, which has a detection range up to 10 km with a 60 W output and can detect drones in the nano to mini class. This is coupled with the Controp MEOS-U uncooled thermal imaging camera, with the option to add day/night capabilities and laser rangefinders. Spectrum monitoring and jamming is provided by Netsense and C-Guard systems, respectively, both of which are provided by Netline. The Drone Dome system adds a fourth layer of countermeasure capability with lasers adapted from the Iron Beam system, which Rafael has been demonstrating for ground-based air defense.

As an example of a system developed through a partnership-based strategy, the U.K.-based Anti-UAV Defence System (AUDS) has been successfully demonstrated to the U.S. military (see ***Figure 4***). Radar detection is provided via Blighter's A400 radar system, which is a Ku-Band FMCW GaAs-based radar that offers 4 W of output power, with a 10 km range detecting targets down to 0.01 m^2 RCS. The radar is coupled with Chess Dynamics Hawkeye DS & EO Video Tracker system, comprising the Piranha 46 HR camera, a thermal camera and an EO video camera. Enterprise Control Systems provides



▲ **Fig. 5** **Market estimate for airport counter-drone radar systems.**

the Directional RF Inhibitor, which features an RF jammer and quad-band antenna system to provide disruption and inhibition capabilities.

The Guardion modular drone system is another example of a partnership-based capability. Led by Rohde & Schwarz, the system features all four elements described earlier. The sensors include the Rohde & Schwarz Ardronis system, which provides RF analysis of the surrounding environment using DF. This is coupled with sensors that include a 360 degree radar, an acoustic array and a PTZ and IR camera. Effectors are based around disrupting Wi-Fi, jamming of the remote control links, GNSS waypoint jamming and a Diehl-based HPEM capability. This is complemented with a command and control system provided by ESG, which connects all the systems and fuses the sensor data to a map display. The system is also configured to allow personnel in the field to monitor the environment with tablet equipment. This system was used during the 2015 G7 Summit and the U.S. presidential trip to Hanover in 2016.

THE MARKET FOR COUNTER-UAS

The market for counter-UAS systems remains at a preliminary stage, and the early market demand continues to be driven primarily by the military sector. The airport industry presently has the largest pain point, given threats posed by potential collisions with aircraft and the disruption to other operations around commercial airports, such as drones used to disrupt boarding. Trafficking of illicit goods is another potential early market driver, to stop drugs and other contraband being smuggled across borders or into facilities such as prisons. Other factors that need to be resolved include the regulations governing drone use in civilian airspace, although progress is being made.

Strategy Analytics forecasts the market for airport counter-drone radars alone will grow to $50 million by 2026 (see ***Figure 5***).

CONCLUSION

The success of UAS in providing real-time information to military commanders has contributed to both mission effectiveness and protecting personnel. Despite budgetary pressures, an expansion of the mission envelopes will help drive continued demand for UAS platforms. The expansion of commerical UAS could bring about disruptive uses, intentional or not, as well as their use in asymmetric warfare. Combating these potential threats will require a new front in electromagnetic spectrum operations, using a combination of radar and EW, in conjunction with other technologies. The market for counter-drone systems is still in the pre-event phase, with threats seen as hypothetical and no budgets allocated. Dedicated systems are needed to effectively counter the drone threat, and the market should avoid trying to shoehorn military systems into the commercial space.■

INVITED PAPER

Extending Wireless Radio Spectral Efficiency—The Next Frontier

Bernard Prkić,
DragonWave, Ottawa, Canada

We inhabit a world replete with ubiquitous wireless communications. People expect to have access to wireless broadband services at any place and at any time, at least in the more affluent parts of the world, while the rest of the world is catching up swiftly. A growing demand for higher speed data while on the move is fueled by addictive, bandwidth-hungry video services and improvements in video resolution like HD and 4K video. On top of that, technology improvements, cost reductions, ever expanding applications and new "must have" devices to fulfill the latent and emerging needs of humanity may help to establish augmented reality (AR) and virtual reality (VR) in the consumer market, increasing data consumption to unprecedented levels.

With the emergence of affordable flat-rate mobile data plans, at a price point comparable to fixed flat-rate plans, part of the fixed access traffic will move into the mobile access domain, greatly boosting mobile data demand. Then, streaming 4K video across a mobile network from a fixed location will not look like an oddity or a mere marketing gimmick.

QUENCHING THE THIRST

So, how will the wireless industry quench the apparently never-ending thirst for higher speed data? Focusing on a single radio link, rather than on a wireless access or transport network as a whole, traditional tools in the telecommunications engineer's toolbox are well known and consist of:

Adding spectrum—Doubling spectrum, all other factors remaining the same, doubles capacity. This is the most straightforward way to double throughput in any wireless link. It is the telecom engineer's equivalent to the automotive engineer's "there's no substitute for cubic inches" design principle. There is no substitute for bandwidth, but spectrum is limited, and good spectrum is expensive and congested, which often eliminates this option.

Increasing spectral efficiency—This is the telecom engineer's equivalent to the automotive engineer's forced induction toolkit, i.e., turbocharging or supercharging an engine for higher output and/or efficiency per cubic inch. Spectral efficiency can be increased in several well known ways:

- Higher-order modulation is equivalent to adding characters to the alphabet, there-

by encoding more information (bits) per transmitted symbol and increasing the data rate.

- Polarization diversity uses the same communication channel in two orthogonal directions (polarizations) and applies dual-polarization interference cancellation to double spectral efficiency and throughput. This technology is usually denoted as cross polarization interference cancellation (XPIC).
- Spatial multiplexing uses N, where N ≥ 2, transmitting/receiving antennas inside a single channel and polarization for transporting N distinct data streams, exploiting spatial diversity in a signal propagation path to distinguish between the N data streams. This scheme allows for a boost in spectrum efficiency of up to N times under ideal circumstances, and is commonly denoted as multiple input multiple output (MIMO).
- Data compression is the lossless compression of user payload data that enables a data link to carry more. Compression gain typically ranges between 10 and 110 percent, depending on payload compressibility. In most use cases 30 to 50 percent is achievable.

EXAMPLE APPLICATION

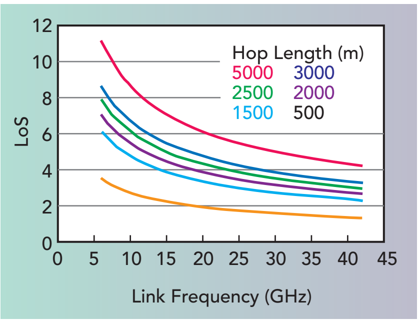
What can these tools deliver in terms of throughput? Let's apply them to a typical fielded point-to-point microwave radio link (a so-called 1+0 link), assuming a single 56 MHz channel, one polarization, 256-QAM modulation and no payload compression. The baseline capacity of this link is 363 Mbps. With the spectral efficiency tools applied sequentially, we can increase capacity in the following ways:

- Increasing the modulation to 2048-QAM yields 500 Mbps, a 38 percent increase, at the expense of approximately 9 dB of link budget. This means maintaining the same link performance (e.g., range, availability and antenna sizes), we must increase the system hardware gain by 9 dB, typically by increasing power and power consumption. Alternatively, the same performance can be provided at the baseline capacity of 363 Mbps while using adaptive modulation to provide 500 Mbps for a smaller portion of time.

▲ **Fig. 1** **One end of a typical 2+0 XPIC point-to-point microwave radio link with traditional single-carrier transceivers that provides 1 Gbps data rates.**

- Expanding the link to a 2+0 XPIC link (see ***Figure 1***) achieves 1 Gbps, greater than a 100 percent increase, by roughly doubling the hardware expense—although some new systems do this more efficiently by providing XPIC in a single unit. Using XPIC may also increase spectrum fees, typically 50 percent, although the increase can be as high as 100 percent.
- Expanding the link to a 2+2 XPIC+MIMO link, which has a capacity of 2 Gbps (another doubling) at the expense of precisely doubling the hardware expense and doubling the number of antennas and, hence, the site lease cost. Line-of-sight MIMO (LoS MIMO) is challenging to implement with point-to-point microwave links because the antenna spacing required can easily exceed 10 m, requiring very specific and scarce tower or rooftop locations.
- Enabling data compression yields 2.6 Gbps. Data compression is one of the most affordable ways to increase spectrum efficiency, as it requires no additional or improved hardware and does not incur recurring spectrum or tower lease fees. The limitations are that the gain depends on the compressibility of the user's payload; encrypted payloads do not compress well.

By simultaneously applying all of the spectral efficiency tools available in the toolbox, at least in theory, we can increase the baseline capacity of an average 1+0 point-to-point microwave radio link using a 56 MHz channel more than 7x to greater than 2.6 Gbps. The spectrum efficiency would be an impressive 46 bps/Hz, half of that per polarization. However, this approach would:



▲ **Fig. 2** **Optimal LoS MIMO antenna spacing vs. frequency and hop length.**

- Increase the hardware cost as much as 4x. With optimized dual-carrier hardware, the cost of a 2+2 XPIC-MIMO configuration would be about 2.7x that of a 1+0 single-carrier baseline.
- Increase spectrum fees by 50 to 100 percent.
- Double the tower lease cost.
- Require up to 9 dB higher system gain for the same link availability target at the higher data rate, implying higher hardware costs and power consumption.
- Require payload compression prior to encryption to reap the full benefits of payload compression gain.

It is unlikely that LoS MIMO can be applied in the majority of real world deployments, because of the unwieldy optimum antenna spacing requirement, as shown in ***Figure 2***. The optimal antenna spacing that delivers ~100 percent efficiency is impractical or even prohibitive for lower to medium frequency bands, i.e., below 15 to 28 GHz, and medium-range and long hops (2 km and greater). Hence, the maximum throughput achievable on our sample link would be 1.3 Gbps (rather than 2.6 Gbps), which still represents a significant 3.6x improvement in throughput and spectral efficiency. This level of improvement implies:

- Increased hardware cost, as much as 2x. With optimized du-

al-carrier hardware, the cost of a 2+0 XPIC configuration would be about 1.35x the baseline cost.

- Increased spectrum fees of 50 to 100 percent.
- 9 dB higher system gain to achieve the same link availability target at the higher data rate.
- Payload compression prior to encryption.

THE NEXT FRONTIER

With the tools described in the previous section, representing existing and proven technologies, rather impressive spectral efficiencies in the range of 23 to 46 bps/Hz (50 percent of that per polarization) are possible. If required, as much as 2.6 Gbps through a 56 MHz channel can be achieved. This is equivalent to transmitting an entire 4.7 GB DVD in just 14.8 seconds!

But can we increase spectral efficiency beyond this? Not so long ago, I would probably have said "not by much under real-life circumstances." It appeared that we had all but exhausted our options.

Surely, modulation can be, and has been, increased beyond 2048-QAM. However, the relative spectral efficiency gain is modest (less than 9 percent per step and decreasing), and the loss of radio frequency performance is significant. To double spectral efficiency through modulation alone, taking 2048-QAM as a baseline, would require developing 262,144-QAM and compensating for a significant 21 dB loss of system gain. That is prohibitive.

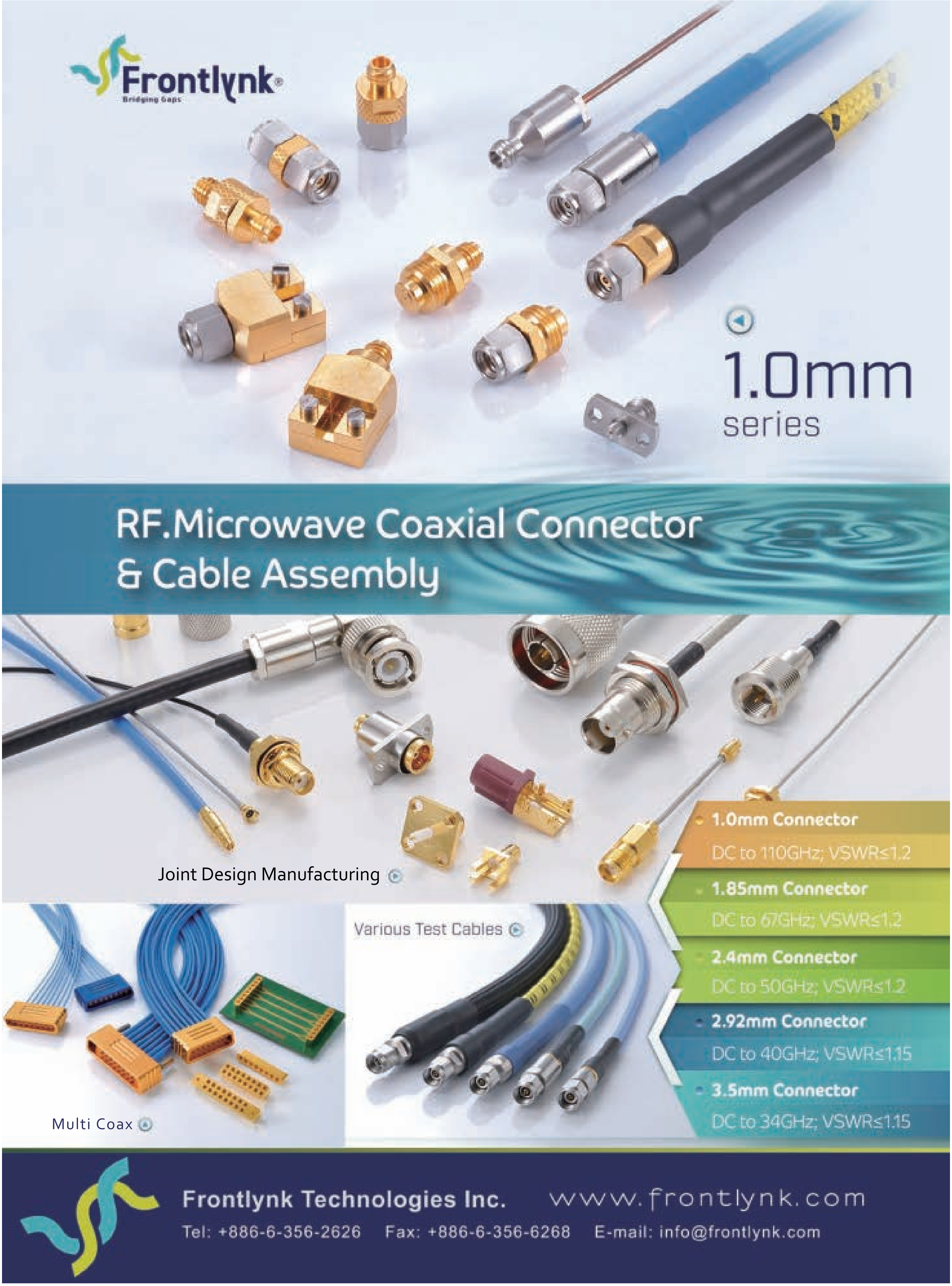
XPIC simply does not scale beyond two carriers, as there are only two spatially orthogonal polarizations available. Two by two LoS MIMO is already hard to deploy, and scaling up to higher-order LoS MIMO for point-to-point microwave links in a single polarization is even less attractive. Four by four LoS MIMO typically relies on 2 x 2 LoS MIMO in two polarizations, so it is not "true" 4 x 4 MIMO, rather 2 x (2 x 2 LoS MIMO) operating in XPIC mode. It is a combination of LoS MIMO and XPIC.

Fortunately, there are other, more promising approaches on the horizon: full duplex radio and spiral modulation. Both approaches promise a significant improvement in spectral efficiency: full duplex radio by 87 to 100 percent and spiral modulation, potentially, by more than 400 percent.

FULL DUPLEX RADIO

Full duplex radio is simply simultaneous transmission and reception in a single channel. Despite its conceptual elegance, nearly all of today's full duplex transceiver systems use either frequency division duplex (FDD) or time division duplex (TDD), rather than full duplex radio, for separating strong outgoing from weak inbound signals. With FDD, the system transmits and receives simultaneously but on different frequency channels (separated by the duplex spacing), using comparatively simple and inexpensive devices like bandpass filters to suppress the transmitted signal at the local receiver. With TDD, the system's transmission and reception do not occur simultaneously, rather at pre-defined consecutive time intervals (bursts) and are hence separated in the time domain rather than the frequency domain. With a rapid switching (time slicing) between the transmitting and receiving mode, traffic flow appears to be continuous. FDD and TDD provide comparatively simple and inexpensive means for separating the strong, locally transmitted signal from the much weaker received signal, which is why they are popular.

The significant technical challenge to implementing full duplex radio is the reduction of self-interference by the transmitter. A large amount of transmitter-to-receiver signal suppression is needed in a typical high-performance wireless communication system—typically > 110 dB, assuming a –90 dBm receiver noise floor and +20 dBm of transmitter power, so that self-interference does not adversely impact system performance. This is more challenging since the transmitter analog signal is distorted nonlinear-


Frontlynk
Bridging Gaps
1.0mm series
RF.Microwave Coaxial Connector
& Cable Assembly
Joint Design Manufacturing
1.0mm Connector
DC to 110GHz; VSWR≤1.2
1.85mm Connector
DC to 67GHz; VSWR≤1.2
2.4mm Connector
DC to 50GHz; VSWR≤1.2
2.92mm Connector
DC to 40GHz; VSWR≤1.15
3.5mm Connector
DC to 34GHz; VSWR≤1.15
Various Test Cables
Multi Coax
Frontlynk Technologies Inc.
www.frontlynk.com
Tel: +886-6-356-2626
Fax: +886-6-356-6268
E-mail: info@frontlynk.com

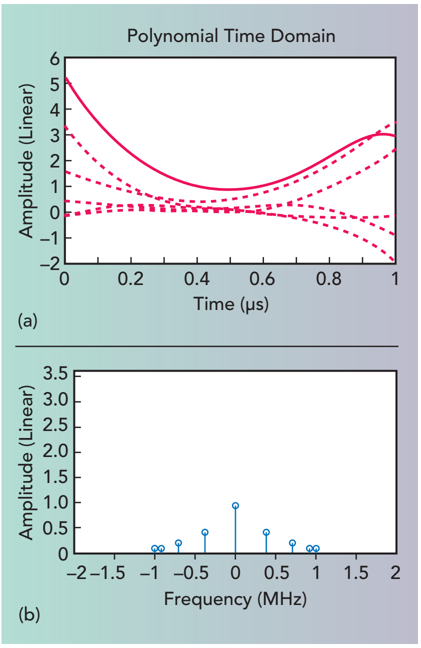
ly, consisting of the desired transmitted signal, its harmonics and (random) transmitter noise.

Until recently, no one had been able to accomplish this feat. However, a team from Stanford University[1] has built a prototype that achieved a median spectrum efficiency gain of 87 percent in a Wi-Fi-based proof of concept, using a standard 802.11ac full duplex radio and a clever combination of analog and digital self-interference cancellation techniques. This represents a technical breakthrough. Although several challenges remain, such as miniaturization of the prototype hardware, extension of the concept to MIMO systems with the added complexity, cost reduction and possible regulatory challenges in FDD spectrum, full duplex radio will most likely become a new and valuable tool in the spectral efficiency toolbox. The technology is being commercialized by Kumu Networks.[2]

SPIRAL MODULATION

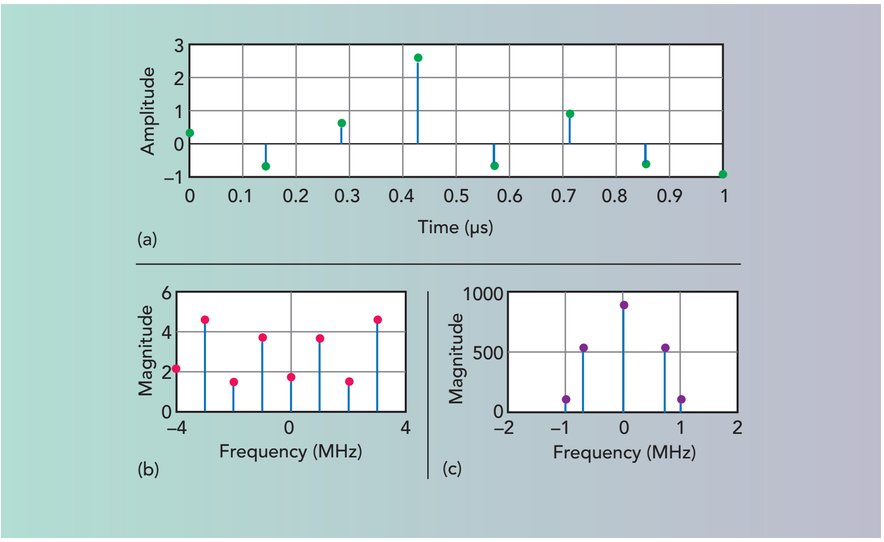
Spiral modulation is a term coined by its inventors at Astrapi Corp.[3] The concept is based on new mathematics and leads to a potential breakthrough in spectral efficiency by exploiting the properties of a continuously-varying spectrum. Due to its mathematical foundations, the spiral modulation concept is more difficult to comprehend and explain than the intuitive concept of full duplex radio. Unlike full duplex radio, there is no working transceiver prototype implementing spiral modulation—yet. This is work in progress. Spiral modulation is a more fundamental innovation, a paradigm shift, as it holds the promise of much greater spectral efficiency gain, on the order of more than 400 percent. A full duplex radio, on the other hand, is inherently maxed-out at 100 percent spectral efficiency improvement.

The foundational mathematics for current telecommunications is Euler's formula. This generates sinusoids with constant amplitude, which are the bases for symbol waveforms in digital communication. The Fourier transform (FT), used for spectral analysis, is also derived from Euler's formula. Effectively, the FT averages spectral information over a time interval. Astrapi introduced a generalization of Euler's formula that describes spirals in the complex plane. This mathematics leads to a disciplined and precise method for describing symbol waveforms generated from sinusoids with continuously-varying amplitude, i.e., "spiral modulation." It also provides a technique called instantaneous spectral analysis (ISA) for describing a time-varying or "non-stationary" spectrum at each moment in time, not averaged over an interval as with the FT (see ***Figure 3***).



▲ **Fig. 3 ISA example decomposing a random Taylor polynomial of degree 15 (a) into sinusoids with continuously-varying amplitudes, shown at an arbitrary time of 0.2 µs (b). Used with permission of Astrapi Corp.[4]**

This conceptually simple generalization from circles to spirals has profound implications. The Shannon-Hartley law, which establishes an upper bound on spectral efficiency related to the available bandwidth and the signal-to-noise ratio (SNR), contains an implicit assumption that the spectrum is stationary, through the use of the FT, to prove the sampling theorem. In principle, the design of signals featuring a continuously non-stationary



▲ **Fig. 4 ISA applied to a time amplitude sequence (a), comparing the stationary FT (b) and t_0 ISA (c) spectrums. In this example, the ISA range of frequencies with nonzero amplitude is 25 percent of the range from the FT representation. Used with permission of Henry Rodrigues, Inatel.[5]**

spectrum using the tools provided by spiral modulation opens the door to much higher spectral efficiencies than were previously thought possible—in theory limited by hardware rather than solely by available bandwidth and SNR (see ***Figure 4***).

Astrapi's research on spiral modulation, which has been funded by the U.S. National Science Foundation (NSF), is not at a stage where it is ready for commercialization. However, since spiral modulation is the only technology that can, in principle, offer indefinite improvements in spectral efficiency by exceeding the Shannon limit, it is worthy of consideration. Astrapi is developing spiral modulation collaboratively and is open to new partnerships with companies and research institutions willing to help shape the technology from its current stage.

CONCLUSION

Mobile data consumption is growing steadily, fueled by high-definition video applications, fixed-rate "all you can eat" data plans, fixed-mobile substitution and novel, emerging bandwidth-hungry applications. At the same time, the most useful available spectrum is inherently limited, as is the spectrum that can be used to backhaul data from cellular base stations where wireless backhaul is used. Maximizing spectral efficiency is, therefore, of paramount importance for the telecommunications community.

While consumption is growing, the steady increase of spectral efficiency in telecommunication systems has been tapering off. Two independent developments, full duplex radio and spiral modulation, may reverse the trend and enable the telecommunications industry to push the envelope way beyond what is considered to be the current state-of-the-art in spectral efficiency. Those two technologies, combined, may spur an 8x or higher increase in spectral efficiency, enabling spectacular growth in the traffic-carrying ability of wireless telecommunication systems. With this combination of technologies, it is conceivable to have a 10 Gbps or greater wireless link, even with today's narrow spectrum allocations.

There are exciting years ahead of us!■

References

1. D. Bharadia, E. McMilin and S. Kattihttp, "Full Duplex Radios," *SIGCOMM'13*, August 2013.
2. www.kumunetworks.com.
3. www.astrapi-corp.com/about/.
4. Dr. J. Prothero, "Technical Introduction to Spiral Modulation," *Technical Report R-201-1*, Astrapi Corp., February 2017, www.astrapi-corp.com/wp-content/uploads/2017/03/R-2017-1_Technical_Introduction_to_Spiral_Modulation.pdf.
5. H. D. Rodrigues, "Instantaneous Spectral Analysis (ISA)," *Inatel-Brasil*, October 2016, www.astrapi-corp.com/wp-content/uploads/2017/02/ISA-Presentation-Henry-Rodrigues.pdf.

Interface Gauges

Spectrum
Elektrotechnik GmbH

A small investment helps avoiding big trouble.

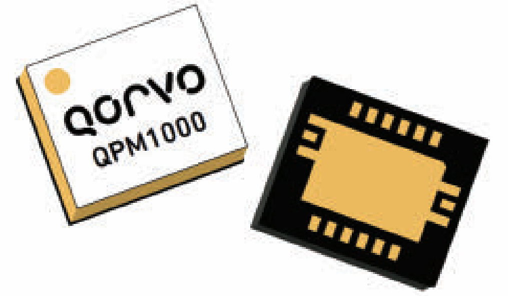
Please see our other products, starting at Connectors, rigid and flexible Cable Assemblies for High Performance, High Power, Phase Stability, Coaxial Adapters, Waveguide to Coax Adapters, Passive Components, such as Phase Shifters, Isolators, Circulators, Terminations, Cal Kits and Super Components.

80905 Munich, Germany P.O. Box 450533

Telephone: +49-89-3548-040 Facsimile: +49-89-3548-0490

www.spectrum-et.com * Email: Sales@Spectrum-et.com

Interface GaugesE



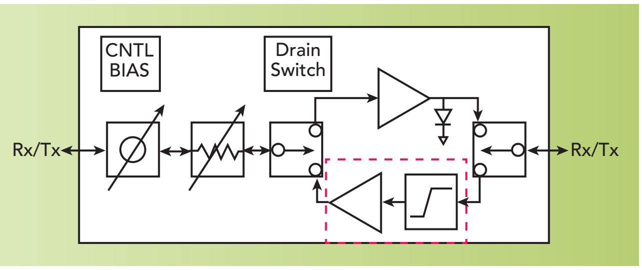
2 to 20 GHz Limiter/ Low Noise Amplifier

Qorvo Inc.
Greensboro, N.C.

The QPM1000 is a high performance, 2 to 20 GHz multichip module (MCM) that combines a limiter and low noise amplifier (LNA) within a small surface-mount package. It addresses traditional and emerging military system requirements for the receive arm in a variety of transmit/receive (T/R) architectures. Not only does the QPM1000 pull from Qorvo's portfolio of performance-leading MMICs, a mainstay of the defense and aerospace markets, it leverages Qorvo's high volume and low-cost packaging technology, used in traditional consumer and commercial markets. The result is a compelling and affordable surface-mount limiter/LNA that optimizes performance and footprint.

MILITARY MARKET NEEDS

Without sacrificing performance, defense and aerospace systems continue to choose commercial products to drive down nonrecurring and unit costs, as well as development schedules. While the use of commercial off-the-shelf (COTS) products has become the norm over the past several years, applying commercial packaging technologies to integrated RF front-end assemblies has lagged. Using commercial packaging technology is an opportunity to further shrink footprint, reduce cost and maintain the highest level of performance in military architectures.

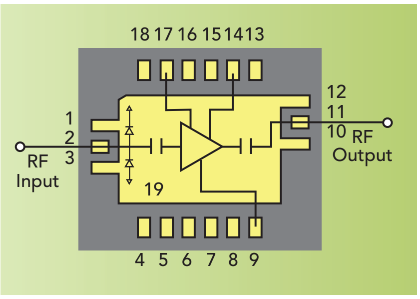


▲ **Fig. 1 Block diagram of a typical T/R module, showing the QPM1000 functionality (inside dashed lines).**

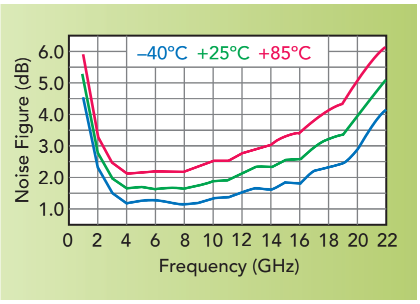
Figure 1 shows the block diagram of a conventional T/R module, with the functionality of the QPM1000 indicated. Although a highly integrated, single chip solution offers the smallest size, it comes with high development cost and compromised performance. Alternatively, MCMs enable choosing the "right junction for the function," resulting in the highest level of performance available using existing MMICs and a much shorter development cycle time, with only a modest penalty in size. The surface-mount QPM1000 and related MCMs are compatible with low-cost assembly to a second-level PCB using standard solder reflow processes. In comparison, a T/R module using single-function packaged components yields a footprint that is typically 10x larger—even greater—than an MCM solution.

HIGH VOLUME, LOW-COST HERITAGE

Qorvo is a world leading supplier of MCMs for handsets, shipping hundreds of millions of units each year. Although the mobile device market is quite different from defense and aerospace, commercial capabilities can be leveraged in a crossover play: global sourcing, design rules, materials, assembly processes and production test.



▲ **Fig. 2** QPM1000 functional block diagram.



▲ **Fig. 3** QPM1000 noise figure vs. frequency and temperature (V_D = 5 V, I_{DQ} = 100 mA, V_{G2} = 1.3 V).

Qorvo has invested substantially in laminate technology (i.e., a highly engineered soft board) and a robust manufacturing and supply chain. Design rules established over the years in concert with fab processes minimize trace width and gap geometries while maintaining high assembly yield. These laminate materials form the base for mixed technology assemblies that include die attach, wire bond and surface-mount component attach processes. Importantly, Qorvo routinely spins custom laminate designs quickly and at low-cost. These commercial capabilities have been tapped to establish a military-focused development engine that brings high performance MMICs together to create MCM solutions.

DESIGN AND PERFORMANCE

The QPM1000 combines two separate MMICs into a multichip module (see ***Figure 2***). The limiter is a broadband, high-power limiter chip based on Qorvo's GaAs VPIN technology. This MMIC operates through 20 GHz and has 10 W peak power handling. The LNA MMIC, fabricated using Qorvo's 3MI 0.15 µm power PHEMT process, has 2.5 dB typical noise figure at 10 GHz and flat gain past 20 GHz.

The module design features a customized laminate base, which optimizes the RF performance by minimizing die-to-die spacing and the associated bond wire interconnects. The RF transitions were designed and verified for operation through 40 GHz, and the air cavity package design provides high performance through 20 GHz, the operating frequency range. The layout yields an overall 6 mm × 5 mm land grid array footprint. The QPM1000, both lead-free and RoHS compliant, can be surface-mounted to a second-level PCB using standard solder reflow assembly processes. It is assembled and tested in the U.S.

The QPM1000 delivers 17 dB small-signal gain, with gain control, and greater than 18 dBm output power at 1 dB compression. The noise figure ranges from 1.5 to 4 dB across frequency (see ***Figure 3***). The integrated limiter handles up to 4 W of incident power without performance degradation. IM3 measures less than 20 dBc at 25°C, with 0 dBm input power per tone. The typical bias conditions are 5 V_D, 100 mA I_{DQ} and 1.3 V_{G2}.

Qorvo's QPM1000 is an integrated limiter/LNA providing robust performance over the 2 to 20 GHz frequency range. It combines high performance MMIC die into a low-cost, laminate-based MCM assembly to optimize performance in a small surface-mount package.

FUTURE TRENDS

Higher levels of integration in the future will increase functionality and enable proportional shrinks in MCM footprint. As the performance of single-function MMICs improve, MCM T/R architectures will benefit accordingly. The same packaging technology used with the QPM1000 has been extended to GaN MMICs, enabling MMIC combinations that leverage the optimum device technology for each RF component. To reduce unit cost and improve environmental robustness, overmold packaging can be used in place of air cavity, when warranted to meet the requirements of next-generation military systems.

Qorvo Inc.
Greensboro, N.C.
www.qorvo.com

StarLab 50 GHz–Designed to Meet the 5G Challenge

MVG
Paris, France

Soon, the arrival of 5G will lay the foundation for a hyper-connected society: a world in which everything that benefits from being connected will be connected. Internet connections will move from computer and smartphone screens to a world of objects communicating directly among themselves. All sectors of society will be transformed by this technology, from Industry 4.0, with smart factories; to the automobile industry, with self-driving cars; to the healthcare sector, with remotely controlled robotic surgical procedures; to connected homes and smart cities. Indeed, 5G will enable wireless connectivity in a wide range of markets and industries, going far beyond what has been done with LTE.

During development, the technology required to realize 5G will be put to the test—literally. To address this challenge, MVG has developed the StarLab 50 GHz, which the company says reinvents high frequency antenna and over-the-air (OTA) performance testing. Delivering ultra-fast and accurate test results, StarLab 50 GHz provides a future-proof, turnkey solution for high frequency system development, meeting the 5G testing challenge.

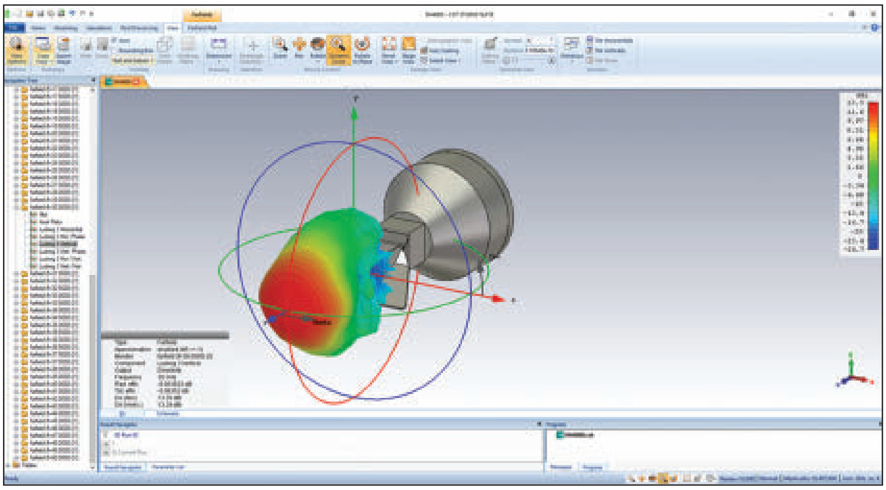
5G CHALLENGES

5G is based on three cornerstones. The first is an increase in bandwidth and network capacity to transmit greater quantities of data to an increasingly large number of users. The second is ultra-reliable wireless connections with low latency, allowing critical real-time applications to function securely, such as self-driving cars and remote surgery. The last is wireless connectivity that requires little bandwidth and energy to prepare for the extensive deployment of connected objects, such as sensors. By making permanent connections possible, the arrival of 5G will be accompanied by the large-scale usage of cloud computing, which will make it possible to efficiently operate many new services. The success of many of these services will depend on wireless connection quality. Wireless connection performance will be a parameter that is difficult to control, as it is based on the quality of the networks deployed and the specific implementation of wireless connectivity solutions in the device.

To verify performance, tests and measurements of devices and 5G network equipment must be conducted, differing considerably from what is done currently. 5G will, in addition to using the frequency ranges used in current cellular networks, use higher frequency bands where the hardware will not have physical connectors. In these cases, products will be tested exhaustively in wireless mode (OTA); traditionally, many tests are conducted in wired mode. This will lead to an ever-increasing number of scenarios and test cases requiring OTA testing to ensure both compliance with standards and good user experience in real-life applications.

Beyond these technical challenges, there are others related to convenience and the ease-of-use of the test system. Large anechoic chambers traditionally need dedicated infrastructure, with extensive real estate and building construction. As a convenient and flexible alternative, MVG has created a series of compact, portable, all-in-one antenna

▲ **Fig. 1 The SH 4000 dual ridge horn antenna, used as a test case for the StarLab 50 GHz.**



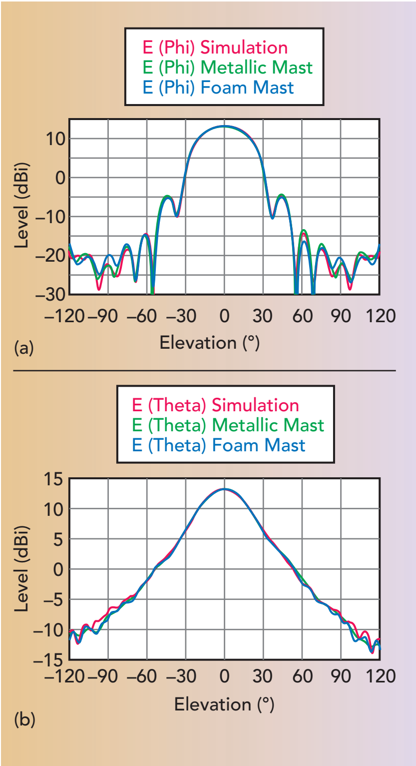
▲ **Fig. 2 Simulation of the SH 4000 using CST MWS.**

measurement tools called "Little Big Lab," that adheres to the motto "Little in size, BIG in performance."

THE SOLUTION

The StarLab 50 GHz is the latest innovative addition to MVG's product range. It is designed to meet high frequency testing challenge and is based on the combined knowhow of the company, from telecom OTA testing to aerospace and defense high frequency testing. Because it is compact and portable, the StarLab 50 GHz frees up space in laboratories and production environments and saves costs.

With its ultra-fast, electronically-scanned probe array—testing 10x faster than standard ones—it is ideal for mmWave antenna measurement and OTA testing. Accuracy is enhanced thanks to its capability to measure with limited movement, owing to patented oversampling technology. Its spherical configuration enables all types of antenna measurements, from low to high directivity. This 50 GHz version has been designed with a keen sense of detail in every component: wedge absorbers optimized to minimize reflections; cutting-edge probes that are wideband (18 to 50 GHz), low directional and dual-polarized; and accurate stabilizers, offering stability and fine level adjustment.



▲ **Fig. 3 Simulation vs. measurement of the SH 4000 at 30 GHz, with phi = 0° (a) and 90° (b).**

ANTENNA TEST CASE

To illustrate the capability of the StarLab 50 GHz, the following test case evaluates an MVG SH 4000, a dual ridge horn antenna (see ***Figure 1***), which is typically used as a gain reference in test ranges and as a reflector feed for high gain applications in compact ranges. It is the reference antenna in the 30 GHz antenna test case described here. The simulation of the antenna radiation pattern is performed with the CST MWS simulation software (see ***Figure 2***), with only the antenna included in the simulation model. The interface on which the antenna is installed and the cable that feeds it are not included in the simulated results, though they will have an influence on the actual antenna performance. Despite this, good correlation is shown between the simulation and the measurements performed with StarLab 50 GHz.

Figure 3 shows a comparison between the measured and simulated radiation patterns, with phi = 0 and 90 degrees. One measurement was realized with a metal mast, which offers better positioning precision but impacts the radiation pattern. The second measurement was performed with a foam mast, which provides less mechanical positioning accuracy but limits the impact on the radiation pattern, since the foam is electrically transparent at the measured frequencies. For both measurements, the curves of the simulated and measured antennas correlate well. This demonstrates that the results measured with the StarLab 50 GHz are accurate, and the fast, multi-probe concept can be applied successfully to high gain, high frequency antenna testing. In this case, the performance at 30 GHz is particularly relevant for 5G. At high frequencies, the 5G new radio (NR) will initially be rolled out and deployed in the 24 to 30 GHz frequency range, depending on the region.

MVG
Paris, France
www.mvg-world.com/en

E-Band Quadrature Mixer

The quadrature mixer, commonly known as the I/Q mixer, is configured with two individually balanced mixers and their respective LOs driven from the outputs of a 90-degree hybrid. It is widely used when single sideband (SSB) rejection is required. In communication systems, the I/Q mixer is often used as a SSB modulator or demodulator, where the image band signals, either upper or lower, can be rejected by appropriately phasing the IF signals. In Doppler radar systems, the I/Q mixer as a demodulator delivers two orthogonal IF signals that represent the direction of a moving target, either approaching or receding. It can also be used as a modulator for simulating a Doppler radar target.

SAGE Millimeter has released an E-Band quadrature mixer for radar and communications systems operating at E-Band (75 to 84 GHz). The SFQ-79379315-1212SF-E1 has a typical conversion loss of 15 dB, with an LO drive of +7 dBm and external bias of +4.5 VDC and 2 mA (typical). LO to RF isolation is typically 22 dB, and the IF bandwidth extends from DC to 2 GHz. Since the IF ports are DC coupled, the mixer can be used as a phase detector. Typical amplitude and phase balance of the I/Q outputs are ±1 dB and ±15 degrees, respectively. The mixer can be configured as an image rejection mixer or SSB modulator by adding an IF quadrature coupler.

The quadrature mixer uses WR12 waveguide with UG387/U flanges for the RF and LO ports and female SMA connectors for the IF ports. DC bias is applied via soldered pins. The mixer is packaged in a gold-plated housing weighing 1.8 oz and measuring 1.15 in x 1.15 in x 0.88 in, making it convenient for system integration.

SAGE Millimeter offers a family of quadrature mixers for the entire 18 to 110 GHz spectrum.

VENDORVIEW

SAGE Millimeter Inc.
Torrance, Calif.
(424) 757-0168
www.sagemillimeter.com

EDI CON China Back to Beijing!

EDI CON 2018

Electronic Design Innovation Conference

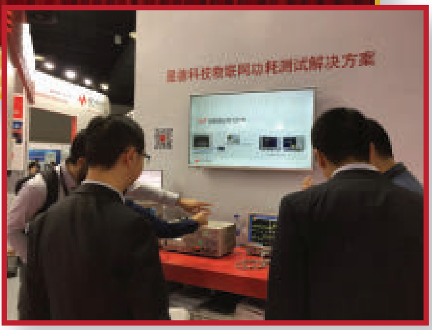
电子设计创新大会

Reserve your booth now to reach engineers in China working on RF, microwave, and high-speed digital designs

March 20-22

China National Convention Center

Beijing China



Plan Now to Exhibit!

Reach professionals working in:

- RF and Microwave
- Signal Integrity and Power Integrity
- High-Speed Digital Design
- Semiconductors
- Test & Measurement Equipment
- Materials and Packaging
- EDA/CAD
- EMC/EMI

Call for Abstacts Open!

The conference includes technical sessions, workshops, panels, short courses, poster sessions and plenary keynotes.

November 30, 2017 – Abstracts Due
January 2, 2018 – Notice of Acceptance
February 27, 2018 – Final Materials Due

Sign up now to choose your booth! **EDICONCHINA.com**

Host Sponsor: KEYSIGHT TECHNOLOGIES

Diamond Sponsor: ROHDE&SCHWARZ

Corporate Sponsor: NATIONAL INSTRUMENTS

Organized by: horizon house® Microwave Journal China 微波杂志

Flexible VNA Test Cables Provide Precise Results

Ideal for test benches, Pasternack's high-performance, flexible vector network analyzer (VNA) test cables support precision measurements to 110 GHz.

They are assembled with a PE-TC110 coaxial cable, 1.0 mm stainless steel connector interfaces and a non-conductive Nomex® outer sleeve. The light-duty armoring protects the small, 0.27 in diameter cable and improves stability during flexure—maintaining excellent phase and amplitude stability. The cables have 50 Ω impedance, with a maximum VSWR of 1.5:1 and low insertion loss. They operate over a wide range of temperatures, from −65°C to +125°C, and are RoHS and REACH compliant.

To ensure the highest levels of quality, each VNA test cable assembly is serialized, fully tested and shipped with the test data. Standard 6 and 12 in lengths with male-to-male or male-to-female configurations are available off-the-shelf, i.e., in-stock and ready for immediate shipment with no minimum order quantity restrictions.

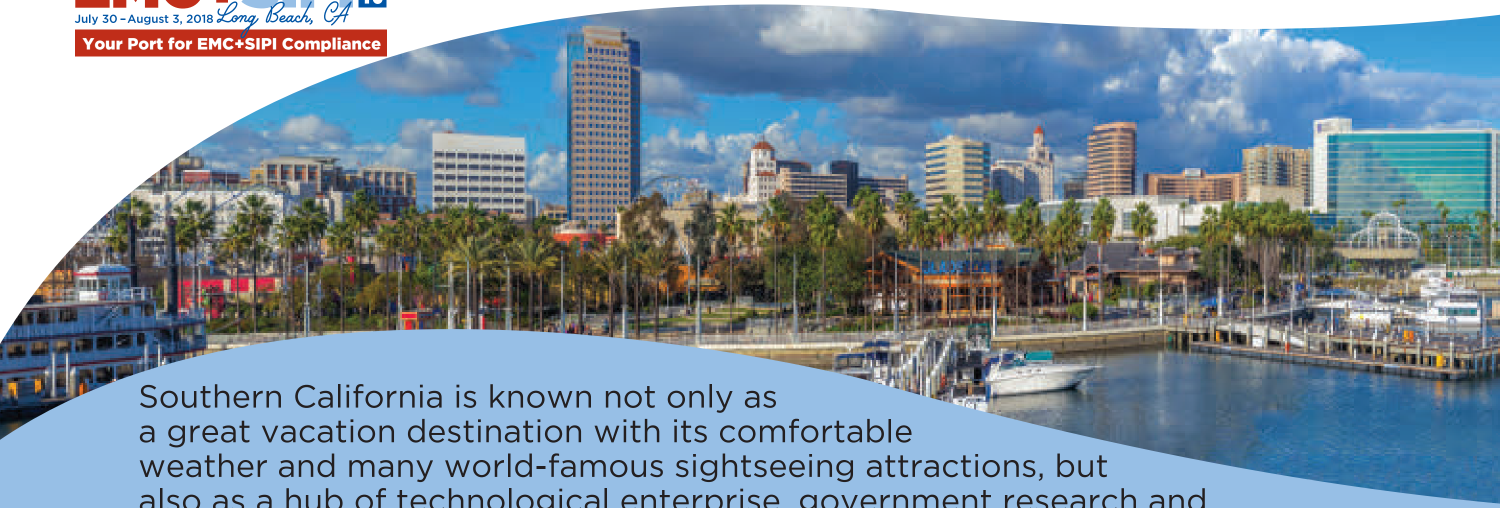
In addition to VNA testing, Pasternack's precision VNA cables are well suited for use with radar, microwave and mmWave radio systems.

VENDORVIEW

Pasternack
Irvine, Calif.
www.pasternack.com

EMC+SIPI 2018
July 30 – August 3, 2018 Long Beach, CA
Your Port for EMC+SIPI Compliance

2018 IEEE SYMPOSIUM ON ELECTROMAGNETIC COMPATIBILITY, SIGNAL AND POWER INTEGRITY



Southern California is known not only as a great vacation destination with its comfortable weather and many world-famous sightseeing attractions, but also as a hub of technological enterprise, government research and academic powerhouses making it an ideal location for hosting EMC+SIPI 2018.

CALL FOR PAPERS

Get Your Ideas Published!

EMC+SIPI 2018 is a Technical Symposium. Technical Papers are the essence of our Technical Program. Original, unpublished papers on all aspects of EMC+SIPI are invited.

- Preliminary Full Paper Manuscript Submission Period: November 1, 2017 - January 14, 2018
- Notification of Acceptance: February 21, 2018
- Final Paper Due: May 3, 2018

Call for Experiments & Demonstrations

Experiments and demonstrations utilize hardware and software to demonstrate a principle or phenomena of EMI/EMC. The presentations are informal and non-commercial and will be conducted in a specific area at the symposium.

Call for Abstract Reviewed Papers

Abstract Reviewed Papers provide opportunities to exchange experiences and ideas. Only an abstract is required for initial submission, papers are included in the conference proceedings; however, these papers are not published in the IEEE Xplore.

- Proposals Accepted: November 1, 2017 - February 21, 2018
- Acceptance Notification: March 27, 2018
- Final Paper Due: May 3, 2018

Call for Special Sessions

Special Sessions focus on targeted areas of interest. Acceptance criteria are the same as for Technical Papers, and Special Session papers are published in IEEE Xplore.

- Proposals Accepted: November 1, 2017 - December 20, 2017
- Notification of Acceptance: January 10, 2018
- Preliminary Papers Due: March 6, 2018
- Final Papers Due: May 3, 2018

Call for Workshops & Tutorials

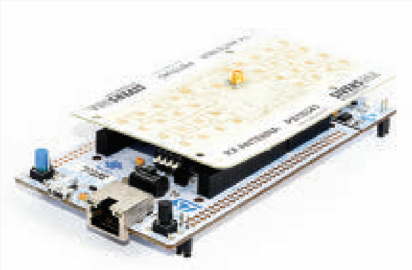
Workshops and Tutorials are informal, interactive educational presentations, typically addressing the practical side of understanding and solving EMC issues. These sessions typically are held on Monday and Friday.

- Proposals Accepted: November 1, 2017 - January 16, 2018
- Notification of Acceptance: February 21, 2018
- Final Presentations Due: May 3, 2018

IEEE | EMC SOCIETY

For more information, see the Symposium website

www.emc2018usa.emcss.org



24 GHz Radar Sensor Evaluation Kit

The EVK02401/00 is a complete 24 GHz radar, intended as a platform for the development of customer specific sensing solutions. It integrates an antenna, analog front-end, an ARM M7 microcontroller unit (MCU) board with radar firmware and signal processing software into an easy-to-use sensor (the RSE02401/00), enabling customers to create high performance systems using radar. Both FMCW and Doppler functionality provide immediate distance and speed measurements. Other features include USB connectivity, low power consumption, the option to use an external antenna, an easy-to-use graphical user interface (GUI) showing distance and speed and raw data logging.

The sensor incorporated in the EVK02401/00 evaluation kit—the RSE02401/00—is a fully integrated K-Band FMCW radar. To achieve low unit price and high volume, it utilizes low-cost, surface-mount packaged components and no tuning is required. The user can control the unit and receive data over the USB serial interface. A reconfigurable patch antenna is included, or an optional external antenna may be used.

The sensor has been designed from the ground up using a modular approach, allowing rapid customization and adaption to a customer's application specific requirements. The primary intended applications involve short range distance or speed measurements in commercial and industrial applications: level measurement, proximity detection and presence detection where speed or distance measurements are required.

Radar sensing technology offers advantages compared to non-radio technologies, including the capacity to function well in various types of weather and atmospheric conditions and high resolution distance measurement. It is also claimed to offer good range. The sensor penetrates a variety of non-metallic materials and can be mounted invisibly, such as behind a radome.

Sivers IMA
Kista, Sweden
www.siversima.com

Software and Mobile Apps

New Tech-Select® Design Software & Product CD

ATC's new 2017 Tech-Select® Design Software & Product CD, version 9.0, is enhanced with new features. This Design Support Tool provides access to all RF parameters as well as mechanical dimensions for ATC products, including Smith charts, S-parameters, effective capacitance, RF current, RF voltage, ESR, Q, complex impedances and more. RF parameters are achieved at frequencies entered by the user. By selecting and sorting on the desired parameters, this program generates a complete list of product options with part numbers. Users may view and print datasheets or individual performance curves for ATC products.

American Technical Ceramics

www.atceramics.com

AR App of Knowledge Mobile Device App

VENDORVIEW

AR RF/Microwave's mobile app is available as a free download from Apple iTunes and Google Play. Search for "AR App of Knowledge." This app is a quick and easy tool to access various content from AR. Home screen icons give you easy access to basic and full product descriptions, app notes, AR's literature library, YouTube videos, contact information and social media icons. Visit the site to download the app.

AR RF/Microwave

www.arww-rfmicro.com/html/ar-moblie-app.asp

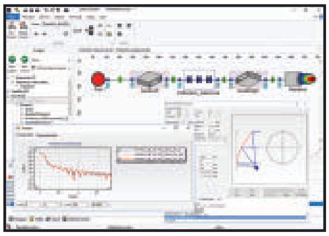
K&L Filter Wizard®

K&L Microwave's Filter Wizard® synthesis and selection tool streamlines identification of RF and microwave filters, meeting customer requirements across a large portion of K&L's standard product offerings. Filter Wizard® accelerates user progress from specification to RFQ over an ever-increasing range of response types, bandwidths and unloaded Q-values. Provide the application with desired specifications, and the software returns a list of products that match, placing response graphs, outline drawings and downloadable S-parameters at your fingertips. Visit the site via computer or mobile device to get started.

K&L Microwave

www.klfilterwizard.com

µWave Wizard 8.1



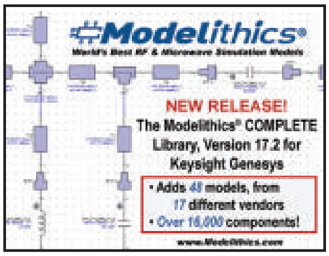
In Version 8.1, the latest release of Mician's hybrid EM-design software µWave Wizard, a tool for the analysis, synthesis and optimization of passive components, radiating boundary conditions are added to the 3D FEM solver, enabling the simulation of antennas with arbitrary shape and material distribution, like slotted waveguide and dielectric resonator antennas. Outer geometries of waveguide horn antennas can be modeled exactly. Also it allows the simulation of single and dual offset reflector antennas using real feed data including tracking mode support.

Mician GmbH

www.mician.com

Modelithics® COMPLETE Library™ v17.2

VENDORVIEW

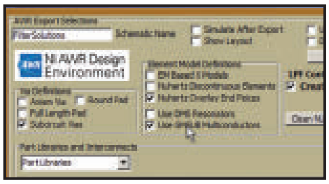


Modelithics has released The COMPLETE Library v17.2 for Keysight Genesys, with 48 new models for passive and active components from 17 different vendors. The new models represent over 1500 individual components added to the extensive collection already available in the COMPLETE Library. Many new models have been added including Microwave Global Models™ for capacitor families. A new nonlinear model is also available. Several new S-parameter models have been added as well. A trial of the Modelithics Library for Keysight Genesys is available for request on the Modelithics website: www.modelithics.com/mvp/genesys.

Modelithics

www.modelithics.com

Filter Design Software from Nuhertz



FilterSolutions© uses Defected Microstrip Structure (DMS) resonator models in exports to AWR to minimize spurious modes in filter designs of hairpin or edge coupled filter models. The program can model tuned notch resonators, exporting the result directly into NI/AWR's Microwave Office™. Optimization goals are automatically set to minimize the first spurious frequency. Optimization goals can then be adjusted to suppress higher order spurs, and the design can be optimized with an electromagnetic analysis program. FilterSolutions distributed element program: $3,900.

Nuhertz Technologies

www.nuhertz.com

Radio and Wireless Week

14-17 January 2018, Hyatt Regency Orange County, Anaheim, CA

radiowirelessweek.org

Steering Committee

General Chair
Rashaunda Henderson, University of Texas, Dallas

General Co-Chair
Charlie Jackson, Northrop Grumman

Technical Program Chair
Robert Caverly, Villanova University

Finance Chair
Nuno Borges Carvalho, Universidade de Aveiro

PAWR Co-Chairs
Gayle Collins, Nuvotronics
Neil Braithwaite, Tarana Wireless

WiSNet Co-Chairs
Luca Roselli, University of Perugia
Rahul Khanna, Intel

SiRF General Chair
Nils Pohl, Ruhr-Universität Bochum

TWIOS Co-Chairs
Thomas Ussmueller, Universität Innsbruck
Charlie Jackson, Northrop Grumman

Executive Committee Chair
Charlie Jackson, Northrop Grumman

Special Sessions Chair
Ahmet Cagri Ulusoy, Michigan State University

Publications Co-Chairs
Spyros Pavlidis, Georgia Tech
Wasif Khan, Lahore University of Management Sciences
Aida Vera Lopez, Intel

Conference Management
Elsie Vega, IEEE

Visa Invitation Letters
Zaher Bardai

Radio and Wireless Week Highlights

Keynote Speaker
Mehmet Yavuz, Vice President, Engineering, Qualcomm Technologies, Inc.

1st IEEE IoT Vertical and Topical Summit on "Connectivity and Communications"
Sunday, 14 January 2018 and Monday, 15 January 2018
Organizers: Multi-Society IEEE IoT Initiative and MTT-S

Workshops
Digital Pre-Distortion and Post-Correction from DC to RF and mm-Wave towards Optical Spectrum
Organizers: Hermann Boss, Rhode & Schwarz and SungWonChung, University of Southern California

Solid State Power Amplifiers for Space
Organizer: Václav Valenta, European Space Agency

TWIOS Microwaves, CubeSats and Small Satellites Workshop
Organizers: Rick Sturdivant, Azusa Pacific University, William Deal, Northrop Grumman Corp, Charlie Jackson, Northrop Grumman Corp.

PAWR Panel Session
The Role of the Active Device in Power Amplifier Design
Chair: Gayle Collins, Nuvotronics

Special Talks
How to Write a Paper for IEEE Journals and Navigate the Review Process
George Ponchak, NASA Glenn Research Center

Automotive Radar – A Signal Processing Perspective on Current Technology and Future Systems
Markus Gardill, InnoSenT

Advanced RF Front-End and Transceiver Systems Design Overview for Carrier Aggregation based 4G/5G Radios
Walid-Ali Ahmad, Qualcomm

Wireless Above 100GHz
Mark Rodwell, University of California, Santa Barbara

Young Professionals Forum and Networking Event
Panelists: Ken Cooper, California Institute of Technology, C. S. Lam, Skyworks Solutions, and Gerhard Schoenthal, Virginia Diodes, Inc., Usama Zaghloul, Broadcom Ltd.

Exhibits and Demos
Monday, 15 January 2018 and Tuesday, 16 January 2018

All accepted papers will be published in a digest and and be included in IEEE Xplore Digital Library.

NEW PRODUCTS

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

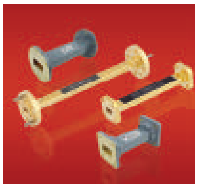
COMPONENTS

Sensor for Radar

The SDLAC21802B is a new version of radar sensor covering 2 to 18 GHz with sensitivity of -78 dBm (TSS) and a dynamic range of 77 dB and a pulse response of 12/20 nSec (rise/fall time). The sensitivity of this product makes it possible to detect signals 2.5x the distance of any other product available on the market and yet maintains excellent high speed pulse performance. This product is thin film construction and is designed for air, land and sea applications.

Advanced Microwave Inc.
www.advmic.com

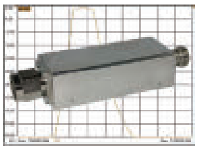
Straight Waveguide Sections



Fairview Microwave Inc. has launched a new line of straight waveguide sections that operate in the frequency range of 5.85 to 110 GHz and in 13 waveguide bands from C- to W-Band. Typical applications include test benches, instrumentation, MILCOM, SATCOM, telecom, radar and high-efficiency RF/microwave transmission networks. Fairview's new line of straight waveguide sections consists of 61 models that are available in sizes ranging from WR-10 to WR-137.

Fairview Microwave Inc.
www.fairviewmicrowave.com

916 MHz Bandpass Filter

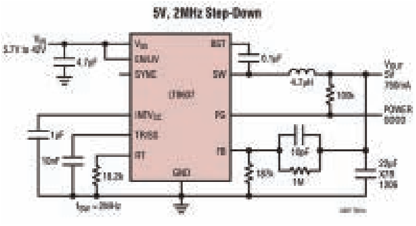


KR Electronics part number 3012-916 is a 916 MHz bandpass filter designed for positive train control (PTC) applications. The filters are encapsulated/ruggedized for enhanced shock and vibration resistance. Thousands are currently installed and operating successfully in the field with major rail companies. Other frequencies and bandwidths are available.

KR Electronics Inc.
www.krfilters.com

Step-Down Switching Regulator

VENDORVIEW

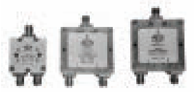


Analog Devices Inc., which recently acquired Linear Technology Corp., announces the LT8607, a 750 mA, 42 V input synchronous step-down switching regulator. A unique synchronous rectification topology delivers 93 percent efficiency while switching at 2 MHz, enabling designers to avoid critical noise-sensitive frequency bands, such as AM radio while using a very compact solution footprint. Burst Mode® operation keeps quiescent current under 3 μA in no-load standby conditions, ideal for always-on systems. The device's 3 to 42 V input voltage range is well suited for automotive applications that must regulate through cold-crank and stop-start scenarios with minimum input voltages as low as 3 V and load dump transients in excess of 40 V. Its internal 1.2 A switches deliver up to 750 mA of continuous output current.

Linear Technology Corp.
www.linear.com

Multi-Octave 2-Way Power Dividers

VENDORVIEW



MECA expands its extensive power divider line to include a variety of multi-octave 2-way Wilkinson power dividers which are optimized for excellent performance covering; 3 to 5 (802-2-4.000-M01), 2 to 8 (802-2-5.000) and 8 to 18 GHz (802-2-13.000) with typical spec's isolation 25 dB, VSWR's 1.25:1, 0.3 dB insertion loss and amplitude balance of 0.2 dB. Made in the U.S. with 36 month warranty.

MECA Electronics Inc.
www.e-MECA.com

Multi-Function Modules

Microwave Solutions Inc. offers the microwave system designer with the option of specifying multiple signal control functions within a single, standard size drop-in module. Originally designed for radar and microwave test instruments, these Multi-Function Modules (MFM) can provide gain control, amplification, coupler and/or detection for an integrated automatic level control (ALC) function all within a single package. Examples include an attenuator-amplifier-coupler-detector module, a coupler-sampler module with multiple sample ports and a coupler-coupler-detector module for both coupling and power level detection.

Microwave Solutions Inc.
www.microwavesolutions.com

Electromechanical Switches

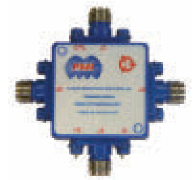
VENDORVIEW

Pasternack has unveiled a new series of low insertion loss repeatability electromechanical switches. Test and measurement applications require signal processing component performance to be highly accurate and repeatable over long periods and under extreme conditions. In automated test systems where electromechanical switches are used for signal monitoring and routing applications, every switch will add repeatability error. Electromechanical switches which exhibit low insertion loss repeatability over millions of switching cycles play a critical role to ensure overall system measurement accuracy is maintained at optimum levels.

Pasternack
www.pasternack.com

Pin Diode Transfer Switch

VENDORVIEW



PMI Model No. PSX-500M18G-60-SFF is a pin diode transfer switch that operates over the 500 MHz to 18 GHz frequency range. Specifications include 60 dB minimum isolation, 3 dB maximum insertion loss, VSWR In/Out 1.9:1 maximum, +20 dBm CW maximum input power and 100 ns maximum switching speed. This model incorporates a TTL compatible driver for easy system integration. Hermetically sealed units are available as an option. Features SMA (F) RF connectors, lightweight design 1.4 oz and package size of 1 in x 1 in x 0.5 in.

Planar Monolithics Industries Inc.
www.pmi-rf.com/products/switches/PXS-500M18G-60-SFF.htm

New**Products**

High-Power Bandpass Filter

RLC Electronics manufactures high-power cavity bandpass filters for military and commercial applications. These filters exhibit sharp attenuation and low loss. The unit pictured is a 1280 MHz bandpass filter with 65 dB rejection at 1000 and 1800 MHz. The filter is rated for 400 W cW and 2000 W peak (20 percent duty cycle) and has low loss (0.3 dB). RLC also offers other high-power products such as switches, couplers, power dividers and filters (highpass, bandpass, band reject and lowpass filters, including absorptive designs).

RLC Electronics Inc.
www.rlcelectronics.com

Ka-Band Full Waveguide Junction Isolator

VENDOR**VIEW**

Model SNF-28-ID1-H is a Ka-Band, waveguide junction isolator that covers the frequency range of 26.5 to 40 GHz. The full band isolator is designed and manufactured to provide a low insertion loss of 0.50 dB typical with good flatness. Compared to a Faraday isolator, it offers a much shorter insertion length for system integration. The isolator also offers a moderate isolation of 17 dB and a forward power handling of 25 W.

Sage Millimeter
www.sagemillimeter.com

0.3 to 1000 MHz Transformer

The TM1-0 is a surface mount, low cost, wideband transformer covering the frequency range from 0.3 to 1000 MHz in a 1:1 impedance ratio. This transformer is supplied in an open core design of 0.15 cubic inches. The transformer incorporates a transmission line design ideal for broadband applications. Insertion loss is typically 1.25 dB and power handling is 0.25 W maximum. The TM1-0 also offer a very good return loss of 16 dB typical.

Synergy Microwave Corp.
www.synergymwave.com

CABLES & CONNECTORS

Voltage Variable Equalizer

VENDOR**VIEW**

The VAEQ-1220+ is a 50 Ω voltage variable equalizer built into a shielded case (size of 0.394 in × 0.394 in × 0.150 in; 10 mm × 10 mm × 3.8 mm). This model offers excellent performance over a wide frequency range of 50 to 1220 MHz with the variable slope providing great flexibility in a small 10 mm package. The VAEQ-1220+ is often used to compensate RF chain gain flatness or cable loss versus frequency.

Coaxial Matching Pad

Mini-Circuits' UNMP-R5075-33+ is a coaxial 50/75 Ω matching pad covering the DC to 3000 MHz frequency range, supporting impedance matching in a wide range of systems. This model is ideal for 50/75 Ω impedance matching in systems where minimizing overall signal loss is a priority. The matching pad housed in a rugged unibody construction with N-Male (50 Ω) to N-Female (75 Ω) connectors.

Mini-Circuits
www.minicircuits.com

Coaxial PCB Connectors

SV's complete line of coaxial PCB connectors meet the industry need for high-performing, easy-to-use compact designs. Single and multi-port SMA, 2.92 mm, 2.4 mm, SMP, SMPM and SMPS series available. When performance and reliability matter, choose SV to connect you.

SV Microwave
www.svmicrowave.com

Precision Cable Assemblies

The WT500 and WT670 cable assembly (DC to 50 GHz and 67 GHz, respectively) are claimed to have very good insertion loss and high phase/amplitude stability in relation to temperature. The W-Test series is a complete line of high precision cable assemblies, designed specifically for stable phase testing, with a design that is based on excellent microwave interconnection technologies.

Withwave
www.with-wave.com

AMPLIFIERS

New Solid State Pulsed Amplifiers

VENDOR**VIEW**

AR just added three new solid state pulsed amplifiers to its existing 19 models. The new 1000, 12,000 and 15,000 W models cover 2.7 to 3.1, 1 to 2 and 2 to 4 GHz, respectively. They provide higher reliability with better performance than traditional TWTA's for automotive, aviation, military EMC radiated immunity susceptibility testing, as well as radar and communication applications.

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

Solid-State High-Power Amplifier

Comtech PST (CPST) offers solid-state high-power amplifier products for X-Band radar applications including TWT replacements. Comtech featured an 8 kW solid-state high-power amplifier system that combines 8 higher power amplifier modules using a waveguide combiner. It also integrates system status/control assembly and an AC-DC power supply. This fully-protected system is housed in a single rack-mountable chassis measuring 19 in × 17.78 in × 12.25 in. The forced air cooled amplifier is designed to interface with your radar in airborne or ground installations.

Comtech PST
www.comtechpst.com

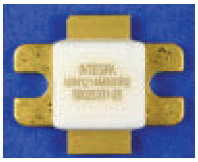
SSPA AMP Module

VENDORVIEW

Exodus new wideband SSPA Module AMP1090 covers the full 2 to 8 GHz frequency band at 10 W min. and up to 50 W power levels. The AMP1090 uses CW GaN devices and operates from a 32 VDC supply at 3 A max. with gain flatness of 3 dB max peak to peak. This module is suitable for use with all modulation standards and features built-in protection circuits. With high-reliability and ruggedness, typical applications would include EMI/RFI, S- and C-Band, RADAR, EW, SATCOM, among others.

Exodus Advanced Communications
www.exoduscomm.com

GaN/SiC Transistor



Integra Technologies' GaN/SiC transistor IGN1214M500R2 is 550 W, 1.2 to 1.4 GHz and is designed for L-Band radar applications. This high-power GaN-on-SiC HEMT transistor supplies 550 W of peak pulsed output power at 50 V drain bias, with 17 dB gain and 70 percent efficiency, at 100 microseconds, 10 percent pulse conditions.

Integra Technologies
www.integratech.com

W-Band Solid State Power Amplifier

QuinStar Technology Inc. announces the release of QPW 81863741, a new GaAs-based SSPA featuring high-efficiency performance in a compact (6 in × 6 in × 3.6 in) and lightweight (5 lbs) housing. This SSPA operates at 81 to 86 GHz and offers 5 W of saturated power at CW operation for high-reliability communication links and general test equipment. QuinStar is a Southern California-based engineering firm offering innovative RF solutions for communications, radar and scientific research.

QuinStar Technology Inc.
www.QuinStar.com

RF Power GaN-on-SiC Transistor

Richardson RFPD Inc. announced the availability and full design support capabilities for a new GaN-on-SiC depletion-mode HEMT from NXP Semiconductors. The AFG24S100HR5 is a 125 W CW RF power GaN transistor that operates from 1 to 2700 MHz and includes input-matching for extended bandwidth performance. With its high gain and high ruggedness, this device is suitable for a range of CW, pulse and wideband RF applications, including public mobile radios, ISM (industrial, scientific and medical), wideband laboratory amplifiers and wireless cellular infrastructure.

Richardson RFPD
www.richardsonrfpd.com

Bi-Directional SSPA

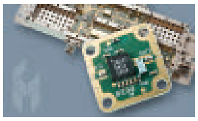
The TTRM1109 is a bi-directional SSPA for domestic and foreign military and public safety wireless links. It can handle any modulation and outputs 10 W typical BPSK and 3 W typical 64QAM OFDM.

Triad RF Systems
www.triadrf.com

SEMICONDUCTORS

RF/Microwave Circuits

VENDORVIEW



Custom MMIC announced an expanded collaboration with X-Microwave LLC, developers of a modular/drop-in simulation, prototyping and production system for solderless and reconfigurable RF/microwave circuits up to 67 GHz. The X-MWblock™ system enables efficient and expedient microwave and mmWave circuit development and testing, using industry grade nonlinear online simulation tools powered by Keysight's Genesys Spectrasys engine. The expanded partnership will bring over 35 of Custom MMIC's leading LNAs, PAs, distributed smplifiers, driver amplifiers, low phase noise amplifiers, phase shifters, switches and mixers to the X-Microwave system.

Custom MMIC
www.custommmic.com

SOURCES

T1265 TCXO

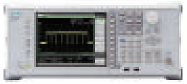
Greenray Industries Inc. has announced the availability of the T1265 Series TCXO. The new T1265 TCXO (temperature compensated crystal oscillator) is available from 50 to 125 MHz, with squarewave CMOS output to drive a 15 pf load. With very low phase noise, the T1265 delivers OCXO-like performance without their input power requirements and warm-up characteristics. The T1265 offers temperature stability down to ±0.5 ppm and has external voltage control with sufficient pull range to cover the total stability of the oscillator over the lifetime of the part.

Greenray Industries Inc.
www.greenrayindustries.com

TEST & MEASUREMENT

Signal Analyzer

VENDORVIEW



Anritsu Co. introduces the Signal Analyzer MS2850A that can cost efficiently and accurately evaluate 5G signals with the 800 MHz modulation bandwidth (8 × 100 MHz channels) associated with 5G designs. With analysis

MICRO-ADS

ES MICROWAVE LLC.
Since 1985 we have offered our custom design filters and sub-assemblies in combline, interdigital and suspended-substrate technologies.
Broadband
Suspended-Substrate
Filters, Diplexers, Triplexers, Quadruplexers, Quintuplexers, Sextuplexers...
DC-40 GHz Filters
Multiplexers &
Switch Filter Banks
ES Microwave, LLC
8031 Cessna Avenue, Gaithersburg, MD 20879
P: 301-519-9407 F: 301-519-9418
www.esmicrowave.com

KR Electronics
www.krfilters.com
ISO 9001:2008 Certified
Custom & Standard Filters
40+ Years of Military & Commercial Applications
Bandpass
Anti-Aliasing
Highpass
Video Filters
Diplexers
Delay Equalized
Surface Mount
Lowpass
Notch
Root Cosine
Equalizers
Linear Phase
Absorptive
Matched
KR Electronics, Inc.
Avenel, NJ
www.krfilters.com
sales@krfilters.com
Phone 732.636.1900
Fax 732.636.1982

ELECTRICALLY CONDUCTIVE
COATINGS
Ideal for EMI/RFI Shielding
MB600G
Graphite filler
MB600S
Silver filler
MB600SCN
Silver coated nickel filler
MASTERBOND®
ADHESIVES | SEALANTS | COATINGS
www.masterbond.com

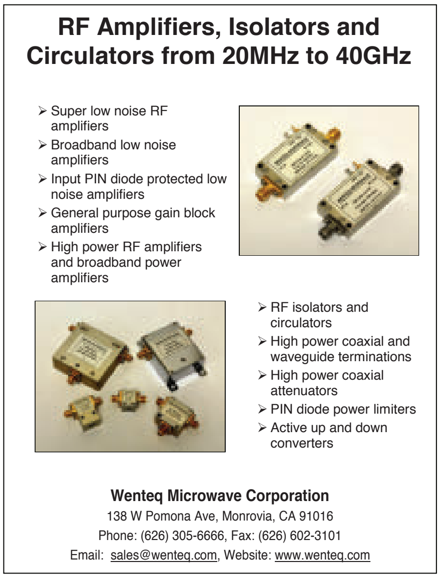
SECTOR MICROWAVE INDUSTRIES, INC.
* DPDT
* TYPE N, SMA, BNC, TNC
* MANUAL OVERRIDE
* DC THROUGH 23 GHZ.
(631) 242-2300 FAX (631) 242-8158
www.sectormicrowave.com

SWA
southwest antennas
High Performance Broadband Antennas & Accessories
Commercial ▪ Military ▪ Law Enforcement
Homeland Security ▪ Broadcast Video
UAV / Robotics ▪ Oil & Gas ▪ M2M / IoT
southwestantennas.com

REVOLUTIONARY
HERMETIC SMP CONNECTORS
These SMPs meet the requirements of MIL-STD-348, but utilize unique housing interface features, which significantly improves reliability and production assembly yields. Proprietary techniques are used to independently control plating thickness on pin and housing.
For use with Aluminum, Kovar and other package material
SHP
SPECIAL HERMETIC PRODUCTS, INC.
PO BOX 269 – WILTON – NH – 03086
(603) 654-2002 – Fax (603) 654-2533
E-mail: sales@shp-seals.com
Website: www.shp-seals.com

TECH PLUS
MICROWAVE Inc.
HIGHEST QUALITY FILTERS
FOR ANY
APPLICATION OR ENVIRONMENT
COMMERCIAL * MILITARY *
SPACE * PUBLIC SAFETY
WWW.TECHPLUSMICROWAVE.COM
916-672-6356

YIG OSCILLATOR
Vida Products
DCMIC-VCO
S/N B103
D/C 1703
You will believe in Magic!
www.vidaproducts.com
VIDA products
engineering the perfect wave



RF Amplifiers, Isolators and Circulators from 20MHz to 40GHz
➢ Super low noise RF amplifiers
➢ Broadband low noise amplifiers
➢ Input PIN diode protected low noise amplifiers
➢ General purpose gain block amplifiers
➢ High power RF amplifiers and broadband power amplifiers
➢ RF isolators and circulators
➢ High power coaxial and waveguide terminations
➢ High power coaxial attenuators
➢ PIN diode power limiters
➢ Active up and down converters
Wenteq Microwave Corporation
138 W Pomona Ave, Monrovia, CA 91016
Phone: (626) 305-6666, Fax: (626) 602-3101
Email: sales@wenteq.com, Website: www.wenteq.com

UNITED STATES POSTAL SERVICE

Statement of Ownership, Management, and Circulation (All Periodicals Publications Except Requester Publications)

1. Publication Title Microwave Journal	2. Publication Number 3 9 6 - 2 5 0	3. Filing Date September 30, 2017
4. Issue Frequency Monthly	5. Number of Issues Published Annually 12	6. Annual Subscription Price Domestic: $120.00 Foreign: $200.00
7. Complete Mailing Address of Known Office of Publication (Not printer) (Street, city, county, state, and ZIP+4®) HORIZON HOUSE PUBLICATIONS, INC. 685 Canton Street Norwood, MA 02062-2610		Contact Person Barbara Walsh Telephone 781-769-9750 x2025

8. Complete Mailing Address of Headquarters or General Business Office of Publisher (Not printer)

same as above

9. Full Names and Complete Mailing Addresses of Publisher, Editor, and Managing Editor (Do not leave blank)

Publisher (Name and complete mailing address)

Carl S. Sheffres, Horizon House Publications, Inc., 685 Canton Street, Norwood, MA 02062-2610

Editor (Name and complete mailing address)

Patrick Hindle, Horizon House Publications, Inc., 685 Canton Street, Norwood, MA 02062-2610

Managing Editor (Name and complete mailing address)

Jennifer DiMarco, Horizon House Publications, Inc., 685 Canton Street, Norwood, MA 02062-2610

10. Owner (Do not leave blank. If the publication is owned by a corporation, give the name and address of the corporation immediately followed by the names and addresses of all stockholders owning or holding 1 percent or more of the total amount of stock. If not owned by a corporation, give the names and addresses of the individual owners. If owned by a partnership or other unincorporated firm, give its name and address as well as those of each individual owner. If the publication is published by a nonprofit organization, give its name and address.)

Full Name	Complete Mailing Address
Horizon House Publications, Inc.	685 Canton Street, Norwood, MA 02062-2610
William M. Bazzy, CEO	" " " " " " "
Ivar A. Bazzy, President	" " " " " " "
Jared M. Bazzy, Vice President	" " " " " " "
Joan B. Egan, EVP	" " " " " " "

11. Known Bondholders, Mortgagees, and Other Security Holders Owning or Holding 1 Percent or More of Total Amount of Bonds, Mortgages, or Other Securities. If none, check box ✓ None

Full Name	Complete Mailing Address

12. Tax Status (For completion by nonprofit organizations authorized to mail at special rates) (Check one)
The purpose, function, and nonprofit status of this organization and the exempt status for federal income tax purposes:
☑ Has Not Changed During Preceding 12 Months
☐ Has Changed During Preceding 12 Months (Publisher must submit explanation of change with this statement)

13. Publication Title Microwave Journal		14. Issue Date for Circulation Data Below YTD	September 30, 2017
15. Extent and Nature of Circulation 50K		Average No. Copies Each Issue During Preceding 12 Months	No. Copies of Single Issue Published Nearest to Filing Date
a. Total Number of Copies (Net press run)		40,891	42,968
b. Paid Circulation (By Mail and Outside the Mail)	(1) Mailed Outside-County Paid Subscriptions Stated on PS Form 3541. (Include paid distribution above nominal rate, advertiser's proof copies, and ex change copies)	31,818	32,216
	(2) Mailed In-Country Paid Subscriptions Stated on PS Form 3541 (include paid distribution above nominal rate, advertiser's proof copies and exchange copies)	0	0
	(3) Paid Distribution Outside the Mails Including Sales Through Dealers and Carriers, Street Vendors, Counter Sales, and Other Paid Distribution Outside USPS®	5,465	4,371
	(4) Paid Distribution by Other Classes of Mail Through the USPS (e.g. First-Class Mail®)	0	0
c. Total Paid Distribution (Sum of 15b(1), (2), (3), and (4))		37,283	36,587
d. Free or Nominal Rate Distribution (By Mail and Outside the Mail)	(1) Free or Nominal Rate Outside-Country Copies included on PS Form 3541	771	711
	(2) Free or Nominal Rate In-Country Copies Included on PS Form 3541	0	0
	(3) Paid Distribution Outside the Mails Including Sales Through Dealers and Carriers, Street Vendors, Counter Sales, and Other Paid Distribution Outside USPS®	0	0
	(4) Free or Nominal Rate Distribution Outside the Mail (Carriers or other means)	2,670	5,552
e. Total Free or Nominal Rate Distribution (Sum of 15d (1), (2), (3) and (4))		3,531	6,263
f. Total Distribution (Sum of 15c and 15 e)		40,814	42,850
g. Copies not Distributed (See Instructions to Publishers #4 (page #3))		77	118
h. Total (Sum of 15f and g)		40,891	42,968
i. Percent Paid (15c divided by 15f times 100)		91.35%	85.38%

16. Publication of Statement of Ownership
✓ If the publication is a general publication, publication of this statement is required. Will be printed in the November, 2017 issue of this publication.
☐ Publication not required.

17. Signature and Title of Editor, Publisher, Business Manager, or Owner	Date
[signature] Carl S. Sheffres, Publisher	September 30, 2017

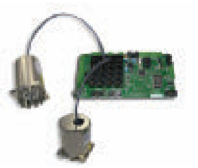
I certify that all information furnished on this form is true and complete. I understand that anyone who furnishes false or misleading information on this form or who omits material or information requested on the form may be subject to criminal sanctions (including fines and imprisonment) and/or civil sanctions (including civil penalties).

IPS Form 3526, September 2007 (Page 2 of 3)

bandwidth up to 1 GHz, excellent dynamic range and high flatness performance, the MS2850A provides wireless equipment manufacturers and mobile operators with a comprehensive and affordable tool to evaluate base stations and terminals, satcom and broadband communications equipment, as well as to monitor satellite communications.

Anritsu Co.
www.anritsu.com

MS-Control Kits



MS-Control Kits are low budget solutions best suited for ATE, test bench and system integrated applications, catering to those who are comfortable assembling components on their own. Depending on the type of controls, two kits are available consisting of an Ethernet or GPIB control board and 12x RJ11-4 straight cables (to be used with Dow-Key CAN bus switches). RF switches are not included and are purchased separately.

Dow Key Microwave
www.dowkey.com/ate/

Custom Spring Probes

Beyond a comprehensive portfolio of off-the-shelf spring probe solutions for a wide range of applications, ECT offers solutions fully designed to customer specifications when standard products do not meet an entire set of requirements. Whether a requirement is as simple as special tip geometry or as complex as a custom coax RF probe, ECT's engineers combine state-of-the-art design, materials and production know-how, with ECT's long-term experience in spring probe technology to deliver results that truly meet customers' expectations.

Everett Charles Technologies (ECT)
www.ectinfo.com

Mini-Source Module

OML's mini-source module series is specifically designed as a portable solution for mmWave signal generator. Utilizing the handheld spectrum analyzer tracking generator as an LO source and the built-in DC supply/USB 5 V, this product is currently available in waveguide bands WR-42 (26 to 40 GHz), WR-15 (50 to 75 GHz), WR-12 (60 to 90 GHz) and extended WR-12 (56 to 96 GHz). For testing in the emerging application areas such as WiGig, 5G, collision avoidance radar systems, E-Band backhaul and military and defense.

OML Inc.
www.omlinc.com

Spectrum Analyzer and Monitoring Receiver

The SM200A is a high-performance spectrum analyzer and monitoring receiver, priced at $11,900 USD. It tunes from 100 kHz to 20 GHz, has 160 MHz of instantaneous bandwidth, 110 dB of dynamic range, 1 THz/sec sweep speed at 30 kHz RBW (using Nuttall windowing) and phase noise performance that is so good that it contributes less than 0.1 percent error to EVM measurements and rivals even the most expensive spectrum analyzers on the market. Available December 2017.

Signal Hound
www.signalhound.com

Microwave/RF Test Assemblies

W. L. Gore & Associates (Gore) announced that Rohde & Schwarz (R&S) is endorsing GORE® PHASEFLEX® Microwave/RF Test Assemblies for use with its new R&S ZNBT20 multi-port VNA. The new R&S ZNBT20 is the first true multiport vector network analyzer in the microwave range with up to 16 integrated test ports. The unique hardware architecture from the R&S ZNBT8 has been extended to 20 GHz. This allows users to characterize multiple devices under test in parallel and thus increase throughput tremendously.

W. L. Gore & Associates
www.gore.com

An Introduction to Passive Radar

Hugh D. Griffiths and Christopher J. Baker

Passive radar systems encompass a class of radar systems that detect and track objects by processing reflections from non-cooperative sources of illumination in the environment, such as commercial broadcast and communications signals. This book explains how passive radar works, how it differs from the active type and demonstrates the benefits and drawbacks of this technology. It covers an overview of the field since the earliest experiments and goes through the physics and mathematics of passive radar systems, identifying the unique challenges for passive radar.

The book starts by introducing the basic principles and the key technologies of performance prediction, detection and tracking of passive radar. The book then introduces the application of bistatic passive radar system paradigm, including kinds of illuminators and various processing cases which provide important technical support and reference for the design and processing of the novel passive radar system. Properties of illuminators, including ambiguity functions, digital versus analog, digitally-coded waveforms, vertical-plane coverage and satellite-borne and radar illuminators are explored as well. It also covers future developments and applications along with the latest technical progress in recent years.

"An Introduction to Passive Radar" provides readers with introductory material on the subject, so is a good overview for those not familiar with the topic, and then addresses the more advanced subjects. Readers will find practical guidance on direct signal suppression, passive radar performance prediction and detection and tracking. This book provides real-world examples of systems and results, including analog TV, FM radio, cell phone base stations, DVB–T and DAB, HF skywave transmissions, indoor Wi-Fi, satellite-borne illuminators and low-cost scientific remote sensing. Future developments and applications of passive radar are also presented to conclude with full coverage of the topic.

To order this book, contact:

Artech House
685 Canton St.
Norwood, MA 02062
800-225-9977
or
16 Sussex St., London, SW1V 4RW, UK
+44 (0)20 7596 8750

Pages: 234, $199, £66
ISBN: 978-1-63081-036-8

Advertising**Index**

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.
(NJ, Mid-Atlantic, Southeast, Midwest, TX)
4 Valley View Court
Middletown, MD 21769
Tel: (301) 371-8830
FAX: (301) 371-8832
mhallman@mwjournal.com

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

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

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

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

China
Shenzhen
Michael Tsui
ACT International
Tel: 86-755-25988571
FAX: 86-10-58607751
michaelt@actintl.com.hk

Shanghai
Linda Li
ACT International
Tel: 86-21-62511200
lindal@actintl.com.hk

Beijing
Cecily Bian
ACT International
Tel: +86 135 5262 1310
cecilyb@actintl.com.hk

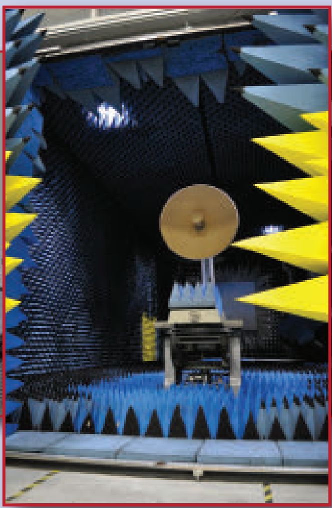
Hong Kong, Taiwan, Singapore
Mark Mak
ACT International
Tel: 852-28386298
markm@actintl.com.hk

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

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

FABS and LABS

Cobham Performs From Deep Ocean to Deep Space



Cobham is a global technology and services innovator with leading market positions in wireless data communications, SATCOM, defense electronics, air-to-air refueling, aviation services and life support /mission systems. Their two facilities in Exeter, N.H., part of the Advanced Electronic Solutions Sector, offer critical radar and communication solutions for land, sea, air and space applications. Off-the-shelf and customized products include RF/microwave, antenna subsystems, high-reliability microelectronics, application specific integrated circuits (ASIC), MMICs and motion control. Cobham employs about 350 people in Exeter, where they manufacture a range of RF/microwave products such as waveguide, cables and cable assemblies, antennas, rotary joints and integrated waveguide assemblies.

The company uses various simulation tools for product design and development, RF circuit analysis, electromagnetic (EM) modeling, finite element analysis and computer-aided engineering. Vertically integrated, Cobham makes most products from raw materials, tightly controlling each step of the manufacturing process for optimal quality and performance. The Exeter facility has extensive machining capabilities, with numerous CNC machines, electronic discharge machining (EDM), casting, brazing, plating, irridite/chem film coating, hydro hone and impregnation processing. In addition, an internal manual model shop is used extensively for prototyping. These capabilities enable fabrication of antennas and other structures serving a broad range of product types and sizes.

With metal brazing tanks up to six feet in diameter, Cobham's waveguide assembly manufacturing line is probably the largest on the East Coast. It includes two dip braze tanks, rinse tanks, two preheat ovens, a cooling table, with various plating and painting stations and full environmental testing. Cobham can assemble most any waveguide size and shape and integrate other components, such as filters, couplers and transitions into the assembly. In addition to the traditional rectangular waveguide, flexible (WR940 to 22) and double ridge waveguide (WRD475 to 180) are also manufactured. Extensive quality assurance and inspection capabilities, with custom measurement tables and fixtures, ensure all products meet performance specifications.

The Exeter site also builds high-power cables and cable assemblies, producing raw cable, phased matched cable sets and connectors of various sizes. Many connectors are fabricated in-house and machines handle insulator wire wrapping, cable jacket weaving and outer casing extrusion.

Cobham's antenna manufacturing capability includes machining slot antennas up to several feet in diameter. The EDM process produces 3 μm Rz or 16 μm Ra surface finish with 0.0001 in flatness, using just three passes. For antenna testing, the Exeter site has three near field planar scanners up to 8 ft x 8 ft and a very large 21 ft x 24 ft x 60 ft anechoic chamber with a one ton hoist and positioning equipment with roll over azimuth over elevation capabilities. Testing can be performed from 2 to 50 GHz in compact range mode. Some products are designed to withstand extreme temperatures (from –254°C to +649°C) and forces up to 15,000 g.

Manufacturing rotary joints is another area of excellence. The Exeter facility can design and manufacture from single to 33-channel rotary joints and has redesigned many systems using a modular approach that provides higher reliability and ease of service. Rotary joints are used on most FAA radar systems, and Cobham is the official FAA repair depot center. Cobham also supplies all rotary joints to the U.S. Navy for their periscope applications.

Cobham's broad portfolio of high performance products reflects the acquisition of many recognized industry brands: Aeroflex, Atlantic Microwave, BAE Lansdale, Kevlin, Litton Airtron, MACOM, MDC, Nurad and Remec. Cobham has combined these operations into efficient, state-of-the-art manufacturing facilities, like the two in Exeter, to better serve their customers.

www.cobham.com

WERLATONE®

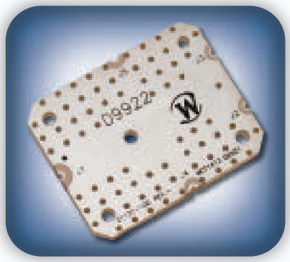
We Are High Power

Surface Mount (SMT) & Drop-In Components

- Multi-Octave Designs
- Superior Electrical Performance
- **Send Us Your Specs!**
- Excellent Repeatability
- Compact Designs

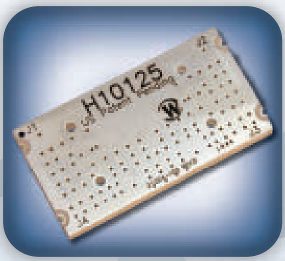
Directional Couplers

0° Combiners



90° Hybrid Couplers

180° Combiners



Directional Couplers

Model	Type	Frequency (MHz)	Power (W CW)	Coupling (dB)	Insertion Loss (dB)	VSWR (ML)	Mounting Style	Size (Inches)
C8740	Dual	20-512	200	40	0.3	1.15:1	Tabs	1.5 x 0.95 x 0.55
C9655	Dual	20-1000	100	30	0.7	1.25:1	Tabs	1.5 x 0.95 x 0.55
C8631	Dual	20-1000	150	40	0.35	1.25:1	Tabs	1.5 x 0.95 x 0.55
C10561	Dual	20-1000	250	50	0.1	1.25:1	SMT	1.35 x 1 x 0.15
C7962	Bi	450-2500	100	30	0.2	1.20:1	SMT	1.15 x 0.7 x 0.07
C8025	Bi	500-3500	125	30	0.3	1.25:1	Drop-In	1.3 x 1 x 0.07
C8098	Bi	800-2000	200	30	0.7	1.20:1	Drop-In	1.3 x 1 x 0.07

0° Combiners/Dividers

Model	Type	Frequency (MHz)	Power (W CW)	Insertion Loss (dB)	VSWR	Isolation (dB)	Mounting Style	Size (Inches)
D9888	2-Way	1000-3000	500	0.35	1.35:1	15	SMT	2.8 x 2.2 x 0.27
D9922	2-Way	2000-6000	200	0.35	1.40:1	15	SMT	1.4 x 1.1 x 0.14

Hybrids

Model	Type	Frequency (MHz)	Power (W CW)	Insertion Loss (dB)	VSWR	Amplitude Balance (±dB)	Mounting Style	Size (Inches)
QH10738	90°	20-1000	150	0.8	1.40:1	0.25	Tabs	3 x 2.75 x 1
QH9056	90°	30-520	400	0.8	1.30:1	1.2	Drop-In	4 x 1.7 x 0.29
QH9304	90°	60-1000	150	1.0	1.40:1	1.0	Drop-In	2 x 1 x 0.16
QH8849	90°	80-1000	250	0.65	1.40:1	1.0	Drop-In	2.9 x 2.1 x 0.31
QH8100	90°	100-512	250	0.45	1.30:1	0.5	Drop-In	3.3 x 1.52 x 0.28
QH10245	90°	100-1300	150	0.75	1.30:1	0.75	SMT	2.5 x 1.7 x 0.16
QH8922	90°	150-2000	100	0.75	1.40:1	1.0	SMT	1.47 x 1.13 x 0.16
QH7900	90°	450-2800	125	0.55	1.35:1	0.45	SMT	1.5 x 1.1 x 0.095
QH7622	90°	500-3000	150	0.55	1.35:1	0.6	Drop-In	1.65 x 1.1 x 0.09
QH10541	90°	700-6000	100	0.5	1.35:1	0.6	SMT	0.66 x 0.86 x 0.09
QH10089	90°	800-2800	200	0.35	1.30:1	0.4	SMT	1.25 x 0.55 x 0.08
QH7741	90°	800-3000	200	0.3	1.40:1	0.45	Drop-In	1.35 x 0.65 x 0.09
H10125	**180°**	**1000-3000**	**350**	**0.5**	**1.35:1**	**0.2**	**SMT**	**2.31 x 1.21 x 0.25**
QH10637	90°	1000-6500	100	0.65	1.45:1	0.6	SMT	0.86 x 0.66 x 0.09
QH8193	90°	2000-6000	100	0.25	1.30:1	0.75	SMT	0.85 x 0.33 x 0.14
QH10148	90°	2000-6000	100	0.3	1.30:1	0.5	SMT	0.75 x 0.45 x 0.08
H10126	**180°**	**2000-6000**	**100**	**0.8**	**1.35:1**	**0.4**	**SMT**	**1.15 x 0.6 x 0.14**
QH10707	90°	2500-5500	200	0.25	1.25:1	0.35	SMT	0.65 x 0.4 x 0.12
QH10651	90°	3000-3500	150	0.2	1.20:1	0.25	SMT	0.56 x 0.35 x 0.1

Werlatone, Inc.
17 Jon Barrett Road
Patterson, NY 12563
T 845 278 2220
F 845 278 3440
sales@werlatone.com
www.werlatone.com