Vol. 59 • No. 7

July 2016

Microwave Journal
.com

A Shift in the Industry

MVP
NI
Simplifying Antenna Design

horizon house®
Founded in 1958


MCL B 744
ADP-2-10
MCL A 745

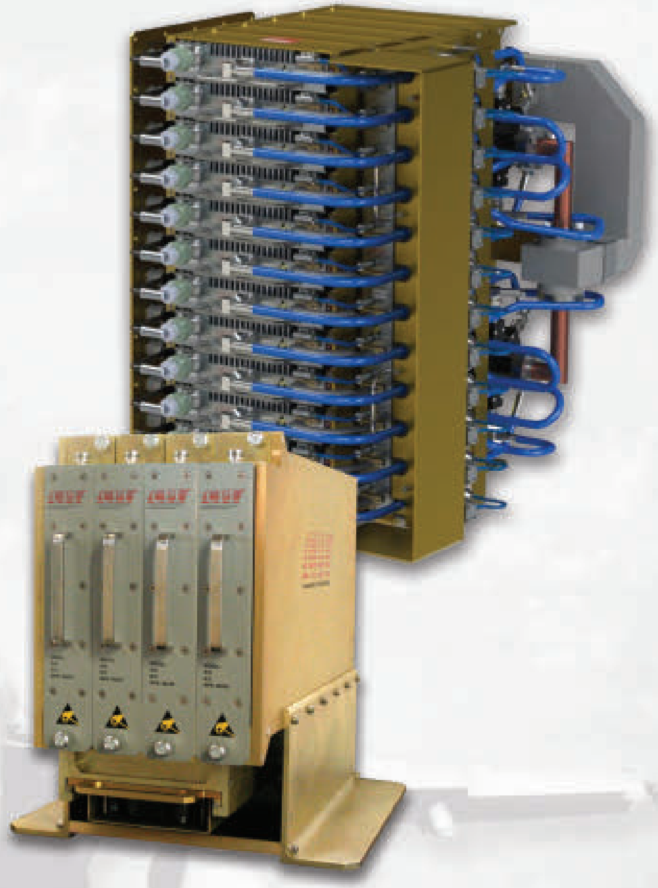
Communications & Power Industries

Beverly Microwave Division

For more information contact us at:
150 Sohier Road • Beverly, MA 01915
+1 (978) 922-6000 • bmdmarketing@cpii.com
www.cpii.com/bmd

Solid State Power Amplifiers

State of the art GaN technology

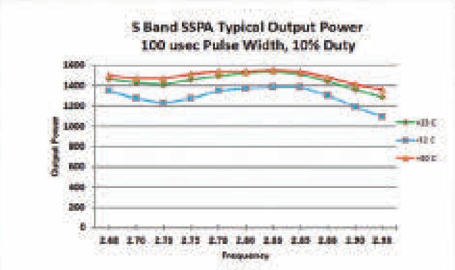


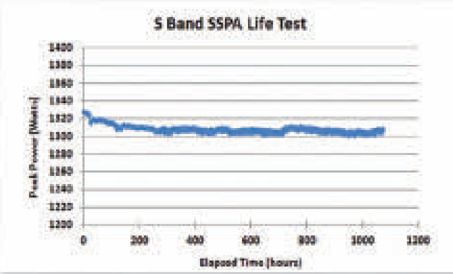
Features:

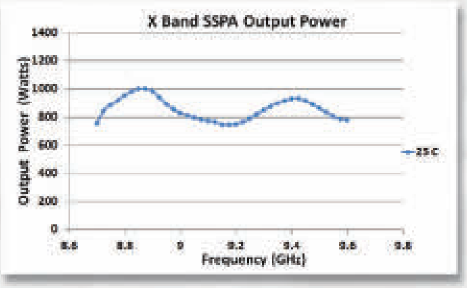
- High efficiency pulsed modules (10% duty)
- BIT and controls via EIA-422
- Compact light weight
- 9.0 - 9.2 GHz X-Band: 1 kW modules
- 5.2 - 5.9 GHz C-Band: 1.1 kW modules
- 2.7 - 2.9 GHz S-Band: 1.3 kW modules
- 1.2 - 1.4 GHz L-Band: 700 W modules
- Power combine modules up to 25 kW

Benefits:

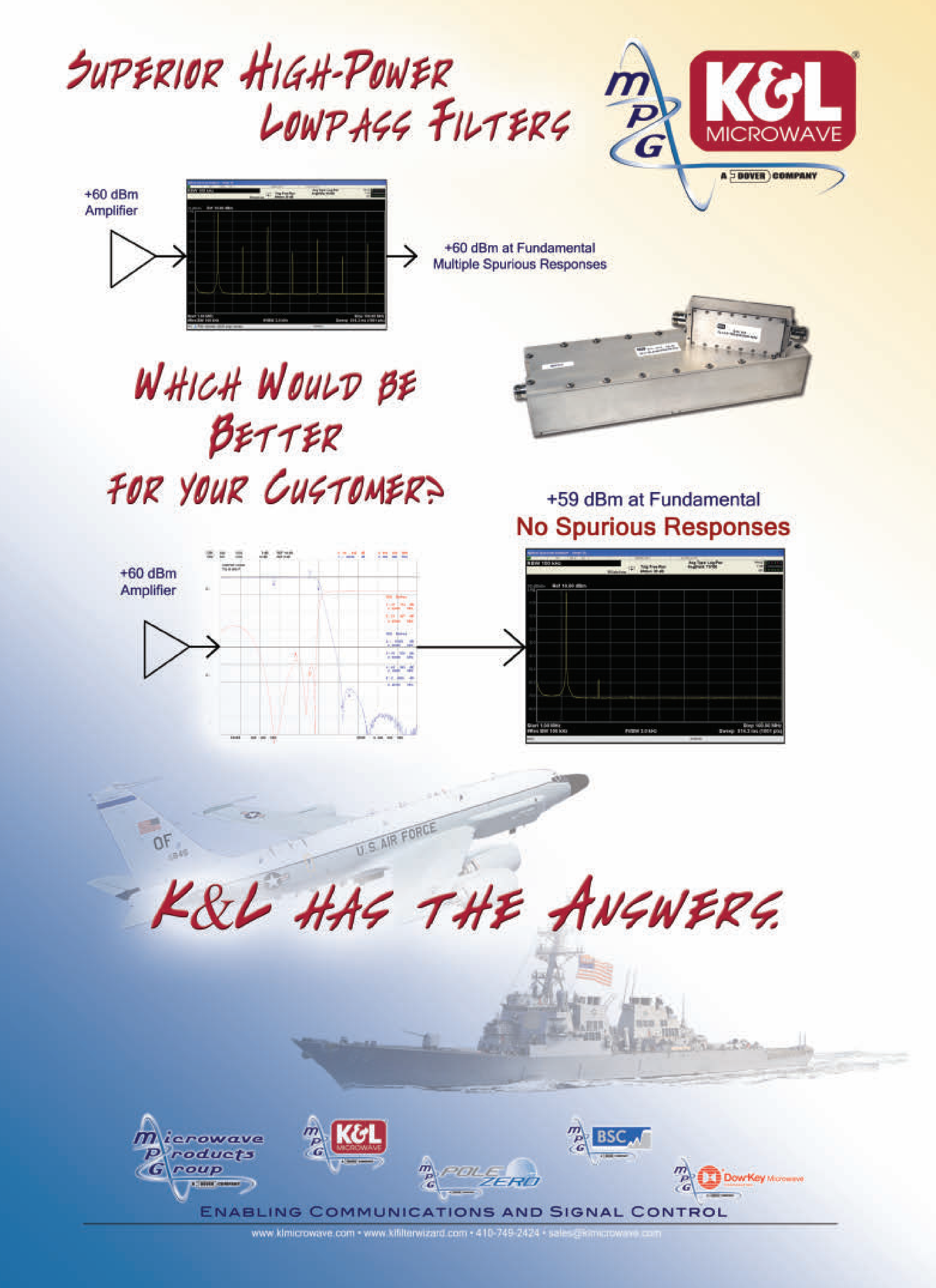
- High reliability
- Field replaceable modules





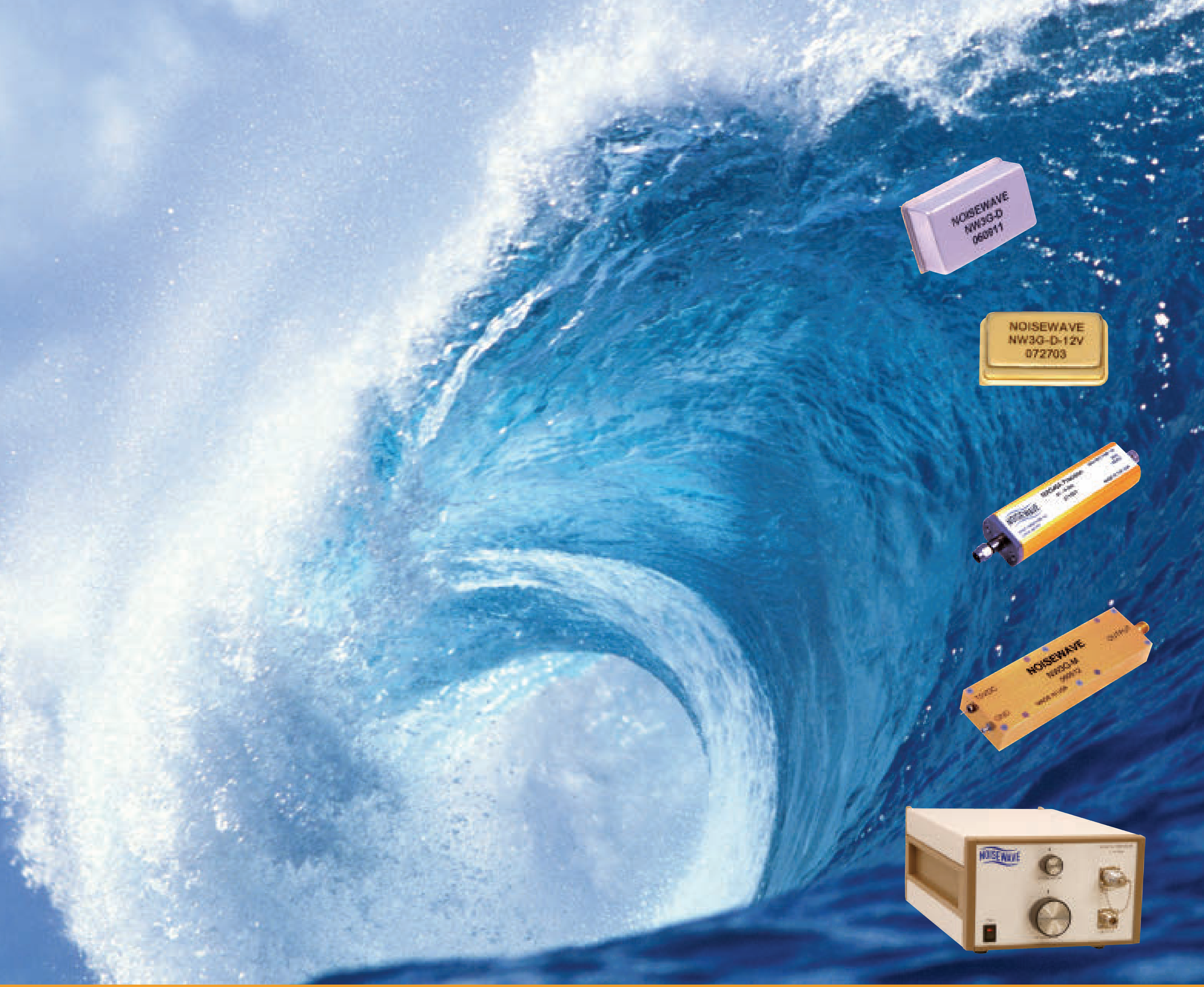


- Solid State Power Amplifiers • Integrated Microwave Assemblies • Receiver Protectors
- Control Components • Transmitters • Amplifiers • Modulators • Magnetrons • Crossed Field Amplifiers
- Ring Loop Traveling Wave Tubes • Power Couplers



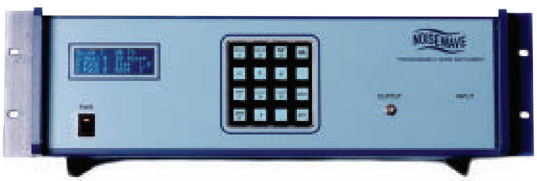
Superior High-Power Lowpass Filters
K&L MICROWAVE
A DOVER COMPANY
+60 dBm Amplifier
+60 dBm at Fundamental
Multiple Spurious Responses
Which Would be Better for your Customer?
+59 dBm at Fundamental
No Spurious Responses
+60 dBm Amplifier
U.S. AIR FORCE
K&L has the Answers.
Microwave Products Group
K&L MICROWAVE
POLE ZERO
BSC
DowKey Microwave
Enabling Communications and Signal Control
www.klmicrowave.com • www.klfilterwizard.com • 410-749-2424 • sales@klmicrowave.com

New Wave in Noise



NoiseWave

your supplier of high performance, precise equipment for AWGN



NOISEWAVE

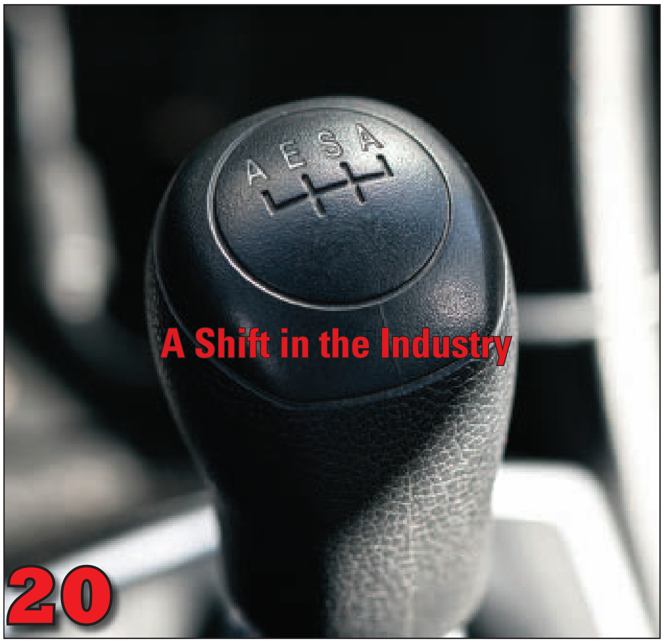
The new wave in NOISE

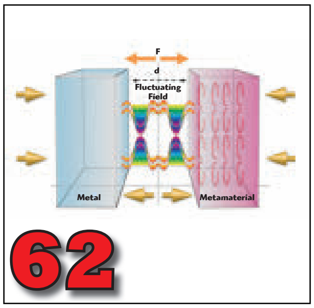
Ph. (973) 386-1119 • Fax (973) 386-1131 • info@noisewave.com • www.noisewave.com

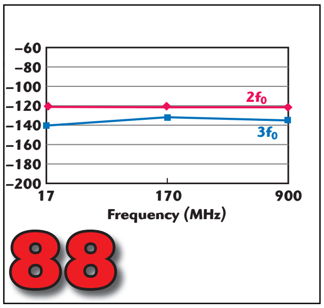
Microwave Journal

CONTENTS

July 2016
Vol. 59 • No. 7
Software and Design
mwjournal.com







Cover Feature

20 **E Pluribus Unum: An Integrated Design Flow for Phased Arrays**

Daren McClearnon, EEsof EDA, Keysight Technologies

MVP: Most Valuable Product

36 **Simplifying Antenna Design Without Compromise**

National Instruments, AWR Group

Technical Features

62 **Möbius Metamaterial Strips: Opportunity, Trends, Challenges and Future**

Ulrich L. Rohde, Federal Armed Forces University; Ajay K. Poddar, Synergy Microwave

88 **High Linearity RF Switches for DOCSIS 3.1 Applications**

Peter Bacon and Kinana Hussain, Peregrine Semiconductor

Application Note

96 **Using Model-Based Design for Software-Defined Radio**

Mike Donovan, MathWorks; Andrei Cozma and Di Pu, Analog Devices Inc.

AUGMENTED REALITY: HOW IT WORKS

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

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

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

Look for the Layar logo on participating pages.

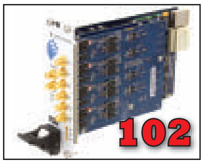
AR pages may expire after 30 days.

59 YEARS OF PUBLISHING EXCELLENCE

Microwave Journal

CONTENTS

mwjournal.com



Product Feature

102 High Speed PXIe Digitizers
Spectrum Systementwicklung Microelectronic GmbH

Tech Briefs

106 225 to 450 MHz Low Loss Coupler Handles 200 W
Mini-Circuits

106 CS-ESA Software for EMC Analysis with Spectrum Analyzer
Langer EMV-Technik GmbH

108 PADS Adds DC Drop and Thermal Analysis
Mentor Graphics Corp.

Departments

17	Mark Your Calendar	110	Catalog Update
18	Coming Events	112	New Products
43	Defense News	118	Book End
47	International Report	120	Advertising Index
51	Commercial Market	120	Sales Reps
54	Around the Circuit	122	Fabs and Labs

Errata: Please note the following correction to "A Compact Balanced-to-Unbalanced Diplexer Using Interdigital Line Resonators," published in the April 2016 issue. In the right-hand column on page 156, 11 lines under the heading "Balanced-to-Unbalanced Diplexer," the text "low return loss" should be "high return loss." Also, Equation 3 below the text should read:

$$\left|\Gamma_2^{dd}(f_{CH1})\right| \approx 0, \left|\Gamma_2^{dd}(f_{CH2})\right| \approx 1, \left|\Gamma_3^{dd}(f_{CH2})\right| \approx 0 \text{ and } \left|\Gamma_3^{dd}(f_{CH1})\right| \approx 1$$

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

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

EXECUTIVE EDITORIAL OFFICE
685 Canton Street, Norwood, MA 02062
Tel: (781) 769-9750
FAX: (781) 769-5037
e-mail: mwj@mwjournal.com

EUROPEAN EDITORIAL OFFICE
16 Sussex Street, London SW1V 4RW, England
Tel: Editorial: +44 207 596 8730 Sales: +44 207 596 8740
FAX: +44 207 596 8749

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

BPA WORLDWIDE

www.mwjournal.com

Printed in the USA

Microwave Journal Online

Scan page using layar app

Visit us @ mwjournal.com

eLEARNING free webinars

Improving Base Station Design - RF INNOVATIONS
Sponsored by: IDT 7/20

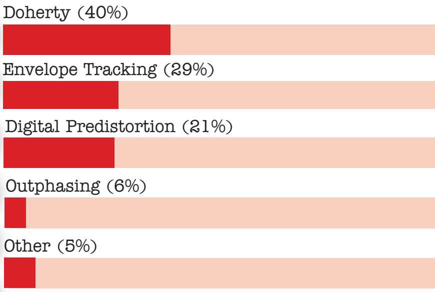
Access webinars on-demand from the archived webinars and events page at www.mwjournal.com

Web Survey

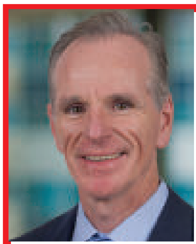
What is the biggest shift underway in the RF industry?

Look for our multiple choice survey online at mwjournal.com

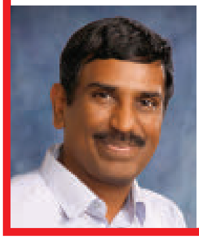
May Survey
Which technology offers the greatest increase in amplifier efficiency?



Executive Interviews



Liam Griffin, newly appointed president and CEO of **Skyworks Solutions**, discusses the future of connectivity, the seeds of Skyworks' success and how the company plans to stay in the lead.



Sailesh Chittipeddi, CTO and VP of operations at **IDT**, talks about the company's decision to enter RF, the markets they serve and their unique portfolio of products.

WHITE PAPERS

NATIONAL INSTRUMENTS
Integrating EM Simulation Technologies within an RFIC Design Flow

KEYSIGHT TECHNOLOGIES
PXI Interoperability – How to Achieve Multi-Vendor Interoperability in PXI Systems

NATIONAL INSTRUMENTS
Optimizing IP3 and ACPR Measurements

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

.COM

photo courtesy of the
U.S. Military & NASA

AUGUST

MARK YOUR CALENDAR

1

EDI CON 2017 Electronic Design Innovation Conference 电子设计创新大会

Initial Call for Abstracts

www.ediconchina.com

10

IEDM 62nd International Electron Devices Meeting

Call for Papers Deadline

www.ieee-iedm.org

24-26

RFIT 2016

Taipei, Taiwan

The 2016 IEEE International Symposium on Radio-Frequency Integration Technology (RFIT 2016) is a focused yet interdisciplinary advanced forum for microwave and microelectronics technologies. RFIT provides a forum for the integrated circuit and technology communities to meet and present the latest developments in integrated circuit design, technology and system integration, with emphasis on wireless communication systems and emerging applications such as biology and healthcare, as well as THz and 3D integration technologies.

www.rfit2016.org

1-4

NIWeek August 1-4, 2016 | Austin, Texas

NIWeek 2016

Austin, Texas

The 22nd annual NIWeek conference presented by NI brings together the brightest minds in engineering and science. More than 3,200 innovators representing a wide spectrum of industries, from automotive and telecommunications to robotics and energy, will discover the latest technology to accelerate productivity for software-defined systems in test, measurement and control.

www.ni.com/niweek

17-18

COMSOL

Multiphysics Intensive Training

Albuquerque, N.M.

www.comsol.com/events

29-9/2

EUSIPCO 2016

Budapest, Hungary

EUSIPCO2016

The 2016 European Signal Processing Conference will feature a comprehensive technical program addressing all the latest developments in research and technology for signal processing. EUSIPCO 2016 will feature world-class speakers, oral and poster sessions, keynotes, exhibitions, demonstrations and tutorials, and is expected to attract many leading researchers and industry figures from all over the world.

www.eusipco2016.org

FOR DETAILS, VISIT MWJOURNAL.COM/EVENTS

Coming**Events**

CALL FOR PAPERS

EDI CON China 2017
August 1, 2016

LAMC 2016
August 1, 2016

DesignCon 2017
August 16, 2016

88th ARFTG Conference
October 7, 2016

mwjournal.com

AUGUST

NIWeek 2016
August 1–4, 2016 • Austin, Texas
www.ni.com/niweek

RFIT 2016
August 24–26, 2016 • Taipei, Taiwan
www.rfit2016.org

SEPTEMBER

CTIA Super Mobility
September 7–9, 2016 • Las Vegas, Nev.
www.ctiasupermobility2016.com

Tower and Small Cell Summit
September 7–9, 2016 • Las Vegas, Nev.
www.towersummit.com

IEEE AUTOTESTCON 2016
September 12–15, 2016 • Anaheim, Calif.
www.autotestcon.com

ION GNSS+ 2016
September 12–16, 2016 • Portland, Ore.
www.ion.org/gnss

Metamaterials 2016
September 17–22, 2016 • Crete, Greece
http://congress2016.metamorphose-vi.org

EDI CON USA
September 20–22, 2016 • Boston, Mass.
www.ediconusa.com

IRMMW-THz 2016
September 25–30, 2016 • Copenhagen, Denmark
www.irmmw-thz2016.org

OCTOBER

EuMW 2016
October 3–7, 2016 • London, UK
www.eumweek.com

The 2016 Defence, Security and Space Forum at EuMW
October 5, 2016 • London, UK
www.eumweek.com

ICUWB 2016
October 16–19, 2016 • Nanjing, China
http://icuwb2016.njupt.edu.cn

Phased Array 2016
October 18–21, 2016 • Waltham, Mass.
www.array2016.org

IME/China 2016
October 19–21, 2016 • Shanghai, China
www.imwexpo.com/siteengine.php?do=en/index

IEEE CSICS 2016
October 23–26, 2016 • Austin, Texas
www.csics.org

AMTA 2016
October 30–November 4, 2016 • Austin, Texas
www.amta2016.org

NOVEMBER

MILCOM 2016
November 1–3, 2016 • Baltimore, Md.
www.milcom.org

ITC/USA
November 7–10, 2016 • Glendale, Ariz.
www.telemetry.org

DECEMBER

IEEE International Electron Devices Meeting (IEDM)
December 3–7, 2016 • San Francisco, Calif.
www.ieee-iedm.org

APMC 2016
December 5–9, 2016 • New Delhi, India
www.apmc2016.org

88th ARFTG Microwave Measurement Conference
December 6–9, 2016 • Austin, Texas
www.arftg.org

IEEE MTT-S Latin America Microwave Conference (LAMC 2016)
December 12–14, 2016 • Puerto Vallarta, Mexico
www.lamc-ieee.org

JANUARY

RWW2017
January 15–18, 2017 • Phoenix, Ariz.
www.radiowirelessweek.org

DesignCon 2017
January 31–February 2, 2017 • Santa Clara, Calif.
www.designcon.com

FEBRUARY

Mobile World Congress 2017
February 27–March 2, 2017 • Barcelona, Spain
www.mobileworldcongress.com

COVER FEATURE
INVITED PAPER

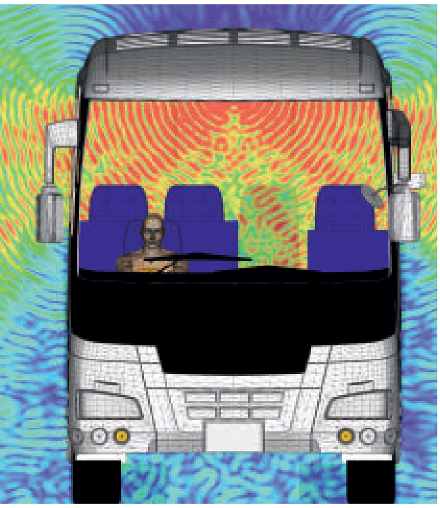
Scan page using layar app

E Pluribus Unum: An Integrated Design Flow for Phased Arrays

Daren McClearnon
EEsof EDA, Keysight Technologies, Santa Rosa, Calif.

Multichannel antenna arrays are key enablers in the next generation of defense and wireless communications systems, for beam steering and multiple-input-multiple-output (MIMO) architectures. They allow both electronic warfare (EW) and consumer systems to provide precise, dynamically allocated and robust service levels, supporting mobility business models that were unthinkable a few years ago. Approaching this new technological complexity begins in R&D, where similar breakthroughs in design tools and verification methodologies can address phased array beam forming challenges efficiently, in a lean commercial environment. This article shows how a connected suite of standard tools can streamline the design process while enabling trade-offs in RF and digital beam forming performance.

Multi-antenna techniques such as beam forming (RF, digital and hybrid) and massive MIMO are now major trends in 5G and satellite communications systems and EW, thanks to their ability to provide precise, dynamically allocated and robust service levels. These techniques solve different problems at the system level and can be used together to deliver more bits per Hz in a crowded area, with less interference. What has enabled these elaborate technologies to advance from their use in specialized military applications to low cost, high volume consumer-oriented platforms, over the course of just a few years? The answer lies with semiconductor improvements gained in keeping with Moore's Law, specifically reduced cost, size and power and increased bandwidth and microwave performance. Consumer demand is playing a role in driving beam forming and MIMO into the commercial sector, leading to mobility business models that were unthinkable only a few years ago.



For all the good that comes with these technologies, their complexity creates challenges, especially with the design of phased arrays. Overcoming these challenges to achieve an optimal system design requires a new, top-down system-level methodology, one that streamlines the design process, from assessing beam forming strategies and system-level scenarios to system implementation.

PHASED ARRAY DESIGN CHALLENGES

When designing phased array systems, several design flow challenges — both technical and economic — must be addressed. For example, to gain a system perspective of the economic and service-level trade-offs, the impact of realistic analog, electromagnetic (EM) and digital signal processing (DSP) performance must be considered. However, a system perspective is often hard to achieve. One challenge is the sheer number of engineering disciplines required to develop a phased array, most operating independently. Different toolsets are used for analyzing antennas and EM, RF transceivers and manifolds (which can take the form of ICs, modules and boards), as well as the integration of RF, digital and hybrid beam forming architectures — which cross boundaries between the baseband ASIC/FPGA and RF architectures.

While beamwidth and sidelobe levels are typical measures of array performance, the larger goal of any phased array subsystem is delivering higher system-level performance. Beam forming is used to concentrate RF power in specific directions, which reduces the RF power needed to achieve a given link quality (e.g., data throughput). Secondly, this also reduces interference for other users while improving their link quality and conserving battery life. At a higher level, the underlying RF impairments of the array affect the final sidelobe levels and beam patterns, reducing system-level performance.

In phased array transmitters, sidelobe levels from imperfectly formed beams may interfere with external devices or make the transmitter visible to countermeasures. In radar systems, sidelobes may also cause a form of self-induced multipath, where multiple copies of the same radar signal arrive from different sidelobe directions. These additional propagation paths can exaggerate ground clutter and must be removed with sophisticated DSP algorithms. Degraded RF array performance can also misdirect the main beam, widen it or reduce its directivity. Examples of this are "squinting," (e.g., frequency dependent beam distortion that occurs during each radar chirp, as shown in ***Figure 1***) and AM-AM/AM-PM distortion. In a military system, the reduction in effective radiated power (ERP) reduces the power illuminating a distant target and its probability of detection and effective standoff range. For communication link budgets, the effect

is on the signal-to-noise ratio (SNR) and coverage area.

In phased array receivers, poor RF array performance may add noise. It may also increase reception from unwanted directions, from sidelobes and misplaced nulls, or widened beams from overloading. These effects reduce sensitivity and range, increase susceptibility to interferers or jammers and degrade the overall error vector magnitude (EVM), bit error rate (BER) and throughput (or probability of detection). Gain/Temperature (G/T) is a common measurement for receiver arrays, combining several underlying degradations into a composite figure-of-merit (similar to SNR) over a range of received spherical angles (see ***Figure 2***). The array may be programmed to "listen" in a certain direction, yet how well does it achieve that goal?

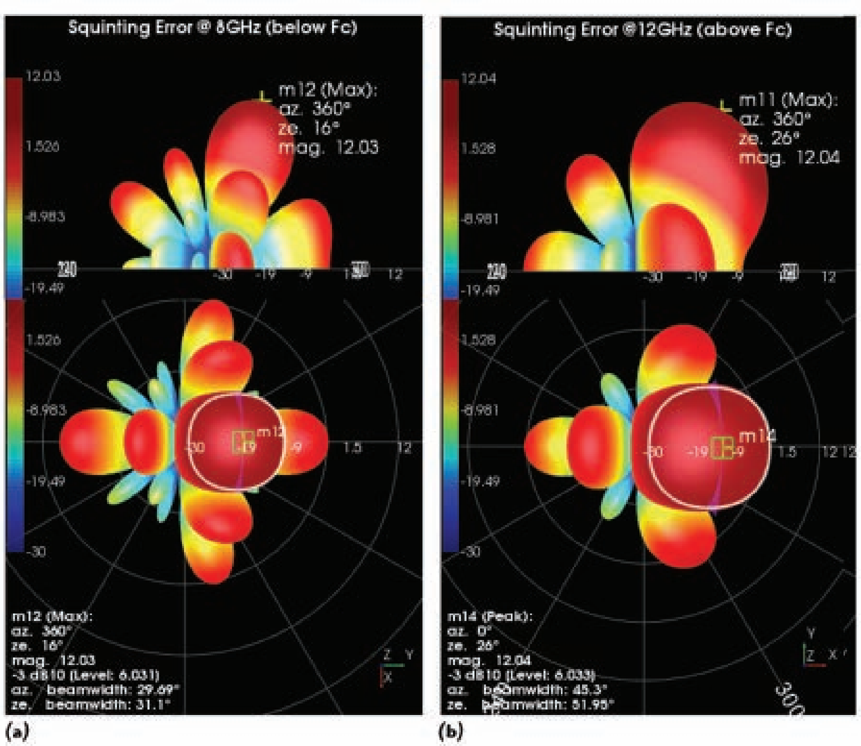


Fig. 1 Array antenna patterns at 8 GHz (a) and 12 GHz (b) showing beam squinting and sidelobe variation.

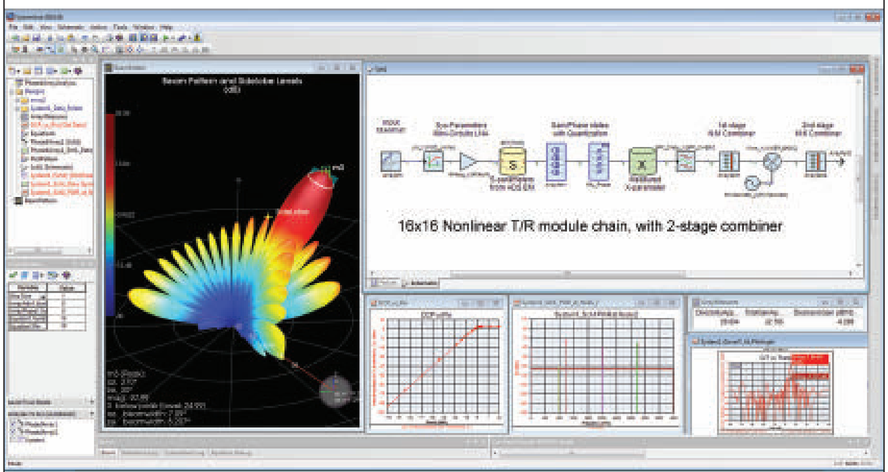
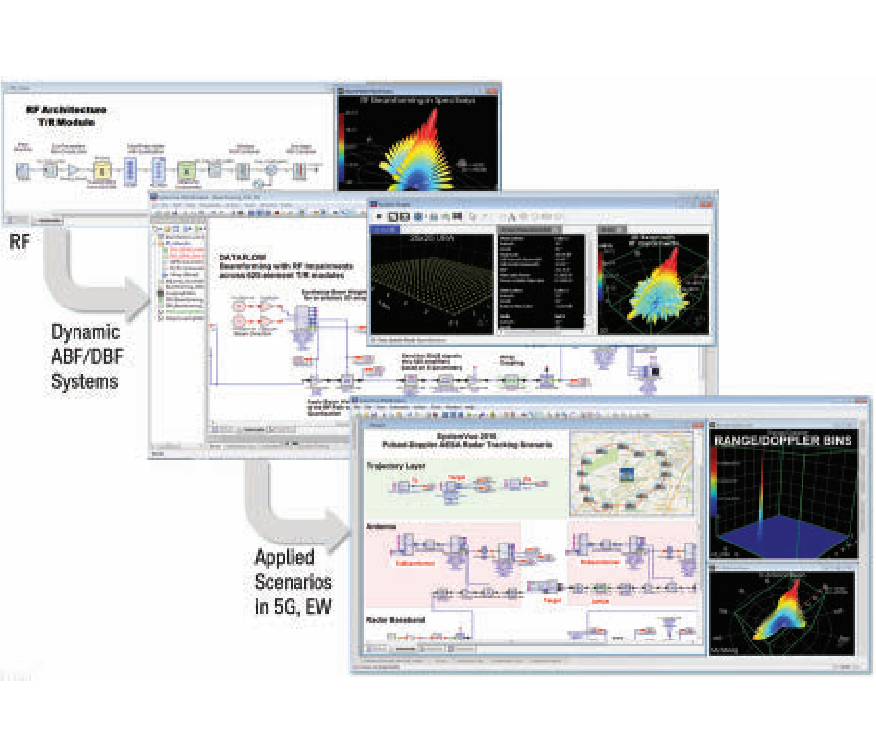


Fig. 2 G/T analysis for a T/R module, showing sidelobes and directivity.

Although MIMO techniques are related to beam forming, they have subtly different issues from forms of crosstalk and correlation. Depending on the architecture, these techniques may be used in tandem on the same platform. MIMO improves the robustness of communication links in dense mobility environments, while improving spectral efficiency. Since MIMO requires individually-addressable signal paths for each "stream," the cost and power of the digital-to-analog and analog–to-digital converters (DAC and ADC) and dedicated signal processing adds dramatically to the size, weight and power (SWaP) of the array subsystem. Functionally, analyzing multiple data streams from a single user (MIMO), compared to individual data streams from multiple users in a multi-function array, requires the array and its impairments to be accessed at the higher system-level.

In hybrid beam forming (HBF) and composite arrays comprised of multiple single-function sub-arrays, the likelihood of self-interference increases. HBF is gaining popularity in the 5G community as it allows cost-benefit trades between analog beam forming (ABF) and digital beam forming (DBF). In HBF, there are still multiple distinct baseband signals, but they drive ganged sub-arrays at the RF beam forming levels; these sub-arrays perform phase shifting at the transmit carrier frequency. Splitting the functionality achieves both directionality (beam forming) and throughput (MIMO) at lower cost and power from RF ASICs, ADCs and DACs.

A final concern is whether physically imperfect arrays really work across their intended bandwidths at their microwave or millimeter wave carrier frequencies and in their propagation environments. Until recently, this has been difficult for a disjointed set of simulation tools to predict, requiring dependence on hardware prototyping. Each engineering group has its own

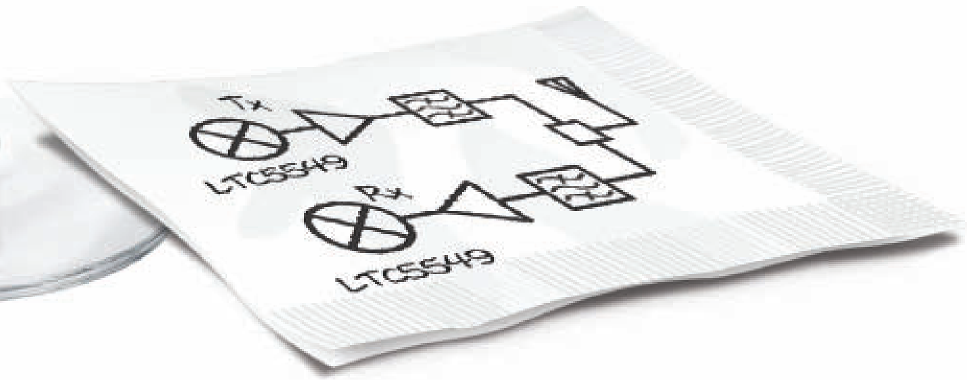


▲ *Fig. 3 System analysis using multiple platforms, from the RF components to end use scenarios.*

established tool chains and methodologies which are difficult to combine across disciplines. Back annotating engineering changes up to the system level is also difficult.

Collectively, the number of toolsets for architecting and validating phased arrays is daunting and needs much investigation and improvement. Given these challenges, a predictive, system-level design flow can greatly reduce iterations and the need for hardware validation, indoor/outdoor antenna ranges and flight time.

In addition to these design flow challenges, there are softer design flow risks to consider: In some environments, intellectual property (IP) is concentrated in people rather than tools. Preserving and re-using design experience and project IP is a strategic concern. Issues like controlling R&D "overhead" costs not assigned to a contract, technology turnover, time-to-deployment and high skill requirements add to the demand for streamlined model-based engineering (MBE) across multiple domains.



Upgrade Your Mixer

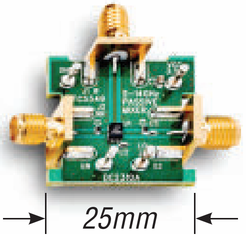
2GHz–14GHz, 0dBm LO Drive

The LTC5549 microwave mixer upgrades your transmitter and receiver performance with a +22.8dBm IIP3 at 12GHz. Its 0dBm LO drive and an on-chip frequency doubler eliminate the need for an external LO power amplifier and allow use of commonly available low frequency PLL/synthesizers, reducing power consumption and solution costs — all in a tiny 3mm x 2mm package that keeps your solution size small.

▼ Features

- +22.8dBm IIP3 at 12GHz
- 0dBm LO Drive
- Upconversion or Downconversion
- –30dBm LO Leakage
- Tiny 3mm x 2mm Package

Demo Board



▼ Info & Free Samples

www.linear.com/product/LTC5549

1-800-4-LINEAR

LINEAR TECHNOLOGY

ADDRESSING THE CHALLENGES

Established electronic design automation (EDA) tool chains from companies like Keysight are being expanded to improve coverage for systems that use phased arrays and beam forming. These expanded tool chains help address several issues that arise from the use of disjointed design flows:

Choosing the right level of abstraction. Finding the right level of simulation abstraction, especially in the RF design flow, can be difficult. If the models are too idealized for speed, then the simulations will not be accurate. That leads to increased hardware validation and cost. On the other hand, if excessive physical detail is included, the huge simulations will be too slow to validate meaningful portions of a "test plan" and not very scalable beyond 100-element arrays. Fortunately, there is a middle ground. Behavioral modeling balances the many orders of simulation magnitude between multi-user 5G and radar system scenarios, with active signaling, beam forming algorithms, nonlinear RF T/R modules and EM solver physical design details. Intelligent choices about "which powers of 10" to combine can make the flow scalable to thousands of array elements and unite the teams, while still preserving essential accuracy.

Scaling up to size. Once the right level of abstraction is found, the next step is applying it to larger arrays (>1000 elements). Although spreadsheets are often used for architecture studies, they give up too much flexibility and do not consider noise, nonlinearities, X-parameters®, component variations and statistics, frequency dependence, mismatch or other factors. Circuit-level tools can be "brute forced" into array analysis, but that comes at a huge price for usability and speed. Instead, an intermediate modeling level can be used where nonlinear, multi-stage arrays are modeled in seconds using a simple use model, preserving the idea of "predictive" accuracy (i.e., a simulation that will tell you something you didn't already know).

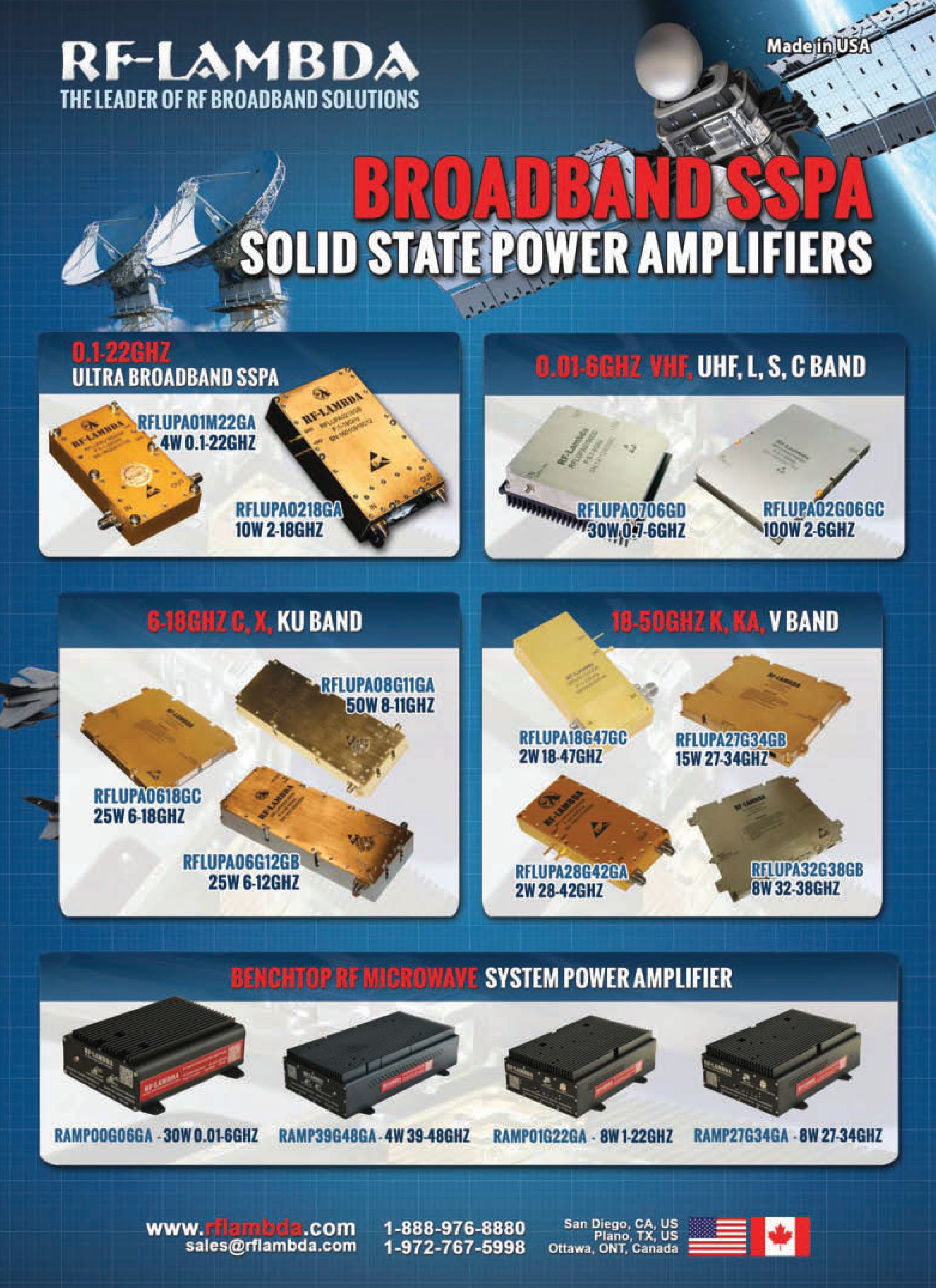
Validating the rendered beam (baseband with realistic RF). The ability to drive the accurate RF array model, from the previous steps, with realistic baseband beam forming algorithms is necessary to validate the beam integrity of the array under a range of 3D array configurations, scan angles, windowing tapers, sub-array partitioning, operating frequencies and other conditions. MATLAB algorithms by themselves do not save design iterations without some level of RF accuracy informed from the actual design process. Conversely, without complex algorithmic behaviors and baseband corrections, the benefit of static RF models can only be inferred at the array subsystem. Both domains must work together to predict the performance of the whole subsystem and reduce the cost of prototyping and test.

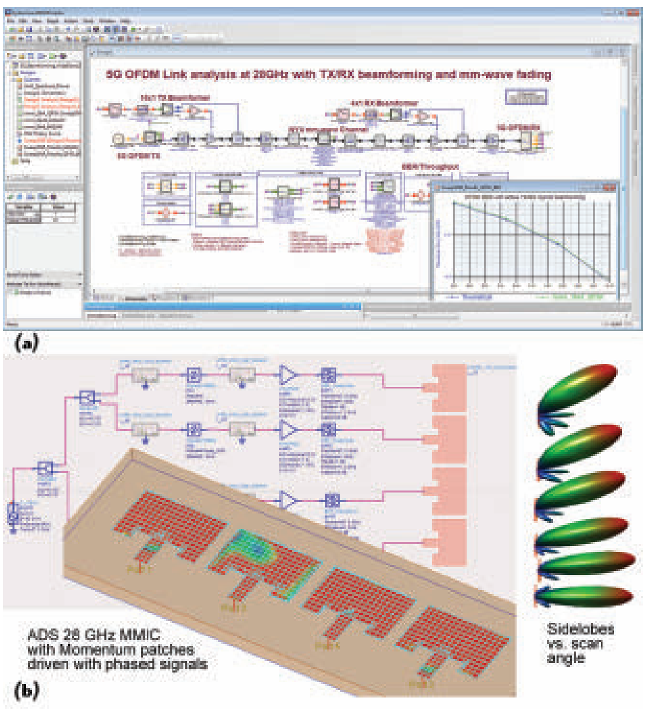
Handling dynamic, system-level scenarios. Array subsystems are designed to deliver a certain level

of system performance, whether a 5G, EW or emerging satellite platform. A given array subsystem must be validated with format-realistic signaling and receiver processing in dynamic scenarios to ensure it is compliant with published standards, interoperable with other equipment under specified conditions and meets other performance minimums. Most organizations wait until operational hardware prototypes are available to do this validation, which typically requires access to indoor and outdoor test ranges, flight time and other expensive assets. This leads to late discovery and troubleshooting of architectural flaws at the pilot production stage. A connected, top-down, system-level design flow enables diagnosing and quickly addressing "preventable" errors before requiring more rigorous testing; expensive assets are only needed at the end. The connection of "proposal" to "final design," in the terms of the customer's own delivered performance, makes this step worth pulling into the R&D phase, as part of a soft, simulation-based test plan.

This final point has a large economic payoff. However, the following three capabilities are required to realize the benefits of a unified phased-array workflow:

- Exchanging design information — From an MBE perspective, a team works from the top down within a single discipline, such as moving beam forming algorithms from floating point into working FPGAs or ASICs. From the system perspective, maintaining this MBE approach across disciplines requires additional tool connectivity that is less common. Humans become the design flow bridge, often using word processors and spreadsheets in lieu of design files; however, this requires interpretation that inserts risk into the process. Direct exchange of design information enables faster cross-validation and engineering changes to back-propagate to the system architect, in the event of a lower level technical (or material) change. Design information formats include MATLAB models, System C/C++, VHDL and Verilog, S- and X-parameters, SysParameters, 3DEM far field pattern files and waveform files.
- External scripting and automation for formalized cross-validation — An environment like Keysight's SystemVue can be used to assemble meaningful baseband-RF co-validation scenarios. These scenarios are automated with external applications to run a regular regression harness of automated verifications, such as for a nightly build process. The ability to cross-validate a project continuously, from the very first day, improves transparency, enables better project management and lowers risk.
- Integration with test — Finally, design simulation is helpful, yet it often remains separate from real world integration, variations and results. The ability to connect the


RF-LAMBDA
THE LEADER OF RF BROADBAND SOLUTIONS
Made in USA
BROADBAND SSPA
SOLID STATE POWER AMPLIFIERS
0.1-22GHZ
ULTRA BROADBAND SSPA
RFLUPA01M22GA
4W 0.1-22GHZ
RFLUPA0218GA
10W 2-18GHZ
0.01-6GHZ VHF, UHF, L, S, C BAND
RFLUPA0706GD
30W 0.7-6GHZ
RFLUPA02G06GC
100W 2-6GHZ
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



▲ *Fig. 4 Link analysis of 28 GHz 5G OFDM link (a) and 4 × 1 receive array modeled in Momentum (b).*

EDA world directly to wideband, multi-channel test and measurement, with support for real-time prototyping and instrument personalities, means that design insight can be preserved in a closed modeling loop using a consistent approach, from proposal into hardware. Combining simulation with versatile software-defined measurement platforms allows earlier architecture validation and enables flexible verification strategies that reduce project cost and increase utilization of test assets.

Progress in each of these areas is possible using a design flow that connects tools and reference IP in several domains into an open flow. Keysight SystemVue, for example, provides a phased-array design personality and can also operate as a co-validation backplane. The following case studies show how a unified, model-based design approach for phased arrays might work in the real world.

EW ARRAY

Consider a basic EW scenario in which a central monostatic radar beam forms in "tracking" mode to follow a radar cross section (RCS) target, such as an aircraft, as it flies in a path around a city, using latitude, longitude, altitude waypoints. As the position of the RCS target moves, both the transmitter and receiver arrays are steered to follow its direction. The arrays are each 25 × 25 uniform rectangular with a Taylor taper, whose complex weights are dynamically updated at the system level using adaptive algorithms. The arrays can either be purely behavioral or incorporate some effects from a T/R module chain modeled in an RF simulation domain. In ***Figure 3***, the range-Doppler bins are shown at the system level, along with the beam quality.

In the RF array, it is possible to account for the X-parameters of components, designed in ADS or measured on the bench. It is also possible to account for noise, nonlinearities, mismatch and frequency response, as well as the use of quantized phase, delay or amplitude states. Coupling between array elements, based on a true EM simula-

tion, and realistic far field patterns for the radiating elements may be taken into account in the final, working beam patterns. As the array scans to more extreme angles, the scan loss and grating lobes degrade the performance. If the highest accuracy is needed for troubleshooting, a few key RF pieces may be directly co-simulated with the ADS circuit envelope/Ptolemy simulators — although for larger arrays, a comprehensive co-simulation approach can be impractical. For baseband, if FPGA algorithms are being co-verified, key algorithms can be co-simulated with either an HDL simulator, a Xilinx Virtex 7 FPGA board running in hardware-in-the-loop (HIL) mode or even an instrument. To account for atmospheric fading and terrain, SystemVue can be scripted to connect with the STK software from Analytical Graphics Inc. (AGI). This allows key time-varying quantities like range delay, Doppler shift and propagation loss to be rendered with accurate, fully-coded radar signaling.

With this verification backplane, it is possible to design the phased array and use it in a meaningful, scripted scenario that validates a range of conditions, statistical variations or countermeasures. In this way, an entire organization can contribute files and IP to a common tool and cross validate all the way to the test bench.

5G ARRAY

A likely 5G scenario comprises a wideband, 28 GHz MIMO OFDM link between a planar 4 × 4 array at the base station (i.e., eNodeB) and a 4 × 1 array at the user's equipment (UE). The beams are dynamically steered using hybrid beam forming (see ***Figure 4***). The link is faded through a millimeter wave 3D MIMO fading model, based on 5G research at New York University. The baseband reference designs for the transmitter and receiver provide the OFDM framing and resource mapping on a flexible level; these designs go beyond LTE-A and include receiver synchronization and demodulation back to the data payload. This complex BER/throughput example includes the effect of the array, beam forming accuracy and an industry-standard fading model. As more UEs and interferers are added, the adaptive beam forming algorithms, the modulation and coding strategy, as well as the RF architecture can be assessed. In this scenario, the flexibility to conduct system-level research, while using a practical RF basis to perform the modeling, allows the system architect to assess how large of an array is needed, the required performance and the risk to the company.

CONCLUSION

The practical design challenges for phased array subsystem design go beyond simple technical performance issues associated with individual RF component design. A view of the subsystem's performance can directly assess overall performance margins across baseband and RF and help designers make trade-offs between the domains, while delivering realistic performance. The critical capability is tying together the circuit simulators, beam forming and DSP algorithms, antenna patterns, system scenarios, FPGA implementations and test equipment in a unified model-based design flow. This can be accomplished using an electronic system-level platform like SystemVue. The resulting connected suite of standard tools helps to significantly streamline the design process. Adding a phased array beam forming personality adds more power, unlocking cross-functional insight.■

5G App Note:
For more information, visit http://literature.cdn.keysight.com/litweb/pdf/5992-1448EN.pdf


Mini-Circuits
PMA3-83LN+

Most Valuable Product

Simplifying Antenna Design Without Compromise

National Instruments
AWR Group, NI
El Segundo, Calif.

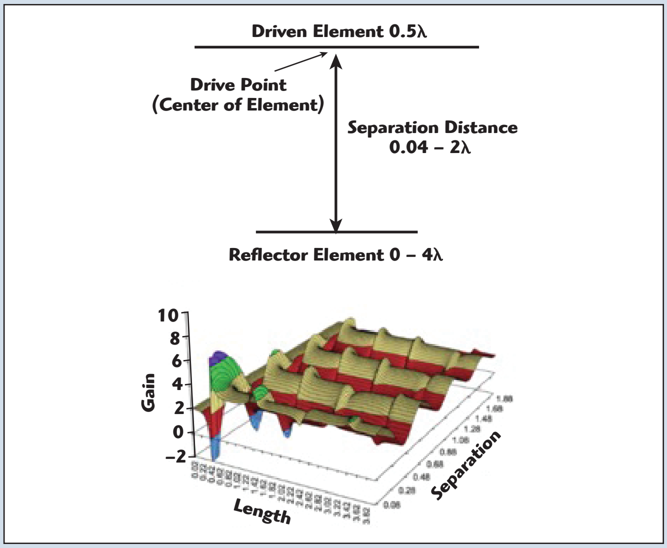
Growing demand for wireless connectivity relies more and more on integrated antenna solutions customized for optimal system performance, cost and size. Achieving multiple performance metrics such as impedance matching, gain, radiation efficiency and operating bandwidth is a time consuming process involving numerous iterative simulations and a significant amount of design knowledge. With the demand for design experience greatly exceeding the current supply of antenna engineers, an alternative approach is needed.

Fortunately, research into the use of the evolutionary algorithms (EA), a programmatic method to explore the design space and automatically locate superior antenna designs, offers a means to accelerate the overall design process. EA is proving to be highly effective at generating antenna structures with greater performance than would otherwise be developed by traditional methods. AntSyn™, a combination of EA with RF/microwave simulation, has been successful in the development of a variety of antenna types for aerospace applications, and it is now available as a commercial product from National Instruments (NI).

AntSyn is an automated antenna design, synthesis and optimization tool that enables users to input antenna engineering requirements and output antenna designs. AntSyn was designed to be used both by experts and those who are relatively new to antenna design.

THE DESIGN BOTTLENECK

A properly designed antenna is typically characterized by a number of critical performance metrics that are driven by the target application. Chief concerns relate to the directional characteristics (as depicted in the antenna's radiation pattern) and the resulting gain. As a result, the range of antenna design types is extensive, with a very large number of shapes, sizes, requirements and applications. Designing and optimizing antennas by hand requires significant domain expertise. This time and labor intensive process depends on the aptitude or expertise of the designer to identify a suitable initial design that can



▲ *Fig. 1 Antenna design complexity illustrated by the range of gain from varying the dipole length and reflector separation of a simple antenna.*

be optimized to achieve the desired results (see ***Figure 1***).

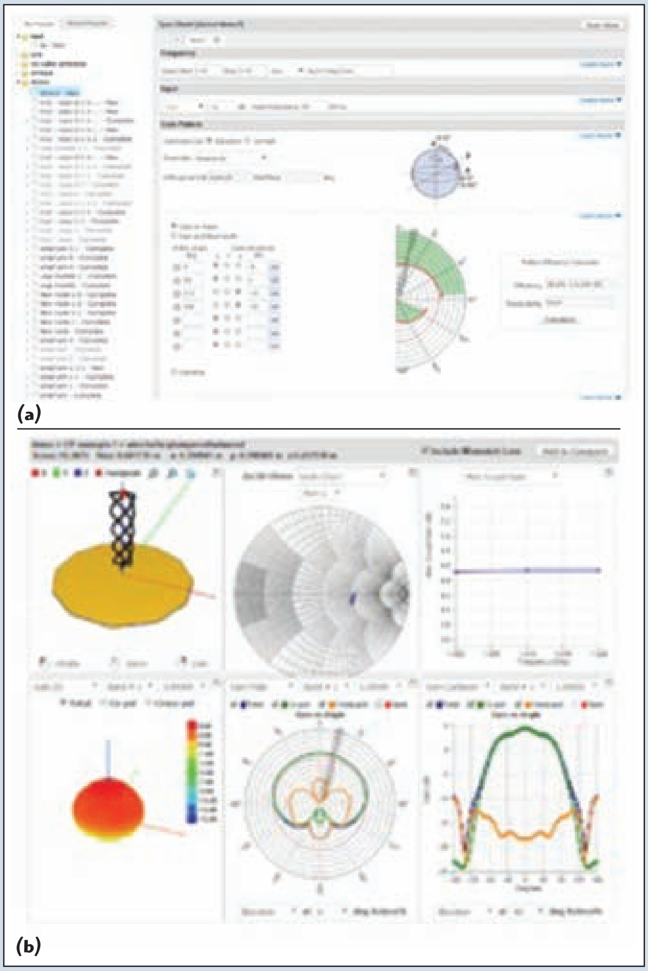
It is not uncommon for an experienced engineer to consume several months developing a new antenna design, depending on the level of difficulty defined by the antenna specifications. The time and effort invested increases significantly when addressing factors such as antenna interaction with the platform or wireless device and co-site interference. Design delays are compounded when program requirements change, such as in early stage development or where antenna integration requires in-situ optimization. The ability to conduct rapid antenna design and redesign is a growing concern as the number of wireless devices proliferates.

As an alternative or adjunct to designing by hand, since the early 1990s, researchers have been investigating methods based on evolutionary antenna design and optimization. One highly successful technique from NI is based on EA. This technology has been developed into a complete antenna synthesis tool, AntSyn, and has been used successfully by companies and government agencies operating in aerospace, communications and wireless electronics markets to design antennas operating at frequencies from below HF (2 MHz) to above Ka-Band (40 GHz). In contrast to the man-months of engineering time typically required for a final antenna design, AntSyn can generate a design in hours, optimizing trade-offs between criteria and often producing counter-intuitive designs that outperform traditional antennas.

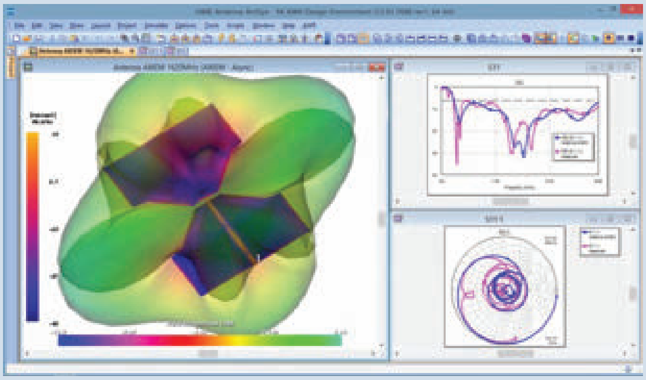
DESIGN BY REQUIREMENTS

AntSyn operates on a "what you want is what you get" principle, where the user inputs the antenna requirements, rather than a (parameterized) physical design. Antenna specifications such as frequency band, target impedance match (return loss), and gain pattern are input into the intuitive "spec sheet" user interface, which is automatically organized into a project file (see ***Figure 2a***). By running the spec sheet, AntSyn returns one or more optimized antenna designs, the results of which are viewed using a customizable dashboard for rapid evaluation (see ***Figure 2b***).

The user-specified dashboard can be set to view the proposed 3D model, input impedance (match) versus frequency in several formats, maximum gain versus frequency, radiation pattern cuts and qualitative star rating, all of which help identify good performers quickly. AntSyn has been used to develop a wide range of antenna types: single band, dual band, multiband, broadband and ultra-wideband (>100:1),



▲ *Fig. 2 The AntSyn user interface spec sheet (a) defines the antenna requirements and the AntSyn results dashboard (b) enables rapid evaluation.*



▲ *Fig. 3 The AntSyn design is easily exported for final verification, whether to AXIEM or Analyst, within NI AWR Design Environment, or other 3D EM simulators.*

high efficiency, loaded, electrically small, phased array, wire, patch, conformal, handset, multifunction and multiport.

EXAMPLES

Several types of antennas that generate modest gains with good linear or circular polarization over significant bandwidths include:

- Microstrip patch, which is made up of one or more "patches" of metal, separated from a ground plane by a dielectric substrate


Innovation
Thats Open.
Introducing OpenRFM™
Meeting new government interoperability and affordability requirements in Radar, Electronic Warfare and Signals Intelligence, requires innovative approaches in advanced RF/Microwave and digital signal processing. OpenRFM is the first RF/Microwave open system approach that leverages best available commercial-item technology to deliver sophisticated, interoperable sensor processing subsystems to dominate the electromagnetic spectrum. OpenRFM is the better alternative for affordable RF subsystems for our war fighters and allies alike.
MERCURY SYSTEMS™
INNOVATION THAT MATTERS™
MADE IN AMERICA
Visit mrcy.com/OpenRFM and download our technical whitepaper:
Advantages and Benefits of OpenRFM™
Copyright © 2015 Mercury Systems, Innovation That Matters and OpenRFM are trademarks of Mercury Systems, Inc. - 3142

MostValuableProduct

- Helix antenna, a helical wire wound with a circumference of about one wavelength (1λ) and a pitch of λ/4 over a ground plane with a 1λ minimum diameter
- Single or crossed dipoles, which are center-fed radiating elements, each about λ/2 long with rods that are parallel to and over a ground plane of about λ/4 minimum diameter
- Quadrifilar antenna, similar to short helix, and slot, which uses a small cutout in a ground plane and can conform to the skin of a satellite
- Spiral antenna, which is wideband and may be cavity backed, two or three dimensional
- Horn antenna, either used as the "feed" for reflector antennas or stand-alone.

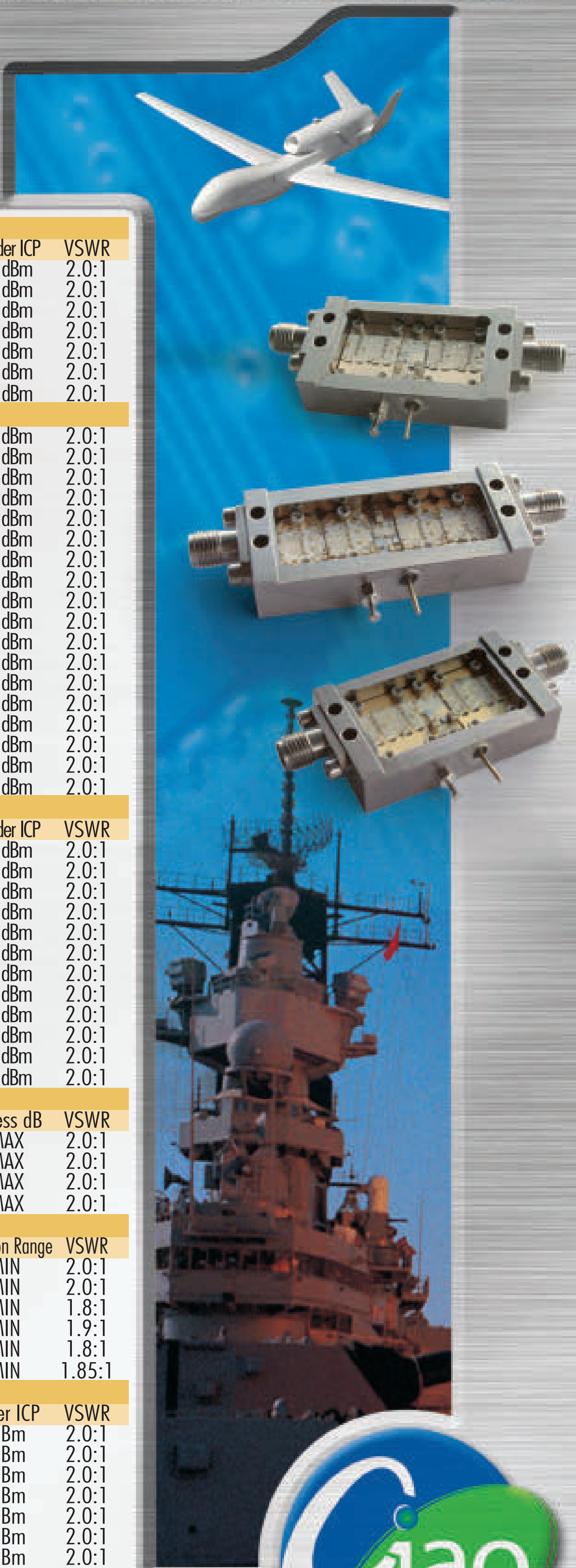
Navigating which of these antenna configurations achieves the best overall performance for the reduced size, weight and cost demands is a challenging task, especially as non-traditional companies jump into wireless-enabled devices called for by the Internet of Things (IoT) and small satellite (NanoSat or CubeSat) markets. NI is addressing this challenge with smarter design and test solutions spanning early concept through final verification.

Designers can expect to benefit from easily comparing the trade-offs between these different antenna types and then exploring more of the design space through smarter, knowledge-guided optimization. After achieving satisfactory design results, AntSyn antenna data can be transferred for verification in NI AWR Design Environment™, specifically AXIEM planar EM simulator, Analyst™ 3D finite element method (FEM) simulator or other third-party EM tools from Sonnet, ANSYS HFSS and CST Microwave Studio (see ***Figure 3***). This ability further extends design capabilities and the assurance of optimum results.

AntSyn provides an automated antenna design, synthesis and optimization tool that is well suited for helping designers of antennas, RF components and system engineers of many skill levels to address the challenges of next-generation antenna design and integration.

VENDORVIEW

National Instruments
AWR Group, NI
El Segundo, Calif.
awrcorp.com/antsyn



Scan page using layar app

DefenseNews
Cliff Drubin, Associate Technical Editor

CODE Moves Toward Sophisticated, Resilient and Collaborative UAS

VIEW VIDEO

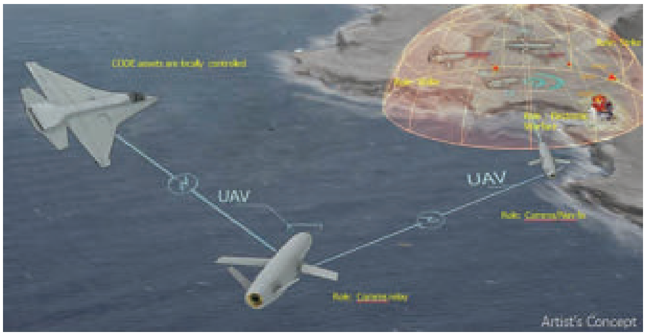
DARPA's Collaborative Operations in Denied Environment (CODE) program seeks to help the U.S. military's unmanned aircraft systems (UAS) conduct dynamic, long-distance engagements of highly mobile ground and maritime targets in denied or contested electromagnetic airspace, all while reducing required communication bandwidth and cognitive burden on human supervisors. In an important step toward that goal, DARPA recently awarded Phase 2 system integration contracts to Lockheed Martin Corp. (Orlando, Fla.) and Raytheon Co. (Tucson, Ariz.).

Further, the following six companies, all of which had Phase 1 contracts with DARPA to develop supporting technologies, will collaborate in various ways with the two prime contractors: Daniel H. Wagner Assoc. (Hampton, Va.), Scientific Systems Co., Inc. (Woburn, Mass.), Smart Information Flow Technologies, LLC (Minneapolis, Minn.), Soar Technology, Inc. (Ann Arbor, Mich.), SRI International (Menlo Park, Calif.), and Vencore Labs dba Applied Communication Sciences (Basking Ridge, N.J.)

CODE's main objective is to develop and demonstrate the value of collaborative autonomy, in which UAS perform sophisticated tasks both individually and in teams under the supervision of a single human mission commander. CODE-equipped UAS perform their mission by sharing data, negotiating assignments, and synchronizing actions and communications among team members and with the commander. CODE's modular open software architecture on board the UAS enable multiple CODE-equipped unmanned aircraft to navigate to their destinations and find, track, identify and engage targets under established rules of engagement. The UAS also recruit other CODE-equipped UAS from nearby friendly forces to augment their own capabilities and adapt to dynamic situations such as attrition of friendly forces or the emergence of unanticipated threats.

"During Phase 1, we successfully demonstrated, in simulation, the potential value of collaborative autonomy among UAS at the tactical edge, and worked with our performers to draft transition plans for possible future operational systems," said Jean-Charles Ledé, DARPA program manager. "Between the two teams, we have selected about 20 autonomous behaviors that greatly increase the mission capabilities of our legacy UAS and enable them to perform complex missions in denied or contested environments in which communications, navigation and other critical elements of the targeting chain are compromised."

CODE's prototype human-system interface (HSI) is designed to allow a single person to visualize, supervise, and command a team of unmanned systems in an intuitive manner. Mission commanders can know their team's status and tactical situation, see pre-planned and alternative courses of action, and alter the UAS' activities in real time.



Source: DARPA

Top Three Subcontractors Selected by OneWeb Satellites

OneWeb Satellites, a joint venture equally owned by Airbus Defence and Space and OneWeb, has selected the first three top-tier subcontractors. The supply contracts have been signed with MacDonald, Dettwiler and Associates Ltd. (MDA) from Canada, Sodern from France and Teledyne Defence (a business unit of Teledyne Microwave Solutions) from the UK.

To equip each of the 900 satellites forming the OneWeb fleet, MDA will provide on board antenna systems, Sodern has customized to constellation its star tracker technology, while Teledyne Defence has designed communications repeater equipment derived from its high volume manufacturing heritage.

With this milestone OneWeb Satellites is pursuing its industrial development and rapidly moving forward. In April, Florida was announced as the site for its high volume satellite manufacturing factory.

The space segment of OneWeb will initially comprise a constellation of 648 operational satellites and replacement satellites, all of which will be identical. Each satellite will weigh approximately 150 kg and will operate in low Earth orbit. Arianespace and Virgin Galactic will begin launching the spacecraft in 2018 after which the satellites will be moved to their operational orbits using electrical propulsion.

The constellation to be operated by OneWeb will provide high-speed internet services with global coverage. The joint venture will also be able to produce satellites, platforms or equipment to be marketed by Airbus Defence and Space for the benefit of other operators of future constellations.

NRL Invokes Cost Effective Approach to Improve Joint ISR Missions

The U.S. Naval Research Laboratory (NRL) Radar Division has teamed with San Diego-based General Atomics Aeronautical Systems Inc. to integrate maritime mode inverse synthetic aperture radar (maritime-ISAR) imaging capability with GA-ASI's Lynx Multi-Mode

For More Information

Visit mwjournal.com for more defense news

Radar deployed on its Unmanned Aerial Systems (UAS).

Developed for the U.S. Air Force (USAF) through funding by General Atomics Aeronautical Systems Inc. (GA-ASI), the MQ-9 unmanned aerial vehicle (UAV) is designed to execute time-sensitive targets with persistence and precision, and destroy or disable those targets. GA-ASI has teamed with the U.S. Naval Research Laboratory to implement an Inverse Synthetic Aperture Radar (ISAR) imaging capability in the GA-ASI's Lynx Multi Mode Radar currently deployed on UASAF MQ-9 UAVs.

"Because ships and small watercraft at sea are usually in motion — having both forward velocity and other linear and angular motions, for example, pitch and roll and heave and sway — this creates a problem for typical ISAR platforms," said Thomas Pizzillo, head, NRL Radar Analysis Branch. "The addition of a maritime-ISAR mode to the General Atomics Lynx radar, as a software only upgrade, is the most cost effective alternative to introduce this capability to the MQ-9 fleet."

Synthetic Aperture Radar (SAR) is a radar imaging method using multiple pulses transmitted from a moving platform. The received signals are combined to form a high quality two-dimensional (2D) image of the ground-terrain of interest. Classical SAR algorithms assume the target scene (background) is stationary and any motion in the scene shows up as a smear or streak in the image. ISAR algorithms assume the target itself is moving, and through a set of complex algorithms, calculates enhanced angular or cross-range resolution by analyzing subtle differences in range-rates caused by the target motion. The net effect is to focus the image of a moving target without smearing.

Courtesy U.S. Air Force/Lt. Col. Leslie Pratt

"NRL has successfully adapted the necessary changes to ISAR image formation in which the rotational motion of the target is not known beforehand," Pizzillo says. "This provides the end-user with an imaging software tool that can produce high-quality imagery in conditions with significantly complex target motion."

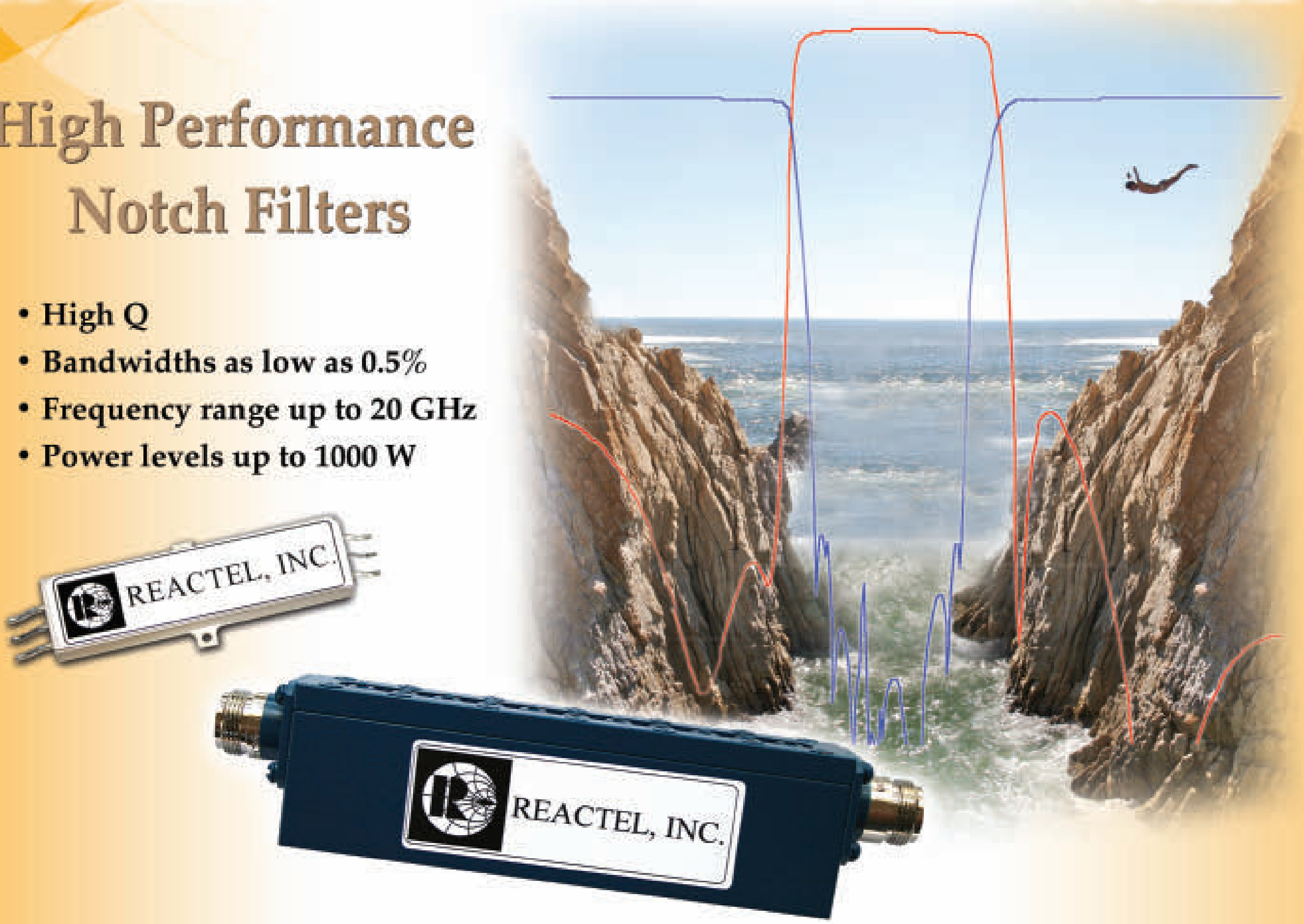
Reactel, Incorporated

Reacting First to All Your Filter Needs.

A Sheer Descent into the Noise

High Performance Notch Filters

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



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

- 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 • Fax: (301) 519-2447
For general inquiries, please email reactel@reactel.com • http://twitter.com/reacteljim • Go online to www.reactel.com to download your Reactel catalog today.

Intertek

RoHS Compliant

@reacteljim

The 2016 Defence, Security and Space Forum

At European Microwave Week

EuMA

Microwave Journal
Frequency Matters.

Wednesday, 5 October – ExCel, London – Rooms 8 to 11

A focused Forum addressing the application of RF and microwave technology to Complex Urban Environments.

The emphasis will be on complex urban environments, encompassing the challenges and opportunities for indoor/enclosed and urban communications and sensing technologies. The Forum has the scope to cover topics including: Smart City initiatives; 3D tracking technologies in complex and indoor environments; sensing complex targets in dense target environments; congested spectrum and network issues.

Programme:

09:00 – 10:40 EuRAD Opening Session

11:20 – 13:00 Complex Urban Sensing and Communication

Speakers from industry and academia will present RF solutions and systems that address the challenges imposed by operation in complex urban environments. Confirmed speakers include:

- New Transceiver Technology Applied to Standoff Submillimetre-Wave Imaging Radar – *Ken Cooper, JPL*
- Indoor and Urban Environment Location of Moving People and Vehicles Using Signals of Opportunity – *Pierfrancesco Lombardo, University of Rome*
- Communication Satellite Impact on TV and Data Broadcasting Through Urban Environments – *Erdem Demircioğlu, Turksat International*

13:10 – 14:10 Strategy Analytics Lunch & Learn Session

This session will add a further dimension by offering a market analysis perspective, illustrating the status, development and potential of the market.

14:20 – 16:00 *Microwave Journal* Industry Panel Session

The session offers an industrial perspective on the key issues facing the defence, security and space sector.
In accordance with the theme for 2016, the Panel will address: *Complex Urban environments, encompassing the challenges and opportunities for indoor/enclosed and urban communications and sensing technologies*. Confirmed speakers include:

- Spectral Detection and Visualisation with Distributed RF Receivers – *Raymond Shen, Keysight Technologies*
- How do Mobiles Develop the 6th Sense? – An Introduction to LTE-based Device-to-Device (D2D) Communication Principles – *Meik Kottkamp, Rohde & Schwarz*

16:40 – 18:20 EuMW Defence & Security Executive Forum

High-level speakers from leading defence and security companies present their views and experiences on RF microwave technology trends and its use in urban environments. Confirmed presentations include:

- Challenges for Maritime Border Surveillance Radar –*Tony Brown, EASAT*
- Challenges in the 'Future Borders' Concept - Combining Technology, People and Processes – *Roger Cumming, Fenley-Martel (ex UK Home Office)*
- Challenges in Urban Sensing and Communications [Preliminary Title] –*Ian Beresford, QinetiQ*

18:20 – 19:00 Cocktail Reception

Register online at www.eumweek.com

EuMW 201
Microwaves Everywhe

Registration and Programme Updates

Registration fees are £10 for those who have registered for a conference and £40 for those not registered for a conference.

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

Sponsors:

KEYSIGHT TECHNOLOGIES · Peregrine Semiconductor · QinetiQ · qorvo all around you · ROHDE&SCHWARZ

LTE Networks Pass 500 Milestone

The Global mobile Suppliers Association (GSA) confirmed that the number of commercially launched LTE networks passed the 500 milestone during May 2016. The historic milestone was reached in 77 months from first service launch, almost five years less than the time taken by 3G/WCDMA systems, and six months faster than HSPA systems.

GSA data for Q1 2016 LTE subscriptions revealed that LTE gained 182 million connections in Q1 2016, almost four times faster than 3G/HSPA systems. 3G/HSPA subscriptions grew by 48 million, while GSM subscriptions fell by 120 million in the same quarter. The number of LTE and LTE-Advanced subscriptions is expected to pass the 3G/WCDMA-HSPA global total in 2020, and possibly sooner.

The Asia region, with over 734 million LTE subscriptions, further grew its share of global LTE subscriptions quarter on quarter to reach 56.9 percent. By March 2016 China had passed 511 million LTE subscriptions, adding 96.3 million in the quarter. North America remains the second largest LTE market with 253 million, though its share of the world market further declined 2.6 percent in the quarter to 19.6 percent of the global total. The European share of the global total is 14 percent.

> "...LTE is now connecting over 1 in 6 mobile subscribers worldwide..."

Strong growth was recorded again in the Latin America and Caribbean region to reach 67 million 4G/LTE subscriptions. 11.1 million LTE subscriptions were added in the Middle East region in Q1 to reach 46.6 million. Russia has 16.7 million LTE subscriptions, Africa has 9 million LTE subscriptions and India has almost four million.

Alan Hadden, vice president, GSA said, "LTE subscriptions were signed up during Q1 2016 at an average of two million per day and the rate is accelerating. LTE is now connecting over 1 in 6 mobile subscribers worldwide."

Project Lifts Cloud from European Telecommunication Companies

The EU-funded MOBILE CLOUD NETWORKING project, which was officially completed at the end of April 2016, has effectively integrated domains, cloud computing services and mobile networks in order to provide the canvas upon which Europe's future mobile network services can be run. This is vitally important. If European companies are to take advantage of the technologies offered by cloud computing, then communication networks must be appropriately redesigned.

EU action in the telecommunications sector has in recent decades led to greater consumer choice, falling call costs and higher standards of service. However, mobile services have yet to fully tap the vast commercial potential offered by cloud computing, which is why the results of the MOBILE CLOUD NETWORKING project could be of great industry interest.

By leveraging Europe's excellence in mobile communications and extending this into the cloud arena—at present almost exclusively in the hands of US companies — the project will help European telecommunication companies remain globally competitive in an industry worth around €300 billion in the EU alone.

> ...the project will help European telecommunication companies remain globally competitive...

The proliferation of mobile internet access and services has driven huge increase in mobile data traffic. The internet now performs millions of tasks, from online banking to tsunami monitoring, and data traffic volumes are expected to grow 12-fold by 2018. Tapping the full potential of the cloud, as this EU-funded project has done, is a key way of reducing infrastructure expenditure, achieving efficiencies and creating space for further anticipated data growth.

GLIS 2016 Focuses on Space and 'Connected' World

The Global Conference on Space and the Information Society (GLIS 2016), organized by the International Astronautical Federation (IAF), and held at the International Telecommunication Union (ITU) in Geneva, Switzerland in June, drew attention to the fact that space and space applications have a major role to play in the shaping of a future 'connected' world.

The international community faces substantial challenges: digital divide, disaster management, cybersecurity, big data analysis and climate change, to name a few. The next years will see governments, industry, academia and NGOs work together in a new era of connectivity. A combination of factors, such as the implementation of the UN Space Development Goals, the deployment of new mega constellations and the launch of new digitalized systems will strongly contribute to reaching this goal. International organizations, such as the United Nations and its agencies, ITU and UNOOSA, along with the IAF, aim to extend cooperation in space to achieve a better connected world.

"ITU is committed to maintaining right of access to the radio-frequency spectrum and satellite-orbit resources, and to ensuring their rational, equitable, efficient and economical use, free from harmful interference," said ITU Secretary-General Houlin Zhao. "Through our concerted efforts, we can help remove the obstacles that impede the development of new satellite networks and applications and bring them into operation to connect the unconnected around the world."

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

> "...connect the unconnected around the world."

"Activities in space contribute enormously towards shaping the information society," said François Rancy, director of the ITU Radiocommunication Bureau. "These involve the production of big data, the provision of global positioning information, the distribution of television programmes, the provision of emergency services, the prevention and mitigation of natural and man-made disasters, the forecasting of weather, the understanding, monitoring and protection of Earth natural resources and the connection of the world population to broadband services. Indeed, satellite systems play a critical role in supporting each and every one of the 17 sustainable development goals adopted last year by the United Nations."

Mobile and Broadcast Converge in New ETSI Specification Group

The European Telecommunications Standards Institute (ETSI) has unveiled a new Industry Specification Group, the Mobile and Broadcast Convergence (MBC) ISG. It will explore the deployment and business models of converged networks from the perspectives of all interested parties. The group will study the means to support delivery of media including linear and nonlinear elements over converged networks, taking into account the potential benefits and challenges from a commercial and technical perspective.

TV delivery has traditionally been dependent on one-way, one-to-many delivery networks to fixed TV sets (i.e., broadcasting). Nowadays, an increasing number of consumers watch linear or non-linear content on their traditional home screens as well as on their smartphones and tablets. Although much of this content is currently delivered via Wi-Fi networks, these new forms of media consumption dramatically increase the load on mobile networks. This situation may require new solutions, such as the leveraging of a one-to-many broadcasting approach.

"Increasingly consumers are using smartphones and tablets to access linear and nonlinear content interchangeably and the old model of a screen in the living room to watch TV broadcasting is becoming more and more irrelevant. Broadcasters and mobile operators will have to adapt their business models to these changed bandwidth flows and there is uncertainty about the optimum technology choices. This ISG is to allow all interested parties to engage with the technical debate now, ahead of whatever standardization work will be needed subsequently," said David Hendon, convenor of the MBC ISG.

While the ISG will not make recommendations about spectrum allocation, spectrum authorization models, which impact the regulatory framework and/or business model, may need to be considered in the ISG work.

100W POWER AMPLIFIERS

700-2700 MHz

$8,995 each

48 dB Gain, ±1.7 dB Flatness

Output power up to 100W with consistent performance across a wide frequency range for a fraction of the cost of competitive products! Mini-Circuits' new HPA-272+ high power rack mount amplifiers are ideal for a wide variety of high power test applications including EMI, reliability testing, power stress testing, and burn-in of multiple units at once. This model provides 48 dB gain with ±1.7 dB gain flatness over its entire frequency range and 89 dB reverse isolation. Housed in a rugged, 19-inch rack-mountable chassis, the amplifier operates on a self-contained 110/220V power supply and includes internal cooling, making it easy to use in most lab environments. Extensive built-in safety features include over-temperature protection and the ability to withstand opens and shorts at the output.* They're available off the shelf for an outstanding value, so place your order on minicircuits.com today for delivery as soon as tomorrow!

*at 3 dB compression point.

Mini-Circuits®

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

537 rev org

Scan page
using layar app

Cliff Drubin, Associate Technical Editor

Internet of Things to Overtake Mobile Phones by 2018

The latest edition of the Ericsson Mobility Report reveals that the Internet of Things (IoT) is set to overtake mobile phones as the largest category of connected devices by 2018.

Between 2015 and 2021, the number of IoT connected devices is expected to grow 23 percent annually, of which cellular IoT is forecast to have the highest growth rate. Of the 28 billion total devices that will be connected by 2021, close to 16 billion will be IoT devices.

Western Europe will lead the way in adding IoT connection — the number of IoT devices in this market is projected to grow 400 percent by 2021. This will principally be driven by regulatory requirements, for example for intelligent utility meters, and a growing demand for connected cars including the EU e-call directive to be implemented in 2018.

Rima Qureshi, senior vice president and chief strategy officer, Ericsson, says, "IoT is now accelerating as device costs fall and innovative applications emerge. From 2020, commercial deployment of 5G networks will provide additional capabilities that are critical for IoT, such as network slicing and the capacity to connect exponentially more devices than is possible today."

Smartphone subscriptions continue to increase and are forecast to surpass those for basic phones in Q3 this year. By 2021, smartphone subscriptions will almost double from 3.4 to 6.3 billion. Also revealed in the report, there are now 5 billion mobile subscribers — unique users — in the world today, which is testament to the phenomenal growth of mobile technology in a relatively short period of time.

> 16 billion connected devices forecast to join the Internet of Things by the end of 2021.

Detailed in the report is a dramatic shift in teen viewing habits: use of cellular data for smartphone video grew 127 percent in just 15 months (2014-15). Over a period of four years (2011-15) there has been a 50 percent drop in the time teens spend watching TV/video on a TV screen, and in contrast an 85 percent increase in those viewing TV/video on a smartphone. This, and the fact that the upcoming generation of mobile users are the heaviest consumers of data for smartphone video streaming (Wi-Fi and cellular combined), makes them the most important group for cellular operators to monitor.

In 2016, a long anticipated milestone is being passed with commercial LTE networks supporting downlink peak data speeds of 1 Gbps. Devices that support 1 Gbps are expected in the second half of 2016, initially in markets such as Japan, U.S., South Korea and China, but rapidly spreading to other regions. Mobile users will enjoy extremely fast time to content thanks to this enhanced technology, which will enable up to two thirds faster download speeds compared with the fastest technology available today. Further highlights include:

A global growth story: mobile broadband subscriptions will grow fourfold in the Middle East and Africa between 2015 and 2021; mobile data traffic in India will grow fifteen times by 2021; and despite being the most mature market, mobile traffic in North America will grow 50 percent in 2016 alone.

Data traffic continues unabated growth: global mobile data traffic grew 60 percent between Q1 2015 and Q1 2016, due to rising numbers of smartphone subscriptions and increasing data consumption per subscriber. By the end of 2021, around 90 percent of mobile data traffic will be from smartphones.

LTE subscriptions grew at a high rate during Q1 2016: there were 150 million new subscriptions during the quarter — driven by demand for improved user experience and faster networks — reaching a total of 1.2 billion worldwide. LTE peak data speeds of 1 Gbps are anticipated to be commercially available in 2016.

Additional spectrum harmonization needed between countries planning early 5G deployment: 5G is expected to start more quickly than anticipated, and spectrum harmonization is needed between countries planning early roll-outs. This is in addition to the current process for WRC-19, which focuses on spectrum for commercial 5G deployments beyond 2020.

5G Key Technology in Enabling V2X Communication in Future Cars

VIEW VIDEO

By 2025, 67 million automotive 5G vehicle subscriptions will be active—three million of which will be low latency connections mainly deployed in autonomous and driverless cars. ABI Research highlights that 5G will unify connectivity in autonomous vehicles; enabling broadband multimedia streaming, cloud services for vehicle lifecycle management, the capturing and uploading of huge volumes of sensor data, and cooperative mobility through V2X (vehicle-to-vehicle and vehicle-to-infrastructure) communication.

"V2X is a key requirement for the connected and autonomous vehicle of the future," says Dominique Bonte, managing director and vice president at ABI Research. "It is closely linked to the concept of cooperative mobility, allowing vehicles to exchange both status and event information with each other via reliable, low-latency communication technologies. With it, vehicles can be proactive, capturing and sharing critical events happening locally with each other, ultimately ensuring safer driving practices."

But for V2X to become a reality, the automotive and transportation industries must first expand the scope and relevance of 5G cellular connectivity. ABI Research anticipates this to dramatically increase through 2025, allowing

For More Information

Visit mwjournal.com for more commercial market news

connectivity providers to bring more value-added services to the table and better position themselves in the automotive ecosystem. From there, new business models will emerge and ultimately more closely align the automotive and telecom industries.

ABI Research suggests that 5G's most promising capability for automotive will be its low latency, which could be as low as one millisecond. However, Bonte says that this will require underlying ultra reliable low latency 5G capabilities based on the use of millimeter wave bands, latency reduction techniques, and advanced device-to-device communication.

> V2X is a key requirement for the connected and autonomous vehicle of the future, but 5G is needed to make it a reality.

"The extent to which these latencies will be achieved will heavily depend on the 5G standards and deployment strategies, but the question is not so much if, but when the industry will embrace the disruptive approach," continues Bonte. "While right now, the industry is leveraging and upgrading current LTE/4G networks, it will eventually build new RAN networks based on millimeter waves. Once this happens, starting from the second half of the next decade, very low-latency capabilities will be achievable and V2X-enabled smart mobility applications will be possible."

Retail Sees 400 Percent Growth in Wi-Fi Indoor Analytics Installations

VIEW VIDEO

Calculations show that total Wi-Fi location technology installations in retail were up almost 400 percent YoY in 2015. Driving the growth is a combination of start-ups and access point vendors, such as Cisco Systems, Ruckus Wireless and Zebra Technologies that are adopting new pricing models, technologies and a large number of platform partners to help them win new business.

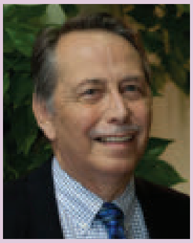
"Previous iterations of Wi-Fi location platforms were expensive and not ideal for customer engagement," says Patrick Connolly, principal analyst at ABI Research. "But retailers and vendors quickly grasped that Wi-Fi's role in this space centers on gathering customer analytics.

"The ongoing challenge is a simple one: there is always new technology around the corner," concludes Connolly. "Retailers are only beginning to grow accustomed to Wi-Fi and iBeacons, yet the industry is already shifting toward a new generation of technologies, such as magnetic field, sensor fusion, and Google's Project Tango. Many Wi-Fi and beacon vendors are also developing their own high accuracy proprietary solutions, which will start to penetrate the market in 2016."

Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

The Industry Mourns Anthony S. Tirollo



▲ *Anthony S. Tirollo*

Anthony S. Tirollo, founder, owner and chief technology officer at TRM Microwave in Bedford, N.H., passed away on May 21, 2016. He founded the company in 1970 and guided its growth through the company's 45th anniversary in 2015, when it became a woman-owned small business. He was born on December 4, 1940 in New Haven, Conn. the son of Joseph Tirollo, Sr. and Angelina Tirollo, father to 3 daughters, Robin Tirollo, Tracy Erdahl and Maureen Corriea. He was the husband of Wendy D. Tirollo. They were married on February 14, 1998 in Key West, Fla. Tony graduated from New Haven School of Electronics in New Haven, Conn. He had a wonderful sense of humor and shared many jokes with his family, friends and employees. Tony loved spending winters at his home in Bonita Springs, Fla. He enjoyed utilizing his God given engineering talents for many projects, as well as entertaining family and friends. His contributions to family, friends, colleagues, animals and TRM are lasting. He will be missed.

MERGERS & ACQUISITIONS

Mercury Systems Inc. announced the completion of its previously reported acquisition of the embedded security, RF and microwave, and custom microelectronics businesses from **Microsemi Corp.** Pursuant to the terms of the stock purchase agreement applicable to the acquisition, Mercury acquired these businesses for a total purchase price of $300 million, subject to adjustment for certain working capital items. The acquisition and associated transaction expenses were funded with a combination of a new $200 million bank term loan A facility and Mercury cash on hand, which includes net proceeds of approximately $94 million from Mercury's recent issuance of common stock in an underwritten public offering.

COLLABORATIONS

Keysight Technologies Inc. and **Datang Telecom Group** announced the signing of a Memorandum of Understanding (MOU) to establish a strategic partnership on research and development of 5G communication technologies. 5G is the next generation of wireless communication technologies, featured as big data, massive connections and diverse user scenarios. Both companies are committed to co-work on the 5G enabling technologies, standardization, prototype verification and evaluations, aiming to move 5G innovations forward.

X-Microwave LLC and **Peregrine Semiconductor Corp.** announced their collaboration and the addition of Peregrine's RF products to X-Microwave's online simulation tool and hardware prototyping system. X-Microwave's building-block system simplifies the modular design process and enables RF engineers to easily simulate and prototype RF and microwave circuits. To kick off this relationship, 16 Peregrine products are being added to the X-Microwave system as drop-in X-MWblock™ components.

Sivers IMA announced it has signed an agreement with **Blu Wireless Technology**, a company that designs and licenses baseband modem IP for mmWave applications — including the 802.11ad standard within the Wi-Fi Alliance (also known as WiGig®). Under the agreement, Blu will integrate and optimize its WiGig Hydra baseband modem IP with Sivers IMA's WiGig RFIC. This will enable Sivers IMA to market a complete WiGig solution compliant with the 802.11ad standard. This includes a baseband modem and a transceiver with steerable antennas.

NEW STARTS

Richardson RFPD Inc. announced that its distribution of a large portfolio of serial digital interface (SDI) video and optoelectronics products from **M/A-COM Technology Solutions** has expanded into Europe. MACOM's high-performance analog portfolio grew significantly as a result of the company's 2013 acquisition of Mindspeed Technologies. The product range features SDI video and optoelectronics products, including crosspoints, signal conditioners, redrivers, CDRs and SDI reclockers, SDI cable equalizers and SDI cable drivers.

Delta Electronics Manufacturing Corp. unveiled a new brand identity and website that captures the company's position as a leading global provider of precision interconnect and innovative solutions. The company will also launch a redesigned website at www.deltarf.com.

CONTRACTS

Harris Corp. has received an eight-year, $96 million ceiling, single-award IDIQ contract from the **U.S. Naval Air Systems Command** to supply precision approach radars (PAR) to the U.S. Navy, Air Force and Army. The contract was awarded during the fourth quarter of Harris' fiscal 2016. Under the contract, Harris will supply high-performance PAR systems to help the three services upgrade their precision approach and military air traffic management capabilities. Harris has produced sophisticated radar technology for more than 70 years, pioneering the development of air traffic control and 3-D air defense radars for tactical applications.

AT&T is the sole awardee of a contract worth up to $74.6 million over five years, if all options are exercised, from the **Defense Information Systems Agency**. AT&T will provide

For More Information

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

highly secure telecom services that support U.S. senior leadership communications between select Department of Defense aircraft and ground stations across the continental U.S. and around the world. AT&T will provide long-haul telecommunications and related transmission circuits. These support the government's restricted-use, ultra-high frequency communications platform. The services are highly reliable and resilient to keep continuous communications under duress.

BAE Systems has received a $29.4 million competitively awarded contract from the **U.S. Navy** to maintain the USS Gettysburg (CG 64), a Ticonderoga-class guided missile cruiser. The contract includes options that if exercised would raise the total value to $31.8 million. The special selected restricted availability of the Gettysburg will begin in June and be completed in December. BAE Systems' Norfolk, Va. shipyard will perform the repair, maintenance, and modernization work aboard the 567-foot-long ship. The Gettysburg is equipped with the Aegis Combat System, which provides air defense for aircraft carrier battle groups. The ship was commissioned in 1991.

Comtech Telecommunications Corp. announced that during its fourth quarter of fiscal 2016, its subsidiary, **Comtech Systems Inc.**, received an order from a foreign prime contractor for approximately $7 million to design and install a number of fixed troposcatter terminals. The systems will be used by a foreign military end-customer for communications between off-shore islands. It was also announced that during its third quarter of fiscal 2016, its subsidiary, Comtech Systems Inc., received an order from a foreign military totaling approximately $1.5 million to provide troposcatter equipment to a prime contractor for use in early testing, characterization and network integration activities as part of an upcoming deployable communications network for an Asia Pacific military.

Cobham recently received a series of orders for electronic warfare components and subsystems for an airborne electronic intelligence (ELINT) platform totaling approximately $5.5 million. Cobham's electronics are integrated into a sensor suite that provides intelligence, surveillance and reconnaissance (ISR) capability. The work will be performed by Cobham Microelectronic Solutions, a business unit of the Cobham Advanced Electronics Solutions sector. Cobham Advanced Electronic Solutions' ISR related products include microelectronics, waveguide, rotary joints, and integrated assemblies for radar and electronic warfare applications.

Mercury Systems Inc. announced it received a $4.2 million follow-on order from a leading defense prime contractor for high-performance digital signal processing modules for an unmanned airborne synthetic aperture radar (SAR) application. The order was booked in the company's fiscal 2016 fourth quarter and is expected to be shipped by its fiscal 2017 second quarter.

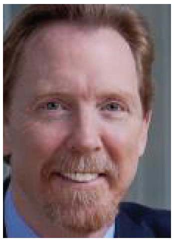
The **U.S. Navy** awarded a contract modification to **General Dynamics Mission Systems** to build and deliver more than 30 new AN/USC-61(C) Digital Modular Radios (DMR), along with related materials and equipment for new Navy surface vessels and submarines. The software-

Around the **Circuit**

defined radios are a mission critical communications hub for Navy vessels and submarines. A majority of the work will be done at General Dynamics' Scottsdale, Ariz. location.

PEOPLE

▲ *Liam K. Griffin*

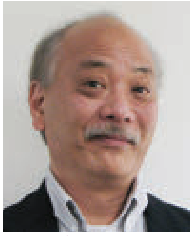


▲ *David J. Aldrich*

Skyworks Solutions Inc. announced that its board of directors has appointed **Liam K. Griffin** as chief executive officer. Griffin was also elected to the board of directors of Skyworks effective May 11, 2016. **David J. Aldrich**, Skyworks' chief executive officer since 2000, will assume the newly established role of executive chairman and, in that position, will continue to serve as the chairman of Skyworks' board of directors. Skyworks has substantially outpaced the broader semiconductor market: growing the top line at a 25 percent annual rate from $1.1 billion in fiscal 2010 to over $3.2 billion in fiscal 2015.

▲ *Barry Black*

▲ *Jodie Davoll*



▲ *Dale Azuma*

▲ *Peter Leary*

IMS announced the promotion of **Barry Black** to sr. manager of sales and marketing. Black will be responsible for worldwide sales operations including overall direction and strategy of the company's global sales initiative. **Jodie Davoll** has been appointed as marketing coordinator. Davoll will focus on maintaining the website and marketing comunications programs. **Dale Azuma** has been appointed as regional sales manager. Azuma will be responsible for day to day sales operations in the Western territory. **Peter Leary** has been appointed as sales applications engineer. Leary is customer oriented, Solidwork certified and loves using Sonnet EM software.

▲ *Jason Smith*

Teseq, now a unit of **AMETEK Compliance Test Solutions** and a developer of instrumentation and systems for electromagnetic compatibility (EMC) emission and immunity testing, has hired **Jason Smith** as regional sales manager. Smith, a veteran in EMC sales and marketing, will use his extensive industry experience to help the AMETEK CTS growing sales force support its customers, representatives and factory teams. Before joining AMETEK CTS, Smith worked for HV Technologies,

Manassas, Va., where he served for more than four years as EMC sales and marketing manager.

▲ Dave Kendall

Link Electronics announced the retirement of founder **Bob Henson**, and new ownership by industry veteran **Dave Kendall**. With 30 plus years in the technology and electronics industry, along with electrical engineering experience as an officer in the U.S. Navy, Kendall brings a wealth of insight and perspective to his new role. He started in sales and marketing and worked his way into executive roles, bringing extensive knowledge, passion, leadership and drive for innovation.

REP APPOINTMENTS

Anritsu Corp. announced that they have signed a distribution agreement with **Electro Rent UK**. The distribution agreement extends Electro Rent's existing relationship with Anritsu as a preferred reseller and rental partner in the United States and Canada. Under the terms of the new agreement, Anritsu's field analyzers will be now also be available in the UK through Electro Rent.

Richardson Electronics Ltd. announced a new global distribution agreement with **Anaren Inc.**, a designer, manufacturer and seller of custom high-frequency solutions and standard components for the wireless communications, space and defense electronics, wireless consumer electronics, and IoT markets. The agreement aligns with both companies' commitment to finding innovative ways to create and provide solutions for customers.

PLACES

Arrow Electronics Inc., a global leader in IT asset disposition, announced it upgraded its Columbus, Ohio-area value recovery facility, adding state-of-the-art automated equipment and a new layout to further increase processing efficiency and chain-of-custody security. As a result of the upgrades, the facility's IT asset processing capacity has increased 500 percent.

Lockheed Martin Canada opened the doors of its IMPACT Centre in Ottawa, with a ribbon cutting event showcasing the innovative demonstration centre. The centre is designed to be a significant economic driver across Canada, bringing Canadian industry and academia together for critical research, development and advancement of technology. Lockheed Martin created the IMPACT Centre with a vision to promote the growth of small Canadian businesses, advance research, support sustainability and enhance Canada's capability for major exports in defence and technology sectors. At the heart of the IMPACT Centre, is an initial core focus on naval systems and the competitive naval combat systems world market.

INVITED PAPER

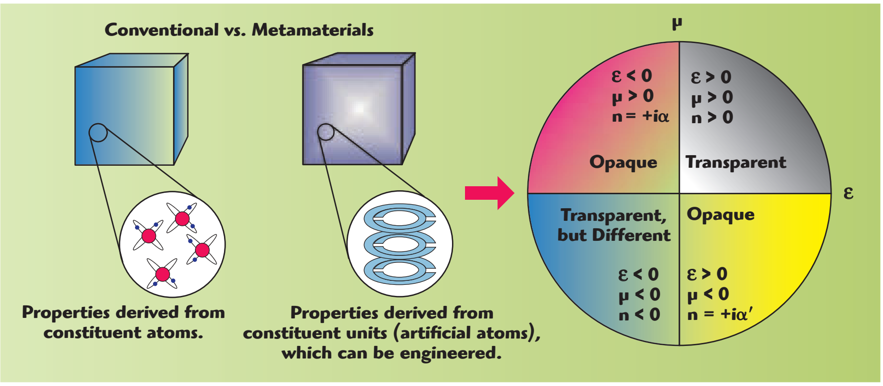
EDITOR'S NOTE

This is the concluding article of the three part series exploring the theory and applications of Möbius metamaterials. The previous articles appeared in *Microwave Journal's* May and June 2016 issues.

Möbius Metamaterial Strips: Opportunity, Trends, Challenges and Future

Ulrich L. Rohde
Federal Armed Forces University, Munich, Germany
Ajay K. Poddar
Synergy Microwave, Paterson, N.J.

The MMS (Metamaterial Möbius Strip) is an artificial composite structure with a negative index of refraction ($n=-\sqrt{\varepsilon\mu}$; $\varepsilon < 0$, $\mu < 0$), where n is the refractive index, ε is the electrical permittivity and μ is the magnetic permeability of the medium. It has emerged as a cutting edge of science relating physics, chemistry, biology, material science, optics, acoustics and electronics. For most naturally existing materials, μ is close to 1; hence, magnetic susceptibility of natural materials is small as compared to the electric/dielectric susceptibility. This phenomenon limits the interaction of atoms to the electric component of the electromagnetic (EM) wave, leaving the magnetic component mostly unexploited. Magnetism is primarily weak at optical frequencies as well, because the relaxation times of paramagnetic and ferromagnetic processes are considerably longer than an optical period, electron movement in atoms is the only mechanism for creating the magnetic response. This is why the magnetic field component is usually not involved in light-matter interactions. The reason for weak magnetism is mainly due to limitations of the material properties imposed by chemical composition and constituent components (atoms and molecules). On the contrary, MMS resonant nanostructures, in principle, can exhibit a broad range of magnetic permeability values.[1-75] A number of stimulating phenomena and applications associated with MMS structures are discussed in part 1 (MWJ May 2016) and part 2 (MWJ June 2016) of this series. This issue addresses the prospects, challenges and future directions of MMS inspired components for various applications including the Gravitational Casimir Effect.



▲ *Fig. 1 Characteristics of conventional materials vs. metamaterials.*

Recent research in the field of metamaterials[69-75] has not only established interesting physical phenomena but also lead to opportunities for utilizing negative index components and devices for next generation energy-efficient electronic circuits and systems. ***Figure 1*** compares the properties of natural and artificially engineered composite materials.[1] Unlike conventional materials that interact with EM waves based on their chemical compositions, the properties of metamaterials are derived from their topologies and geometric structures.

TechnicalFeature

The typical metamaterial consists of periodically or arbitrarily disseminated structured cells with dimensions and spacings much smaller than a wavelength of the incident EM waves.[1-3] As a consequence, the microscopic detail of each unit cell structure cannot be sensed by EM waves. What is important to understand is the average result of the collective response of the entire assemblage, comprised of inhomogeneous matter. In other words, such a collection of inhomogeneous matter can be characterized by an equivalent homogenous material with effective constitutive relative permittivity ($\varepsilon_{r,eff}$) and permeability ($\mu_{r,eff}$) at the macroscopic level. The key aspect of an MMS inspired structure is that effective permittivity ($\varepsilon_{r,eff}$) and permeability ($\mu_{r,eff}$) can be controlled and tuned by a suitably designed disseminated element for broadband operation.

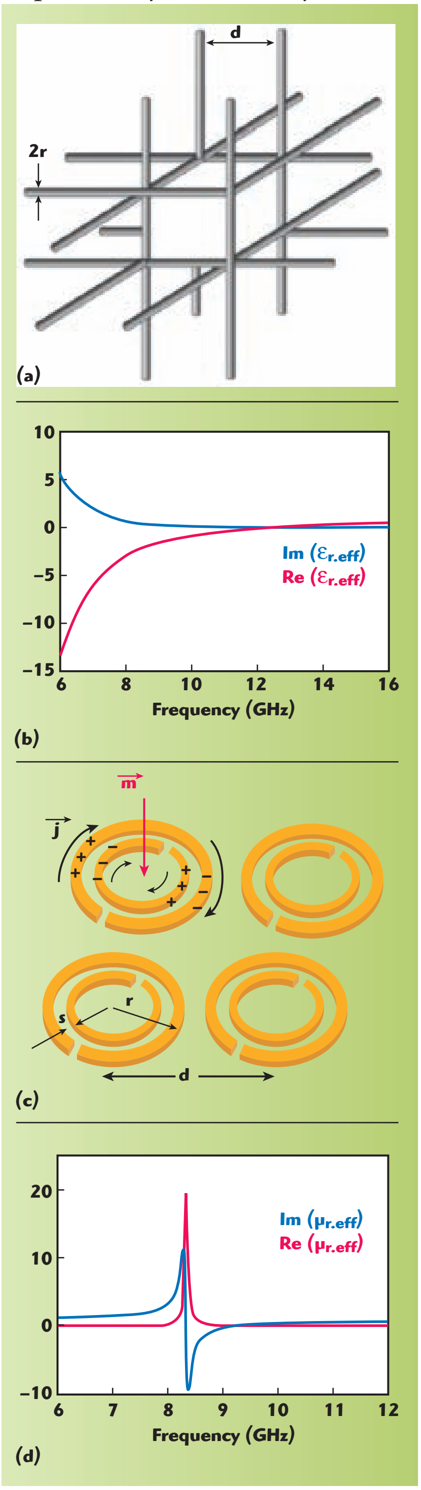


Fig. 2 Typical negative index structure for the realization of artificial electric and magnetic responses; periodic wires arranged in a simple cubic lattice (a) effective permittivity of wire medium, acting as dilute metal with extremely low plasma frequency (b) a magnetic field penetrating an SRR induces a current, and hence, a magnetic moment (c) and SRR effective permeability at resonance (d).[8]

In classical EM theory, the characteristics of matter illustrated in Figure 1 can be described by the Drude–Lorentz model[6] as

$$\varepsilon_r(\omega) = \left[1 - \left(\frac{\omega_{p,e}^2}{\omega^2 - \omega_{0,e}^2 + i\omega\gamma_e}\right)\right] \quad (1)$$

$$\mu_r(\omega) = \left[1 - \left(\frac{\omega_{p,m}^2}{\omega^2 - \omega_{0,m}^2 + i\omega\gamma_e}\right)\right] \quad (2)$$

where ω_p is the plasma frequency, ω_o is the resonant frequency, subscripts 'e' and 'm' represent electric and magnetic response, and γ is the damping factor associated with material losses.

Figure 2 shows a typical metamaterial structure,[4-5] realized by the combination of split ring resonators (SRR) and thin metallic wires. The effective relative permittivity ($\varepsilon_{r,eff}$) and effective relative permeability ($\mu_{r,eff}$) obey the Drude–Lorentz[6-9] model as

$$\varepsilon_{r,eff}(\omega) = \left[1 - \left(\frac{\omega_{p,eff}^2}{\omega(\omega + i\omega\gamma_{eff})}\right)\right],$$

$$\omega_{p,eff}(\omega) = \frac{e^2}{\varepsilon_0}\left(\frac{n_{e,eff}}{m_{e,eff}}\right) = \frac{2\pi c^2}{d^2\left(\ln\frac{d}{r}\right)},$$

$$\gamma_{eff} = \varepsilon_0\left(\frac{d^2\omega_p^2}{\pi r^2\sigma}\right) \cong 0.1\omega_{p,eff} \quad (3)$$

Planar Monolithics Industries, Inc.

18 to 40 GHz Minature DLVAs & SDLVAs

- **Amplifiers – Solid State**
- **Attenuators – Variable/ Programmable**
- **Couplers (Quadrature, 180° & Directional)**
- **Detectors – RF/Microwave**
- **DLVAs, ERDLVAs & SDLVAs**
- **DTOs, VCOs, PLO, DROs, & Frequency Synthesizers**
- **Filters & Switched Filter Banks**
- **Form, Fit, Functional Products & Services**
- **Frequency Discriminators & IFMs**
- **Integrated MIC/MMIC Assemblies (IMAs)**
- **IQ Vector Modulators**
- **Limiters – RF/Microwave**
- **Log Amplifiers**
- **Millimeter Wave Components (Up to 50 GHz)**
- **Miscellaneous Products**
- **Multifunction Integrated Assemblies (MIAs)**
- **Phase Shifters & Bi-Phase Modulators**
- **Power Dividers/Combiners (Passive & Active)**
- **Pulse Modulators (SPST)**
- **Rack & Chassis Mount Products**
- **Receiver Front Ends & Transceivers**
- **SDLVAs, ERDLVAs & DLVAs**
- **Single Side Band Modulators**
- **SMT & QFN Products**
- **Switch Matrices**
- **Switched Filter Banks**
- **Switches – Solid State**
- **Systems – Fly Eye Radars**
- **Threshold Detectors**
- **USB Products**

PMI offers a variety of DLVAs and SDLVAs covering the 18 to 40 GHz frequency range. PMI's DLVAs and SDLVAs offer high dynamic range along with excellent temperature stability.

- Hermetic Sealing
- Temperature Compensation
- Small Quantity Requirements Accepted
- Military or Stringent Screening
- CW Immunity & Matched Sets
- Specialized Testing & Custom designs welcome!

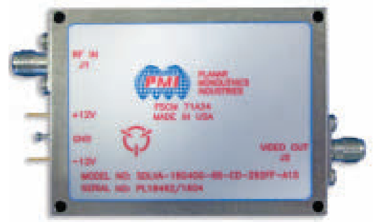
- **Package Size: 1.86" x 1.69" x 0.40"**
- **DC Voltage:**
  +15 VDC @ 37 mA - Measured
  -15 VDC @ 42 mA - Measured

Model DLVA-18G40G-42-50-CD-1
Detection Log Video Amplifiers (DLVA)

Frequency Range	18.0 to 40.0 GHz (Operational)
	30.0 to 31.0 GHz (Full Performance)
Flatness @ -23 dBm	±0.25 dB - Measured ±0.1 dB
VSWR (In/Out)	1.5:1 Max - Measured 1.18
TSS	-34 dBm @ 25 °C - Measured -39.8 dBm
Logging Range	-32 to +10 dBm
Log Slope	50 ± 3 mV/dB - Measured 51.83 mV/dB
Log Linearity	±0.5 dB - Measured +0.4, -0.35 dB
DC Offset	0 to ±75 mV - Measured +45 / -4 mV
Output Stability (-54 to +85 °C)	±0.75 dB

Model SDLVA-18G40G-65-CD-292FF-A15
Successive Detection Log Video Amplifier (SDLVA)

Frequency Range	18.0 to 40.0 GHz
TSS	-67 dBm @ 25 °C - Measured -68 dBm
Input Power Handling	10 dBm Max
Video Log Range	-63 dBm to +2 dBm
Video Log Linearity	±1.5 dB Max - Measured +1.27, -1.48 dB
	±3.0 over Temp Max
Video Log Slope	25 mV/dB nominal - Measured 24.4 mV/dB
Video Freq Flatness	±2.5 dB Max @ 25°C - Measured ±2.10 dB
Pulse Width Range	30 ns to CW
Video Rise Time	11 ns (8 ns typ) - Measured 10.04 ns
Recovery Time	60 ns (40 ns Typ) - Measured 60 ns
Delay Time	15 ns (5 ns Typ) - Measured 14.6 ns
	7 ns Over Temp Typ
Video Output Impedance	50 Ohm
Input VSWR (50 Ohm)	2.5:1 - Measured 2.34:1
Operating Temperature	-55 to +85 °C



- **Package Size: 2.37" x 1.80" x 0.42"**
- **DC Voltage:**
  +12 VDC @ 310 mA - Measured
  -12 VDC @ 150 mA - Measured

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

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

sales@pmi-rf.com • www.pmi-rf.com

ISO9001 REGISTERED

$$\mu_r(\omega) = 1 = \frac{F\omega^2}{\omega^2 - \omega_0^2 + i\Gamma\omega},$$

$$F = \frac{\pi \times r^2}{d^2},$$

$$\omega_0 = \sqrt{\frac{3sc^2}{\pi^2 r^3}}, \Gamma = \frac{2}{r^\sigma \mu_0} \qquad (4)$$

where σ is the conductivity of metal wire, d is the lattice constant, ω_0 represents the resonant frequency, $\omega_{p,eff}$ is the effective plasma frequency, F is the filling ratio of the SRR, and Γ is the damping term. From (3), the effective plasma frequency is $\omega_{p,eff}$ = 7.52×10^{10} rad/sec; assuming that the metal wire conductivity σ $=10^7\ \Omega^{-1}\ m^{-1}$, the metal wire radius r = 1×10^{-6} meters and the lattice constant d = 3.5×10^{-3} meters. From (4), the resonant frequency f_0 = 8.324 GHz; assuming that for the SRR, d = 4×10^{-3} meters, r =1×10^{-3} meters, and s = 1×10^{-4} meters. This corresponds to a free space wavelength of 3.6×10^{-2} meters which is about 10 times larger than d.

From (3) and (4), $\varepsilon_{r,eff}$ of metallic wire and $\mu_{r,eff}$ of the SRR exhibit the typical Drude-Lorentz characteristics,[8] plotted in ***Figures 2b*** and ***d***. Equations (3) and (4) provide approximate analytical solutions for the effective constitutive parameters (permittivity, permeability) with reasonable accuracy, valid for the simple structure shown in Figure 2. For a complex structure, however, and especially for an MMS inspired negative index metasurface, this is not true.

The alternative approach is to retrieve the effective parameters from numerical simulations[9-12] described in detail.[70] The first step of the retrieval procedure is to calculate the transmission and reflection of the composite MMS based on numerical algorithms, such as finite-difference time-domain (FDTD) and finite element method (FEM). Some commercial software, including ADS, Ansys HFSS, CST Microwave Studio, COMSOL Multiphysics and SONNET are widely used but none of these provide error free solutions. The refractive index and impedance are related to the transmission coefficient (t) and reflection coefficient (r) by equations[9]

$$Z_{eff} = \pm\left[\frac{(1+r)^2 - t^2}{(1-r)^2 - t^2}\right]^{1/2} \qquad (5)$$

$$n_{eff} = \pm\cos^{-1}\left[\frac{1}{k_0 L}\left(\frac{1-r^2+t^2}{2t}\right)\right] + \frac{2\pi m}{k_0 L},$$

$$k_0 = \frac{2\pi}{\lambda_0} \qquad (6)$$

$$\varepsilon_{r,eff}(\omega) = \frac{n_{eff}(\omega)}{z_{eff}(\omega)} \qquad (7)$$

$$\mu_{r,eff}(\omega) = n_{eff}(\omega) \times z_{eff}(\omega) \qquad (8)$$

where k_0 is the wave vector in vacuum, L is the thickness of the metamaterial, and m is an integer.

From Equations (5) and (6), effective impedance and refractive index can be determined provided that the metamaterial structures act like a passive medium; this implies that the real part of z_{eff} and the imaginary part of

BNC Berkeley Nucleonics Corp

Berkeley Nucleonics Corp., 2955 Kerner Blvd. San Rafael CA 94901
Email RFsales@berkeleynucleonics.com, Call 800-234-7858 or LIVE-Chat @ www.berkeleynucleonics.com

We've changed the face (or at least the front panel) of RF and Microwave Instrumentation

Phase Noise Test Systems

Less than $50k

"Not all good things come in big packages"

Phase Noise Measurement & Signal Sources Analysis from 2 MHz to 26.5 GHz

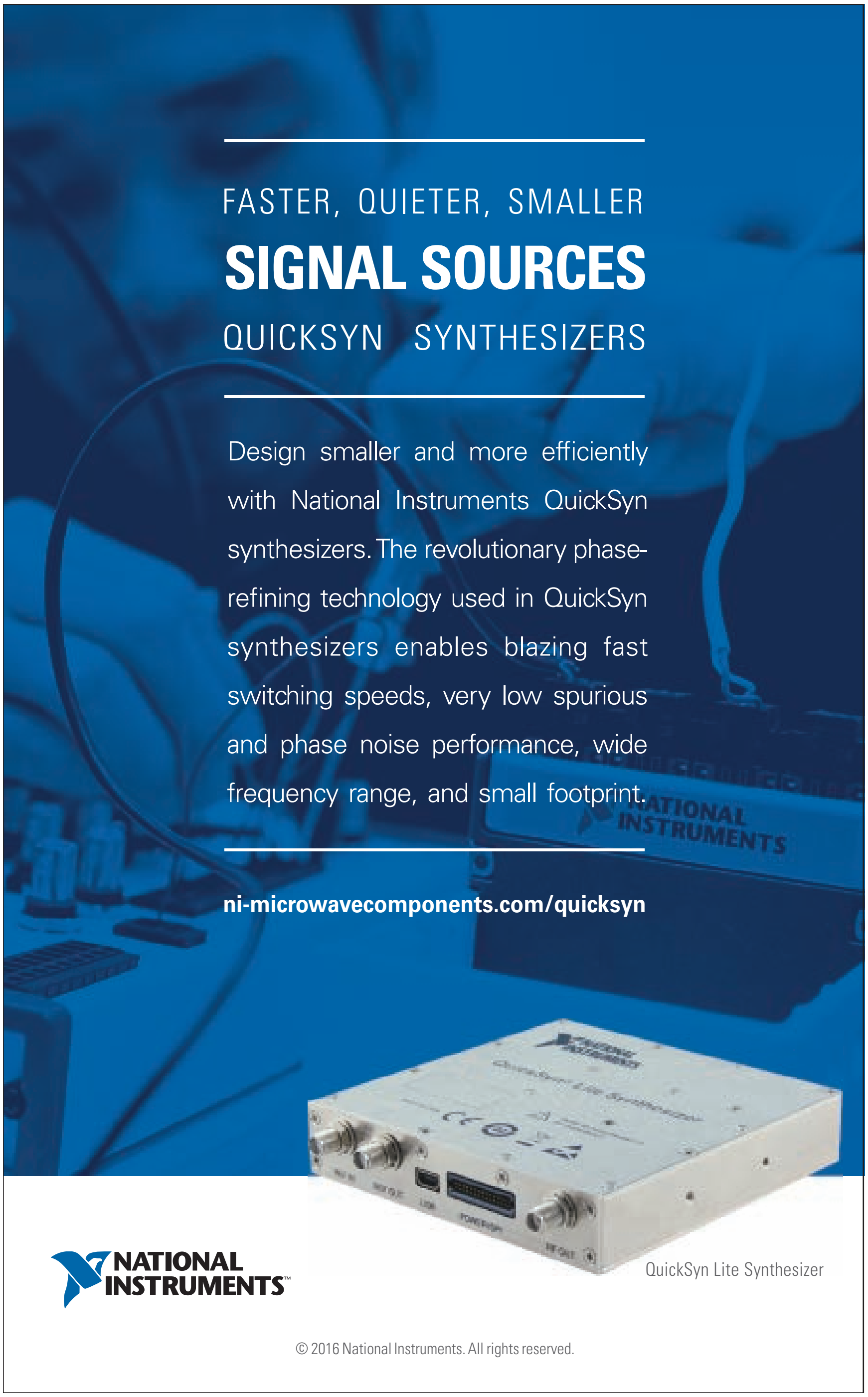
- **Instrument noisefloor down to -185 dBc/Hz**
- **Absolute AND Residual measurements, .01 Hz to 50 MHz offsett**
- **Super fast ATE optimized measurements**
- **External or ultra-low noise internal references w/ industry leading sensitivity**

RF / Microwave Signal Sources

Real-Time Spectrum Analyzers

n_{eff} are positive.[9] Note that the effective parameter retrieval process is a challenging task, especially when metamaterial structures fall into the category of anisotropic or bi-anisotropic, and EM wave is obliquely incident.[12] Parameter retrieval becomes even more complex for nonlinear metamaterial composite structures.

The metamaterial structure shown in ***Figure 3a*** is a combination of metallic wires and SRRs; however, these artificially engineered structures pose fabrication problems. A simplified structure reported in literature is the Fishnet structure[14-16] that consists of two layers of metal meshes separated by a dielectric layer (see ***Figures 3b*** and ***3c***). Paired stripes oriented parallel to the electric field provide negative $\varepsilon_{r,eff}$ (ω), while the other pairs of stripes parallel to the magnetic field support negative $\mu_{r,eff}$ (ω). Since the dielectric thickness of the fishnet structure is easy to control, the fabrication burden is significantly eased as compared to the conventional approach of using SRRs and metallic wires.[8] Moreover, in order to produce a negative refractive index, EM waves are incident normal to the fishnet surface, whereas the structure fabricated by SRRs and wires requires oblique incidence to excite SRRs with out-of-plane magnetic fields for strong magnetic resonances.



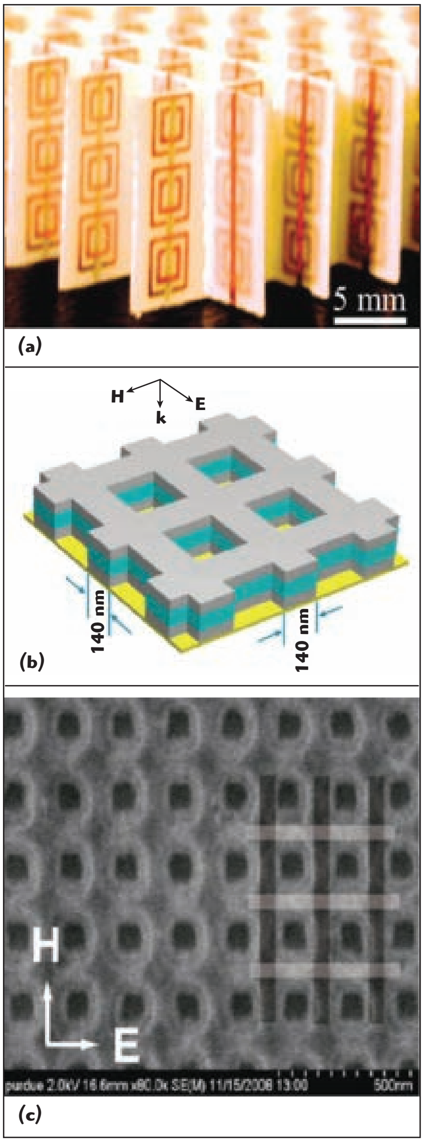
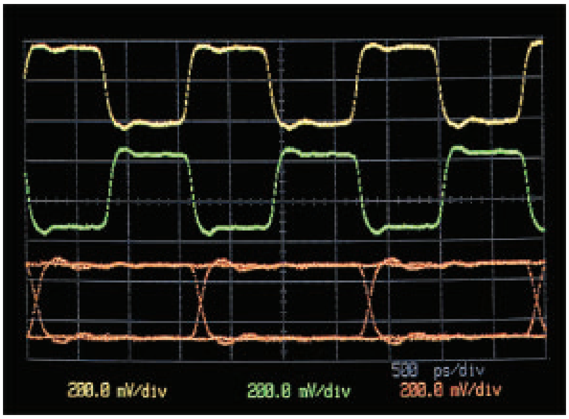


Fig. 3 Typical arrangement of artificially engineered negative index medium; copper SRRs and wires deposited lithographically on standard circuit boards for microwave frequencies where the size of the unit cell is 5×10^{-3}meters (a)[13] NIM fishnet structure for the visible region (yellow) where two layers of metal mesh (gray) are separated by a dielectric layer (cyan) (b) and a scanning electron microscope (SEM) image of the fishnet structure fabricated by electron beam lithography (c).[14]

2 GHz Clock Generator

- ***Square wave clocks from DC to 2.05 GHz***
- ***Random jitter <1 ps (rms)***
- ***80 ps rise and fall times***
- ***16-digit frequency resolution***
- ***CMOS, LVDS, ECL, PECL, RS-485***
- ***Phase adjustment & time modulation***



Plot shows complementary clocks and PRBS (opt. 01) outputs at 622.08 Mb/s with LVDS levels. Traces have transition times of 80 ps and jitter less than 1 ps (rms).

The CG635 generates clock signals—flawlessly. The clock signals are fast, clean and accurate, and can be set to standard logic levels.

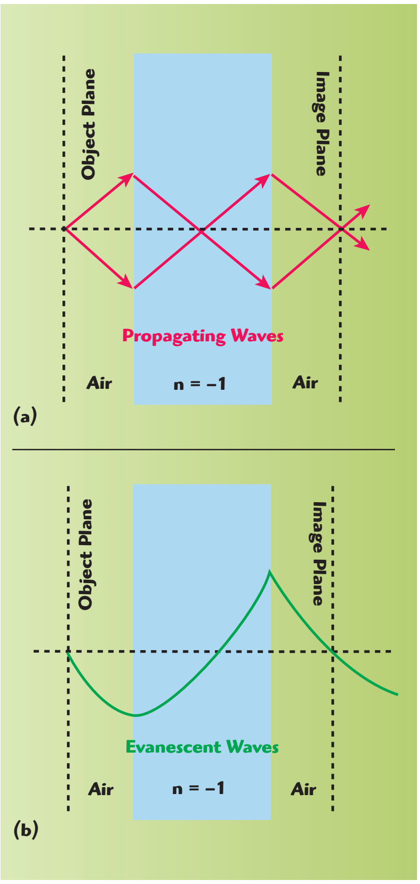
How fast? Frequency to 2.05 GHz with rise and fall times as short as 80 ps.

How clean? Jitter is less than 1 ps and phase noise is better than –90 dBc/Hz (100 Hz offset) at 622.08 MHz.

How accurate? Using the optional rubidium timebase, aging is better than 0.0005 ppm/yr, and temperature stability is better than 0.0001 ppm.

You would expect an instrument this good to be expensive, but it isn't. You no longer have to buy an rf synthesizer to generate clock signals. The CG635 does the job better—at a fraction of the cost.

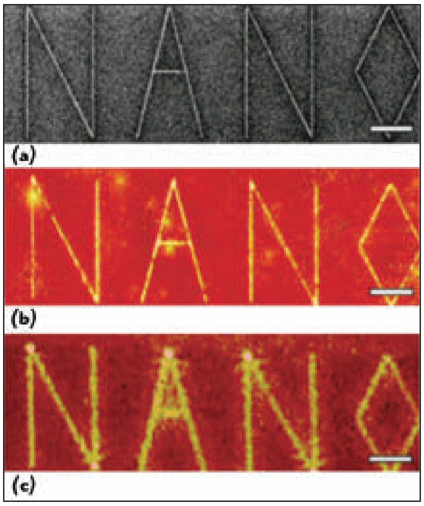
SRS
Stanford Research Systems
Phone: (408)744-9040 • Fax: (408)744-9049 • info@thinkSRS.com • **www.thinkSRS.com**



▲ *Fig. 4 Metamaterial slab shows the properties of a perfect lens; focusing all light rays from a point source (a) and amplifying evanescent waves (b) to provide perfect imaging at the image plane.*

METAMATERIAL OPPORTUNITIES AND EMERGING TRENDS

The aerospace, defense and biomedical electronics sectors are viewed as the most vibrant market areas for metamaterial products applications. The rise of drones and related weight considerations, the need for improved military communications, and the burgeoning demand for new and more sophisticated biosensors are all areas where metamaterial technology can help propel things forward.



▲ *Fig. 5 Experimental demonstration of an optical silver superlens; object mask (a) metamaterial superlens image (b) and conventionally focused image (c).*

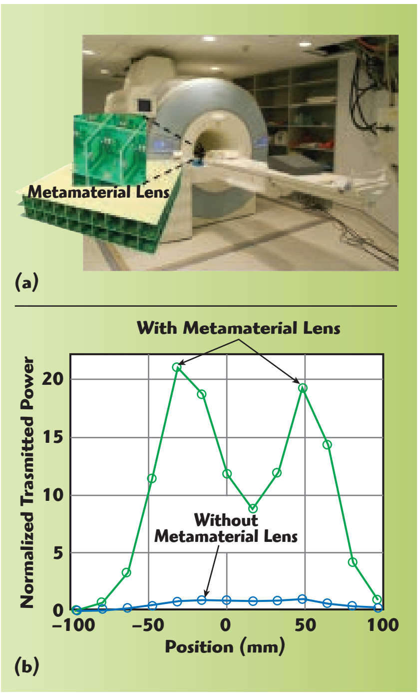
Imaging

Metamaterial structures have been used in magnetic imaging, microwave circuit components, antennas, and perfect lenses with imaging resolutions beyond the diffraction limit.[1-21] In conventional optical systems, it is not possible to determine two points separated less than l/2n, where n is the refractive index of the ambient medium. This fundamental limitation exists because the information of the object's fine features and textures are carried by evanescent waves, which exponentially decay in space. All the information relevant to the sub-wavelength details of the object is lost, before reaching the imaging plane. It is interesting to note that a metamaterial slab acts as a perfect lens to recover all the lost information.[20] This extraordinary property of perfect lens arises from the fact that the initially decayed evanescent waves are now amplified through the slab. Meanwhile, the propagating waves are focused due to the negative refraction and reversed phase front. As a result, a metamaterial slab, incredibly, brings both propagating and evanescent waves to a perfect focus (see ***Figures 4a*** and ***4b***), without suffering the traditional constraint imposed by the diffraction limit.

This shows promise in the realization of metamaterial super lenses, which are lenses that are almost free of aberrations and that can focus images below the diffraction limit. The recorded image "NANO" (see ***Figure 5b***) reproduces the fine features from the object mask (see ***Figure 5a***) in all directions with good fidelity, while the image in the control experiment without the super lens (see ***Figure 5c***) shows a much wider line width.[22] In the seminal paper, Pendry et al.,[5] predicted the enhanced nonlinear optical properties by inserting nonlinear

elements into the gap of SRRs, arising from the giant local-field amplification.

Figure 6 shows the typical measurement setup for an MRI measurement at 8.5 MHz for prostate cancer detection. Metamaterial inspired (µ = -1) split ring resonators loaded with capacitors and inductors enabled a 20 times increase in the magnetic field. As shown in ***Figure 6b***, the lens resolves two magnetic sources indistinguishable without the lens.[76]



▲ *Fig. 6 MRI measurement setup shows the use of metamaterial lens for imaging (a) and the measurement response with and without the lens (b).*[76]

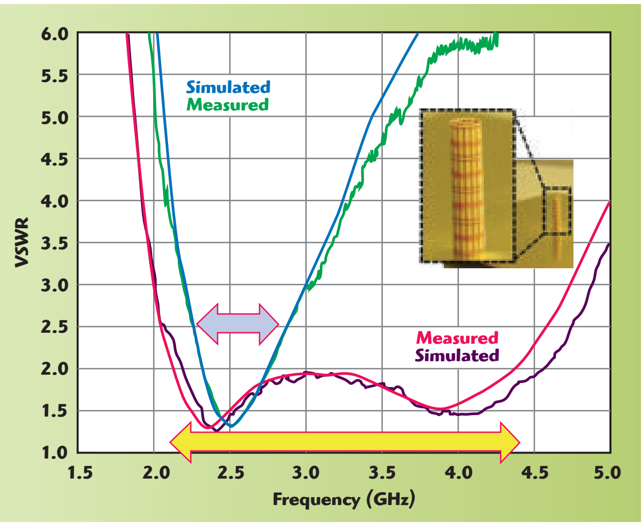
Lightweight Metamaterial

Metamaterial technology is an enabler to build lighter and more compact antenna systems. ***Figure 7*** shows the performance of the typical light weight inspired monopole antenna. The data shows that the bandwidth increased to over an octave while preserving the radiation characteristics of a simple monopole.

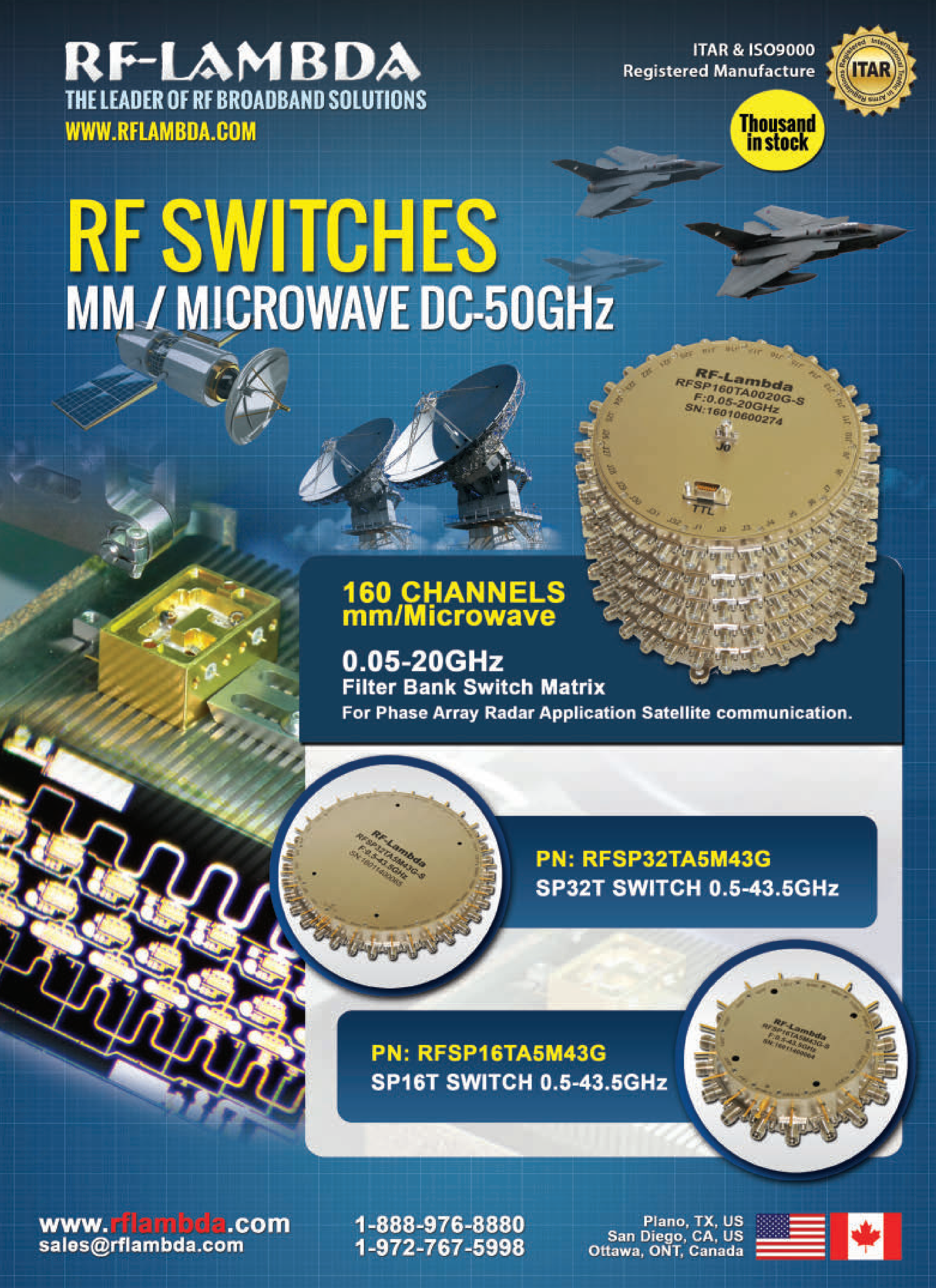
Light Manipulation

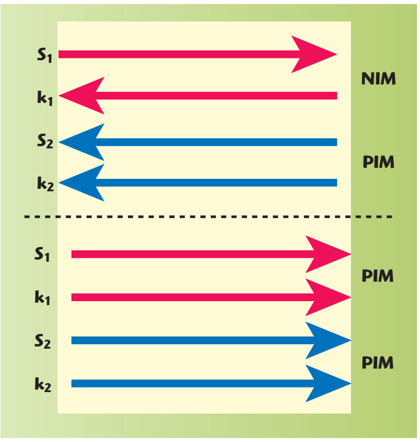
Metamaterial technology offers unparalleled opportunities for light manipulation. Recent developments in the field have fueled new opportunities for light propagation, establishing a new paradigm for spin and quantum related phenomena in optical physics. Nonlinear metamaterials, with properties depending on the intensity of EM waves, is an emerging research topic with novel phenomena such as hysteretic transition,[23] unusual wave mixing[24] and solitary wave propagation.[25-26]

The other interesting phenomenon is the reversed Manley–Rowe relation and backward phase matching condition for second-harmonic generation (SHG) or optical parametric amplification (OPA).[27] Suppose a metamaterial has a negative refractive index at the fundamental frequency ω_1 and a positive refractive index at the second-harmonic frequency ω_2. At ω_1 the energy flow (Poynting vector) points from left to right, for example; then the wave vector $\vec{k_1}$ must point from right to left arising from negative index sample at ω_1. The phase matching condition i.e. $\vec{k_2} = 2\vec{k_1}$ requires that the wave vector $\vec{k_2}$ at the second harmonic frequency ω_2 also travels from the right to the left. Since the metamaterial possesses a positive refractive index at ω2, the energy flow is at the same direction as the wave vector. As a result, the second harmonic signal is maximal at the incident interface rather than at the exit interface of the metamaterial slab, in sharp

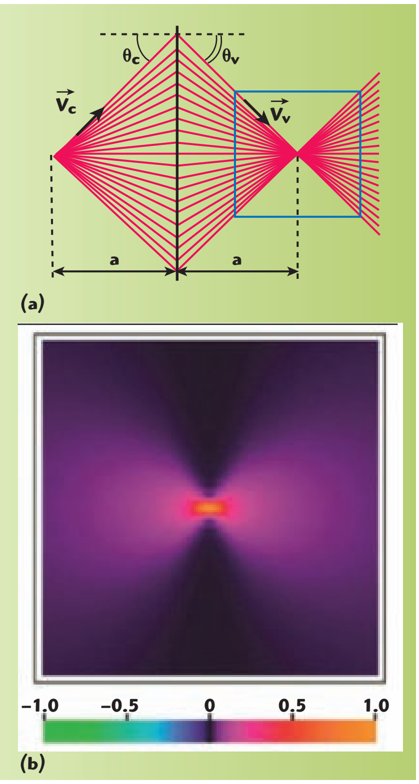


▲ *Fig. 7 Data showing increased antenna bandwidth using metamaterial.*[77] *Simulated monopole alone (blue line), measured monopole alone (green line), simulated monopole with metamaterial (red line), measured monopole with metamaterial (purple line).*


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
J0
TTL
160 CHANNELS
mm/Microwave
0.05-20GHz
Filter Bank Switch Matrix
For Phase Array Radar Application Satellite communication.
PN: RFSP32TA5M43G
SP32T SWITCH 0.5-43.5GHz
PN: RFSP16TA5M43G
SP16T SWITCH 0.5-43.5GHz
www.rflambda.com
sales@rflambda.com
1-888-976-8880
1-972-767-5998
Plano, TX, US
San Diego, CA, US
Ottawa, ONT, Canada

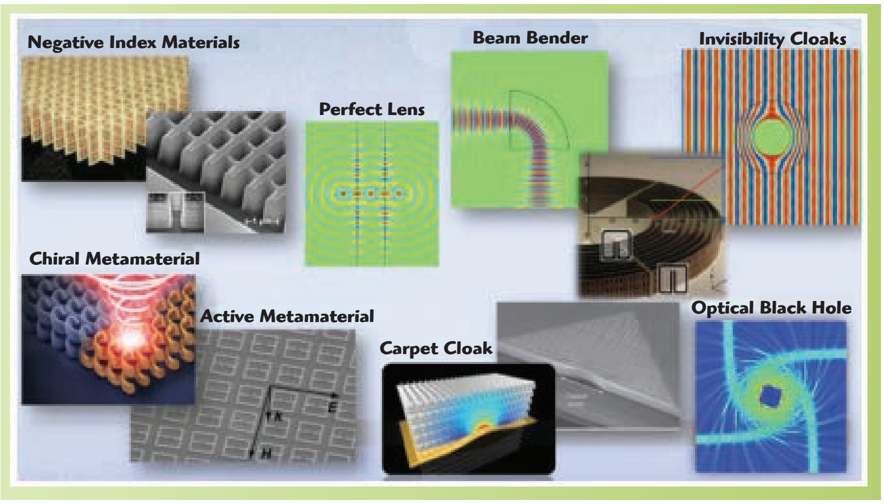


▲ *Fig. 8 Schematic of a second harmonic generation with negative index materials in comparison with normal SHG with only positive index materials.*



▲ *Fig. 9 Focusing of electrons by a grapheme p–n junction; trajectories of electrons diverging from a source at distance a from the junction and becoming convergent after negative refraction (a) and the interference-induced pattern in the charge current near the focal image (b).[32]*

contrast to SHG in normal dielectric materials (see ***Figure 8***). Moreover, artificial magnetic metamaterials could provide additional ways to boost the nonlinear process.[28] In terms of applications, tunable metamaterials[29-30] and memory devices[31] have been experimentally demonstrated based on nonlinear metamaterial composites.



▲ *Fig. 10 Metamaterial technology and transformation optics approaches.*

Metamaterials may manifest fascinating phenomena in the quantum world. In principle, the metamaterial concept could be applied to any wave at any scale, including the matter wave which is the wave description of particles, such as electrons and neutrons, in quantum mechanics. Indeed, researchers have made theoretical efforts in this direction. Cheianov et al.,[32] theoretically demonstrated that negative refraction and focusing of electrons can be achieved in graphene (see ***Figure 9***), a monolayer of graphite.

Figure 10 illustrates the technology and transformation optics approach that enables unprecedented design flexibility and novel device applications.

TECHNOLOGY CHALLENGES

The metamaterial technology and transformation optics shown in Figure 10 promise unparalleled opportunities; but at the same time, metamaterial composites fabrication is challenging. The real challenge is to predict the topology and geometry of negative index microstructures even though they tend to have simple shapes. The topology optimization method allows selection of geometric and topological configuration of multi-physical functional materials while taking into account the MMS material composition. Commercialization is primarily a manufacturing problem due to the lack of effective tools to economically pattern large volumes of material.

The immediate step is to improve the homogenization methodology for the design of multi-function nonlinear metamaterial devices, improving the bandwidth, and providing smaller/more compact structures. More investigation of pulse propagation in optical fiber and speed control by means of nonlinear refractive index for the space-time cloak, solitons and their variants is needed in negative refractive index composites.

FUTURISTIC OUTLOOK

The emerging future is likely to be in the area of the Gravitational Casimir effect and signal processing where the space-time cloak acts as a means of prioritizing data channels, rather than theoretically attempting to combine space-time and spatial cloaks. In addition to this, Möbius transformations that exploit hyperbolic characteristics could be interesting for a variety of Minkowski-based relativistic scenarios including spinning cosmic strings.

Gravitational Casimir Effect

Figure 11 shows the practical evidence of the Casimir force 'F' on parallel plates kept in vacuum. The effective force $F \propto A/d^4$, where A is the area of plate and d is the distance between the plates. The Casimir force[67] (see ***Figure 12***) arises from the interaction of the surfaces with the surrounding electromagnetic spectrum, and includes a complex dependence on the full dielectric function of both surfaces and the region between. On the more theoretical side, the MMI structure can produce a powerful Casimir effect (force from nothing), which will allow the transport of matter; this implies the ability to attract or push away physical matter.

As shown in Figure (12),[56] the polaritonic contribution is responsible

SMP connectors with great performance up to 40 GHz

HUBER+SUHNER SMP snap-on connectors provide a robust, proven and fully compatible plug-in solution for applications up to 40 GHz. Interface design and materials provide true compatibility with all MIL-STD-348 SMP connectors in the market.

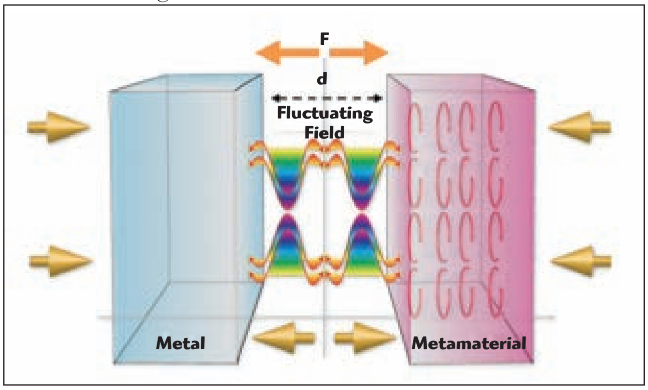
The broadband characteristics, the small size, MIL-STD-348 compliance and the good performance make this product the ideal standard snap-on solution for Aerospace+Defense and Test+Measurement applications.

› hubersuhner.com

HUBER+SUHNER AG 9100 Herisau/Switzerland
HUBER+SUHNER INC. Charlotte NC 28273/USA

for the change in sign of the Casimir force between a metallic and a metamaterial mirror. For $L \geq \lambda_r/5$ the binding TM polariton, which dominates at short distance, is overwhelmed by the joint repulsion due to the anti-binding TM and TE polaritons. This shows that, for mixed configurations as well, surface plasmons are crucial in determining both the strength and the sign of the Casimir interaction.

One of the exciting properties of MMI structures is that they can bend light in a way that is mathematically equivalent to the way space-time bends light, enabling topological exploration for the realization of low cost gravitational wave detector. ***Figure 13*** shows the gravitational Casimir effect, with a two plate setup. The change in the refractive index of the plates causes the gravitational wave to refract, where k represents the wave vector of the incident, transmitted, and reflected gravitational waves, and γ is the corresponding angle with respect to the surface normal.[68] The Casimir effect has also been investigated in weak gravitational fields to see the effect the slightly curved space time background would have on the Casimir energy.[68]

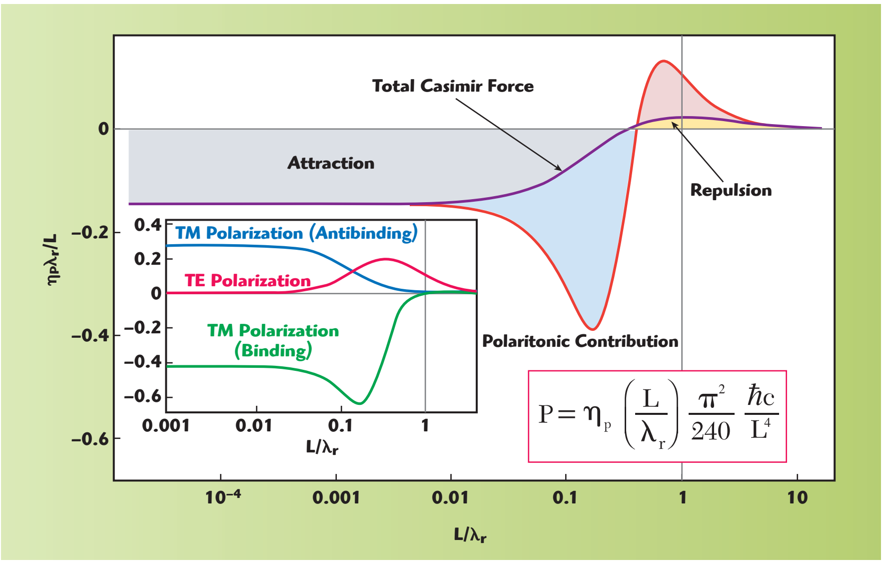


▲ *Fig. 11 The repulsive Casimir force 'F' on parallel plate kept in vacuum.*[56]

Gravitational Wave Reflector and the Gravitational Characteristic Impedance of Free Space

Thin metamaterial superconducting films are predicted to be highly reflective mirrors for gravitational waves at microwave frequencies. There are four conventionally accepted fundamental forces of nature: (i) gravitational, (ii) electromagnetic, (iii) strong nuclear, and (iv) weak nuclear. Each one is understood as the dynamics of a field. The gravitational force is modeled as a continuous classical field. Interestingly, of the four fundamental forces of nature, only gravity and electricity have long range, inverse square laws.

The Maxwell-like representation of Einstein's equations of general relativity describe the coupling of weak gravitational fields to slowly moving matter. In the asymptotically flat space-time coordinate system of a distant inertial observer, the four equations in SI units are:



▲ *Fig. 12 The polaritonic contribution is responsible for the change in sign of the Casimir force between a metallic and a metamaterial mirror.*[56]

$$\nabla \times \overline{E}_G = -\frac{\partial \overline{B}_G}{\partial t} \quad (9)$$

$$\nabla \times \overline{B}_G = \mu_G \left(-j_G + \varepsilon_G \frac{\partial \overline{E}_G}{\partial t} \right) \quad (10)$$

$$\nabla . \overline{E}_G = -\frac{\rho_G}{\varepsilon_G} \quad (11)$$

$$\nabla . \overline{B}_G = 0 \quad (12)$$

where the gravitational analog of the electric permittivity ε_G and magnetic permeability μ_G of free space is given by

$$\mu_G = \frac{4\pi G}{c^2} = 9.3\text{x}10^{-27} \quad (13)$$

$$\varepsilon_G = \frac{1}{4\pi G} = 1.2 \times 10^9 \quad (14)$$

The value of ε_G is fixed by demanding that Newton's law of gravitation be recovered from the Gauss-like law (12), whereas the value of μ_G is fixed by the linearization procedure from Einstein's field equations. These two constants express the strengths of the coupling between sources (i.e., of masses and mass currents, respectively) and gravitational fields, and are analogous to the two constants ε_0 (the permittivity of free space) and μ_G (the permeability of free space), which express the strengths of coupling between sources (charges and charge currents, respectively) and electromagnetic fields in Maxwell's theory.

In the above set of equations, the field $\overline{E}_G$ is the gravito-electric field, which is to be identified with the local acceleration g of a test particle produced by the mass density ρ_G, in the Newtonian limit of general relativity. The field $\overline{B}$ is the gravito-magnetic field produced by the mass current density j_G and by the gravitational analog of the Maxwell displacement current density

$$\varepsilon_G \left(\frac{\partial \overline{E}_G}{\partial t} \right)$$

of the Ampere-like law (10). The resulting magnetic-like field $\overline{B}_G$ can be regarded as a generalization of the Lense-Thirring field of general relativity. Because these equations are linear, all fields will obey the superposition principle not only outside the source (i.e., in the vacuum), but also within the matter inside the source, provided the field strengths are sufficiently weak and the matter is sufficiently slowly moving. Note that the fields $\overline{E}_G$ and $\overline{B}_G$ in the above Maxwell-like equations will be treated as classical fields, just like the fields $\overline{E}_G$ and $\overline{B}_G$ in the classical Maxwell's equations.

An important physical property follows from the above Maxwell-like equations, namely, the characteristic gravitational impedance of free space Z_G.[63-65]

$$Z_G = \sqrt{\frac{\mu_G}{\varepsilon_G}} = \frac{4\pi G}{C} = 2.8 \times 10^{-18} \quad (15)$$

This quantity is a characteristic of the vacuum, i.e., it is a property of space-time itself, and it is independent of any of the properties of matter per se. As with

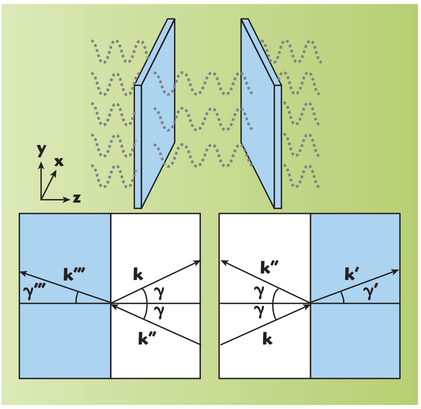
$$Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377$$

ohms in the EM case,

$$Z_G = \sqrt{\frac{\mu_G}{\varepsilon_G}} = 2.8 \times 10^{-28}$$

will play a central role in all gravitational radiation coupling problems.

In practice, the impedance of a material object must be much smaller than this extremely small quantity before any significant portion of the incident gravitational-wave (GW) power can be reflected. In other words, conditions must be highly unfavorable for dissipation into heat. Because all classical material objects have extremely high levels of dissipation compared to Z_G,



▲ *Fig. 13 The Gravitational Casimir effect.*[68]

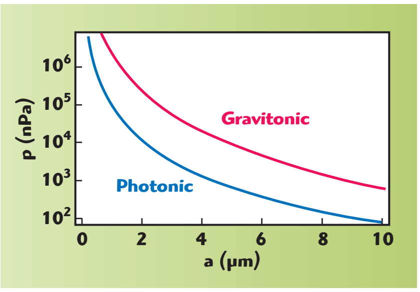


Fig. 14 Typical CAD simulated plots of gravitonic (red line) and photonic (blue line) contributions to the Casimir pressure of parallel plates kept in vacuum.[68]

even at very low temperatures, they are inevitably very poor GW reflectors.[65-66] The question of GW reflection from macroscopically coherent quantum systems such as superconductors requires a separate analysis due to the effectively zero resistance associated with superconductors, i.e., the lack of dissipation exhibited by matter in this unique state, at temperatures near absolute zero.

Peters[78] reported on the gravitational refractive index n_G, which was much larger than that generated by just considering induced quadruple moments, suggesting that his model encapsulates the dominant GW interaction with matter, given as

$$n_G = 1 + \frac{2\pi G\rho}{\omega^2} \quad (16)$$

where ρ is the density of the medium.

Minter[57] et al., give the reflection coefficient of a superconducting film from an incident GW as

$$r_G = \frac{1}{1 + \frac{2\delta^2}{c \times d}\xi} \quad (17)$$

where δ is the EM skin depth of the superconducting film and d is the film thickness.

From (17), the gravitonic contribution to the Casimir pressure for superconducting lead (Pb) of thickness d = 2 nm at zero temperature is plotted in ***Figure 14***.[68] The EM skin depth of Pb is δ = 37 nm. This result is compared with the photonic contribution to the Casimir pressure of superconducting lead. The EM reflection coefficient is [79]

$$r_E = \frac{1}{1 + \frac{2\lambda\delta^2}{c \times d}\xi} \quad (18)$$

where λ = 83 nm is the coherence length. The photonic contribution to the Casimir pressure is calculated by using Equation (18).

James[68] claims that Casimir pressure is an order of magnitude larger than that predicted from the photonic contribution alone. This would be the first experimental evidence for the validity of the H-C theory and the existence of gravitons. This would open a new field in the way of graviton detection.

CONCLUSION

This series of articles discussed the opportunities, emerging trends, challenges and future direction promoted by the scientists, experimentalists and technologists whose focus is in translating metamaterials into practical systems and devices. Their unique electromagnetic properties have attracted considerable attention from researchers across multiple disciplines. With the complete degree of freedom to control over material properties, what is possible is limited only by our imagination. Magneto electric couplings can be a source of new behavior in Casimir systems, metamaterial Casimir repulsive effects can lead to anti-gravity and low cost solution for levitation. As a final comment, the authors acknowledge that MMS metasurfaces can provide nearly infinite group delay, which is very helpful in understanding Einstein precession, geodetic effects and provides new evidence for refining our understanding of the relativistic corrections to Newtonian celestial mechanics. For example, multi-knots Möbius strips can be considered as tiny strings that can vibrate in multiple dimensions, and depending on how they vibrate, they might be seen in 3-dimensional space as matter, light or gravity. The vibration of the string which determines whether it appears to be matter or energy, and every form of matter or energy is the result of the vibration of the string. The authors consciously set out to describe a model of the universe as a “Möbius Universe,” unbounded in the form of Möbius loop along the plane of space-time fabrics.

ACKNOWLEDGMENTS

The authors would like to thank Dr. Ignaz Eisele (EMFT Fraunhofer Institute, Munich, Germany) for developing prototypes and custom structures, Dr. Karl-Heinz Hoffmann

(Bavarian Academy of Science, Germany), Dr. Shiban Koul (IIT-Delhi, India), Dr. Tatsuo Itoh (UCLA, USA), Dr. Matthias Rudolph (BTU Cottbus, Germany), Dr. Afshin Daryoush (Drexel University, Philadelphia, USA) and Dr. Arye Rosen (Rowan University, NJ, USA) for their valuable inputs, technical discussions and developing prototype for the theoretical proof and experimental validation. The authors would also like to thank the Indian Government in 1990s for supporting the negative index Möbius strips based RF&MW components for space applications. A special heartfelt thank you goes to our close friend Prof. D. Sundararajan who passed away on 22nd September 2014. Prof. Sundararajan and Dr. Poddar had been working on this mysterious Metamaterial Mobius strips since 1990 and were the first ones to demonstrate Möbius strips sensors for the applications in underground mine detections, memory devices, RFID for the detection of chemical explosives and weapons made of plastics, and composite materials which were often missed and undetected by RADAR.■

References

1. D. R. Smith, S. Schultz, P. Markoš and C. M. Soukoulis, "Determination of Effective Permittivity and Permeability of Metamaterials from Reflection and Transmission Coefficients," *Physical Review B*, Vol. 65, No. 19, April 2002, pp. 195104-1-5.
2. D. R. Smith, D. C. Vier, Th. Koschny and C. M. Soukoulis, "Electromagnetic Parameter Retrieval from Inhomogeneous Metamaterials," *Physical Review E*, Vol. 71, No. 3, March 2005, pp. 36617-1-11.
3. J. B. Pendry, A. J. Holden, D. J. Robbins and W. J. Stewart, "Low Frequency Plasmons in Thin.-Wire Structures," *Journal of Physics: Condensed Matter*, Vol. 10, No. 22, June 1998, pp. 4785-4809.
4. J. B. Pendry, A. J. Holden, W. J. Stewart and I. Youngs, "Extremely Low Frequency Plasmons in Metallic Mesostructures," *Physical Review Letters*, Vol. 76, No. 25, June 1996, pp. 4773–4776.
5. J. B. Pendry, A. J. Holden, D. J. Robbins and W. J. Stewart, "Magnetism From Conductors and Enhanced Nonlinear Phenomena," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 47, No. 11, November 1999, pp. 2075–2084.
6. J. D. Jackson, "Classical Electromagnetics," John Wiley & Sons, 3rd Edition, New York, 1999.
7. V. G. Veselago, "Electrodynamics of Substances with Simultaneously Negative Values of Sigma and Mu," *Soviet Physics Uspekhi*, Vol. 10, 1968, pp. 509–514.
8. Y. Liua and X. Zhang, "Metamaterials: A New Frontier of Science and Technology," *Chemical Society Reviews*, Vol. 40, January 2011, pp. 2494–2507.
9. D. R. Smith, S. Schultz, P. Markoš and C. M. Soukoulis, "Determination of Effective Permittivity and Permeability of Metamaterials from Reflection and Transmission Coefficients," *Physical Review B: Condensed Matter*, April 2002, Vol. 65, April 2002, pp. 195104-1-5.
10. X. Chen, B. I. Wu, J. A. Kong and T. M. Grzegorczyk, "Retrieval of the Effective Constitutive Parameters of Bianisotropic Metamaterials," *Physical Review E, Statistical Physics, Plasmas, Fluids, and Related Interdisciplinary Topics*, Vol. 71, No. 4, April 2005, pp. 046610.
11. D. R. Smith, D. C. Vier, Th. Koschny and C. M. Soukoulis, "Electromagnetic Parameter Retrieval from Inhomogeneous Metamaterials," *Physical Review E: Statistical, Nonlinear, Biological, and Soft Matter Physics*, Vol. 71, March 2005, pp. 036617-1-11.
12. C. Menzel, T. Paul, C. Rockstuhl, T. Pertsch, S. Tretyakov and F. Lederer, "Validity of Effective Material Parameters for Optical Fishnet Material," *Physical Review B: Condensed Matter*, Vol. 81, No. 3, January 2010, pp. 035320/1-5.
13. R. A. Shelby, D. R. Smith and S. Schultz, "Experimental Verification of a Negative Index of Refraction," *Science*, Vol. 292, No. 5514, April 2001, 292, pp. 77–79.
14. S. Xiao, U. K. Chettiar, A. V. Kildishev, V. P. Drachev and V. M. Shalaev, "Yellow-Light Negative-Index Metamaterials," *Optics Letters*, Vol. 34, No. 22, 2009, pp. 3478–3480.
15. S. Zhang, W. Fan, N. C. Panoiu, K. J. Malloy, R. M. Osgood and S. R. J. Brueck, "Experimental Demonstration of Near-Infrared Negative-Index Metamaterials," *Physical Review Letters*, Vol. 95, September 2005, pp. 137404.
16. G. Dolling, C. Enkrich, M. Wegener, C. M. Soukoulis and S. Linden, "Simultaneous Negative Phase and Group Velocity of Light in a Metamaterial," *Science*, 2006, Vol. 312, No. 5775, May 2006, pp. 892–894.
17. M. C. K. Wiltshire1, J. B. Pendry, I. R. Young, D. J. Larkman, D. J. Gilderdale and J. V. Hajnal, "Microstructured Magnetic Materials for RF Flux Guides in Magnetic Resonance Imaging," *Science*, Vol. 291, No. 5505, February 2001, pp. 849–851.
18. C. Caloz, A. Sanada, and T. Itoh, "A Novel Composite Right/Left-Handed Coupled-Line Directional Coupler with Arbitrary Coupling Level and Broad Bandwidth," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 52, No. 3, March 2004, pp. 980–992.
19. A. Kurs, A. Karalis, R. Moffatt, J. D. Joannopoulos, P. Fisher and M. Soljačić, *Science*, Vol. 317, No. 5834, July 2007, pp. 83–86.
20. J. B. Pendry, "Negative Refraction Makes a Perfect Lens," *Physical Review Letters*, Vol. 85, October 2000, pp. 3966–3969.
21. X. Zhang and Z. W. Liu, "Superlenses to Overcome the Diffraction Limit," *Nature Materials*, Vol. 7, June 2008, pp. 435–441.
22. N. Fang, H. Lee, C. Sun and X. Zhang, "Sub-Diffraction-Limited Optical Imaging with a Silver Superlens," *Science*, Vol. 308, No. 5721, April 2005, pp. 534–537.
23. A. A. Zharov, I. V. Shadrivov and Yu. S. Kivshar, "Nonlinear Properties of Left-Handed Metamaterials," *Physical Review Letters*, Vol. 91, No. 3, July 2003, pp. 037401-1-4.
24. V. M. Agranovich, Y. R. Shen, R. H. Baughman and A. A. Zakhidov, "Linear and Nonlinear Wave Propagation in Negative Refraction Metamaterials," *Physical Review B: Condensed Matter*, Vol. 69, No. 16, April 2004, pp. 165112.
25. N. Lazarides, M. Eleftheriou and G. P. Tsironis, "Discrete Breathers in Nonlinear Magnetic Metamaterials," *Physical Review Letters*, Vol. 97, October 2006, pp. 157406.
26. Y. Liu, G. Bartal, D. A. Genov and X. Zhang, "Subwavelength Discrete Solutions in Nonlinear Metamaterials," *Physical Review Letters*, Vol. 99, October 2007, pp. 153901.
27. N.M. Litchinitser and V.M. Shalaev, "Photonic

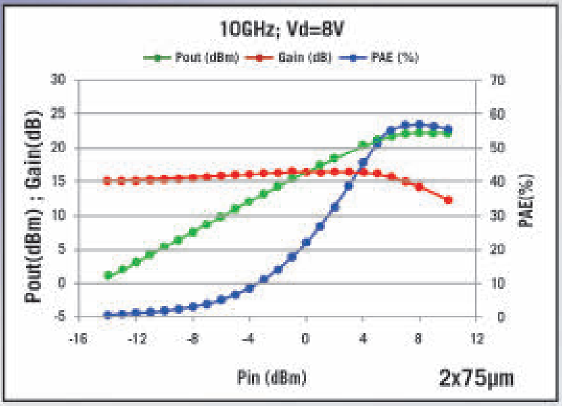
WIN SEMICONDUCTORS

Leading Global Communications

PP25/-21 0.25μm Power pHEMT

- 0.25μm PHEMT process on 100μm substrates
- Power performance at 8V and 10GHz: >1W/mm, PAE 56%, 14dB Gain

PP25-21 (Class-AB) Tuned for Pout



Gain (dB)	P1dB (dBm)	P1dB (mW/mm)	Psat (dBm)	Psat (mW/mm)	PAE Max(%)
15.0	22.1	1086	22.2	1114	56.8

2x75μm device @8V, 10GHz, 150 mA/mm

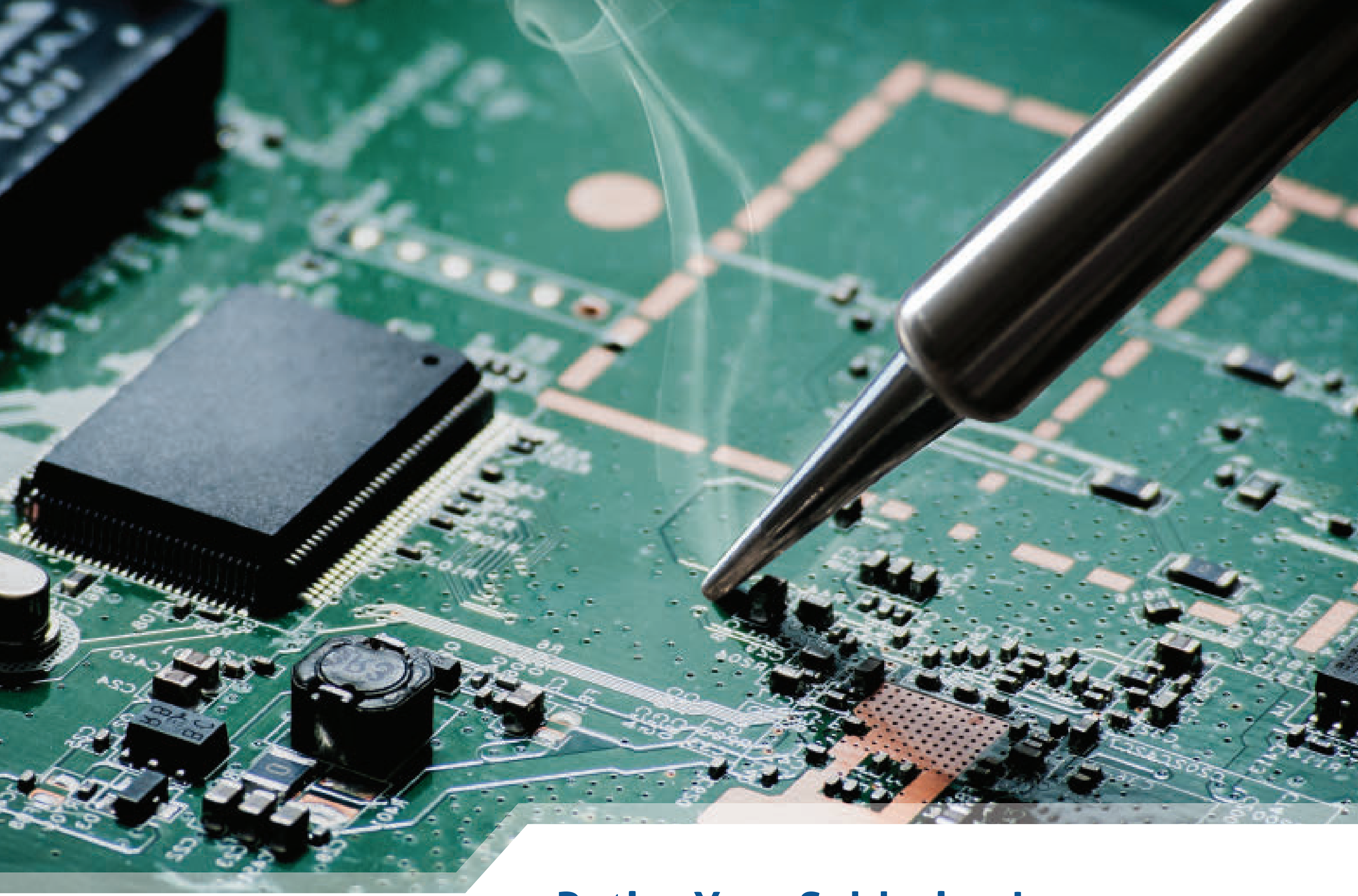
Summary of WIN mmWave pHEMT portfolio

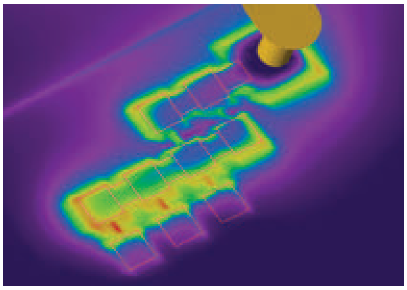
	PP25-21	PP15-50/51	PL15-12	PP10-10/11
Gate length	0.25 μm	0.15 μm	0.15 μm	0.1 μm
Max Drain Bias	8 V	6 V	4 V	4 V
Idmax (Vg=0.5V)	490 mA/mm	620 mA/mm	525 mA/mm	760 mA/mm
Peak Gm	410 mS/mm	460 mS/mm	580 mS/mm	725 mS/mm
Vto	-1.15 V	-1.3 V	-0.7 V	-0.95 V
BVGD	20V(18V min)	16V(14V min)	9V(8V min)	10V(8V min)
f_T	65 GHz	90 GHz	100 GHz	130 GHz
f_{max}	190 GHz	185 GHz	150 GHz	180 GHz
Power Density (2x75μm)	1100 mW/mm @ 8V, 10GHz	870 mW/mm @ 6V, 29GHz	580 mW/mm @ 4V, 29GHz	860 mW/mm @ 4V, 29GHz (2x50μm)

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

Metamaterials," *Laser Physics Letters*, Vol. 5, 2008, pp. 411–420.

28. M. W. Klein, C. Enkrich, M. Wegener and S. Linden, "Second-Harmonic Generation from Magnetic Metamaterials," *Science*, Vol. 313, No. 5786, July 2006, pp. 502–504.
29. I. V. Shadrivov, S. K. Morrison and Y. S. Kivshar, "Tunable Split-Ring Resonators for Nonlinear Negative-Index Metamaterials," *Optics Express*, Vol. 14, No. 20, October 2006, pp. 9344–9349.
30. B. N. Wang, J. F. Zhou, T. Koschny and C. M. Soukoulis, "Nonlinear Properties of Split-Ring Resonators," *Optics Express*, Vol. 16, No. 20, 2008, pp. 16058–16063.
31. T. Driscoll, H. T. Kim, B. G. Chae, B. J. Kim, Y. W. Lee, N. M. Jokerst, S. Palit, D. R. Smith, M. Di Ventra and D. N. Basov, "Memory Metamaterials," *Science*, Vol. 325, No. 5947, September 2009, pp. 1518–1521.
32. V. V. Cheianov, V. Fal'ko and B. L. Altshuler, "The Focusing of Electron Flow and a Veselago Lens in Graphene P-N Junctions," *Science*, Vol. 315, No. 5816, March 2007, pp. 1252–1255.
33. S. Zhang, D. A. Genov, C. Sun and X. Zhang, "Cloaking of Matter Waves," *Physical Review Letters*, Vol. 100, No. 12, March 2008, pp. 123002-1-4.
34. Z. Jacob, J. Y. Kim, G. V. Naik, A. Boltasseva, E. E. Narimanov and V. M. Shalaev, "Engineering Photonic Density of States Using Metamaterials," *Applied Physics B: Lasers and Optics*, Vol. 100, No. 1, July 2010, pp. 215–218.
35. M. A. Noginov, H. Li, Y. A. Barnakov, D. Dryden, G. Nataraj, G. Zhu, C. E. Bonner, M. Mayy, Z. Jacob and E. E. Narimanov, "Controlling Spontaneous Emission with Metamaterials," *Optics Letters*, Vol. 35, No. 11, 2010, pp. 1863–1865.
36. C. Henkel and K. Joulain, "Casimir Force Between Designed Materials: What is Possible and What Not," *Europhysics Letters*, Vol. 72, No. 6, December 2005, pp. 929–935.
37. U. Leonhardt and T. G. Philbin, "Quantum Levitation by Left-Handed Metamaterials," *New Journal of Physics*, Vol. 9, August 2007, pp. 010254-1-11.
38. F.S.S. Rosa, D.A.R. Dalvit and P.W. Milonni, "Casimir-Lifshitz Theory and Metamaterials," *Physical Review Letters*, Vol. 100, No. 18, May 2008, pp. 183602.
39. R. Zhao, J. Zhou, T. Koschny, E. N. Economou and C. M. Soukoulis, "Repulsive Casimir Force in Chiral Metamaterials," *Physical Review Letters*, Vol. 103, No. 10, September 2009, pp. 103602.
40. V. Yannopapas and N. V. Vitanov, "First-Principles Study of Casimir Repulsion in Metamaterials," *Physical Review Letters*, Vol. 103, No. 12, September 2009, pp. 120401.
41. S. I. Maslovski and M. G. Silveirinha, "Ultralong-range Casimir-Lifshitz Forces Mediated by Nanowire Materials," *Physical Review A*, No. 82, No. 2, August 2010, pp. 022511.
42. Y. Yang, H. Zhang, J. Zhu, G. Wang, T. -R. Tzeng, X. Xuan, K. Huang and P. Wang, "Distinguishing the Viability of a Single Yeast Cell with an Ultra-Sensitive Radio Frequency Sensor," *Lab Chip*, Vol. 10, January 2010, pp. 553–555.
43. Y. Cui and P. Wang, "The Design and Operation of Ultra-Sensitive and Tunable Radio-Frequency Interferometers," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 62, No. 12, December 2014, pp. 3172–3182.
44. G. P. Agrawal, *Fiber-Optic Communication Systems*, 3rd ed., Wiley, 2010.
45. A. H. Gnauck, R. W. Tkach, A. R. Chraplyvy and T. Li, "High-Capacity Optical Transmission Systems," *Journal of Lightwave Technology*, Vol. 26, No. 9, May 2008, pp. 1032-1045.
46. R. J. Essiambre and R. W. Tkach, "Capacity Trends and Limits of Optical Communication Networks," *Proceedings of the IEEE*, Vol. 100, No. 5, May 2012, pp. 1035–1055.
47. A. H. Gnauck, P. J. Winzer, S. Chandrasekhar, X. Liu, B. Zhu and D. W. Peckham, "Spectrally Efficient Long-Haul WDM Transmission Using 224-Gb/s Polarization-Multiplexed 16-QAM," *Journal of Lightwave Technology*, Vol. 29, No. 4, February 2011, pp. 373–377.
48. D. J. Richardson, J. M. Fini and L. E. Nelson, "Space-Division Multiplexing in Optical Fibres," *Nature Photonics*, Vol. 7, No. 5, April 2013, pp. 354–362.
49. B. Zhu, J. M. Fini, M. F. Yan, X. Liu, S. Chandrasekhar, T. F. Taunay, M. Fishteyn, E. Monberg and F. V. Dimarcello, "High-Capacity Space-Division-Multiplexed DWDM Transmissions Using Multi Core Fiber," *Journal of Lightwave Technology*, Vol. 30, No. 4, February 2012, pp. 486–492.
50. X, Liu, S. Chandrasekhar, X. Chen, P. J. Winzer, Y. Pan, T. Taunay, B. Zhu, M. Fishteyn, M. F. Yan, J. Fini, E. M. Monberg and F. V. Dimarcello, "1.12-Tb/s 32-QAM-OFDM Superchannel with 8.6-b/s/Hz Intrachannel Spectral Efficiency and Space-Division Multiplexing with 60-b/s/Hz Aggregate Spectral Efficiency," *Optical Express*, Vol. 19, No. 26, December 2011, pp. B958–B964.
51. R. Ryf, S. Randel, A. H. Gnauck, C. Bolle, A. Sierra, S. Mumtaz, M. Esmaeelpour, E. C. Burrows, R. J. Essiambre, P. J. Winzer, D. W. Peckham, A. H. McCurdy and R. Lingle, "Mode-Division Multiplexing Over 96 km of





*3D EM fields are analyzed when selecting the lumped component values in **Full-Wave Matching Circuit Optimization***

Few-Mode Fiber Using Coherent 6 × 6 MIMO Processing," *Journal of Lightwave Technology*, Vol. 30, No. 4, February 2012, pp. 521–531.
52. N. Bozinovic, Y. Yue, Y. Ren, M. Tur, P. Kristensen, H. Huang, A. E. Willner and S. Ramachandran, "Terabit-Scale Orbital Angular Momentum Mode Division Multiplexing in Fibers," *Science*, Vol. 340, No. 6140, June 2013, pp. 1545–1548.
53. N. Bozinovic, S. Golowich, P. Kristensen and S. Ramachandran, "Control of Orbital Angular Momentum of Light, with Optical Fibers," *Optics Letters*, Vol. 37, No. 13, 2012, pp. 2451–2453.
54. P. Gregg, P. Kristensen, S. Golowich, J. Olsen, P. Steinvurzel and S. Ramachandran, "Stable Transmission of 12 OAM States in Air-Core Fiber," *Optical Society of America CLEO 2013 Technical Digest*, June 2013, pp. 1–2.
55. J. Zeng, X. Wang, J. Sun, A. Pandey, A. N. Cartwright and N. M. Litchinitser, "Manipulating Complex Light with Metamaterial," *Scientific Reports*, Vol. 3, No. 2826, October 2013.
56. F. Intravaia and C. Henkel, "Can Surface Plasmons Tune the Casimir Forces Between Metamaterials?" *Institut fuer Physik und Astronomie*, Poster, http://cnls.lanl.gov/casimir/PostersSF/Intravaia-SantaFe-poster.pdf.
57. S. Minter, K. Wegter-McNelly and R. Chiao," Do Mirrors for Gravitational Wave Exist?" *Physica E: Low-dimensional Systems and Nanostructures*, Vol. 42, No. 3, January 2010, pp. 234-255.

58. R.E. Glover and M. Tinkham, "Transmission of Superconducting Films at Millimeter-Microwave and Far Infrared Frequencies," *Physical Review*, Vol. 104, No. 3, November 1956, pp. 844.
59. M. Tinkham, "Introduction to Superconductivity," 2nd ed., Dover, New York, 2004.
60. R. M. Wald, "General Relativity," University of Chicago Press, Chicago, 1984.
61. W.H. Zurek, "Decoherence, Einselection, and the Quantum Origins of the Classical," *Reviews of Modern Physics*, Vol. 75, No. 3, September 2003, pp. 715.
62. B.S. DeWitt, "Superconductors and Gravitational Drag," *Physical Review Letters*, Vol. 16, No. 24, June 1966, pp. 1092.
63. R. Y. Chiao, "Science and Ultimate Reality," J. D. Barrow, P. C. W. Davies, and C. L. Harper (eds.) Jr. (Cambridge University Press, Cambridge, 2004), p. 254.
64. C. Kiefer and C. Weber, "On the Interaction of Mesoscopic Quantum Systems with Gravity," *Annalen der Physik*, Vol. 14, No. 4, April 2005, pp. 253–278.
65. R.Y. Chiao and W. J. Fitelson, "Time and Matter in the Interaction Between Gravity and Quantum Fluids: Are there Macroscopic Quantum Transducers Between Gravitational and Electromagnetic Waves?" *arXiv:gr-qc/0303089*, March 2003.
66. S. Weinberg, "Gravitation and Cosmology," Wiley, New York, 1972.
67. A. Lambrecht, "The Casimir Effect: a Force From Nothing," *Physics World*, September 2002.
68. J. Q. Quach, "Gravitational Casimir Effect," *Physical Review Letters*, Vol. 114, No. 8, February 2015, pp. 081104-1-5.
69. U. L. Rohde and A. K. Poddar, "Möbius Metamaterial Inspired Next Generation Circuits and Systems," *Microwave Journal*, Vol. 59, No. 5, May 2016, pp. 62–88.
70. U. L. Rohde and A. K. Poddar, "Möbius Metamaterial Inspired: Signal Sources and Sensors," *Microwave Journal*, Vol. 59, No. 6, June 2016.
71. U. L. Rohde and A. K. Poddar, "Ka-Band Metamaterial Möbius Oscillator (MMO) Circuit," *IEEE International Microwave Symposium Digest*, May 2016, pp. 1–4.
72. U. L. Rohde and A. K. Poddar, "Möbius Metamaterial Strips Resonator: Tunable Oscillators for Modern Communication Systems," *Microwave Journal*, Vol. 58, No. 1, January 2015.
73. U. L. Rohde and A. K. Poddar, "Metamaterial Resonators: Theory and Applications," *Microwave Journal*, Vol. 57, No. 12, December 2014, pp. 74–86.
74. U. L. Rohde and A. K. Poddar, "Möbius Strips and Metamaterial Symmetry: Theory and Applications," *Microwave Journal*, Vol. 57, No. 11, November 2014, pp. 76–88.
75. U. L. Rohde, A. K. Poddar and D. Sundararjan, "Printed Resonators: Möbius Strips Theory and Applications," *Microwave Journal*, Vol. 56, No. 11, November 2013, pp. 24–54.
76. C. P. Scarborough, Z. H. Jiang, D. H. Werner, C. Rivero-Baleine and C. Drake, "Experimental Demonstration of an Isotropic Metamaterial Super Lens with Negative Unity Permeability at 8.5 MHz," *Applied Physics Letters*, Vol. 101, No. 1, July 2012, pp. 014101-1-3.
77. Z. H. Jiang, M. D. Gregory and D. H. Werner, "A Broadband Monopole Antenna Enabled by an Ultrathin Anisotropic Metamaterial Coating," *IEEE Antennas and Wireless Propagation Letters*, Vol. 10, 2011, pp. 1543-1546.
78. P. C. Peters, "Index of Refraction for Scalar, Electromagnetic, and Gravitational Waves in Weak Gravitational Fields," *Physical Review D*, Vol. 9, April 1974, pp. 2207–2218.
79. S. J. Minter, K. Wegter-McNelly and R. Y. Chiao, "Do Mirrors for Gravitational Waves Exist?" *Physica E 42*, 2010.

INVITED PAPER

High Linearity RF Switches for DOCSIS 3.1 Applications

Peter Bacon and Kinana Hussain
Peregrine Semiconductor, San Diego, Calif.

Driven by consumer demand and the proliferation of electronic devices, data consumption is rising rapidly. The Cisco Visual Networking Index (VNI) predicts that from 2014 to 2019, networked devices and connections will grow globally from 14.2 to 24.4 billion. The report forecasts that global Internet traffic will grow 3.2 fold from 2014 to 2019 at a compound annual growth rate of 26 percent.

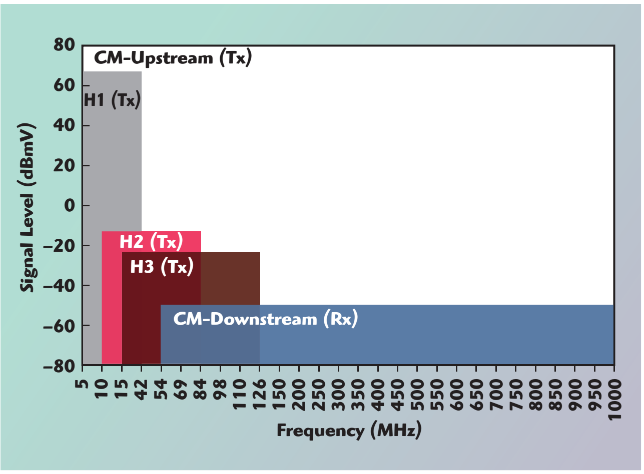
The rapid adoption of higher resolution, video-streaming services has further increased demand for faster connections. In fact, the VNI estimates global Internet video traffic will be 77 percent of all Internet traffic in 2019. It predicts that five million years of video content will cross the Internet each month in 2019. This estimate means nearly a million minutes of video will be streamed or downloaded every second.

The cable industry faces the challenge of supporting this increasing demand for more high-speed home data. The VNI forecasts that 62.8 percent of global Internet traffic in 2019 will be fixed Wi-Fi and 19 percent will be fixed wired.[1] Consumers and businesses are demanding faster connections, which is putting enormous strain on the broadband system. From customer premise equipment (CPE) devices to multi-service operators (MSO) head-end infrastructure, the cable industry is in a race with data consumption.

DOCSIS 3.1 TECHNOLOGY

To meet these growing data requirements, the cable industry developed the DOCSIS 3.1 cable industry standard. The Data Over Cable Service Interface Specification (DOCSIS) is an industry-wide collaboration that is issued by research and development consortium CableLabs. The DOCSIS specifications are used by the cable market to define how the cable modem interacts with the overall data delivery infrastructure, from the back office network to the hybrid fiber/coaxial (HFC) system to the cable modem itself, which delivers services to the end-user. DOCSIS 3.1 is the latest generation. The first standard, DOCSIS 1.0, came out in 1997; past specifications include DOCSIS 3.0, DOCSIS 2.0 and DOCSIS 1.1.

DOCSIS 3.1 technology offers many improvements over its precursor, the DOCSIS 3.0 standard. DOCSIS 3.1 increases speeds up to 10 Gbps downstream and up to 1 Gbps upstream. It allows for greater system capacity with the ability to support up to 4,096 quadra-



▲ *Fig. 1 Nonlinearities of the cable modem upstream can block the downstream receiver from capturing the desired signal.*

ture amplitude modulation (QAM), which is 12 bits/symbol. This is a vast improvement over DOCSIS 3.0, which only supported up to 256 QAM (8 bits/symbol). DOCSIS 3.1 reduces network delays and improves responsiveness with Active Queue Management. Additionally, it is more energy efficient and enables companies to improve their current energy metrics.

One of the main benefits of DOCSIS 3.1 is that it does not require upgrades to existing data-delivery infrastructure. The current HFC network does not need to be modified to work with DOCSIS 3.1 technology; therefore, network capacity can be increased without extensive adjustments. Furthermore, DOCSIS 3.1 maintains backward compatibility with DOCSIS 3.0 technology.

DOCSIS 3.1 allows the cable industry to increase network capacity by more than 50 percent over the same spectrum. It enables cable companies to offer consumers and businesses higher download and upload speeds without sacrificing quality in any way. Consumers not only benefit from higher speeds, but they can enjoy the reduction in network delays and receive higher resolution images. It is also designed to support the latest innovations, such as 4K video and ultra-high definition movies.[2]

LINEARITY & HARMONICS CHALLENGE

The new specification sets an ambitious goal for the cable industry. From an RF perspective, one of the toughest challenges is to comply with the new linearity requirements. For DOCSIS 3.1 technology, high linearity is necessary to support the increased data rates and the upstream/downstream spectral integrity. When transmitting higher data rates, linearity preserves the integrity of the in-band complex modulated waveform. Increased linearity also shows itself in reduced out-of-band harmonic spurious generation—a key factor in assuring that any device that is simultaneously handling both upstream and downstream signals is able to maintain its spectral separation and purity. It is detrimental to have spurious levels from one signal stream overriding the desired signal of the other data stream. Therefore, any switch that is in a position of routing both upstream and downstream signals will have stringent second and third harmonic requirements.

In DOCSIS 3.1, there is a move to orthogonal frequency division modulation (OFDM) for downstream data transmission and orthogonal frequency division multiple access (OFDMA) for upstream data delivery. The frequency range is increasing from 1.002 GHz to at least 1.218 GHz and maybe even 1.794 GHz. Additionally, the number of possible frequency partitions has increased from three to four and the ability to select between partitions has been added. QAM has increased from a maximum of 1,024 to 4,096, with an interleaved option for 16,384 QAM. In general, greater implementation flexibility has been incorporated in the entire specification.

Regarding channel impairments, as QAM level increases the signal-to-noise ratio (SNR) requirement also increases. Thus, implementation of DOCSIS 3.1 implies ever-increasing signal integrity requirements. To maintain a low symbol error rate the SNR must continue to increase as the modulation scheme grows in complexity. For 4,096 QAM an SNR of 45.4 dB is needed to obtain a 10^{-6} probability of a symbol error compared to 13.7 dB for the same error probability using a much simpler QPSK scheme.

Further, nonlinearities of the cable modem upstream can block the downstream receiver from capturing the desired signal. ***Figure 1*** shows signal level vs. frequency for the upstream Tx signal, the downstream Rx signal and the second (H2) and third harmonic (H3) of the Tx upstream signal. The Tx signal level is much higher than the minimum Rx downstream signal the cable modem will receive at its F-connector. If the harmonic generation levels are not considered (H2 and H3), they can be greater than the downstream Rx signal and can block the downstream signal from being received.

A single cable must support both downstream and upstream paths, so bandwidth is frequency divided. The challenge is to ensure that spurious out-of-band emissions of the upstream transmitter do not corrupt the signal of the receiver downstream. Prior to DOCSIS 3.1, there had not been a need to perform frequency selectivity during the operation of the cable modem—a fixed frequency partitioning was sufficient. Now there is a need for greater upstream/downstream frequency band flexibility.

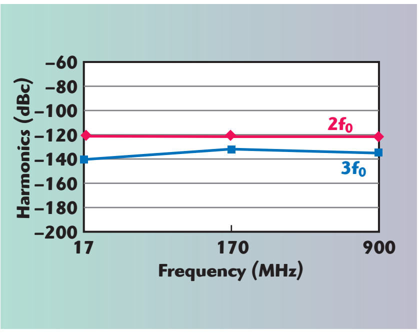
RF SWITCHES ENABLE DUAL-BAND ARCHITECTURE

In response to the DOCSIS 3.1 linearity and harmonic requirements, many companies set out to create a solution. In October 2014, Peregrine introduced a high linearity RF switch with excellent harmonic performance. Subsequently in March 2016, they set a new record for high linearity and introduced an upgraded version switch that reportedly boasts the highest linearity specifications on the market today.

The switches offer to solve the DOCSIS 3.1 linearity challenge even when supporting a dual upstream/downstream band architecture. They are currently the only RF switches that enable dual upstream/downstream bands to reside in the same CPE device. CPE devices, such as set-top boxes, cable modems and home gateways, had previously supported only one upstream/downstream band combination. By using this dual-band architecture, CPEs can comply with the DOCSIS 3.1 cable industry stan-

dard, and MSOs have the flexibility to offer their customers new and expanded services. A dual-band architecture eliminates an extra step in giving customers higher speeds. At the flip of a switch, a cable service provider can repartition its frequency plan when it desires in order to better match the data consumption needs.

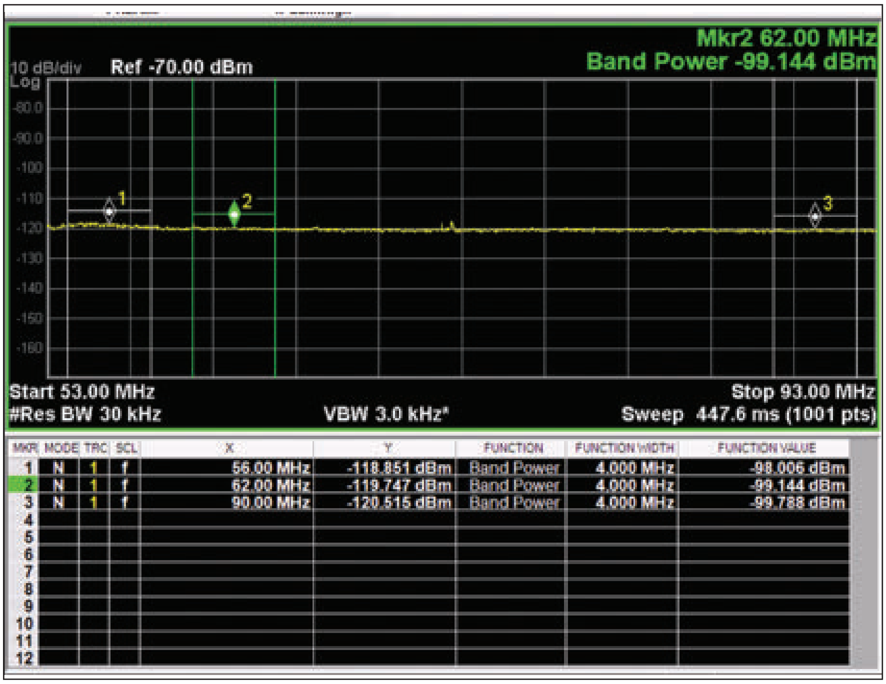
Before the introduction of these products, no switch had been released that met the linearity requirements necessary to support a dual upstream/downstream band architecture. To create this full-frequency architecture, the switch is placed directly at the cable modem (CM) F-connector between the filters and cable input. This switch must maintain frequency duplexing established by the two low-pass and high-pass filters and must deliver high linearity to avoid corruption of the downstream band. Additionally, this switch must comply with the stringent DOCSIS 3.1 CM integrated spurious emissions requirements of –50 dBmV. Such a low spurious level requires the switch harmonic performance to be greater than –115 dBc. An example product that exceeds this specification is the Peregrine PE42723 switch where the second harmonic is –121 dBc and the third harmonic is –140 dBc at 17 MHz. ***Figure 2*** shows the second and third harmonic for this switch when the input power (P_{IN}) is 65 dBmV.



▲ *Fig. 2 Typical harmonic performance of SOI switch. At 17 MHz, the second harmonic is –121 dBc, and the third harmonic is –140 dBc (P_{IN} = 65 dBmV).*

Figure 3 reveals the integrated spurious emissions of the switch in a Murata DOCSIS 3.1 module. The switch was tested with a Keysight signal generator and spectrum analyzer using a DOCSIS OFDMA upstream waveform, an input power of +71.8 dBmV, 24 MHz BW and utilizing 4,096 QAM. The integrated spurious levels were measured across the low end of the downstream band at 56, 62 and 90 MHz center frequencies and over a 4 MHz integration bandwidth. Even with this over-stressed condition of being driven by 71.8 dBmV and delivering more than 69 dBmV to the F-connector, the integrated spurious level for this module remained below the –50 dBmV requirement.

Switches that can meet these stringent requirements are manufactured on the UltraCMOS® process, a patented variation of silicon-on-insulator (SOI) technology on a sapphire substrate. Sapphire is a near perfect insulator, offers excellent RF and microwave properties and has a mature supply chain. UltraCMOS silicon-on-sapphire (SOS) chips feature low defect density for simpler construction; dielectrically isolated transistors for excellent power handling and multiple thresholds; inherent CMOS logic levels; and high ESD ratings. Nonlinear effects from the substrate and metallization are an advantage in meeting strict linearity requirements. The sapphire substrate demonstrates consistent behavior with respect to insertion loss vs. input power. Further, a sapphire substrate demonstrates excellent characteristics with respect to second and third harmonics versus input power. Specifically, a through-line measurement on a sapphire substrate at a fundamental power level of +18 dBm (+65 dBmV) results in harmonic levels of –102 dBm for the second harmonic and –122 dBm for the third harmonic, translating to –120 dBc and –140 dBc, respectively. From a substrate perspective, merely meeting these requirements represents a substantial challenge for other technologies.

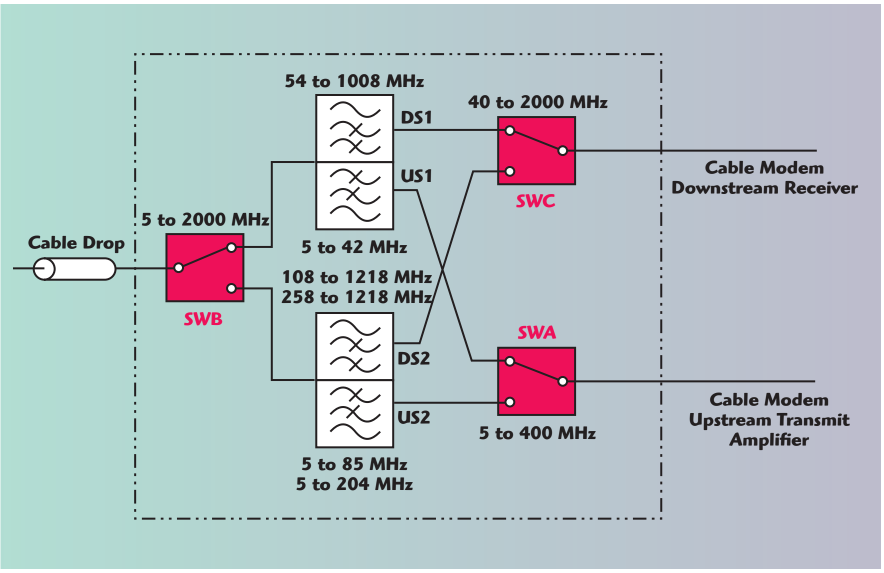


▲ *Fig. 3 Integrated spurious emissions of the SOI switch in a DOCSIS 3.1 module, measuring –50.3 dBmV.*

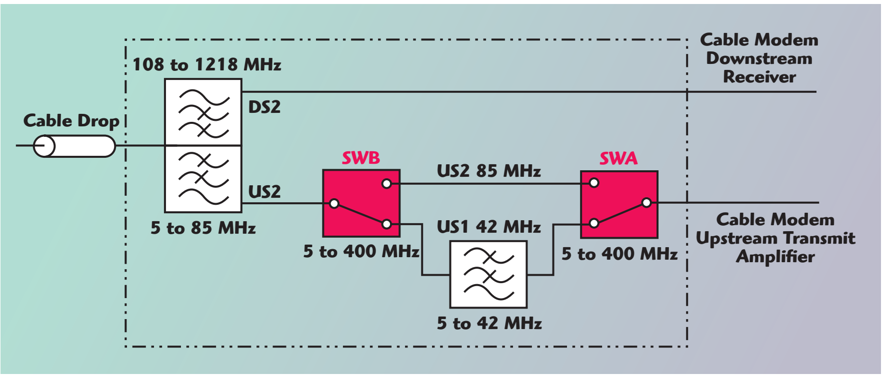
TECHNOLOGY TRANSITIONS FROM CONCEPT TO REALITY

Introduced in 2013, DOCSIS 3.1 implementation is an ongoing process. In previous generations of the DOCSIS standard, implementation has taken several years to go from a concept to deployment. However, the cable industry has made a collaborative effort to rapidly develop and deploy DOCSIS 3.1 technology. ABI Research predicts that nine million broadband subscribers will be using DOCSIS 3.1 equipment by 2017. This represents over one percent of total fixed broadband subscribers worldwide.[3]

In January 2016, CableLabs announced that five cable modem products had received DOCSIS 3.1 certification. Cable modems from CastleNet, Technicolor, Askey, Ubee Interactive and Netgear proved that they could comply with the latest specifications. This product certification announcement was an important milestone for CableLabs. Compared



▲ *Fig. 4 Dual upstream/downstream band architecture with full frequency coverage. The switches must provide high linearity (SWB), high isolation and linearity (SWA) and low insertion loss (SWC).*



▲ *Fig. 5 Dual-band architecture with an optimized upstream band using high isolation switches (SWA and SWB).*

to previous DOCSIS generations, the time from specification development to product certification occurred in half the time.[4]

MSOs are also preparing their systems for the new standard. In December 2015, Comcast announced that they had successfully tested a DOCSIS 3.1 modem at a Philadelphia home. This initial test marked the world's first DOCSIS 3.1 modem on a customer-facing network and proved that DOCSIS 3.1 technology could work on Comcast's existing HFC network. While the technology trials started in Philadelphia, Comcast plans to expand testing to other locations in Pennsylvania, Atlanta, Georgia and Northern California.[5]

As the worldwide cable industry transitions from DOCSIS 3.0 to 3.1 technologies, MSOs need to future-proof their CPE devices with high flexibility in addition to backward compatibility. One of the main benefits of these switches is that they support both DOCSIS 3.0 and 3.1 requirements, allowing for a simple and cost-effective transition to the new standard. In fact, this is a key selling feature for cable modem vendors. Of the five DOCSIS 3.1 certified cable modems, these switches are designed into three of the five cable modems—the three that feature a switchable band-select feature.

DOCSIS 3.1/3.0 DUAL-BAND ARCHITECTURE

Beyond the F-connector switch, there are other critical switch sockets in a DOCSIS 3.1/3.0 cable modem dual-band architecture. ***Figure 4*** shows a dual upstream/downstream band architecture at full frequency. In this example, high performance switches must be placed at sockets SWA, SWB and SWC. As discussed, the switch at the SWB socket must generate near zero out-of-band emissions to mitigate harmonic spurious falling in the DS1 legacy band. These switches can be placed in the SWB switch socket, which is between the cable drop and the filters. Socket SWA in the upstream band requires high isolation and high linearity. Finally, switch socket SWC in the downstream band requires a switch with low insertion loss.

Optionally, ***Figure 5*** depicts a dual-band architecture with an optimized upstream band. In this example, the switch can be placed in the SWB switch socket, which is after the filters on the upstream band. Switch socket SWA on the upstream band requires high isolation.

CONCLUSION

The ability to meet DOCSIS 3.1 standards is crucial for the cable industry. There are currently few switches that are able to meet the DOCSIS 3.1 linearity and harmonics requirements and enable a dual upstream/downstream band architecture, but new UltraCMOS switches from Peregrine Semiconductor are able to meet the stringent requirements. This ability to support dual-upstream/downstream bands in the same CPE device is a critical enabler in making DOCSIS 3.1 a reality. ■

References

1. "Visual Networking Index (VNI) – VNI Forecast Highlights," *Cisco, 2016*, www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/vni-forecast.html. [Accessed: 31- March 2016].
2. "Featured Technology" *CableLabs*, 2016, www.cablelabs.com/innovations/featured-technology/. [Accessed: 31- March 2016].
3. "ABI Research Forecasts 9 Million Broadband Subscribers to Use DOCSIS 3.1 Equipment by 2017," *ABI Research*, 2016, https://www.abiresearch.com/press/abi-research-forecasts-9-million-broadband-subscri/. [Accessed: 30-March 2016].
4. "Five New CableLabs Certified DOCSIS 3.1 Cable Modem Products Usher in a New Generation of Broadband Services," *CableLabs*, 2016, www.cablelabs.com/news/five-new-cablelabs-certified-docsis-3-1-cable-modem-products-usher-in-a-new-generation-of-broadband-services/. [Accessed: 31-March 2016].
5. "World's First Live DOCSIS 3.1 Gigabit-Class Modem Goes Online in Philadelphia," *Comcast*, 2016, http://corporate.comcast.com/comcast-voices/worlds-first-live-docsis-3-1-gigabit-class-modem-goes-online-in-philadelphia. [Accessed: 31-March 2016].

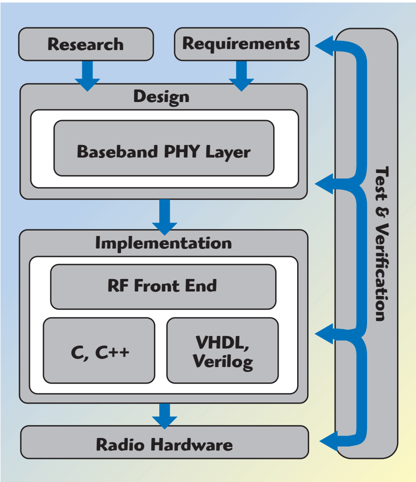
INVITED PAPER

Using Model-Based Design for Software-Defined Radio

Mike Donovan
MathWorks, Natick, Mass.
Andrei Cozma and Di Pu
Analog Devices Inc., Norwood, Mass.

This article outlines, in four steps, how a small team of engineers reduced design delays and failures through an alternative approach that uses a combination of Model-Based Design and Software Defined Radio (SDR) hardware to design signal processing algorithms, configure RF hardware, generate C and HDL code, and integrate the software with radio hardware. Tools used in this example include MATLAB and Simulink from MathWorks, along with hardware from Analog Devices and Avnet.

Building a wireless receiver is a challenging task that requires a diverse set of skills that are often distributed among many different design teams. In a traditional design methodology, these skills include RF design, HDL programming, system on chip (SoC) development, device driver configuration, and hardware/software integration. With a dependency upon multiple groups, the possibility that the design will fail grows as more team members become involved in the project. Common challenges in wireless receiver design often lead to a design process that has a high potential for miscommunicated specifications and interfaces, incompatible design ideas, and unexplored trade-offs.



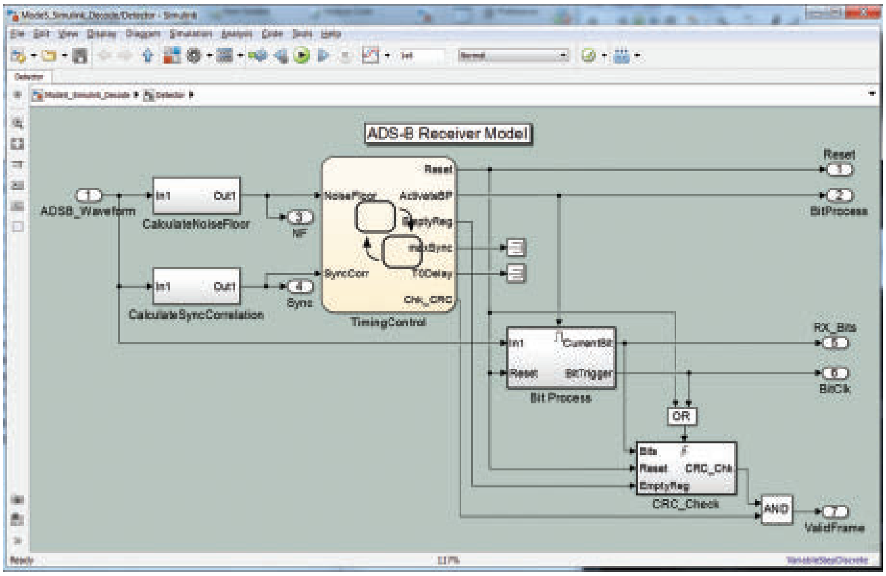
▲ *Fig. 1 Model-based design flow for a wireless receiver.*

Figure 1 shows the steps used to design a receiver using Model-Based Design and SDR hardware. In this approach, a majority of the development effort is spent in the design stage to create a Simulink model of the baseband receiver algorithms. The implementation stage of this process happens quickly because software errors are reduced using code generation, and the SDR hardware provides a configurable RF front-end. Verification time of the code and hardware significantly decreases because the detailed design developed in Simulink accurately reflects the final SDR implementation. An additional benefit of using Model-Based Design is that communication between the engineers is enhanced by working with an executable specification in Simulink, leading to fewer misunderstandings of the overall design and expected performance of the receiver.

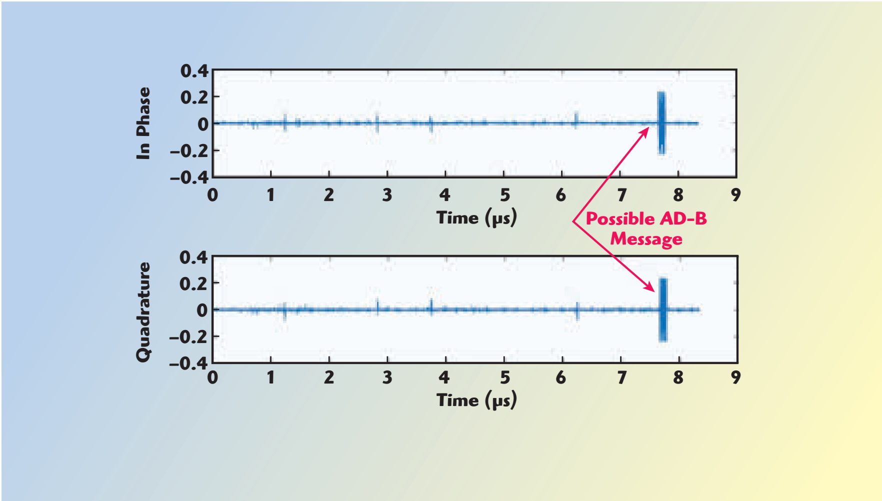
EXAMPLE FRAMEWORK

To demonstrate this approach, a team of three engineers used Model-Based Design to develop an Automatic Dependent Surveillance – Broadcast (ADS-B) receiver running on an Analog Devices AD9361 integrated RF Agile Transceiver™/Xilinx Zynq®-7000 All Programmable SoC Software Defined Radio (SDR) platform. This receiver was developed in a relatively short time with minimal obstacles, drawing on the following resources:

- A comprehensive user interface to configure the Analog Devices AD9361 RF Agile Transceiver to receive ADS-B transmissions and obtain a high quality signal.
- The ability to build a model of an ADS-B receiver in MATLAB and Simulink that generates functional C and HDL source code



▲ *Fig. 2 Simulink model of an ADS-B receiver.*



▲ *Fig. 3 Captured waveform containing possible ADS-B messages.*

```
Aircraft ID: 4005a5 is at altitude 40300
Aircraft ID: 4005a5 is at latitude 42.398, longitude -71.112

Aircraft ID: 4005a5 is travelling at 427.375713 knots
Direction West at 205.000000 knots, direction South at 375.000000 knots
Aircraft ID: 4005a5 is going Down at 1216.000000 feet/min

Aircraft ID: 4005a5 is at altitude 40275
Aircraft ID: 4005a5 is at latitude 42.396, longitude -71.113

Aircraft ID: 4005a5 is at altitude 40250
Aircraft ID: 4005a5 is at latitude 42.393, longitude -71.115

Aircraft ID: 4005a5 is travelling at 428.253430 knots
Direction West at 205.000000 knots, direction South at 376.000000 knots
Aircraft ID: 4005a5 is going Down at 1344.000000 feet/min

Aircraft ID: 4005a5 is at altitude 40150
Aircraft ID: 4005a5 is at latitude 42.386, longitude -71.121

Aircraft ID: 4005a5 is at altitude 40025
Aircraft ID: 4005a5 is at latitude 42.375, longitude -71.128
```

▲ *Fig. 4 Live data results from the ADS-B receiver implemented on the Zynq radio platform.*

(see ***Figure 2***).

- HDL code generation tools that automate many of the hardware/software integration steps.
- Libraries from Analog Devices that enable data communications between the host computer and SDR platform.

THE FOUR STEP PROCESS TO PRODUCTION:

Step 1 – Select the Radio Platform

The SDR platform was composed of two key devices. The Analog Devices AD9361 RF Agile Transceiver is a highly flexible, highly programmable device with the tuning range and bandwidth to support a large number of wireless standards, all in a single integrated IC. The Zynq-7000 All Programmable SoC from Xilinx integrates a dual-core ARM Cortex-A9 processor with a large array of programmable logic. Combined, the Zynq and AD9361 produce a versatile radio platform. The transceiver is capable of acquiring many simple and complex radio waveforms, and the Zynq SoC can be programmed to demodulate and decode a wide variety of digital communication protocols.

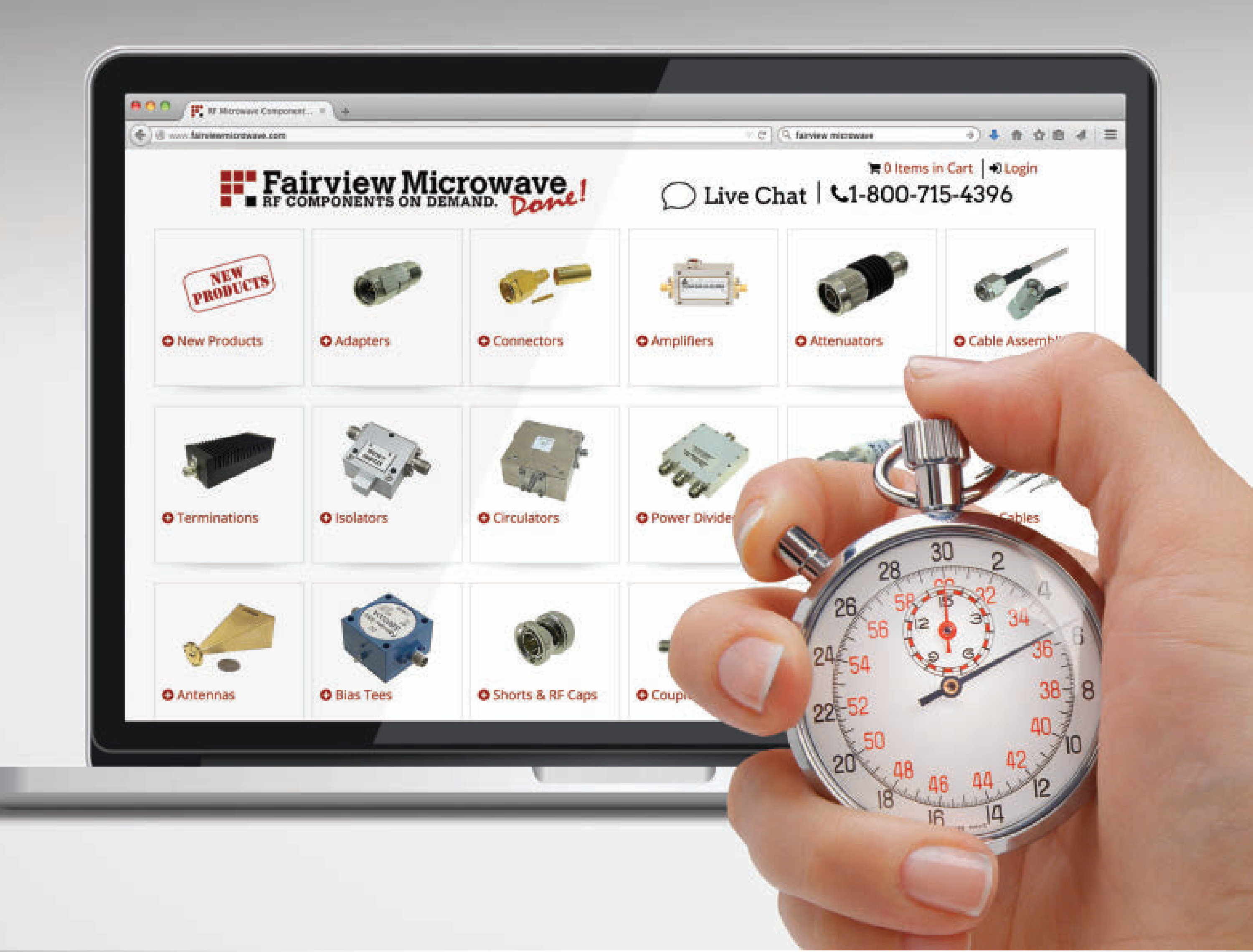
Step 2 – Design the Receiver Algorithms in MATLAB and Simulink

MATLAB and Simulink were used to design signal processing algorithms that receive and decode wireless transmissions. ADS-B uses short messages of 112 bits transmitted at 1 Mb/sec and a form of amplitude modulation called pulse position modulation. Detecting and decoding these messages presents several challenges typical in wireless receiver design, including:

- Detecting transmissions of interest using a message preamble
- Aligning the bit detection algorithm to the first message bit
- Making bit decisions based on modulated waveforms
- Calculating a checksum to verify the message is valid
- Decoding the individual bit fields.

The engineers used MATLAB to test a number of design ideas which allowed them to find a promising solution quickly. The design was then converted to Simulink and elaborations were made to the model to increase the clock rate and reduce the area of design.

The Right RF Parts.
Right Away.



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

fairviewmicrowave.com
1.800.715.4396

Fairview Microwave
RF COMPONENTS ON DEMAND. Done!

Step 3 – Verify the Design with Live RF Signals

Hardware-in-the-loop testing provided a good intermediate step to verify that the radio could be configured correctly and the software design remained error-free. Analog Devices provided an IIO System object that enabled the RF signal captured by the Zynq radio platform to be streamed directly into the Simulink model of the ADS-B receiver.

This incremental step was useful for verifying that the AD9361 transceiver was configured correctly, proving that the Simulink model could successfully demodulate the live ADS-B transmissions, and confirming that the algorithm design would work over the range of environmental conditions experienced by the radio interface. ***Figure 3*** shows an example of ADS-B waveform data captured off the air.

Step 4 – Generate Code and Verify Real-Time Performance

The C and HDL code needed to program the Zynq SoC was generated from the Simulink model of the ADS-B receiver using HDL Coder and MATLAB Coder. The Xilinx Vivado Design Suite was scripted behind the scenes to download the code to the Zynq radio platform, and then tests were run with pre-recorded IQ data to verify the Zynq code was functioning correctly.

The last step in the design-to-production process was to disconnect from the host PC and verify that the ADS-B receiver would run in real-time on the Zynq radio platform. In this demonstration, the receiver successfully decoded ADS-B transmissions from aircraft at a distance of over 50 miles, as shown in ***Figure 4***.

CONCLUSION

There were a number of elements that contributed to the successful design and deployment of the wireless receiver, including:

- The AD9361 transceiver used in this project is a high performance device that is easy to configure, which eliminated the need to develop a custom RF front-end design.
- MATLAB and Simulink provide a complete signal processing design environment for designing and simulating wireless receiver algorithms.
- The C and HDL code used to program the Zynq SoC were generated from a Simulink model, allowing the engineering team to dedicate most of their development time to the design of the receiver.
- Minimal debugging was rquired because the software code matched the design model, and small, incremental steps could be taken to move the design off the host PC and onto the embedded radio platform.

ADS-B is a relatively simple standard that provides a good test case to demonstrate the Model-Based Design approach to building a wireless receiver. Engineers who adopt Model-Based Design and the Zynq SDR platform should be able to follow this workflow to develop more complex and powerful QPSK-, QAM-, and LTE-based SDR systems.■

High Speed PXIe Digitizers

Spectrum Systementwicklung Microelectronic GmbH
Grosshansdorf, Germany

When it comes to modular instrumentation the PXI standard has become today's most popular choice for the automated test industry. With its high quality mechanical and electrical design, and wide range of suppliers and modules, PXI has proven to be the ideal platform for many industrial and mobile applications. Constantly evolving, the latest PXI Express (PXIe) systems are now based on PCI Express (PCIe) technology that provides data throughputs some 10 to 20 times faster than the earlier generation of PXI products. Faster throughput means shorter testing times and improved system productivity.

▲ *Fig. 1 The M4x series includes six new PXIe modules featuring two or four channels, 14- and 16-bit resolution and sampling rates of 130, 250 and 500 MSPS.*

To allow users to harness these capabilities, Spectrum GmbH has released its first high-speed digitizer product line based on the PXIe standard. The M4x.44xx series consists of six new digitizers (shown in ***Figure 1***) each packaged in a dual width 3U PXIe module and incorporating a four lane PCI Express Generation 2 interface. With data transfer speeds in excess of 1.7 GB/s the high-performance interface allows the new modules to be used in today's fastest PXIe mainframe systems (see ***Figure 2***).

However, it's not just data transfer speed that makes these new PXIe digitizers stand out. They also set new standards for sampling rate, resolution and channel density. Versions come with either two or four fully synchronous channels and resolutions of 14 bits, for sampling at rates up to 500 MS/s, or 16 bits for sampling at rates up to 130 or 250 MS/s.

With analog bandwidth up to 250 MHz the digitizers are ideally suited for use in ATE systems where electronic signals in the 1 to 200 MHz range need to be acquired and measured

with the best possible speed and precision. Typical applications include semiconductor and component testing, radar, wireless communications, medical science, transportation, power, physics, surveillance, aerospace and military.

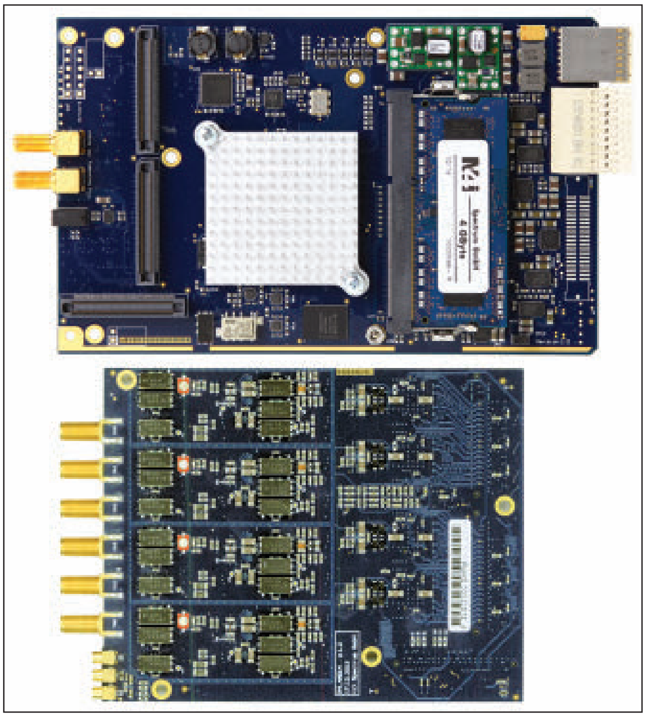
Designed to handle the widest range of input signals the modules incorporate an oscilloscope style front-end. Each channel has its own separate monolithic ADC and low noise signal conditioning circuitry. Fully programmable, the cards provide six gain input ranges (from ±200 mV up to ±10 V), selectable input impedance of 50 Ω or 1 MΩ and AC or DC coupling. A powerful trigger system and versatile clock adds to the overall flexibility. The trigger source can be any of the input channels, either of the two external trigger inputs, any of the eight PXI trigger lines or the PXI star trigger. Trigger modes include positive or negative edge, window (both edges), logical multi-source (pattern), software and rearm.

▲ *Fig. 2 The M4x.44xx series fits into any PXIe system with two free slots.*

The clocking system of the digitizers is cutting edge. The clock can be internally or externally generated (including using the 100 MHz PXIe differential clock and the 10 MHz PXI clock as a source). It has a built-in 10 MHz reference which, if required, can be synchronized with other reference sources. A fine-resolution mode is also available that allows clock rates to be selected with 1 Hz resolution. This useful feature makes it possible to program the sampling rate to match that of other devices or specific input signals.

Each module is equipped with a generous 4 GByte (2 Giga Samples) of on-board acquisition memory, making it simple to acquire long and complex signals. The capability is further enhanced by a variety of data acquisition and readout modes. These include single-shot capture (transient recording), streaming (FIFO), segmented (multiple recording), gated (gated sampling), or the combination of segmented acquisition of fast signals in parallel with slow continuous data recording (ABA mode). A trigger time stamp feature even identifies when events occurred and makes it easy to measure the time between them.

The high-resolution ADCs combine with the low noise front-end electronics and accurate clocks to ensure the digitizers deliver outstanding dynamic range and performance. For example, signal-to-noise ratios (SNR) are typically over 70 dB, spurious free dynamic range (SFDR) is better than 90 dB and total harmonic distortion (THD) is less than -70 dB. These specifications make it possible to detect small signal variations on larger ones and also allow better measurement repeatability, precision and accuracy.



▲ *Fig. 3 The M4x.44xx series has a new base board (top) that accommodates the existing M4i series digitizer (bottom) and generator hardware, allowing rapid product development.*

The new PXIe modules are based on Spectrum's proven M4i series of PCIe cards and deliver the same advanced features and signal quality. As the PXIe modules have a smaller footprint than their equivalent PCIe cards, a new base board was designed (see ***Figure 3***). A modular concept was used so that different digitizer or generator front-ends can be shared by both PCIe and PXIe platforms. This modularity will also enable the release of several new PXIe products within a short time — all sharing a common software interface that's similar to existing PCIe, PCI and PXIe products.

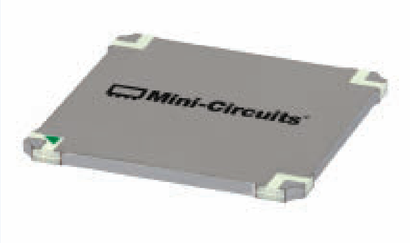
Those users wanting out-of-the-box operation of the digitizers can utilize the powerful SBench 6 program, which supports all the key functions of the digitizer as well as providing data display, storage, analysis and documentation. The program allows both oscilloscope and transient recording modes, including continuous data streaming. A base version of SBench 6 is provided free of charge.

Customers who need to develop their own programs can use the proven Spectrum drivers (available for Windows and Linux), which are included as standard. A set of programming examples is provided to illustrate the card's main signal capture functions. Support covers programming in Visual C++, Borland C++, Gnu C++, LabVIEW, MATLAB, Visual Basic, VB.NET, C#, J# and Delphi code.

The new M4x series modules come complete with software drivers and a two year manufacturer's warranty, together with free technical support, including software and firmware updates.

VENDOR**VIEW**

Spectrum Systementwicklung Microelectronic GmbH
Grosshansdorf, Germany
www.spectrum-instrumentation.com/en



225 to 450 MHz Low Loss Coupler Handles 200 W

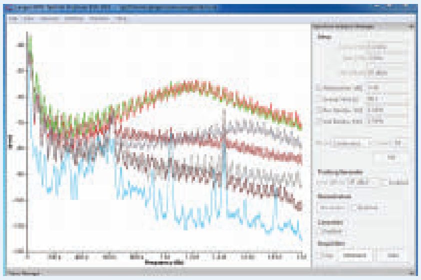
For high power RF systems, such as military and VHF/UHF radio, Mini-Circuits developed a bidirectional coupler that handles 200 W of combined DC and RF power. Covering 225 to 450 MHz, the MBDA-30-451HP provides a 30.5 dB coupled signal with ±0.85 dB flatness across the full band. Coupler directivity is typically 28 dB and mainline loss is 0.15 dB. The typical return loss for input, output and coupled ports is 30 dB. The high directivity ensures accurate sampling from the coupled port, and the good return loss extends over the entire frequency range.

The surface-mount, stripline design operates from –55° to +105°C and measures only 1.0" × 1.0" × 0.05". The coupler is fabricated using a laminated PCB process that includes wrap-around terminations for good solderability and easy visual inspection.

This coupler is a recent addition to Mini-Circuits' new series of stripline-based models that provide extremely high power handling in a miniature, low profile printed laminate form factor. The series is designed for use in power amplifiers and antenna feeds and where high temperature is common. The MBDA-30-451HP is available off-the-shelf.

VENDORVIEW

Mini-Circuits
Brooklyn, N.Y.
www.minicircuits.com



CS-ESA Software for EMC Analysis with Spectrum Analyzer

The ChipScan-ESA analysis software has been designed to record spectrum analyzer measurement curves. It has been custom-designed for EMC measurements in the field and utilizes Langer EMV-Technik GmbH's ESA1 emissions development system. The software allows users to record the type and properties of any number of near-field emission measurements and compare the curves quickly and easily. It is particularly suitable for pre- and post measurements during the EMC optimization of the device under test.

Features include a Trace Manager that allows users to annotate, color or offset the measurement curves, while the Spectrum Analyzer Manager enables users to control the most important spectrum analyzer functions via the user interface. The software enables a random number of measurement curves to be recorded at any one time, which are shown in one diagram for precise analysis. Also, individual measurement curves can be shown or hidden and each curve can be assigned a specific color and extensive comments added. The comments can be used to provide information about the measurement conditions that led to the respective curve.

The Live Trace feature allows a continuous display of the spectrum analyzer's measurements in the relevant window. During the live transmission, previously recorded measurement curves can be shown for comparison. Users can select this feature to check and further optimize the effect of an EMC countermeasure directly.

The ChipScan-ESA software can be used to record any number of measurements from a spectrum analyzer and store them. Measurement curves can be compared directly and user-defined correction curves can be created. Existing correction curves can be imported and applied.

The software can also be used to generate and export image data that may be required for documentation or for presentation. In addition, all measurement curves can be exported to R, Matlab or Excel as a comma separated value (CSV) list for further processing.

Langer EMV-Technik GmbH
Bannewitz, Germany
www.langer-emv.com

FIVE DAYS ■ THREE CONFERENCES ■ ONE EXHIBITION

EUROPEAN MICROWAVE WEEK 2016
EXCEL LONDON, UK
3 - 7 OCTOBER 2016

EuMW 2016
Microwaves Everywhere
EUROPEAN MICROWAVE WEEK
LONDON, UK
3-7 OCTOBER 2016
www.eumweek.com

EUROPEAN MICROWAVE WEEK 2016

REGISTRATION INFORMATION

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

EuMA
European Microwave Association

Official Publication: Microwave Journal

Organised by: horizon house

Supported by: IET The Institution of Engineering and Technology

Co-sponsored by: MTT-S

Co-sponsored by: IEEE

EuMIC 2016
The 11th European Microwave Integrated Circuits Conference
Co-sponsored by: GAAS, Electron Devices Society

46TH EUROPEAN MICROWAVE CONFERENCE 2016
The 46th European Microwave Conference
Co-sponsored by: APS

EuRAD 2016
The 13th European Radar Conference
Co-sponsored by: APS, AESS

Register online at

www.eumweek.com

EuMW 2016
Microwaves Everywhere

EUROPEAN MICROWAVE WEEK
LONDON, UK
3-7 OCTOBER 2016
www.eumweek.com

RETURNING TO LONDON FOR THE FIRST TIME IN 15 YEARS

THE ONLY EUROPEAN EVENT DEDICATED TO THE MICROWAVE AND RF INDUSTRY

EuMW 2016 will be held in the dynamic and historically rich city of London. Bringing industry and academia together, European Microwave Week 2016 is a FIVE day event, including THREE cutting edge conferences and ONE exciting trade and technology exhibition featuring leading players from across the globe. Concentrating on the needs of engineers, the event showcases the latest trends and developments that are widening the field of applied microwaves. It also offers you the opportunity for face-to-face interaction with those driving the future of microwave technology.

EuMW 2016 will see an estimated 1,700 - 2,000 conference delegates, over 4,000 visitors and in excess of 300 international exhibitors (inc. Asia & US).

REGISTRATION TO THE EXHIBITION IS FREE!

Pivotal to the week is the European Microwave Exhibition, which offers YOU the opportunity to see, first hand, the latest technological developments from global leaders in microwave technology.

The exhibition will provide an unrivalled opportunity for visitors to view and ask questions related to the latest products, components and materials from our extensive selection of international exhibitors. It will also feature exhibitor demonstrations, Industrial Workshops and the annual European Microwave Week Microwave Application Seminars (MicroApps).

- **International Companies** - meet the industry's biggest names and network on a global scale
- **Cutting-edge Technology** - exhibitors showcase the latest product innovations, offer hands-on demonstrations and provide the opportunity to talk technical with the experts
- **Technical Workshops** - get first hand technical advice and guidance from some of the industry's leading innovators

BE THERE

Exhibition Dates	Opening Times
Tuesday 4th October	09:30 - 18:00
Wednesday 5th October	09:30 - 17:30
Thursday 6th October	09:30 - 16:30

FAST TRACK BADGE RETRIEVAL

Entrance to the Exhibition is FREE and attending couldn't be easier.

VISITORS

Registering for the Exhibition

- Register as an Exhibition Visitor online at **www.eumweek.com**
- Receive a confirmation email with barcode
- Bring your barcode with you to the Exhibition
- Go to the Fast Track Check In Desk and print out your visitor badge
- Alternatively, you can register onsite at the self service terminals during the Exhibition

Please note NO visitor badges will be mailed out prior to the Exhibition.

EUROPEAN MICROWAVE WEEK
LONDON, UK
3-7 OCTOBER 2016
www.eumweek.com
EuMW 2016
Microwaves Everywhere

EUROPEAN MICROWAVE WEEK 2016
THE CONFERENCES

Don't miss Europe's premier microwave conference event. The 2016 week consists of three conferences and associated workshops:

- **European Microwave Integrated Circuits Conference (EuMIC) 3rd – 4th October 2016**
- **European Microwave Conference (EuMC) 4th – 6th October 2016**
- **European Radar Conference (EuRAD) 5th – 7th October 2016**
- **Plus Workshops and Short Courses (From 3rd October 2016)**
- **In addition, EuMW 2016 will include the 'Defence, Security and Space Forum' on 5th October 2016**

The three conferences specifically target ground breaking innovation in microwave research through a call for papers explicitly inviting the submission of presentations on the latest trends in the field, driven by industry roadmaps. The result is three superb conferences created from the very best papers. For a detailed description of the conferences, workshops and short courses please visit www.eumweek.com. The full conference programme can be downloaded from there.

FAST TRACK BADGE RETRIEVAL

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

CONFERENCE PRICES

There are TWO different rates available for the EuMW conferences:

- **ADVANCE DISCOUNTED RATE** – for all registrations up to and including 3rd September
- **STANDARD RATE** – for all registrations made after 3rd September

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

Online registration is open now, up to and during the event until 7th October 2016

DELEGATES

Registering for the Conference

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

- Sunday 2nd October (16:00 - 19:00)
- Monday 3rd October (08:00 – 17.00)
- Tuesday 4th October (08:00 – 18.00)
- Wednesday 5th October (08:00 – 17.00)
- Thursday 6th October (08:00 – 17.00)
- Friday 7th October (08:00 – 10.00)

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

CONFERENCE REGISTRATION INFORMATION
EUROPEAN MICROWAVE WEEK 2016, 3rd - 7th October, London, UK

Register Online at www.eumweek.com
ONLINE registration is open from 1st June 2016 up to and during the event until 7th October 2016.
ONSITE registration is open from 16:00 on 2nd October 2016.
ADVANCE DISCOUNTED RATE (up to and including 3rd September) STANDARD RATE (from 4th September & Onsite)

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

Eu*M*A membership fees: Professional £19/year, Student £11/year.

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

Reduced Rates for the conferences are also offered if you are a Student/Senior (Full-time students 30 years or younger and Seniors 65 or older as of 1st August 2016).

ADVANCE REGISTRATION CONFERENCE FEES (UP TO AND INCLUDING 3RD SEPT.)

CONFERENCE FEES	ADVANCE DISCOUNTED RATE			
	Society Member (*any of above)		Non Member	
1 Conference	Standard	Student/Sr.	Standard	Student/Sr.
EuMC	£355	£100	£500	£140
EuMIC	£270	£90	£380	£130
EuRAD	£240	£80	£340	£120
2 Conferences				
EuMC + EuMIC	£500	£190	£710	£270
EuMC + EuRAD	£480	£180	£680	£260
EuMIC + EuRAD	£410	£170	£580	£250
3 Conferences				
EuMC + EuMIC + EuRAD	£610	£270	£860	£390

STANDARD REGISTRATION CONFERENCE FEES (FROM 4TH SEPT. AND ONSITE)

CONFERENCE FEES	STANDARD RATE			
	Society Member (*any of above)		Non Member	
1 Conference	Standard	Student/Sr.	Standard	Student/Sr.
EuMC	£500	£140	£700	£200
EuMIC	£380	£130	£540	£190
EuRAD	£340	£120	£480	£170
2 Conferences				
EuMC + EuMIC	£710	£270	£1,000	£390
EuMC + EuRAD	£680	£260	£950	£370
EuMIC + EuRAD	£580	£250	£820	£360
3 Conferences				
EuMC + EuMIC + EuRAD	£860	£390	£1,210	£560

WORKSHOP AND SHORT COURSE FEES (ONE STANDARD RATE THROUGHOUT)

FEES	STANDARD RATE			
	Society Member (*any of above)		Non Member	
	Standard	Student/Sr.	Standard	Student/Sr.
Half day WITH Conference registration	£75	£60	£100	£75
Half day WITHOUT Conference registration	£100	£75	£130	£100
Full day WITH Conference registration	£105	£80	£135	£100
Full day WITHOUT Conference registration	£135	£105	£180	£130

THE EUMW CRUISE ON THE RIVER THAMES - 5th Oct 16

Tickets for the cruise are limited and are available on a first-come -first-served basis at the price of £25.00 for EuMW Delegates and £36.00 for guests.

Proceedings on USB Stick

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

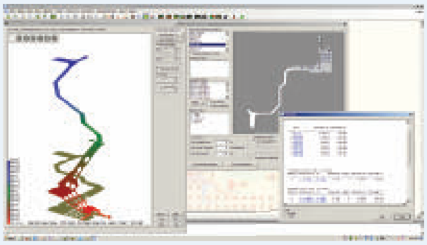
International Journal of Microwave and Wireless Technologies (8 issues per year)

International Journal combined with Eu*M*A membership: £50 for Professionals or £43 for Students.

Partner Programme and Social Events

Full Details and contacts for the Partner Programme and other Social Events can be obtained via the EuMW website **www.eumweek.com**

SPECIAL FORUMS & SESSIONS						
Date	**Time**	**Title**	**Location**	**No. of Days**	**Fee**	
Wednesday 5th October	11:20 - 19:00	Defence, Security & Space Forum	Rooms 8 to 11	1	£10 for delegates (those registered for EuMC, EuMIC or EuRAD)	£40 for all others (those not registered for a conference)



PADS Adds DC Drop and Thermal Analysis

Recognizing that product development is much more than schematic capture and board layout, Mentor Graphics has extended its PADS printed circuit board (PCB) design capabilities by adding HyperLynx® DC Drop and FloTHERM® XT tools to their PADS® PCB software, creating a comprehensive product development platform.

HyperLynx DC Drop enables designers to optimize the power distribution network on the PCB. The software can quickly analyze voltage drops caused by insufficient copper across power supply rails and identify layout areas that contain excessive current density. The HyperLynx DC Drop tool identifies problem areas in the design which would be difficult to find in the lab on a prototype, providing solutions in an easy-to-use environment. Results can be validated in layout to ensure that appropriate guidelines were followed, reducing prototype spins.

FloTHERM XT is a thermal simulation tool that considers all thermal aspects of the design: package, PCB layout, board structure and enclosure. As circuitry becomes faster, smaller and more densely packed, designers need to analyze thermal performance to ensure product reliability; physical testing is not always possible due to time and cost. FloTHERM XT interfaces with all major MCAD vendors and is compatible with all vendor-neutral file formats. The tool can be used as early as placement to identify the thermal effects of the entire system. Using the SmartParts™ feature, designers can build simple models in minutes, apply complex mechanical parts directly from MCAD, create custom CAD geometry and import detailed electronic assemblies from EDA tools.

The PADS HyperLynx DC Drop tool starts at $4,995, and the PADS FloTHERM XT tool starts at $12,500.

Mentor Graphics Corp.
Wilsonville, Ore.
(800) 547-3000
www.pads.com

CatalogUpdate

RF Power Reference Guide

Ampleon announced the launch of its "24/7 RF" e-book manual. This first edition guide is an essential reference for any engineer working on RF power amplifier designs and is available for free download at www.ampleon.com/24-7rf. Composed of RF applications, technologies and RF product portfolio sections, the 24/7 RF highlights design concepts and example schematic diagrams for each specific application sector. The 24/7 RF manual also includes sections on design support, cross references and packaging.

Ampleon
www.ampleon.com

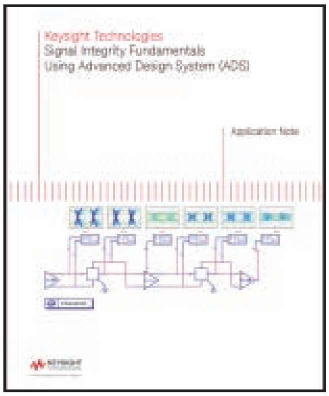
RF Test Systems Brochure

JFW Industries' new RF Test Systems Brochure showcases the company's custom capabilities in RF attenuation and switching systems as well as off-the-shelf automated testing solutions. JFW Industries Inc. designs and manufactures a wide range of attenuators, RF switches, power dividers, test accessories and systems within an ISO 9001:2008 certified quality system. These products meet or exceed the requirements of the most demanding applications. All JFW products are designed to the most exacting standards to provide innovative, high quality and cost effective solutions in a wide variety of global applications.

JFW Industries Inc.
www.jfwindustries.com

Signal Integrity App Notes

VENDORVIEW



"How do I...? Quick Answers to Your Signal Integrity Questions," is a new collection of six application notes from Keysight Technologies. Each application note is an independent list of questions and answers targeting a specific topic related to signal integrity. Find answers to FAQs such as, "How do I start learning about SI simulation?" — "What are the architectures of the high speed SERDES transmitter and receiver?"— and much more. Download all six application notes today.

Keysight Technologies Inc.
www.keysight.com/find/eesof-ads-si-examples

Millimeter Wave Supplement Catalog

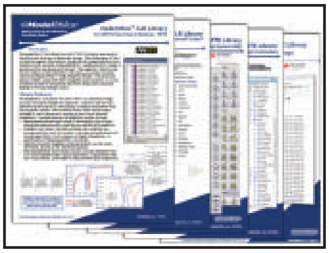
VENDORVIEW

MECA's newest publication, Millimeter Wave Supplement (Issue 2) includes their latest 5G ready components operating up to 40 GHz. Since 1961 MECA Electronics (Microwave Equipment & Components of America) has served the RF/microwave industry with equipment and passive components covering Hz to 40 GHz. MECA is a privately-held ISO9001:2008 certified global designer and manufacturer for the communications industry. Products are manufactured in the U.S. with 36-month warranty.

MECA Electronics Inc.
www.e-MECA.com

New Product Brochures

VENDORVIEW



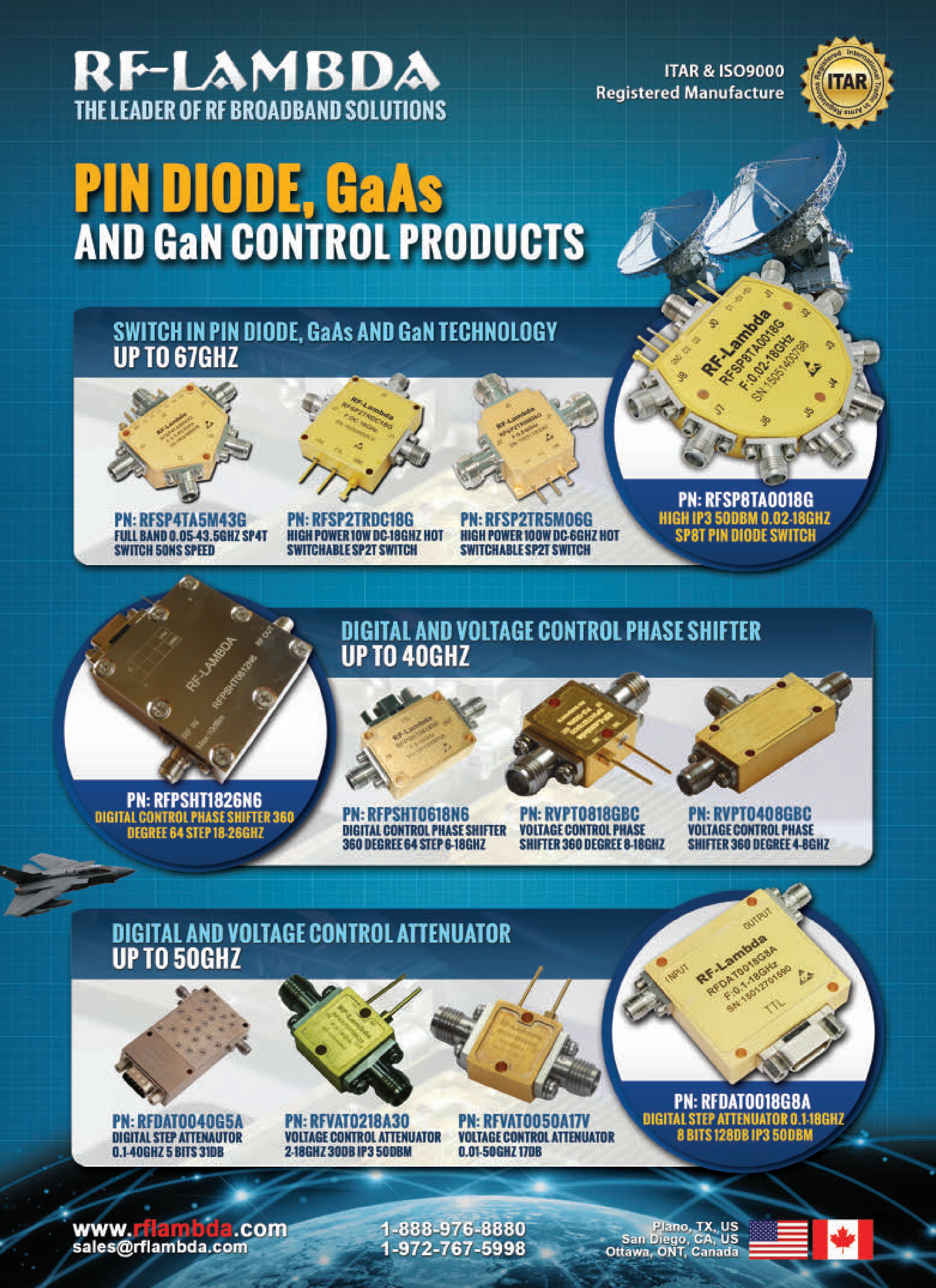
Modelithics has developed new brochures for recently released inaugural model libraries. The first Modelithics® CLR Library for ANSYS® HFSS™ was released in November 2015 and the first Modelithics® CLR Library for Sonnet® Suites™ was released in May 2016. New brochures for these libraries are now available along with those for the Modelithics COMPLETE Library for Keysight ADS, Keysight Genesys and NI AWR Design Environment. The brochures include advanced model feature highlights and an extensive list of commercial electronic parts available as Microwave Global Models™.

Modelithics Inc.
www.modelithics.com/Literature/Brochure

2016 Product Catalog

Request your new 2016 Tektronix and Keithley product catalog with product highlights covering general test and measurement, bench products and video test. This comprehensive catalog provides key product specifications, application details, links to primers, application notes, videos and online demos. Quick-reference selection charts on the complete range products including: oscilloscopes, logic analyzers, signal generators, real-time spectrum analyzers, digital multimeters, power analyzers, power supplies, frequency counter/timers and signal generators, and software solutions.

Tektronix Inc.
www.tektronix.com


RF-LAMBDA
THE LEADER OF RF BROADBAND SOLUTIONS
ITAR & ISO9000
Registered Manufacture
ITAR
PIN DIODE, GaAs
AND GaN CONTROL PRODUCTS
SWITCH IN PIN DIODE, GaAs AND GaN TECHNOLOGY
UP TO 67GHZ
PN: RFSP4TA5M43G
FULL BAND 0.05-43.5GHZ SP4T SWITCH 50NS SPEED
PN: RFSP2TRDC18G
HIGH POWER 10W DC-18GHZ HOT SWITCHABLE SP2T SWITCH
PN: RFSP2TR5M06G
HIGH POWER 100W DC-6GHZ HOT SWITCHABLE SP2T SWITCH
RF-Lambda
RFSP8TA0018G
F:0.02-18GHz
PN: RFSP8TA0018G
HIGH IP3 50DBM 0.02-18GHZ
SP8T PIN DIODE SWITCH
DIGITAL AND VOLTAGE CONTROL PHASE SHIFTER
UP TO 40GHZ
RF-LAMBDA
PN: RFPSHT1826N6
DIGITAL CONTROL PHASE SHIFTER 360 DEGREE 64 STEP 18-26GHZ
PN: RFPSHT0618N6
DIGITAL CONTROL PHASE SHIFTER 360 DEGREE 64 STEP 6-18GHZ
PN: RVPT0818GBC
VOLTAGE CONTROL PHASE SHIFTER 360 DEGREE 8-18GHZ
PN: RVPT0408GBC
VOLTAGE CONTROL PHASE SHIFTER 360 DEGREE 4-8GHZ
DIGITAL AND VOLTAGE CONTROL ATTENUATOR
UP TO 50GHZ
PN: RFDAT0040G5A
DIGITAL STEP ATTENAUTOR 0.1-40GHZ 5 BITS 31DB
PN: RFVAT0218A30
VOLTAGE CONTROL ATTENUATOR 2-18GHZ 30DB IP3 50DBM
PN: RFVAT0050A17V
VOLTAGE CONTROL ATTENUATOR 0.01-50GHZ 17DB
RF-Lambda
RFDAT0018G8A
F:0.1-18GHz
INPUT
OUTPUT
TTL
PN: RFDAT0018G8A
DIGITAL STEP ATTENUATOR 0.1-18GHZ 8 BITS 128DB IP3 50DBM
www.rflambda.com
sales@rflambda.com
1-888-976-8880
1-972-767-5998
Plano, TX, US
San Diego, CA, US
Ottawa, ONT, Canada

NEW PRODUCTS

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

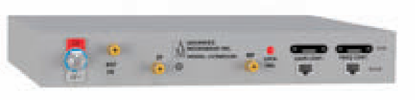
COMPONENTS

L-Band Nano Filter

3H's new L-Band Nano bandpass filter offers low in-band insertion loss of <1.35 dB and >50 dB attenuation at 650 and 1700 MHz while also meeting 45 dB attenuation at 3500 MHz to 7 GHz without the need for a lowpass filter. The filter size is 0.65" × 0.20" × 0.08" and is suitable for automated assembly, meets Mil-Std-202 conditions. For more information contact: sales@3hcomm.com or call (949) 529-1583

3H Communications
www.3Hcommunicationsystems.com

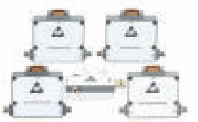
Up/Down-Converter



A complete remote converter system using a computer network control including I/OS, USB, RS232 and Ethernet (RG45). This product can be utilized as an up-converter, down-converter or both, built per customer application using computer controlling the gain up to 30 dB with 0.5 dB LSB. The gain and frequency can be changed by an operator using any computer by typing gain or frequency. This product comes with instructions and hardware/software needed to operate the converter.

Advanced Microwave Inc.
www.advmic.com

Digitally Controlled Programmable Attenuators



Fairview Microwave Inc. announced the release of their new digitally controlled programmable attenuators with performance up to 40 GHz and up to 60 dB attenuation range with 0.03 dB minimum step size. These programmable attenuators are commonly used in electronic warfare, military and space communication systems, radar and test and measurement applications. Fairview's digitally controlled attenuators perform the important function of adjusting the amplitude of signal levels in RF, microwave and millimeter wave systems. The designs utilize PIN diode semiconductor technology that generates extremely fast switching performance between attenuation states over wide frequency bands.

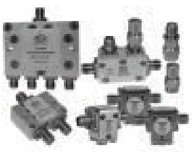
Fairview Microwave Inc.
www.fairviewmicrowave.com

LC Filters

MCV Microwave's LC filters feature center frequencies from 100 kHz to 10 GHz with excellent environmental performance in a rugged surface-mount and connectorized package. It is available in standard and special enhanced performance packages. MCV offers solutions in LC bandpass filters, LC band reject filters, LC highpass filters, LC lowpass filters, LC duplexers, LC multiplexers and LC tunable filters.

MCV Microwave
www.mcv-microwave.com

Millimeter Wave Products



MECA announced its new family of 5G ready millimeter wave power dividers, couplers, isolators, attenuators and terminations covering C to V-Bands. Ideal for Satcom, 5G and backhaul upgrade applications. Ranging from 2 and 4 way power dividers, 10 and 20 dB couplers, attenuators, terminations, isolators, bias tees and DC blocks covering up to 40 GHz with 2.92 mm connectors. Made in U.S. and 36-month warranty.

MECA Electronics Inc.
www.e-MECA.com.

Programmable Attenuator

Mini-Circuits' RCDAT-8000-90 is a general purpose programmable RF attenuator supporting frequencies from 1 to 8000 MHz with attenuation from 0 to 90 dB in 0.25 dB steps.

Its unique design maintains linear attenuation change per dB, even at the highest attenuation settings. The attenuator is controlled via USB or Ethernet-TCP/IP connections and supports both HTTP and Telnet network protocols. It comes housed in a rugged, shielded metal case with input/output SMA(F) RF ports (input/output ports are interchangeable), a standard Ethernet port, and a USB type Mini-B power and control port.

Mini–Circuits
www.minicircuits.com

Lowpass Filter

PMI Model No. 8LP7G-7050-CD-SFF is a lowpass filter with SMA female connectors in and out.

All filters will be machined and silver plated to provide the highest possible Q. Features include 0.5 passband DC to 7 GHz, VSWR in the passband 2.0:1 max., 1.5:1 goal - measured 1.4:1 and insertion loss (passband) 1 dB max. - measured 0.7 dB.

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

High Power 18 GHz SPDT Switch

RLC Electronics announced the addition of a high power 18 GHz SPDT switch with N connectors to its product capabilities. The switch can handle 1000 W at 100 MHz, 200 W at 4 GHz and 125 W at 18 GHz, and provides high-reliability, long life and excellent electrical performance characteristics over the frequency range (including high isolation). Options on the switch include operating mode (failsafe or latching) and coil voltage (12 or 28 VDC), as well as indicator circuitry and a TTL Driver. Control connector options include solder terminals, in addition to special power connectors such as MS and sub-D.

RLC Electronics
www.rlcelectronics.com

V-Band Waveguide Bandpass Filters

Models SWF-65302350-15-B1, SWF-61302350-15-B1, SWF-63302350-15-B1 and SWF-58302350-15-B1 are V-Band, waveguide bandpass filters designed for WiGig applications.

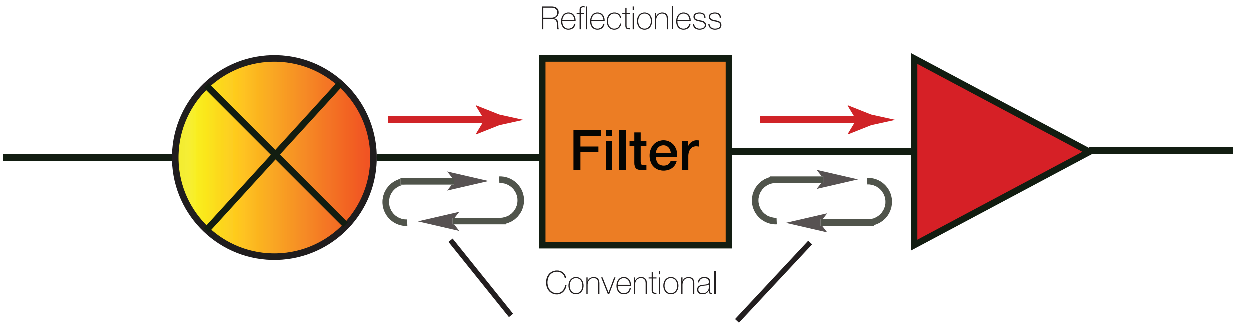
All four filters offer a 2 GHz passband with 50 dB typical rejection. The filters also have a nominal insertion loss of 2.5 dB. Since both low and high end cut off frequencies can be selected by modifying the design, custom models are available.

SAGE Millimeter
www.sagemillimeter.com

NOW! **Revolutionary**

ABSORPTIVE/REFLECTIONLESS FILTERS

DC to 21 GHz!



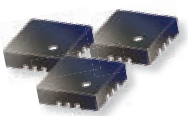
Eliminates standing waves out-of-band

Stops Signal Reflections Dead in Their Tracks!

$6.95[1] ea. (qty. 1000)

Mini-Circuits is proud to bring the industry a revolutionary breakthrough in the longstanding problem of signal reflections when embedding filters in RF systems. Whereas conventional filters are fully reflective in the stopband, our new X-series reflectionless filters are matched to 50Ω in the passband, stopband and transition band, eliminating intermods, ripples and other problems caused by reflections in the signal chain. They're perfect for pairing with non-linear devices such as mixers and multipliers, significantly reducing unwanted signals generated due to non-linearity and increasing system dynamic range by eliminating matching attenuators[2]. They'll change the way you think about using filters in your design!

Jump on the bandwagon, and place your order online today for delivery as soon as tomorrow. Need a custom design? Call us to talk to our engineers about a reflectionless filter for your system requirements.



X-Series

- ✓ High pass, low pass and band pass models
- ✓ Patented design eliminates in-band spurs
- ✓ Absorbs stopband signal power rather than reflecting it
- ✓ Good impedance match in passband stopband and transition
- ✓ Intrinsically Cascadable[3]
- ✓ Passbands from DC – to 21 GHz[4]
- ✓ Stopbands up to 35 GHz

Tiny 3x3mm QFN

[1] Small quantity samples available, $9.95 ea. (qty. 20)
[2] See application note AN-75-007 on our website
[3] See application note AN-75-008 on our website
[4] Defined to 3 dB cutoff point

Protected by U.S. Patent No. 8,392,495 and Chinese Patent No. ZL201080014266.I.
Patent applications 14/724976 (U.S.) and PCT/USIS/33118 (PCT) pending.

Mini-Circuits®

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

550 Rev Orig

NewProducts

Hybrid Splitter

The SLQ-K04 is an octave bandwidth quadrature hybrid splitter that covers the frequency range of 100 to 200 MHz. This unit offers a typical insertion loss across the band of 0.4 dB with a maximum amplitude unbalance of 1 dB. Other specifications include typical phase unbalance of 1 degree, isolation of 15 dB minimum and VSWR of 1.3:1 typical on all ports. Power handling capability is 1 W maximum. This 90 degree hybrid is available in a surface-mount package, 0.385" × 0.3" × 0.2" (L × W × H) with ENIG terminations and operates from -40° to + 85°C.

Synergy Microwave Corp.
www.synergymwave.com

CABLES & CONNECTORS

Waveguide Twists

VENDORVIEW

Pasternack introduced a new family of precision waveguide twists operating from 18 to 110 GHz across seven frequency bands. Ideal for systems requiring a gradual turn in the polarization and waveform, these twists are designed and constructed to prevent unwanted distortion in the signal's transmission. Pasternack's new waveguide twists are useful components when building a waveguide system, as they allow the waveguide to be turned at a precise angle in order to meet the mechanical and electrical constraints of the overall system. These waveguide twists are also beneficial in applications to ensure correct polarization of the signal.

Pasternack
www.pasternack.com

Precision Right Angle Adapters

SGMC Microwave has an extensive line of 2.4 mm, 2.92 mm, 3.5 mm and SMA precision right angle in-series and between-series adapters suited for all your application needs.

All of SGMC's right angle connectors are internally swept and mode free through their respective frequencies. Body components are manufactured from corrosion resistant Type 303 stainless steel, passivated and SGMC's one piece center contacts are manufactured from beryllium copper, gold plated. Ready to ship today from the company's stocking distributor, C.W. Swift & Associates (sales@cwswift.com). Quality, performance and reliability you can count on, from SGMC Microwave.

SGMC Microwave
www.sgmcmicrowave.com

AMPLIFIERS

Solid-State Pulsed Amplifiers

VENDORVIEW

There is now a very attractive alternative to Traveling Wave Tube Amplifiers (TWTA) for automotive and military EMC radiated immunity susceptibility testing, as well as radar and communication applications. AR's new offerings include the following frequency ranges: 1.2 to 1.4 GHz, 2.7 to 3.1 GHz, 1 to 2 GHz and 2 to 4 GHz. Output levels range from 1 to 150 kW. Designs can also be tailored to suit your specific application. Numerous applications include, but are not limited to automotive, MIL STD 464, DO-160 and military radar.

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

8 W GaN Power Amplifier

Model AHP-29043925-G1 is one of Ducommun's newly developed amplifiers that utilize GaN technology in order to achieve high power with small footprint. The amplifier operates within the frequency range of 27 to 31 GHz, with small signal gain at 25 dB and saturated power at 39 dBm. This high power amplifier in Ka-Band is ideal for satellite and ground communications. Ducommun also offers higher power models of this frequency range, contact Ducommun sales for more information.

Ducommun Inc.
www.ducommun.com

UltraCMOS® MPAC – Doherty

The UltraCMOS® PE46130 and PE46140 join the PE46120 MPAC product family in offering phase and amplitude control for Doherty power amplifier applications. The PE46130 provides excellent phase and amplitude accuracy from 2.3 to 2.7 GHz, and the PE46140 extends from 3.4 to 3.8 GHz. Each monolithic phase and amplitude controller (MPAC) integrates a 90-degree hybrid splitter, digital phase shifters, digital step attenuator and a digital SPI interface on a single die.

Peregrine Semiconductor
www.psemi.com

RF Power LDMOS Transistor

VENDORVIEW

Richardson RFPD Inc. announced the availability and full design support capabilities for a new LDMOS transistor from NXP Semiconductors. The MRF8VP13350NR3 is a 350 W CW transistor designed for industrial, scientific and medical (ISM) applications in the 700 to 1300 MHz frequency range. It is capable of 350 W CW or pulse power in narrowband operation. The new device is internally input matched for

NewProducts

ease of use, and it can be used single-ended or in a push-pull configuration. It is qualified up to a maximum of 50 VDD operation and includes integrated ESD protection.
Richardson RFPD
www.richardsonrfpd.com

SOURCES

Microwave Signal Generators

VENDORVIEW

Berkeley Nucleonics released option "FS" for the 845 series microwave signal generators capable of providing extremely fast sweeps in frequency and power as low as 10 us. This performance offering, relative to the price and package, is unmatched within the industry and provide a distinct advantage in defense applications. In contrast to traditional analog sweeps, fast digital sweeps can be synchronized at any time during the sweep and yield very precise frequencies throughout the sweep.
Berkeley Nucleonics
www.berkeleynucleonics.com

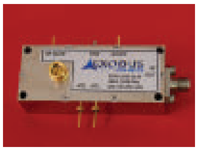
Miniature Low Noise PLL Modules

CTS Corp. announced a new family of phase-lock-loop (PLL) modules, with two initial members, models VFJA1490 and VFJA1491, both supplied in miniature surface-mount packages measuring just 9 mm × 14 mm. The VFJA1490 models work with LVPECL, LVCMOS, and sinewave inputs from 10 to 200 MHz and provide LVPECL outputs at frequencies to 1 GHz with extremely low jitter of 65 fs measured 12 kHz to 20 MHz from the carrier. The phase noise is also low, at just -145 dBc/Hz offset 100 kHz from a 500 MHz carrier.
CTS Corp.
www.ctscorp.com

Dielectric Resonator Oscillator

VENDORVIEW

Exodus Dynamics introduced the EDRO-1035-10.00, a 1 W, 10 GHz ultra low noise dielectric resonator oscillator (DRO), with



TTL RF muting and variable attenuation feature. The unit draws only 360 mA with +12 VDC and provides 19 dB of attenuation with -3 VDC supply.
Exodus Dynamics
www.exodusdynamics.com

Voltage-Controlled Oscillator

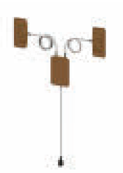
VENDORVIEW

Z-Communications Inc. announced a RoHS compliant voltage-controlled oscillator (VCO) model TRO1800A-LF. The TRO1800A-LF is the first in a line of ceramic resonator VCOs which saves precious board space while delivering exceptional phase noise performance. This innovative VCO covers the frequency of 1800 MHz within a tuning voltage range of 0.5 to 4.5 VDC while featuring a spectrally clean signal of -117 dBc/Hz at 10 kHz offset.
Z-Communications Inc.
www.zcomm.com

ANTENNAS

Body Worn Antennas

VENDORVIEW

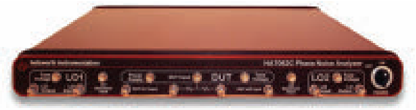


Southwest Antennas offers a full line of body worn antennas for dismounted user applications or covert surveillance operations where the radio and antenna system needs to be concealed on the body. These antennas weigh less than an ounce, and are tuned specifically to be used next to or close to the human body. Southwest Antennas offers models designed to operate in the UHF, L, and S-Band frequency ranges.
Southwest Antennas
www.southwestantennas.com

TEST EQUIPMENT

Phase Noise Analyzer

VENDORVIEW



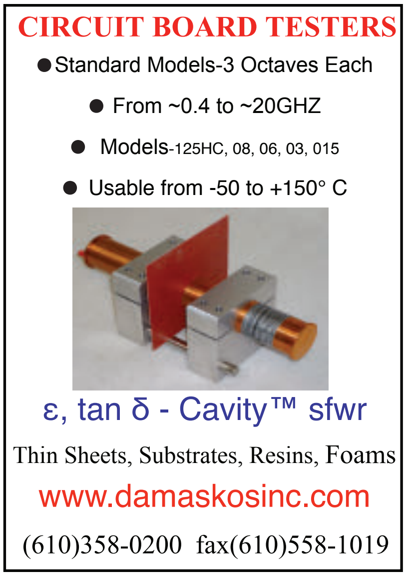
The new HA7062C real time phase noise analyzer is a cross correlation analyzer offering blazing fast data acquisition speeds with 0.1 Hz to 40 MHz measurement offsets. Accuracy is critical and is backed by an ANSI z540 calibration for NIST traceable data. Simultaneous AM/PM measurements with AM/PM isolation. Intuitive absolute and residual measurements and so much more. Holzworth Instrumentation has been designing, manufacturing, and utilizing industry leading phase noise analysis tools for more than a decade. Ultra low phase noise is its business.
Holzworth Instrumentation
www.holzworth.com

Assembly and Test Equipment

Since 1966, West • Bond Inc. has been a design and manufacturer of assembly and test equipment for the microelectronic industry in Southern California. Including automatic, semiautomatic and manual ESD protected bonders, with ultrasonic, thermosonic, and thermocompression wire/ribbon capability. Included in product line are eutectic and epoxy die bonders, insulated wire bonders, and pull testers with its patented X-Y-Z, 8/1 ratio micromanipulator.
West • Bond Inc.
www.westbond.com


Advanced Switch Technology
Switches for the Telecom Industry
WAVEGUIDE SWITCHES - COAXIAL SWITCHES - DUAL SWITCHES
WE ARE THE WAVEGUIDE & COAXIAL SWITCH EXPERTS
YOUR #1 SOURCE FOR MICROWAVE SWITCHES
QUALITY, SERVICE & QUICK DELIVERIES UNMATCHED IN THE INDUSTRY
754 Fortune Crescent, Kingston, ON, K7P 2T3, Canada
Tel: 613 384 3939 - Fax: 613 384 5026
e-mail: info@astswitch.com
www.astswitch.com
VISA

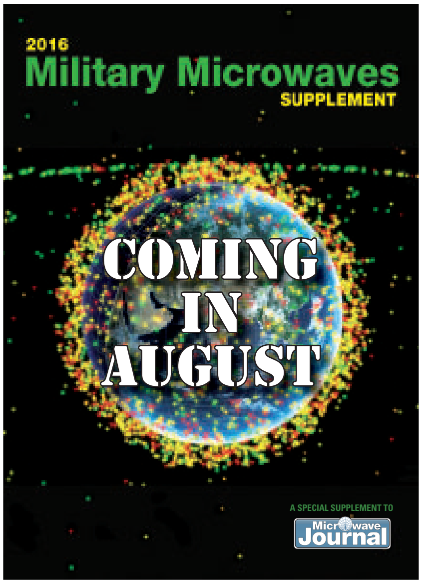

ES MICROWAVE LLC.
Since 1985 we have offered our custom design filters and sub-assemblies in combline, interdigital and suspended-substrate technologies.
Broadband
Suspended-Substrate
Filters, Diplexers, Triplexers, Quadruplexers, Quintuplexers, Sextuplexers...
DC-40 GHz Filters
Multiplexers &
Switch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


CIRCUIT BOARD TESTERS
● Standard Models-3 Octaves Each
● From ~0.4 to ~20GHZ
● Models-125HC, 08, 06, 03, 015
● Usable from -50 to +150° C
ε, tan δ - Cavity™ sfwr
Thin Sheets, Substrates, Resins, Foams
www.damaskosinc.com
(610)358-0200 fax(610)558-1019

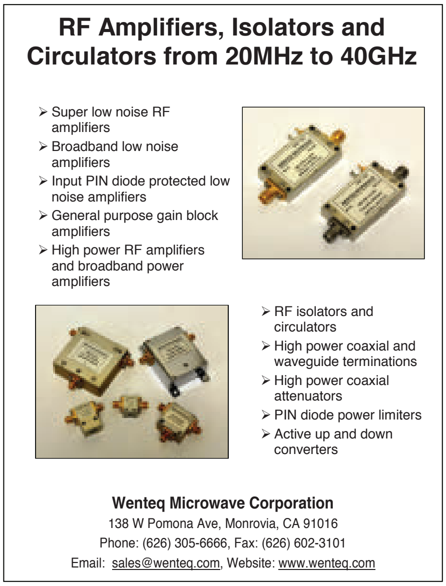

KR Electronics
www.krfilters.com
ISO 9001:2008 Certified
Custom & Standard Filters
40+ Years of Military & Commercial Applications
Bandpass
Anti-Aliasing
Highpass
Video Filters
Diplexers
Delay Equalized
Surface Mount
Lowpass
Notch
Root Cosine
Equalizers
Linear Phase
Absorptive
Matched
KR Electronics,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


ELECTRICALLY CONDUCTIVE
ADHESIVE SYSTEMS
• Epoxies
• Silicones
• Sodium silicate compounds
MASTERBOND
Celebrating our 40 year anniversary
+1.201.343.8983 • www.masterbond.com


SECTOR MICROWAVE
Don't sweat over your switching needs.
Our Waveguide and Coaxial switches are COOL!!
smi
(631)242-2300 PHONE (631)242-8158 FAX
WWW.SECTORMICROWAVE.COM


2016
Military Microwaves
SUPPLEMENT
COMING IN AUGUST
A SPECIAL SUPPLEMENT TO
Microwave Journal


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


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

Understanding Quartz Crystals and Oscillators

Ramón M. Cerda

Our world runs on quartz crystal oscillators. Every electronic system has one — or is locked to one — and every EE has "learned" about them in college and likely seen their schematics in countless block diagrams. Yet, unless you are designing crystal oscillators, you have probably relegated them to the black arts, like antennas. Even if you are tasked with specifying or designing one, learning how to do so is challenging. That's what Ramón Cerda found, and that's what prompted him to write an understandable text for the practicing engineer.

Cerda's goal is to "demystify the field." He does so in 15 chapters, beginning with a thorough discussion of quartz crystals and their piezoelectric properties (discovered by Jacques and Pierre Curie in 1880), encompassing the nuances of flicker noise, drive level sensitivity and the effects of acceleration. Subsequent chapters address the design of crystal oscillators, including tutorials on oscillator theory and choosing the appropriate crystal for the application. A single chapter is devoted to phase noise and jitter, another to specifying performance based on the type of oscillator (clock, voltage controlled, temperature compensated, oven controlled and variations). The remaining chapters address specific oscillator types (Pierce-Gate, Colpitts and Butler), frequency multiplication techniques, characterization (Allan Variance) and testing (both electrical and environmental). For completeness, the book discusses MEMS resonators, given their widespread adoption and use in oscillators. Cerda compares the performance obtained from MEMS to crystal oscillators, concluding that present MEMS oscillators, while having advantages and a "bright future," have higher phase noise and jitter.

"Understanding Quartz Crystals and Oscillators" is understandable, thorough and a good reference to have on your bookshelf.

To order this book, contact:

Artech House
www.artechhouse.com
ISBN: 978-1-60807-118-0
299 pages
$197
Available in hardcover and eBook formats

eLEARNING center

Presented by: Microwave Journal

Scan page using layar app

July Short Course Webinars

Technical Education Training
Improving Base Station Design
Sponsored by: IDT
Live webcast: 7/20/16

Register to attend at mwjournal.com/webinars

Past Webinars On Demand

Technical Education Training Series

- The Power of Testing IoT Devices in All Phases of the Product Lifecycle
- Radar Signal Generation with up to 2 GHz Bandwidth for Single-Channel and Multichannel Receiver Testing
- Faster Analysis of Complex RF Signals
- 802.11ax – High Efficiency Wireless Improving User Throughput in Dense User Environments
- Practical Antenna Design for Advanced Wireless Products
- Expanding the Possibilities of Cellular Wireless Infrastructure with GaN
- Designing Next-Gen Cellular and Wi-Fi Switches Using RF SOI Technology
- Improving Reliability and Efficiency with Solid State Spatial Combining Technology
- Effect of Conductor Profile Structure on Propagation in Transmission Lines
- Minimize Your Y-Factor Noise Figure Measurement Uncertainty
- Doherty at Eighty
- Millimeter Wave and E-Band Vector Network Analyzer Solutions
- Making Noise Work for You
- RF and Microwave Heating Simulation and Application Design
- Critical Aspects of Dielectric Constant Properties for High Frequency Circuit Design
- Demystifying MIMO Radar and Conventional Equivalents

RF/Microwave Training Series

Presented by: Besser Associates

- Introduction to Radar
- RF and Microwave Filters
- Mixers and Frequency Conversion

CST Webinar Series

- Hybrid Simulation for Electrically Large Aerospace Platforms
- Simulation of Implanted Medical Devices

Innovations in EDA

Presented by: Keysight Technologies

- Advances in High Power RF Design
- 5G Physical Layer Modeling: A Communication System Architect's Guide
- Designing X-Band PAs Using SMT Plastic Packaged GaN Transistors

Keysight Technologies Webcast

- LTE in the Unlicensed Spectrum
- Using a Multi-Touch UI to Streamline Signal Analyzer Measurements
- Testing Voice Over LTE on Your Device

Keysight RF and Microwave Basics Education Series

- Simulating, Generating and Analyzing Custom-Modulated Satellite Signals

Keysight FieldFox Series

- Wireless Site Survey, Spectrum Monitoring and Interference Analysis

Advertising Index

Advertisers in blue are enabled with the layar app

Advertiser	Page No.
Advanced Switch Technology	117
American Technical Ceramics	59
AMTA 2016	108
Anokiwave	33
Anritsu Company	13
API Technologies, Inmet	97
API Technologies, Weinschel	103
AR RF/Microwave Instrumentation	71
Artech House	118
B&Z Technologies, LLC	25
Berkeley Nucleonics Corp.	67
Bird Technologies	56
Boonton Electronics (a Wireless Telecom Group Company)	COV 2
Cernex, Inc.	114
Ciao Wireless, Inc.	42
Coilcraft	15
CPI Beverly Microwave Division	6
CST of America, Inc.	21
Custom MMIC	41
Damaskos Inc.	117
dBm Corp.	28
EDI CON China 2017	60
EDI CON USA 2016	91, COV 3
Empower RF Systems, Inc.	26
ES Microwave, LLC	117
ET Industries	72
EuMW 2016	107, 115
EuMW Defence, Security and Space Forum 2016	46
Exodus Advanced Communications, Corp.	32
Exodus Dynamics	78
Fairview Microwave	99
Frontlynk Technologies Inc.	86
G.T. Microwave Inc.	84
Herotek, Inc.	18
Holzworth Instrumentation	22
Huber + Suhner AG	75
IFI, a unit of AMETEK CTS	44
K&L Microwave, Inc.	7
Keysight Technologies	29, 81
KR Electronics, Inc.	117
L-3 Narda-MITEQ	37
Linear Technology Corporation	27
Master Bond Inc.	117
MCV Microwave	40
MECA Electronics, Inc.	3
MegaPhase	95
Mercury Systems, Inc.	39
MiCIAN GmbH	100
Microwave Journal	52, 58, 117, 119
Mini-Circuits	4-5, 16, 35, 49, 50, 61, 87, 101, 113, 121
National Instruments	9, 11
NI Microwave Components	68
NoiseWave Corp.	8
Norden Millimeter Inc.	70
OML Inc.	63
Pasternack	76, 77
Planar Monolithics Industries, Inc.	65
Pletronics, Inc.	64
Polyphase Microwave, Inc.	56
Pulsar Microwave Corporation	66
Quintech Electronics & Communications Inc.	82
R&D Interconnect Solutions	30
Reactel, Incorporated	45
Remcom	85
RF-Lambda	31, 73, 111
Richardson RFPD	19
Rogers Corporation	57
Rosenberger	93
SAF Tehnika	48
Sage Millimeter, Inc.	23
Sector Microwave Industries, Inc.	117
Skyworks Solutions, Inc.	79
Special Hermetic Products, Inc.	117
Spectrum Elektrotechnik GmbH	109
Stanford Research Systems	69
Synergy Microwave Corporation	55, 105
Taconic	89
Teledyne Microwave Solutions	53
Waveline Inc.	116
Weinschel Associates	34
Wenteq Microwave Corporation	117
Wenzel Associates, Inc.	80
Werlatone, Inc.	COV 4
WIN Semiconductors Corp.	83
Z-Communications, Inc.	58

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
Oasis Guo
ACT International
Tel: 86-13011108861
oasisg@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

From Powder to Product – Trans-Tech Does it All

Among the many world-class, high-volume manufacturing facilities located around the world within Skyworks, there is a small gem in Adamstown, Md. called Trans-Tech. Trans-Tech is a wholly owned subsidiary of Skyworks Solutions providing complementary state-of-the-art RF/microwave ceramic products. The company designs and manufactures a complete line of high quality, low cost ceramic based components for a number of applications within the RF/microwave business sector. Their product portfolio includes dielectric resonators and coaxial transmission line elements for DRO and VCO applications, ceramic bandpass filters, ferrite and garnet material for circulators/isolators. They also design and manufacture thermal barrier coatings and bio-ceramics. Trans-Tech services the wireless infrastructure, aerospace, automotive, military and medical markets — a broad reach for a small business.

The company was founded in Rockville, Md. by Dr. Herbert H. Greger in 1955 and was acquired by Alpha Industries, now Skyworks, in 1981. The company currently operates in 140,000 square feet of space in two locations employing about 240 people. Their locations include a circulator and isolator design team in Ireland, as well as sales, marketing engineering and quality workforce in China. Trans-Tech purchased MACOM's isolator business in 2011 and has been improving the ceramic resonator material by reducing its size while maintaining high RF performance levels. This has been accomplished using new ferrite material formulations producing a higher dielectric constant than previously achievable.

Trans-Tech's material expertise sets them apart from other manufacturers because they control the whole process from powder to finished product. The company performs all of the processing from raw materials, forming, firing, finishing, to assembly and test. Trans-Tech uses about 75 different elements and more than 400 compositions of materials to produce these specialized, custom products that provide high performance end products to their customers. For ceramic processing, Trans-Tech does powder preparation via solid-state reactions, vibratory milling, ball milling and spray drying. Their forming processes include dry pressing, extrusion and isostatic presses that use up to 60,000 psi of pressure. Sintering is performed via tunnel, periodic, bottom load and air-fired/pressurized kilns and grinding is performed using many methods including CNC, surface, lapping, through-feed, ID and OD slicing and centerless. They also have extensive analysis equipment to measure the physical and electrical properties of their ceramics and end products.

Trans-Tech is working on replacing typical cavity style filters with a ceramic based SMT or connectorized filters with power handling >100 W. They are also working to extend the typical 5.5 GHz frequency limit with ceramics, achieving designs up to 7 GHz. Work is ongoing to reduce resonator sizes and extend their frequency for 5G applications and others in the future.

As a small business within Skyworks, the culture is a family atmosphere driven to be agile. They respond quickly to customer needs and have an innovative spirit to solve problems with their materials expertise. Many workers have been there 30-plus years and some 40-plus years, demonstrating the close knit family environment. While they are a small group within Skyworks, their products are found in the most demanding wireless applications around the world as they continue to invent new material solutions for the wireless industry.

www.skyworksinc.com

WERLATONE®

Mismatch Tolerant®

High Power | Efficiency | Bandwidth

HIGH POWER COMBINERS
BIG STUFF!

- **Power Levels to 20 kW CW**
- Low Insertion Loss
- Isolated and Non-Isolated Designs
- Rack Mount, Drawer Mount, Radial Type
- Coherent and Non-Coherent Combining

A few of our Customer driven designs.

Model	Type	Frequency (MHz)	Power (W CW)	Insertion Loss (dB)	Isolation (dB)	Size (Inches)
D8265	2-Way	1-50	5,000	0.3	20	15.5 x 11.75 x 5.25
D2075	2-Way	1.5-30	6,000	0.2	20	15.5 x 11.75 x 5.25
D8969	2-Way	1.5-30	12,500	0.2	20	17 x 17 x 8
D6139	4-Way	1.5-32	5,000	0.25	20	13 x 11 x 5
D6774	4-Way	1.5-32	20,000	0.3	20	21 x 17.25 x 11
D6846	6-Way	1.5-30	4,000	0.35	20	3U, 19" Rack
D8421	8-Way	1.5-30	12,000	0.3	20	22.5 x 19.5 x 8.75
D7685	4-Way	2-100	2,500	0.5	20	15 x 13 x 5.5
D2786	4-Way	20-150	4,000	0.5	20	18 x 17 x 5
D6078	2-Way	100-500	2,000	0.25	20	13 x 7 x 2.25
H7521	2-Way (180°)	200-400	2,500	0.3	20	15 x 10 x 2
D7502	2-Way	400-1000	2,500	0.25	NI*	9.38 x 3.38 x 1.25

*NI = No Isolating Terminations

Werlatone, Inc.
We Are High Power

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

Directional Couplers

Combiners/Dividers

90° Hybrids

180° Hybrids

Absorptive Filters