Vol. 54 • No. 8

August 2011

Microwave Journal

SATCOM TRENDS

MVP
Sonnet Version Thirteen

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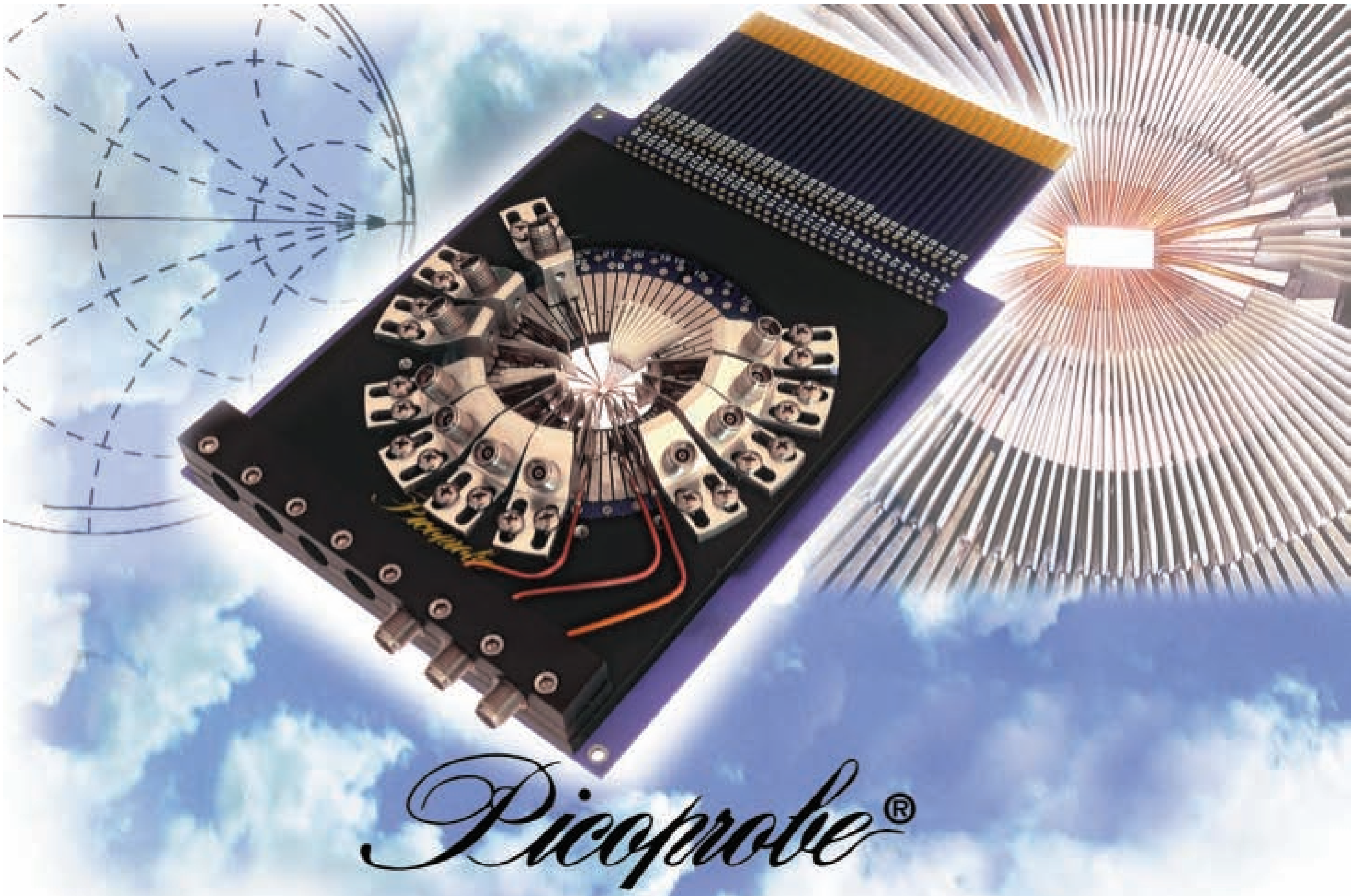

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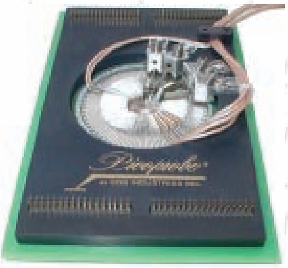

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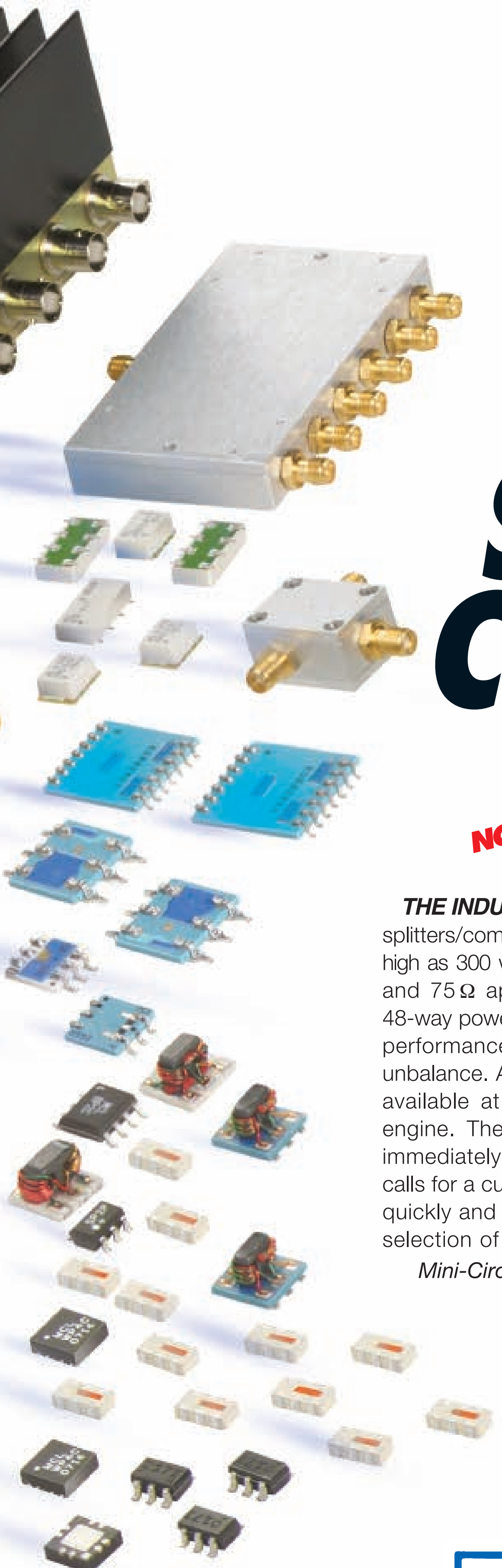

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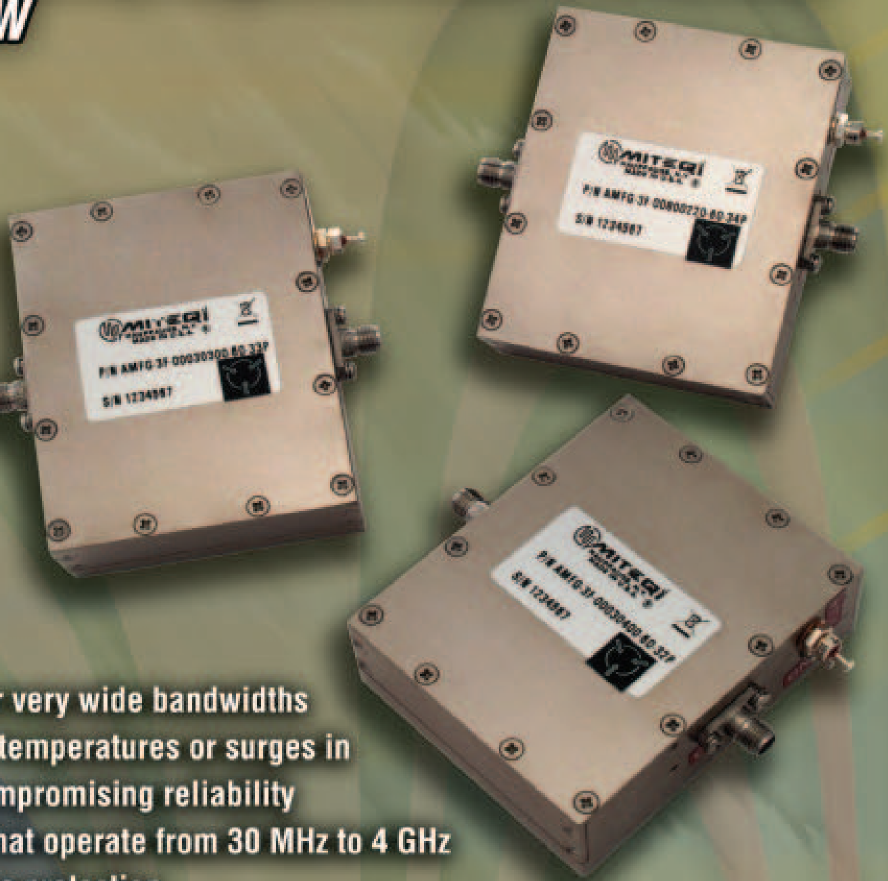

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AMFG-3F-00030400-60-32P	0.03-4	40	2	6	2:2	32	35	750
AMFG-3F-00040250-60-33P	0.04-2.5	40	2	6	2:2.2	33	35.5	670
AMFG-3F-00050100-50-34P	0.5-1	40	1.5	5	1.8:1.8	34	37	750
AMFG-3F-00230025-30-37P	0.23-0.25	50	1	3	1.5:2	37	40	250
AMFG-3F-00700380-60-35P	0.7-3.8	40	2	6	2.5:2.5	35	39	1500
AMFG-3F-00800220-60-35P	0.8-2.2	40	1.5	6	2:2	35	38	900
AMFG-2F-01000300-60-35P	1-3	40	2	6	2:2.2	35	39	1500

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Microwave Journal

AUGUST 2011 VOL. 54 • NO. 8

FEATURES

COVER FEATURE

MVP: MOST VALUABLE PRODUCT

SPECIAL REPORTS

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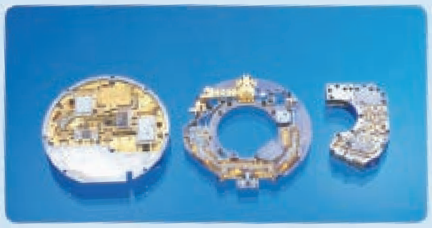

Photo courtesy of U.S. DoD

Microwave Journal

TECHNICAL FEATURES

PRODUCT FEATURES

DEPARTMENTS

Erratum: Last month's Cover Feature "3D EMC/EMI Simulation of Automotive Multimedia Systems" was co-authored by Ralf Kakerow from Continental Automotive of Wetzlar, Germany, and Martin Timm and Matthias Tröscher of CST, Munich, Germany.

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Free Webinars

Agilent Innovations Webcast
Optimizing Battery Operating Time of Wireless Devices

This webinar presents an Agilent feature called "seamless measurement ranging" that overcomes the limitations of traditional techniques for battery current drain testing.

Available on demand after: 8/10/11
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CST: EMC/EMI Series
EMC/E3 Analysis: Rotorcraft Electrical System Exposed to Antenna Radiation and Incident EMP

The bi-directional interaction between electromagnetic fields and the complex cable system is examined, including direct time-domain analysis of voltages and currents induced in cable systems along with nonlinear components to assess the transient protection devices.

Available on demand after: 8/4/11
Sponsored by **CST**

CST: RF & Microwave Series
Optimization of a Reflector Antenna System

This webinar will describe how the new smart assembly mode simulation system in CST STUDIO SUITE 2011 enables the engineer to model complex reflector antenna and feed systems efficiently and accurately.

Live webcast: 8/18/11, 11:30 am ET
Sponsored by **CST**

CST: EDA Series
EDA Workflow from Layout to Eye Diagram

This webinar will present 3D EM Signal Integrity simulation using CST MICROWAVE STUDIO. It will demonstrate the PCB layout import and the 3D full wave simulation of a realistic multilayer PCB. Standard outputs like S-parameters, Time Domain Reflection and Mode Conversion will be shown along with eye diagram and field distribution.

Live webcast: 8/25/11, 11:30 am ET
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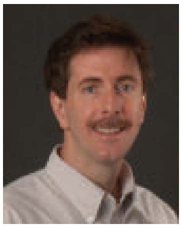
Executive Interview



Scott Langdon, CTO and Co-founder of **Remcom**, discusses the computational EM market, the state of simulation technology and the company's recent contract with the U.S. Department of Homeland Security.

Live Events

MWJ editors travel to Austin, TX for **National Instruments Week** (August 2-4) and **IEEE EMC** in Long Beach, CA (August 16-18). Both events draw large crowds of engineers in high speed and RF/microwave test and design. Read our web exclusive reports from both venues.

Online Technical Papers

Application Guide to RF Coaxial Connectors and Cables
Michael Hannon and Pat Malloy, AR Worldwide

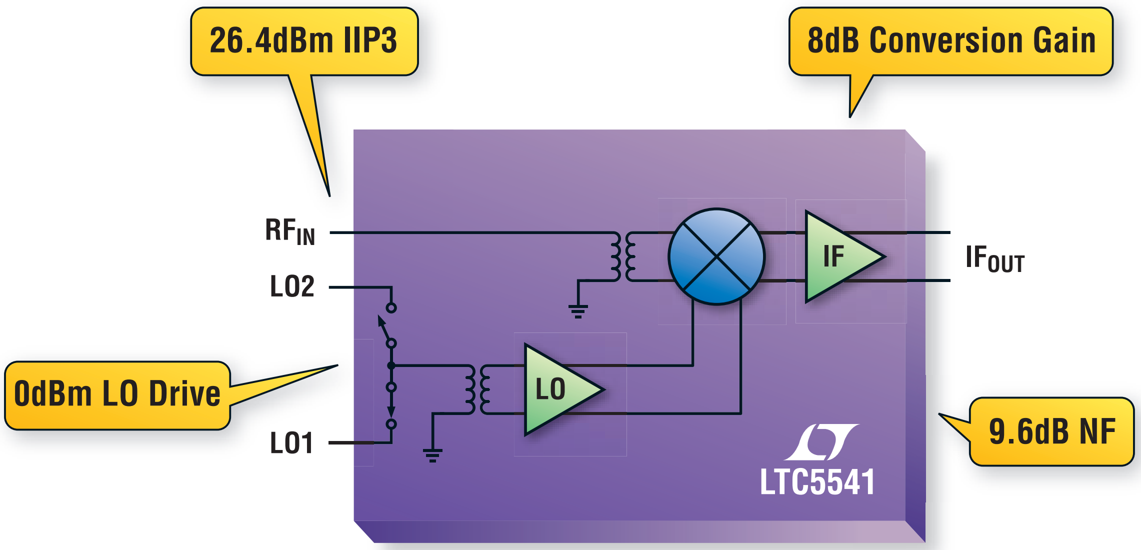
Troubleshooting Passive Intermodulation in the Field
Presented by Anritsu

Solutions for Ultra-Wideband Radar System Design: Integrating Design with Ultra-Wideband Test for Flexible Radar Verification
White Paper, Agilent Technologies

Creating a Radar Threat Simulator and Receiver Calibrator with Precise Angle of Arrival
White Paper, Agilent Technologies

Super-resolving Properties of Metallodielectric Stacks
Presented by COMSOL

Highest Dynamic Range Mixers—Only 660mW



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3.3V Passive Mixer Family

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Operating Frequency	600MHz to 1.3GHz	1.3GHz to 2.3GHz	1.6GHz to 2.7GHz	2.3GHz to 4.0GHz
Input IP3	26dBm	26.4dBm	26.4dBm	24.5dBm
Conversion Gain	8dB	8dB	8dB	8dB
Noise Figure (NF)	9.9dB	9.6dB	9.9dB	10.2dB
NF @ 5dBm Blocking	16.2dB	16.0dB	17.3dB	17.5dB
Power Consumption	0.66W	0.63W	0.65W	0.66W

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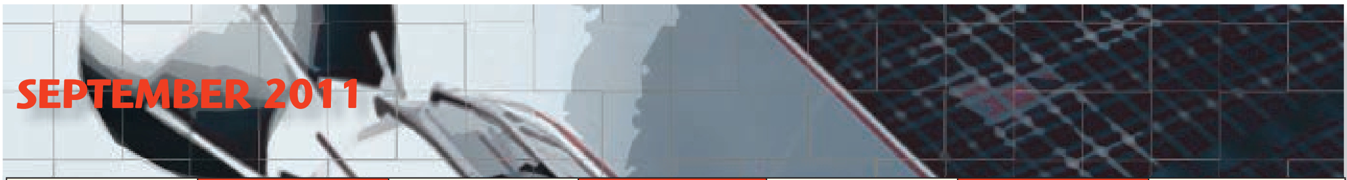

SEPTEMBER 2011

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
28	29	30	31	1 **Webinar: Innovations in EDA Digital Pre-Distortion for Wideband Systems** Sponsored by Agilent Technologies	2	3
4 ◄ IPAC 2011 San Sebastian, Spain (Sept. 4–9)	5	6	7	8 ◄ 11TH Mediterranean Microwave Symposium, Hammamet, Tunisia (Sept. 8–10)	9	10
11 **Call for Papers** Deadline	12 **Call for Papers** ISSCC Deadline	13	14	15	16	17
18	19	20 ◄ ION GNSS 2011 Portland, OR (Sept. 20–23) **MWJ Besser Webinar: Couplers, Dividers and Combiners** Sponsored by MECA	21 **Webinar: Innovations in SA Using Handheld Spectrum Analyzers** Sponsored by Agilent Technologies	22	23	24
25	26	27 **Webinar: A&D Test Equipment Replacement** Sponsored by Rohde & Schwarz	28	29 **Webinar: Rugged LDMOS Transistors for ISM** Sponsored by freescale semiconductor, RichardsonRFPD	30	1

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Coming Events

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MILCOM 2012
Deadline: August 12, 2011
MWC 2012
Deadline: August 25, 2011
IEEE MEMS 2012
Deadline: September 11, 2011
ISSCC 2012
Deadline: September 12, 2011
www.mwjournal.com/events

AUGUST

EMC 2011
IEEE International Symposium on Electromagnetic Compatibility
August 14–19, 2011 • Long Beach, CA
www.emc2011.org

AUVSI Unmanned Systems N. America 2011
August 16–19, 2011 • Washington, DC
http://symposium.auvsi.org/auvsi11/public/enter.aspx

SEPTEMBER

IPAC 2011
International Particle Accelerator Conference
September 4–9, 2011 • San Sebastian, Spain
www.ipac-2011.org

11th Mediterranean Microwave Symposium
September 8–10, 2011 • Hammamet, Tunisia
www.mms2011.com

ION GNSS 2011
September 20–23, 2011 • Portland, OR
www.ion.org

OCTOBER

EuMW 2011
European Microwave Week
October 9–14, 2011 • Manchester, UK
www.eumweek.com

EMC UK 2011
October 11–12, 2011 • Newbury, UK
www.emcuk.co.uk

7th Annual COMSOL Conference
October 13–15, 2011 • Boston, MA
www.comsol.com/conference2011/usa/

MUD 2011
Microwave Update
October 13–16, 2011 • Enfield, CT
www.microwaveupdate.org

AMTA 2011
33rd Annual Symposium of the Antenna Measurement Techniques Association
October 16–21, 2011 • Englewood, CO
www.amta2011.org

MWP 2011
IEEE International Topical Meeting on Microwave Photonics
October 18–21, 2011 • Singapore
www.mwp2011.org

4G World
October 24–27, 2011 • Chicago, IL
www.4gworld.com

RADAR 2011
International Conference on Radar
October 24–27, 2011 • Chengdu, China
www.radar2011.org

NOVEMBER

COMCAS 2011
International IEEE Conference on Microwaves, Communications, Antennas and Electronic Systems
November 7–9, 2011 • Tel Aviv, Israel
www.comcas.org

MILCOM 2011
November 7–10, 2011 • Baltimore, MD
www.milcom.org

AOC 2011
48th Annual AOC International Symposium and Convention
November 13–16, 2011 • Washington, DC
www.crows.org

DECEMBER

APMC 2011
Asia Pacific Microwave Conference
December 5–8, 2011 • Melbourne, Australia
www.apmc2011.com

JANUARY

IEEE RWS 2012
Radio and Wireless Symposium
January 15–19, 2012 • Santa Clara, CA
www.rawcon.org

IEEE MEMS 2012
International Conference on Micro Electro Mechanical Systems
January 29–February 2, 2012 • Paris, France
www.mems2012.org

FEBRUARY

NATE 2012 Conference and Exposition
National Association of Tower Erectors
February 6–9, 2012 • San Antonio, TX
www.natehome.com

ISSCC 2012
IEEE International Solid-State Circuits
February 19–23, 2012 • San Francisco, CA
www.isscc.org

MWC 2012
Mobile World Congress
February 27–March 1, 2012
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MAAL-010705	500 - 1600	21.0	-21.0	32.0	0.5	4	2 mm PDFN
MAAL-010706	1400 - 4000	17.5	-19.0	34.5	0.6	4	2 mm PDFN

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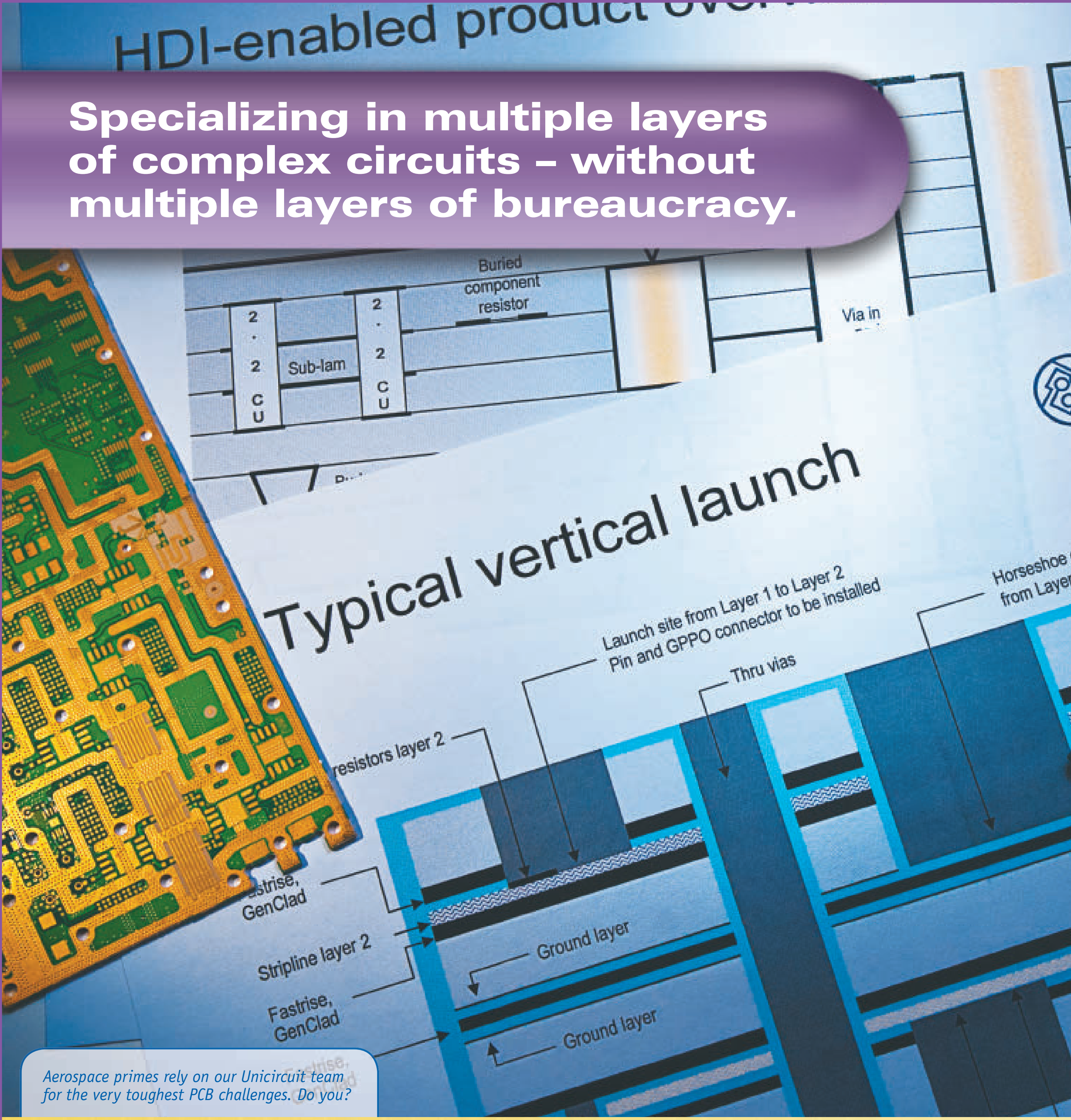

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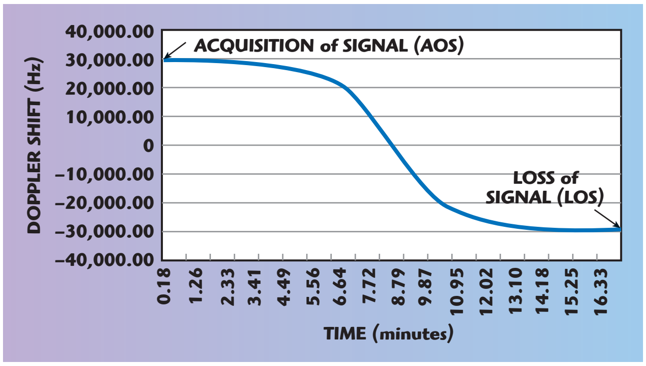
COVER FEATURE
INVITED PAPER

TRENDS IN SATCOM TECHNOLOGY REQUIREMENTS AND MARKET OPPORTUNITIES

Cost pressure, increasing SATCOM dependence and a "do more with less" mantra coming from the halls of the Pentagon, government agencies and commercial satellite owner/operators are leading to innovative thinking from vendors and users alike. Eric DeMarco, President and CEO of Kratos Defense & Security Solutions, has said, "In Operation Desert Storm 1991, the military used approximately 140 bits per second (bps) of satellite bandwidth per deployed person. During Operation Noble Anvil in Kosovo, the U.S. component of this mission increased to almost 3000 bps. In operation Enduring Freedom in Afghanistan, bps usage per person increased to approximately 8300, and by the launch of operation Iraqi Freedom in 2004, bps per person had reached 13,800." In more recent years, this sort of bandwidth increase by the U.S. military and National Security agencies has only continued, with the same trends appearing in the commercial sectors as well.



▲ *Fig. 1 Example Doppler shift curve for a LEO satellite signal received at an Earth terminal.*

The need to drive down costs, while at the same time increase efficiencies and system lifespan is leading to designs that include redundant, fault-tolerant systems with the ability to share network resources. Networks between satellites, for example, allow them to serve as backups for each other. Here, if the star tracker failed on one satellite, another in its constellation could provide the necessary pointing data to allow all of them to continue performing their functions. Or, if one satellite failed completely, others could detect its loss, and its mission activities would automatically be parceled out to other functioning satellites until a replacement satellite could be injected into the affected constellation.

These trends, in addition to recent efforts in commercialization of space, affect everything from R&D to deployment, and from testing to training. In the R&D space, for example, the latest hardware-in-the-loop instruments and tools for RF link simulation and modeling are

STEVE WILLIAMS
RT Logic, an Integral Systems Company, Colorado Springs, CO

enhancing traditional R&D methods. In deployment, interference detection, geolocation and mitigation techniques are rapidly moving forward. Tools being employed in these areas are being designed for multi-purpose use, including test and training.

In response to these trends, vendors are providing advanced, commercially available technology solutions that offer greater efficiencies and lower costs. Also, they are easier to operate, manage and upgrade. The remainder of this article will briefly summarize several of the latest technology advancements, including channel simulation, RF interference detection and mitigation, geolocation, high efficiency, low cost power amplifiers and increased frequency and data rates for critical deployable communications systems.

CHANNEL SIMULATION

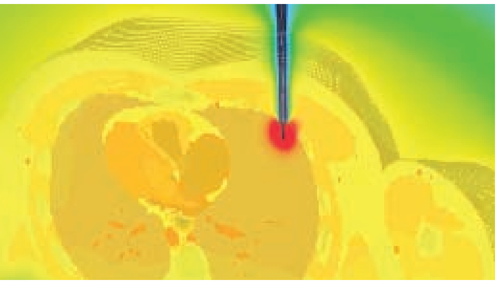
Satellite communication systems involve transmitters and receivers that are constantly moving with reference to one another, routinely operate in harsh environments and are separated by great distances. As a result, these radio signals undergo time-varying carrier and signal Doppler shift, path loss and path delay, as exemplified in ***Figure 1***. These signals are also subject to atmospheric noise and weather-related perturbations, as well as accidental interference and intentional jamming.

Imperfect satellite transponders also impact SATCOM signals with frequency-dependent group delay, phase and amplitude performance, to name several. Multipath also plays an important role in signal quality, particularly where buildings and terrain may result in terrestrial vehicle motion- and position-dependent destructive and/or constructive interference at the receive end (e.g. Rayleigh and Rician fading).

Each of these factors, singly and in combination, must be rigorously simulated during SATCOM system design. To do so, engineers initially employ powerful, physics-compliant software-based simulation and modeling of these signal effects against planned receiver and transmitter specifications, link budget requirements, antenna positions and gain patterns and a wide variety of other key considerations.

As the development cycle proceeds, software-based simulation and modeling gives way to actual transmitter and receiver hardware/firmware/software testing in order to rigorously test these systems with actual RF signals. Physics-compliant RF channel simulator instruments that add deep hardware-in-the-loop test capability facilitate this testing. Typically, such simulators are inserted in the RF path between transmitters and receivers under test, and are driven by the same high fidelity simulation and modeling tools used earlier in the design.

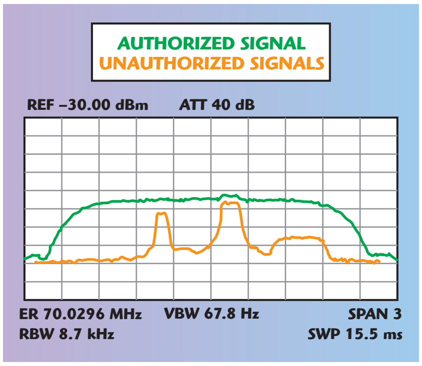
In this way, channel simulators create dynamic, nominal and worst-case RF paths in the lab for emulating signals between fixed or moving terrestrial assets and space platforms (satellites, manned vehicles, rockets, etc.), inter-linkages between platforms,



links between space vehicles and atmospheric assets (UAVs, missiles, aircraft, etc.) and atmospheric vehicle links to terrestrial assets.

Channel simulation technologies advance as the resolution and speed of ADCs and DACs emerge, and as DSP speeds and DSP resource availability climb. Intuitive visual user interfaces enable channel simulator users to focus on their jobs, not on eliciting desired behavior from their instruments.

These advancements, as well as extended RF frequency coverage and wider instrument bandwidths, have caused a marked jump in channel simulator use in R&D, test and training activities worldwide in the past several years. RF channel simulators are increasingly finding their way into signals, interference and operations situations because they create RF signals that precisely mimic those that will occur in nature under various conditions.



▲ *Fig. 2 Example interference detection plot showing authorized and unauthorized signals.*

RF INTERFERENCE DETECTION

Satellite communication is critical to economic and national security. With the proliferation of satellites, aircraft, UAVs and other platforms requiring radio linkages, the skies are jam-packed with radio signals, each of which is increasingly compromised by natural, accidental and intentional interference. This interference threatens the integrity, quality and speed of these links, and therefore, the very missions they support.

As a result, we have seen rapid development and deployment of systems that continuously monitor SATCOM links for even the smallest signs of interference or channel abuse. These monitoring systems have moved well beyond spectrum analyzers running simple spectral masks that define nominal frequency and amplitude characteristics. Instead, modern interference detection systems employ sophisticated DSP techniques to detect and characterize even the smallest and most transient anomalies, including unauthorized signals appearing below authorized signals as in ***Figure 2***.

These interference detection systems also log results and instantly notify appropriate automated systems and personnel when unauthorized signals appear, and when critical nominal signal parameters, such as EIRP, C/No, Es/No, center frequency, occupied bandwidth, are violated. Often employing multiple remote sensors, today's interference detection systems combine signal data from geographically dispersed fixed and moving nodes into single displays for real-time overall RF situational awareness.

Further development of such systems is proceeding rapidly, with key focus on faster detection of a broader

range of interference types in wider frequency segments. Reductions in system size, complexity and price are anticipated, along with improved ease of use. Tighter integration with related automatic functions, such as interference mitigation, traffic re-routing, and signal geolocation, are also on the horizon.

Addressing the continual need for economic efficiency, many interference detection systems are multi-purposed, and are applicable toward a broad range of operational, training and test requirements. This is achieved in part with integrated hardware channel simulators and signal generators capable of injecting physics-compliant target and/or interference signals indistinguishable from their real-world counterparts.

As interference detection system capabilities advance, and as automatic avoidance techniques are developed, the physical size of interference detection systems will decrease. This will spawn "built-in" interference detection and mitigation capabilities, rendering communication system receivers, for example, self-aware of interference and capable of taking link-restoring corrective action without user intervention.

GEOLOCATION

In addition to carrier monitoring and RF interference detection, the ability to accurately locate the source of interference is becoming more important. Interference incidents are on the rise, and will continue to grow due to the proliferation of satellite based services, such as VSAT networks, the emergence of personal satellite communications and the ever-increasing congestion of the geostationary arc.

The most common use of geolocation tools is for locating the source of an interfering signal. More often than not, interference incidents are accidental in nature. Equipment failure, a poorly pointed VSAT antenna, the use of an incorrect frequency or satellite, or RF spill-over from poorly specified ground station transmitting to an adjacent satellite are some examples of how interference can be caused.

Increasingly though, geolocation tools are used to locate intentional jammers who aim to disrupt specific TV or radio broadcasts, or command and control or data communications. Geolocation systems can also be used to detect unauthorized users who pirate bandwidth for their own use. Geolocation technology has advanced a great deal, including improvements in usability, accuracy, processing speed and integration with other adjacent tools. New measurement techniques and analysis of more advanced signals also are being seen in the market. Flexibility and scalability of these tools also continue to improve, allowing for incorporation into widening applications including transportable and mobile systems.

ADVANCEMENTS IN USER TERMINALS

In recent years, increasing bandwidth demands from remote users has spurred advances in VSAT technology. Improvements in satellite EIRP and G/T have enabled the use of smaller, low gain user terminal an-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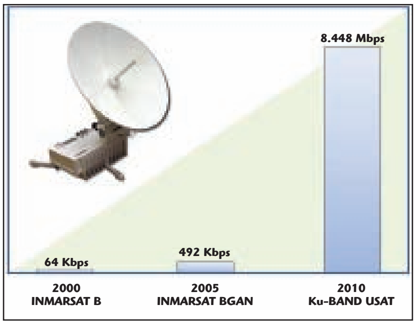
tennas. In conjunction with satellite performance improvements, these smaller antennas meet performance benchmarks that once required larger antennas. User terminals now provide significant throughput and availability in a compact form factor (MANPACK, aircraft mounted, vehicle mounted, etc.).

User terminal advances leverage these space segment performance gains to improve the quality and quantity of information, whether fixed or mobile, that is available to the remote user. Solutions are being packaged in size, weight and power profiles that enable communications support that were previously underserved or not served at all. Advances in waveform and coding, embodied in standards such as DVB-S2/ACM, have served to decrease the amount of power required to close a link and have improved link quality and availability.



▲ *Fig. 3 Data service rates for airline carry-on satellite communications kits.*

Improvements in RF amplifier size, weight and consumed power have created SSPA/BUC elements that provide significant available transmit power in a small form factor compatible with battery-operated terminals and challenging user environments.

Figure 3 shows an airline carry-on sized terminal package to show the significant performance improvements gained in recent years. About 10 years ago, the most efficient terminals supported connection speeds of 64 Kbps. A little more than five years ago, connection speeds increased significantly, but only to about 492 Kbps. Today, due to the advancements discussed above, users can now access approximately 9 Mbps, resulting in a dramatic increase in capabilities to support the end user.

POWER AMPLIFIERS

To cut costs, the industry is relying on smaller antennas. Yet at the same time, users are demanding higher data rates and increased availability. Satisfying both requirements has been a problem in the past, due to available power limitations. Traditionally, engineers had two choices: Solid-state Power Amplifiers (SSPA) or Travelling Wave Tube Amplifiers (TWTA). While older SSPAs offered many reliability and application advantages – better linearity, reliability, noise and lower cost-of-ownership – they provided poor efficiency for the size/weight offered. On the other hand, relying on old, vacuum-based TWTAs was costly and difficult to manage.

In the last year, 25 to 200 W Ku-band SSPAs have been introduced in the market. These products offer an unprecedented combination of small size and efficiency, equaling and/or surpassing the efficiency of typical TWTAs. For example, these new,

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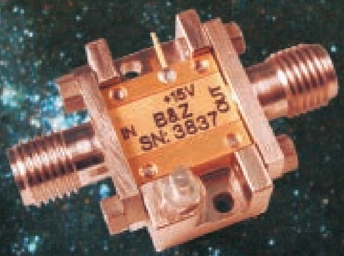

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BZP540A	0.5	40	5.5	25	8	2.5	2.5:1	$985
BZ2640A	26	40	4.5	25	8	2.0	2.5:1	$985
BZ1826A	18	26	2.5	28	8	1.0	2.0:1	$875
BZP518A	0.5	18	2.7	30	10	1.8	2.5:1	$985
BZ0618B	6	18	1.8	30	10	1.5	2.0:1	$985
BZ0412B	4	12	1.6	28	10	1.5	2.0:1	$785
BZP506A	0.5	6	1.4	25	10	1.3	2.0:1	$875
BZP504F	0.5	4	1.3	30	17	1.0	2.0:1	$985
BZ0204F	2	4	1.0	30	17	0.5	2.0:1	$685
BZ0102F	1	2	1.0	30	17	0.5	2.0:1	$685

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more efficient SSPAs achieve typical saturated efficiency ranging from 30 percent for the lower power amplifiers to 24 percent for the 200 W offerings. These are dramatic improvements because, historically, SSPAs operated at 10 percent efficiency or lower. The weight of the new SSPAs range from three pounds for the 25 W SSPA to 23 pounds for the 200 W SSPA. The more advanced SSPAs match TWTAs specification-for-specification in saturated efficiency and size/weight. However, SSPAs have much better linearity and superior size/weight and power consumption for equivalent linear power, while bringing its traditional advantages in reliability, power savings, noise and total cost-of-ownership.

SUMMARY

Increasing SATCOM dependence is driving many critical technology areas toward improved reliability, increased throughput, smaller size, lower cost and/or lower power requirements. Channel simulation in lab and test applications enhances design quality and reliability, and results in designs that perform well even with accidental and intentional interference.

RF Interference Detection systems monitor critical links and provide early warning of impending link degradation due to equipment failure, operator errors or intentional interference. Geolocation systems then assist in mitigation steps and locating the source of interference for rapid link restoration.

Portable user terminals have improved specifications and capabilities, many of which are the result of advancements in power amplifier technologies. These advancements, and many others, enable and are responsive to steadily ramping SATCOM usage requirements. ■

Steve Williams *is an RT Logic Business Area Manager, responsible for R&D and business development activities for RT Logic's RF Channel Simulator, Range Test System, UAV/Target/Missile Test Systems, Spectral Warrior Interference Detection/Characterization Systems and high-rate digitizers. He is a frequent presenter and author on these and related subjects. His 30-year digital and RF engineering career has included R&D, management and business positions at RT Logic, Hewlett-Packard, Agilent Technologies and precisionWave Corp., which he co-founded. Williams holds a BSEE from the University of Illinois.*

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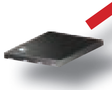

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YSF-122+	800-1200	20.4	0.2	20.5	21.3	3.4	36	2.69
YSF-2151+	900-2150	20.0	0.4	20.0	21.0	3.1	35	2.95
YSF-162+	1200-1600	20.1	0.2	20.0	21.0	3.2	35	2.69
YSF-232+	1700-2300	20.0	0.2	20.0	21.0	2.8	35	2.69
YSF-272+	2300-2700	19.0	0.7	20.0	21.0	2.5	35	2.59
YSF-382+	3300-3800	14.5	0.9	20.0	21.0	2.5	36	2.59
YSF-322+	900-3200	17.0	2.2	20.0	21.0	2.5	35	2.85

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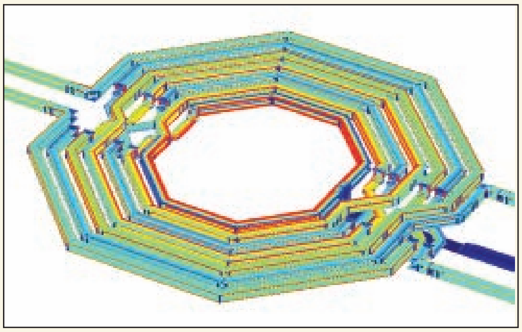

3D PLANAR EM SOFTWARE FOR CUSTOM MICROWAVE DESIGN FLOWS

Fullwave electromagnetic (EM) model extraction has become an essential part of high frequency IC design flows and has become invaluable for extracting highly accurate models for inductors, baluns, MIM capacitors, transmissions, coupled lines, interconnects and even on-chip grounding busses. However, EM model extraction based on full 3D volume meshing can be computationally prohibitive to apply to such processes because physical features of these structures can vary by four orders of magnitude or more. The most stressing feature of this technology is the extremely thin dielectrics in a multi-layer IC process, which may be on the order of 0.1 or even 0.01 microns separating lateral conductors with dimensions on the order of 1000s of microns. It is in this area that 3D planar high frequency EM simulators based on the 3D planar Method of Moments (MoM) find a niche because they mesh only the conductor surfaces and not all of the volume. In this way, 3D planar EM simulators are relatively immune to the difficulties presented by fullwave EM analysis of today's multi-layer silicon and CMOS process stackups.

Sonnet Software has released a new version of its high frequency 3D planar EM software, the Sonnet Suites. Prominent in this new release are features intended to streamline Sonnet's capability to efficiently solve demanding microwave and mm-wave frequency structures on challenging IC processes and to become a more "push-button," on-demand 3D planar EM extraction client to popular high frequency EDA design environment such as Cadence Virtuoso, Agilent EEsof EDA's Advanced Design System (ADS) and the Microwave Office Suite from Applied Wave Research. Sonnet also announces a new MATLAB toolbox, SonnetLab, which is freely available to all Sonnet and Sonnet Lite customers.

FASTER FULLWAVE 3D PLANAR EM SIMULATION

In Release 13, Sonnet's flagship High Performance Solver (HPS) engine increases CPU core utilization to up to 12 physical cores in parallel on high-end computation platforms, decreasing solver run time by an order of 30 percent for workstations with dual hex core processors. The conservatively priced Desktop Solver (DTS) Engine has increased parallel CPU core utilization from 2 to 3 cores – appropriate for the average single-CPU office desktop PC. In addition, the Sonnet Professional matrix solvers have undergone further algorithm improvements for handling large jobs on 64-bit operating systems. Matrix fill is now fully parallelized for large jobs (4 GB), and customers are reporting simulation time reductions by as much as a factor of seven for very large circuit analysis.

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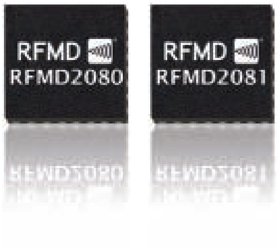

The RFMD2080 and RFMD2081 are extremely broadband devices capable of transmitting from 45MHz to 2700MHz and are suitable for satellite, wireless point-to-point systems, software defined radio, digital repeaters, and other QPSK/QAM modulator applications. The integration of the local oscillator using an advanced fractional-N synthesizer, along with the broadband nature of the components, offers the industry's most competitive combination of functionality, performance, versatility, and size.

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SPECIFICATIONS

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45	2700	18.0	-150.0	-45	-45	3.0	150	QFN	RFMD2080
45	2700	17.0	-162.0	-40	-45	3.0	135	QFN	RFMD2081

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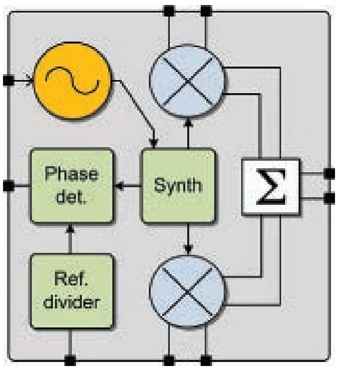

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- **Programmable baseband gain and filtering (RFMD2080)**
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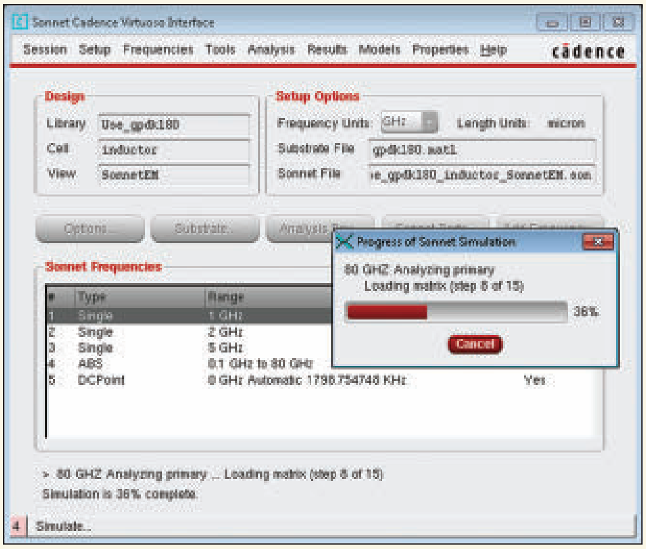
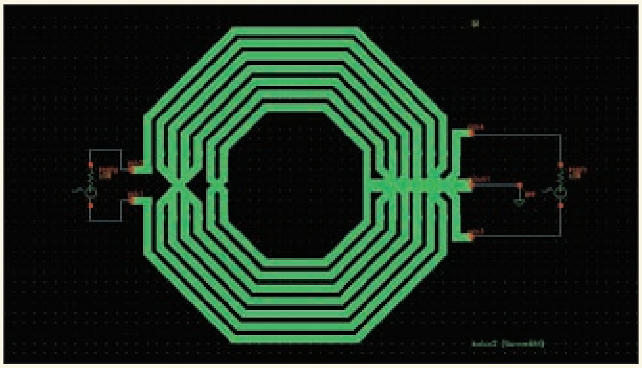


▲ *Fig. 1 Sonnet Suites EM model extraction window in Cadence Virtuoso.*



▲ *Fig. 2 Example balun schematic.*

NEW VIA MODELING FEATURES FOR EFFICIENT RFIC AND MMIC EM MODEL EXTRACTION

Sonnet now provides separate metal definitions for vias, which are more appropriate to the way in which via metals are typically specified in foundry process design kits (PDK). Via metals may now be specified in terms of volume metal or surface impedance characteristics and specified to have either a solid fill or a predefined wall thickness.

New via meshing controls are provided to achieve faster results with fewer descritizations. Vias can now be simulated using filled meshing throughout the via cross-section, meshed with a ring definition for the outline of the via, use mesh elements at only the corners or a single mesh element in the middle of the via. In all cases, the metal loss computation is corrected in the simulator for the meshing that is employed. The mesh definition can be easily and quickly changed for via definitions when the designer wishes to shift between rapid prototyping and minimum-error simulations.

In Release 13, micro via array simplification technology is introduced to accurately model via array interconnects in a highly efficient composite manner. The simplification comes in the form of a new via fill type defined for the EM solver. The simplification is automated and accessible in its GDSII, DXF and Gerber imports, as well as in its RF EDA framework APIs. Multi-layer planar metal stacks (such as those used in silicon RFIC inductors, baluns and transformers) can now be efficiently simulated in Sonnet without manual model adjustments, providing accurate simulation results for kHz through THz frequencies.

A FLEXIBLE EM EXTRACTION CLIENT FOR CUSTOM HIGH FREQUENCY IC DESIGN FLOWS

As independent high frequency 3D planar EM software, Sonnet is capable of standalone use, free of a larger framework, or it can be used as an entirely integrated EM model extraction client for the abovementioned high frequency EDA RFIC and MMIC design environments. The Sonnet API for Cadence Virtuoso (see ***Figure 1***) can now read process stackup and drawing layer map information from a variety of sources, including Assura process files, Helic Veloce/RF technology files, Agilent technology (.tch) files as well as existing Sonnet Material (.matl) and pre-existing Sonnet project files. Complete process stackup and layout-to-material associations can be imported with a single import for any given structure within a process technology. Often these process files come with the technology PDK supported by the parent EDA framework. Alternatively, a stackup definition may be created and stored in the Sonnet API by the EDA tool flow manager for use in all structures simulated for a given process technology.

The Sonnet API for Virtuoso now includes the ability to display an internal simulation progress bar, implementation of Sonnet's unique Co-calibrated Port technology for internal port group calibration and de-embedding, single-click access to show circuit descritization, "simulate and release" capability to allow EM simulation to continue without locking out the Virtuoso framework and the ability to automatically create a symbol for the Cadence Schematic Composer in the form of a layout look alike instance. Sonnet provides both frequency domain model extraction in the form of S-, Y- or Z-parameters, as well as the ability to provide a Spice model extraction using the Sonnet Broadband Model extractor.

Once the EDA tool flow manager has an optimal setup for Sonnet model extraction appropriate for a given process technology, the settings can be saved in the form of an API State. State settings can include model simulation options, sub-sectioning control options, frequency plans, grid controls, layer mapping and process information. By loading an API state, the user obtains an automated EM model extraction starting from a Virtuoso PCell, without having to touch the EM project. This automation makes it possible for RFIC designers in the Cadence Virtuoso environment to generate a schematic symbol ready for use in downstream electrical simulation based on Sonnet's fullwave EM modeling capability in an easy, one-step process (see ***Figure 2***).

Sonnet's APIs for both Agilent ADS and AWR Microwave Office have also been enhanced to result in a smoother, more tightly integrated use. Starting in Release 13, designers will find it less necessary to open the EM project in the Sonnet Project Editor in order to set advanced Sonnet options. Process technology for MMIC or RFIC design can be loaded directly from within ADS or MWO using existing process stackup or substrate definitions already located within the frameworks, often already inherited from a foundry PDK. The API for ADS and MWO will also have the ability to set States with full Sonnet translation and simulation settings for a given process technology, enabling one-click configuration of Sonnet EM model extraction processes. As with the API for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Virtuoso, these APIs can also help users who are not familiar with Sonnet to leverage Sonnet's distinctive accuracy without expert-level tool knowledge.

The new SonnetLab toolbox makes it possible to use MATLAB scripts to automate the construction of a Sonnet project, launch the EM simulation and extract the resulting output model for further processing. It is possible also to use MATLAB for sophisticated control and optimization of Sonnet planar EM projects for a variety of design automation and analysis processes. The SonnetLab toolbox is available for download from the Sonnet website free of charge, and is compatible with all Sonnet Suites, including Sonnet Lite.

EXPANDED CAPABILITY FOR ENTRY-LEVEL SONNET SUITES

Sonnet offers a number of entry-level suites, aimed at students and customers with less demanding structures involving fewer circuit layers and ports. All of the Sonnet entry-level Suites – Lite, LitePlus, Level2 Basic, Level2 Silver and Level3 Gold – have received at least a doubling of allowed memory, making them able to simulate larger problems than before. The Sonnet Level3 Gold Suite has been expanded to allow unlimited circuit ports and a memory use increase of a factor of eight.

EASIER TO FIT TO REAL CIRCUITRY

The Sonnet Release 13 environment has also received additional improvements for flexibility and usability. Some of these features include:

- Rotated edge ports and internal ports, enabling arbitrary entry directions with de-embedding.
- Any port may have an independent reference plane or may share a reference plane with other parallel lines. Shared reference planes enable the de-embedding of parallel line coupling to the reference plane.
- A new visual continuity checker in the user interface that shows DC continuity in the meshed model. This is an error-checking feature that is particularly useful in checking the simulation models for model translation errors prior to simulation.
- A new Conductor Surface Roughness loss model, developed in conjunction with researchers from Rogers Corp., has been introduced to provide loss and transmission line phase velocity changes due to the roughness of conductors on microwave laminates and substrates.
- Heat Flux computation and display for lossy conductors and planar resistors. The data may be exported for post-processing in thermal analysis tools.
- A new Example Browser makes it possible for learners to quickly and easily search for applicable examples and load them into the Sonnet Project Editor for personal observation and experimentation.

The Sonnet Suites Release 13 provides further capability and enhancements in Sonnet's industry-leading 3D planar high frequency EM software and now enables a smooth integration of shielded domain method of moments (MoM) model integration within major high frequency EDA design environments.

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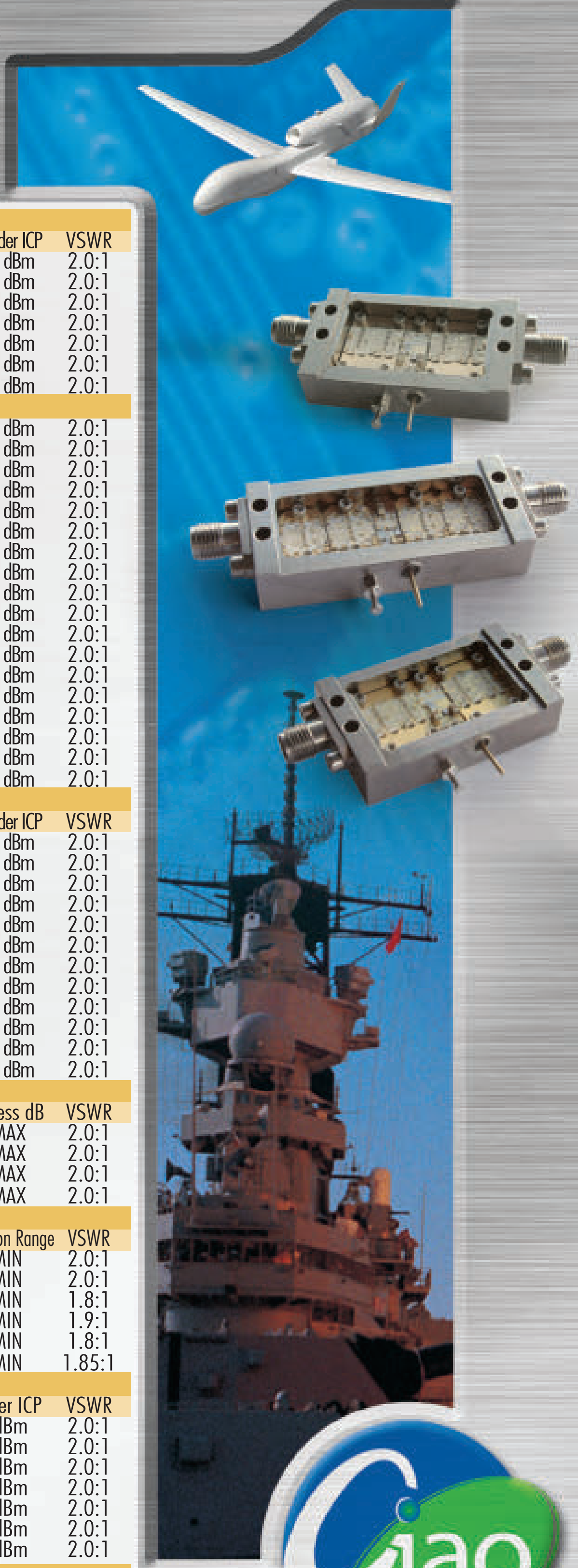

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CA01-2110	0.5-1.0	28	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

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

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

LIMITING AMPLIFIERS

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

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

LOW FREQUENCY AMPLIFIERS

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

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Dan Massé, Associate Technical Editor

Raytheon-Boeing Team Responds to Call for Joint Air-to-Ground Missile

Raytheon Co. submitted its proposal for the U.S. Army and Navy's Joint Air-to-Ground Missile competition and responded as a prime contractor. Raytheon is teamed with The Boeing Co. for the JAGM program. Raytheon and Boeing have proven capabilities that were showcased in the JAGM technology demonstration phase. The team enters the competition with an unmatched 3-for-3 record of success in the contractually required guided test vehicle flights. One of the reasons for the team's success is the use of a proven, tri-mode seeker incorporating semiactive laser, uncooled imaging infrared and millimeter-wave guidance.

"A single rocket motor and uncooled tri-mode seeker provide improved reliability and simplified logistics, while saving the taxpayer money over the life of the program."

"Instead of cobbling together bits and pieces of hardware from legacy programs, we offer a fully integrated tri-mode seeker that provides an exceptionally reliable, low-risk path to engineering and manufacturing development," said Bob Francois, Raytheon Vice President of Advanced Missiles and Unmanned Systems. "Rather than complicating matters by using a cooled seeker, we worked in close concert with our customers to determine smarter and simpler ways to arrive at a superior system solution. The uncooled seeker on the Raytheon-Boeing JAGM is just one example of that, and our overall system solution integrates targeting information from powerful aircraft onboard sensors with our advanced seeker to provide exceptional capability."

In addition to achieving a 3-for-3 success rate in government-funded testing, the Raytheon-Boeing team also went 3-for-3 in company-funded testing. Boeing executives attribute part of that success to the team's use of production-ready hardware. "The team demonstrated that it is possible to give the warfighter a single rocket motor solution capable of withstanding the rigors of fixed- and rotary-wing flight," said Carl Avila, Director of Boeing's Advanced Weapons and Missile Systems. "A single rocket motor and uncooled tri-mode seeker provide improved reliability and simplified logistics, while saving the taxpayer money over the life of the program."

Lockheed Martin Demonstrates JAGM Tri-Mode Seeker in Captive Flight Tests

In addition to the Raytheon-Boeing news, Lockheed Martin's Joint Air-to-Ground (JAGM) tri-mode seeker successfully acquired and tracked multiple moving maritime vessels during recent high speed, captive flight tests. The tests occurred in the Gulf of Mexico, off the shore of Eglin Air Force Base, FL, against multiple maritime targets, including a Revenge Advanced Composites (RAC) state-of-the-art, low-signature, high speed patrol craft. The RAC performed a series of evasive maneuvers against Lockheed Martin's JAGM tri-mode seeker, mounted in the nose section of a Sabreliner Series 60 jet aircraft.

"These tests demonstrated the strong performance of our seeker design," said Frank St. John, Vice President of Tactical Missiles at Lockheed Martin Missiles and Fire Control. "There are many variables in tracking a target at sea, especially a moving target. Lockheed Martin's JAGM has clearly proven it fills all eight critical capability gaps identified and revalidated twice in the Joint Capabilities Integration and Development System (JCIDS) process."

The tests highlighted the robustness of the seeker on fixed-wing aircraft, as well as its performance against one of the most challenging targets in JAGM's target set. The tests also validated superior seeker performance in the demanding, high-humidity environment associated with contingency operations in the world's littorals. The long-range, high speed seeker tests were company funded. They collected data that validated the effectiveness of the seeker against sea targets at the maximum ranges of the fire-and-forget modes. Speeds during the test approached 400 knots at 20,000 foot altitude.

Northrop Grumman Demonstrates STARLite Radar PTDS

Northrop Grumman Corp. announced the successful demonstration of its STARLite radar on a U.S. Army Persistent Threat Detection System (PTDS), an aerostat surveillance platform uniquely positioned to aid in the defense of ground troops. During the demonstration at Yuma Proving Ground in Yuma, AZ, the STARLite system, which carries the military designation AN/ZPY-1, detected vehicles and individuals in the area of interest. STARLite cues the electro-optical infrared camera to targets detected by the radar.

"The success of the STARLite demonstration clearly shows the versatility and technical capabilities of the system that will prove to be a critical asset to our nation's warfighters."

"STARLite performed exceptionally well and exceeded our customer's expectations," said John Jadik, Vice President of Weapons and Sensors for Northrop Grumman's Land and Self Protection Systems Division. "The success of the STARLite demonstration clearly shows the versa-

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tility and technical capabilities of the system that will prove to be a critical asset to our nation's warfighters."

Northrop Grumman's STARLite is a small, lightweight, radar used for supporting tactical operations. By providing precise battlefield intelligence in all types of weather and in battlefield obscurants, day and night, STARLite significantly improves battlefield situational awareness and optimizes force maneuver and engagement for mission success. Each STARLite radar comes equipped with a complete software package that enables easy operator control of all radar functions. STARLite leverages Northrop Grumman's experience from the development of the proven Tactical Endurance Synthetic Aperture Radar and the Tactical Unmanned Aerial Vehicle Radar.

Raytheon Receives $51.6 M Contract for Satellite Communication Support

The U.S. Navy has awarded Raytheon Co. a $51.6 M contract to provide logistics support for the communication terminals of the Navy's Extremely High Frequency Satellite Program (NESP). The performance-based logistics contract calls for Raytheon Technical Services Co. LLC (RTSC) to fulfill all requisitions; warehouse and track government-furnished material; resolve supply-obsolescence or source issues; and evaluate, test, repair and/or modify the communication equipment as needed. The primary work will be performed at the RTSC sites in Norfolk, VA, and Chula Vista, CA, with additional engineering support performed at the Raytheon sites in Marlborough, MA, and Largo, FL.

"NESP provides jam-proof communications for submarines, major surface ships and sites onshore, as well as connectivity with U.S. Army and Air Force communication systems," said RTSC Customized Engineering and Depot Support Vice President Wayne Iurillo. "As such, it is extremely important that the communication terminals remain functional and up to date. That's our commitment, and this contract will ensure that we continue to meet the Navy's need."

"NESP provides jam-proof communications for submarines, major surface ships and sites onshore, as well as connectivity with U.S. Army and Air Force communication systems."


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ITU Teams Up with Leading Asian Standards Organizations

The International Telecommunications Union (ITU) has signed an agreement with key Asian standards developers that will mean new technologies come to market quicker and at lower cost. ARIB (Japan), CCSA (China), TTA (Korea) and TTC (Japan) have signed a Memorandum of Understanding with the ITU recognizing it as the pre-eminent global ICT standards body. The agreement seeks to smooth the way for regional standards, developed in these four key regional bodies, to be internationally recognized.

The MoU will build on the good relationship ITU has built with all four bodies over many years, increase transparency between the organizations, avoid duplication of work and increase efficiency in the publication of standards. All of this means that product manufacturers will be able to more efficiently incorporate globally standardized solutions in their products, leading to greater economies of scale and lower costs to consumers.

"This agreement cements the relationship between ITU and four premier standards organizations..."

The agreement will bring better access for ARIB, CCSA, TTA and TTC to international standards-making activities, allowing all partners to profit from information sharing on the standardization aspects of nascent technologies. The MoU will also encourage the identification of topics for joint work programmes in order to avoid duplication.

Dr. Hamadoun Touré, ITU Secretary-General, said, "China, Japan and Korea have been at the forefront of the development of many of the technologies that underpin the information society. At the same time, all three countries have shown a commitment to the development of the international standards that provide the interoperability needed to seamlessly connect the world. This agreement cements the relationship between ITU and four premier standards organizations in the region."

European Partners Put e-BRAINS Together

The European Best-Reliable Ambient Intelligent Nano Sensor Systems (e-BRAINS) research project will conduct research into the integration of heterogeneous systems using 3D and nanotechnology. Led by Infineon and Fraunhofer Research Institution for Modular Solid State Technologies (Fraunhofer EMFT), the project will run until the end of 2013. Nano-sensors will be combined with other components, such as ICs, power semiconductors, batteries or wireless communication modules, in such a way as to significantly enhance energy efficiency, cost effectiveness, service life and reliability in the operation of e-BRAINS applications.

Vast improvement in the performance of existing applications in fields, such as production monitoring, automotive or medical remote monitoring, can be expected, courtesy of the e-BRAINS research results. The deployment of nanotechnology will allow great improvements in functionality and will open the door to a wide range of applications. Future e-BRAINS applications will require significantly higher integration densities.

The e-BRAINS project aims at sharpening the competitive edge of European companies by addressing a large variety of applications...

The sizes of microelectronic components are continually shrinking in order to reduce energy consumption or achieve higher switching speeds. However, as miniaturization continues its march of progress, the semiconductor industry is increasingly coming up against its physical limits. Growing system complexity is accompanied by higher risk of compromising switching speed. This explains the key role played by the heterogeneous integration of subsystems using 3D technology in which different components are vertically stacked and interconnect length is minimized.

The e-BRAINS project aims at sharpening the competitive edge of European companies by addressing a large variety of applications, such as medical, security and safety. The 19 technology partners of the research project are manufacturers with European production sites, universities and research institutes in Germany, Norway, Austria, Ireland, France, Switzerland, Poland, Belgium and the UK. Infineon is responsible for the overall coordination of the e-BRAINS activities. The total budget is approximately $15.8 M, of which $5.8 M is financed by the partners from industry and research, with the major share, $10 M, funded under the EU's Seventh Framework Program for Research and Technological Development (FP7).

MBDA and ISL Sign International Partnering Agreement

MBDA and ISL (the Franco-German Research Institute of St. Louis) have signed an international partnering agreement thereby extending the scope of the already existing cooperation between the two organizations. The aim of this agreement is to set up a common research framework between ISL, MBDA France and MBDA Germany.

This agreement saw the signing of two national contracts – a new contract between MBDA France and the ISL and the renewal of a previous contract signed in 2006 between MBDA Germany and the ISL. These national

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contracts relate to the preparation of future technologies applicable to missiles and weapons systems in the areas of aerodynamics, optronics, navigation systems, future weapons systems and warheads.

They define the structure of the cooperation with regard to information exchange, cooperative research, the development of prototypes for joint projects and the use of test facilities and the loan of equipment.

According to ISL Directors, Christian de Villemagne and Wolfgang Förster, "This rapprochement between ISL and MBDA France and Germany will result naturally in the stimulation of French and German strengths and of our respective organisations. It also contributes to the emergence of new areas of European cooperation."

ESA, EDA Sign Administrative Arrangement

The European Space Agency (ESA) and the European Defence Agency (EDA) have signed an Administrative Arrangement that aims to provide a structured relationship and a mutually beneficial cooperation between the two agencies through the coordination of their respective activities.

The cooperation will, in particular, aim to explore the added value and contribution of space assets to the development of European capabilities in the area of crisis management and the Common Security and Defence Policy.

"I am convinced that an increased dialogue and coordination between the space and defence communities is of mutual interest and will allow European space programmes to better support Europe's security and defence needs," said ESA Director General Jean-Jacques Dordain. "Reinforcing the cooperation between EDA and ESA will allow us to further develop the security dimension of the European Space Policy in coordination with other EU stakeholders."

> *"...increased dialogue and coordination between the space and defence communities is of mutual interest..."*

"The signature of this Arrangement will allow us to consolidate our already close and fruitful working relations with the European Space Agency," said EDA Chief Executive Claude-France Arnould. "I am looking forward to exploring further synergies between the needs of the defence community and ESA activities to the benefit of our respective Member States."

Building on their specific complementary roles and activities, ESA and EDA are already cooperating on a variety of subjects, including Intelligence, Surveillance and Reconnaissance, Satellite Communication in support of Unmanned Aerial Systems (UAS), and Space Situational Awareness, as well as critical space technologies.

Dan Massé, Associate Technical Editor

Line of Business Products Will Help Boost RFID Software Market to $500 M by 2016

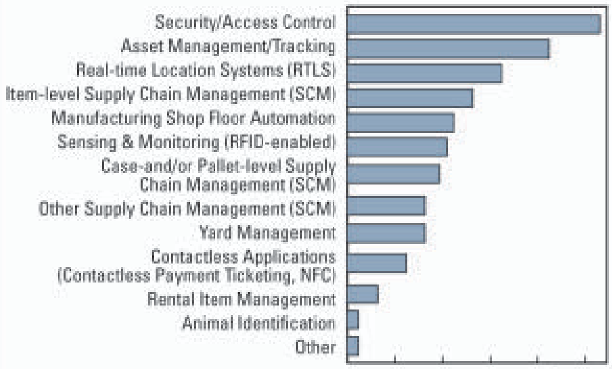
RFID software continues to grow in uptake and, according to the latest forecasts from ABI Research, software revenues are set to increase at a compound annual growth rate (CAGR) of more than 20 percent through 2016. RFID tags and readers may capture real-time data, but it takes software packages to make that data useful to the organization. RFID-focused software revenue should approach $500 M in 2016.

This software belongs to two classes: "Platform" and "Line of Business" (LOB). The LOB software category is growing more rapidly overall. It is becoming easier to configure, and if matched with an appropriate RFID platform, many of the costly integration discussions of the past no longer apply. Most RFID software is produced by vendors focused exclusively on this market, such as Xterprise, Checkpoint Systems (OAT is the software), Insync and S3Edge. At present, North America is the largest regional market for RFID software; APAC follows some distance behind, with Europe the third-largest market.

- How has software for RFID changed in the past five years?
- What makes a software package a "platform"?
- Where is the "middleware" typically located today?

ABI Research's "RFID System Software for Business Optimization" study tracks the evolution of RFID software over the past five years and offers revenue forecasts for the next five. It defines and explores the concept of "platforms" and explains how potential customers evaluate RFID software packages and vendors. The report also includes international survey results. It is part of the firm's RFID Research Service, which also includes other Research Reports, Market Data, ABI Insights, ABI Vendor Matrices and analyst inquiry support.

Which RFID Applications Has Your Organization Already Deployed or is in the Process of Deploying, Piloting, Evaluating, or Testing?



Source: ABI Research

"No New Wire" to Drive Home Automation Market to 12 Million Systems in 2016

Shipments of home automation systems will total about 1.8 million worldwide this year. But, according to ABI Research, that number is set to rise sharply soon, exceeding 12 million in 2016. These figures are contained in a new home automation study from the firm, which confirms its previous forecasts. This robust growth is the result of standards-based, "no new wire" wireless and powerline technologies, such as ZigBee, that drive down system costs and expand the addressable market.

The market is also seeing considerable innovation, such as Google's recently launched Android@Home Framework, including a new low power wireless communications protocol to support device connectivity. Much has been made of Android@Home's potential as a ZigBee Killer, but that largely misses the point. ABI Research believes the Framework is more directly targeted as competition for the software now being provided by vendors such as Control4, Motorola Mobility (via its 4Home acquisition) and iControl. However, these incumbent vendors themselves are engaged in consolidation and partnership development, meaning that Google is now up against the likes of AT&T (Xanboo), Motorola (4Home), iControl (original iControl + uControl), Control4 (Cisco) and Honeywell, rather than the set of small start-ups it would have faced three or four years ago.

The market is also seeing considerable innovation, such as Google's recently launched Android@Home Framework, including a new low power wireless communications protocol to support device connectivity.

- What is driving change and growth in the home automation market and what are the challenges still to be faced?
- What are the size and growth prospects for major regional and market segments of the home automation market?
- Who are the key players in the home automation market and what products and strategies are they utilizing?

ABI Research's "Home Automation and Monitoring" study analyzes the market for home automation and home security technologies and shows how these two markets are increasingly intersecting with the advent of home monitoring and managed home automation. Also central is an examination of trends in the use of cellular wireless technologies. Market forecasts are provided through 2016.

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Microelectronics Component Manufacturers Increase Fiber-Optic Network Capacity

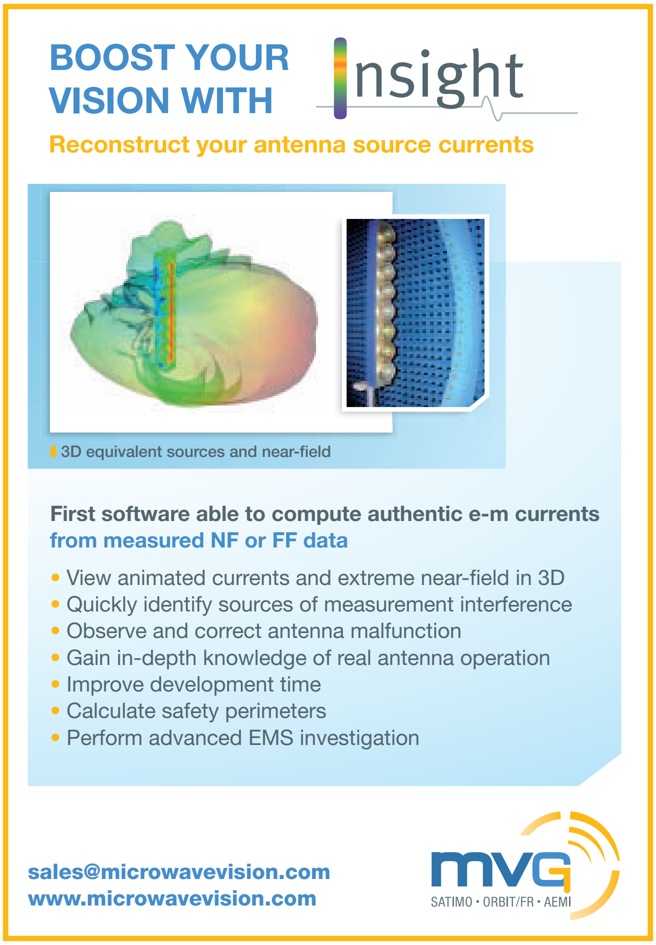
As data consumption, driven by smartphones, video files and faster Internet service, continues to skyrocket, service providers respond by increasing the amount and capacity of high data rate fiber in their transmission networks. The Strategy Analytics GaAs and Compound Semiconductor Technologies Service (GaAs) viewpoint, "Compound Semiconductor Industry Review March 2011: Microelectronics," illustrates product developments for Fiber to the Home (FTTH), Community Access Television (CATV) and RF over Glass (RFoG) applications from industry leaders, TriQuint Semiconductor and Analog Devices. In addition, this viewpoint report captures product, financial, contract and technology announcements for microelectronic companies such as RFMD, Skyworks Solutions, Hittite Microwave, ANADIGICS and NXP for March 2011.

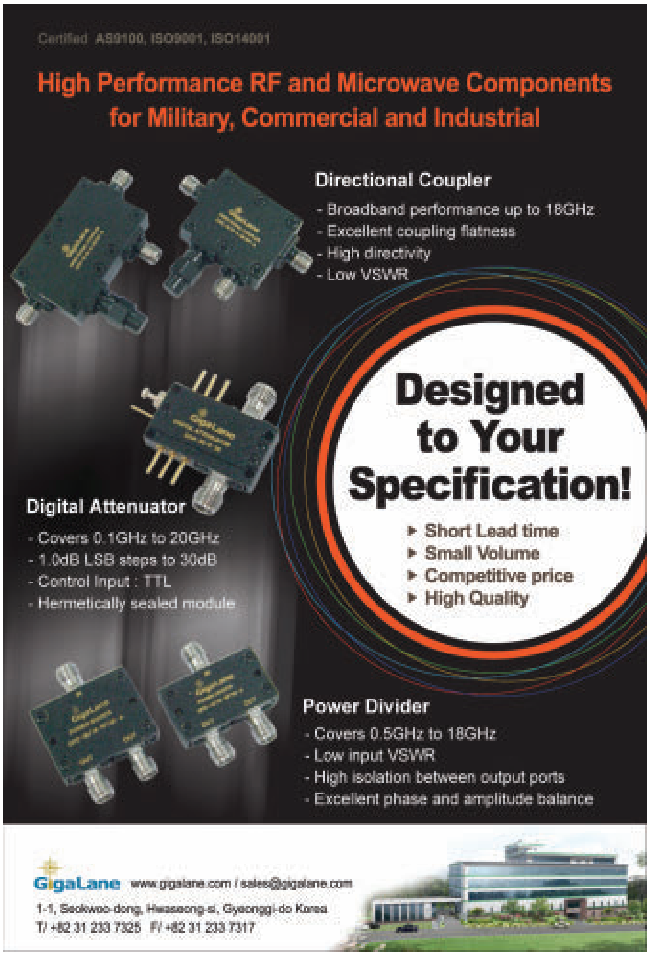
"With the dramatic increase in mobile data consumption, we tend to lose sight of the fact that landlines still transport the largest amount of data and most of the mobile data," noted Eric Higham, Director of the Strategy Analytics GaAs and Compound Semiconductor Technologies Service. "Product announcements show development activity from GaAs manufacturer TriQuint, as well as Silicon manufacturer, Analog Devices, which are aimed at CATV, fiber and RF over Glass (RFoG). These applications will increase capacity for operators providing voice, video and data services."

"...we tend to lose sight of the fact that landlines still transport the largest amount of data and most of the mobile data."

Asif Anwar, Director, Strategy Analytics Strategic Technologies Practice, added, "While the largest portion of the compound semiconductor market revenue resides with handset applications, companies are also developing products for infrastructure, broadband, test and measurement, medical, fiber, CATV and military market applications."

This Strategy Analytics viewpoint summarizes March 2011 financial, product, contract and employment developments from major GaAs and silicon suppliers, addressing a variety of commercial and military applications that use gallium arsenide (GaAs), gallium nitride (GaN), silicon carbide (SiC) and complementary metal-oxide-semiconductor (CMOS) technologies.





Around the Circuit

Kerri Germani, Staff Editor

INDUSTRY NEWS

Skyworks Solutions Inc. closed its acquisition of **SiGe Semiconductor Inc.**, a global supplier of radio frequency front-end solutions. The companies entered into a definitive agreement on May 17, 2011. Skyworks paid cash for the acquisition, which was approved by Skyworks' board and SiGe's board of directors and stockholders.

RF Industries Ltd. has completed the acquisition of Long Island, NY-based **Cables Unlimited Inc.** (CUI), a seller of fiber-optic cabling and connector products, for a total purchase price of $5.6 M, consisting of $2.8 M in cash and 762,738 common shares. Privately owned CUI had revenue of approximately $6.2 M and non-audited non-GAAP adjusted EBITDA of approximately $645,000 in its most recent 12 months ended December 31, 2010.

API Technologies Corp., a provider of electronic systems, subsystems, RF, and secure communications products and services for defense, aerospace, and commercial applications, announced the successful completion of its acquisition of **Spectrum Control Inc.** API completed the acquisition through a merger of a wholly-owned subsidiary with and into Spectrum. As a result of the merger, all outstanding shares of Spectrum common stock were converted into the right to receive $20.00 per share in cash, without interest and less any required withholding taxes.

CommScope has signed an agreement to acquire **Argus Technologies**, a producer of antenna solutions for wireless applications. Argus Technologies, headquartered in Bella Vista, New South Wales, Australia, provides a wide array of high performance, high technology antennas for base stations, stadiums and venues, and other wireless applications.

GigOptix Inc., a supplier of semiconductor and optical components that enable high speed information streaming, announced **Endwave Corp.** stockholders voted to approve the acquisition of Endwave by GigOptix.

Transline Technology Inc., which has been in the printed circuit board business for more than 20 years, broadened its scope of services significantly by acquiring **HI Electronics**. HI Electronics, also 20-year industry veteran, was formerly located in Los Angeles, CA. All of its equipment and staff have now been relocated to the 20,000 square foot facility owned and occupied by Transline Technology in Anaheim, CA. Both companies will now operate under the flagship company's name, Transline Technology.

Renaissance Electronics Corp. of Harvard, MA, is celebrating its 20th anniversary in the RF/microwave industry. The company said its vision to be the preferred supplier of all frequency products is becoming a reality, especially with the acquisition of HXI millimeter-wave company. Renaissance now covers most components, integrated assemblies and other products in frequencies ranging from radio to microwave to millimeter.

RFMW Europe has added a new office in France. In the past few months, RFMW Europe has opened offices in the UK, Germany, Italy and France to join with RFMW Israel in covering Europe, the Middle East and Africa (EMEA).

TriQuint Semiconductor Inc. has been honored with awards recently. TriQuint earned the R&D award at the CS Europe Conference in Germany. Also, TriQuint was named a top ten Most Popular Semiconductor Brand In China at the Conference on Green Manufacturuing.

Agilent Technologies Inc. has received this year's Frost & Sullivan award for market-share leadership in global wireless test equipment.

RF Micro Devices announced it has qualified its GaN1 power semiconductor process technology for 65 V operation. The high reliability power semiconductor process technology supports RFMD's GaN-based power semiconductor product designs and is also available to foundry customers through RFMD's Foundry Services business unit.

CONTRACTS

Harris Corp. has been awarded several contracts recently, including a $9.4 M order from the U.S. Air Force and a $5 M order from the U.S. Marine Corps. The order from the Air Force is for additional Falcon® III AN/PRC-117G multiband manpack radio systems. The order from the Marines is for additional Harris Falcon III AN/PRC-117G wideband manpack tactical radios.

Custom MMIC Design Services Inc. (CMDS) has been awarded its second Small Business Innovative Research (SBIR) Phase II contract from the U.S. Army to develop millimeter-wave, high linearity, high power amplifiers on Gallium Nitride (GaN) for satellite communication systems (SATCOM). CMDS is a fabless design company engaged in the development of high frequency monolithic microwave integrated circuits.

Crane Aerospace & Electronics Power Solutions was selected by **ECE**, a Zodiac Aerospace company, to supply its Transformer Rectifier Units (TRU) on the Electrical Power Distribution Systems (EPDS) for the Airbus A350XWB. There are seven TRUs within the Electrical Power Distribution System. The ECE Electrical Power Distribution Systems control and monitor the electrical DC power distribution to the loads on the aircraft. The Crane TRUs provide 230 VAC to 28 VDC conversion/fault protection and 115 VAC to 28 VDC conversion/fault protection within the EPDS.

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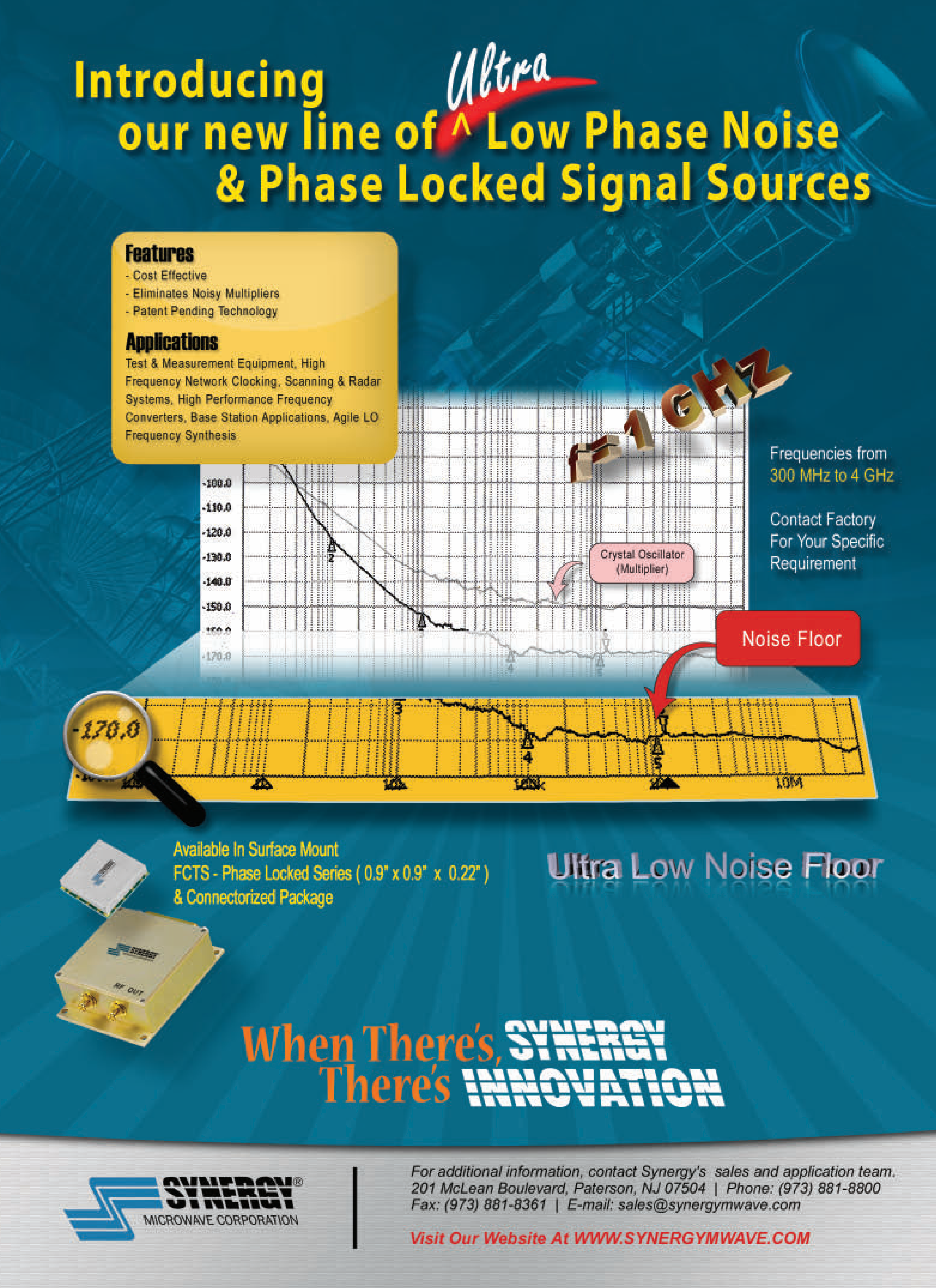

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Delta Microwave, a supplier of filters, filter/amplifiers, multiplexers and integrated microwave assemblies, announces its selection by **NASA**, Goddard Space Flight Center, to design and fabricate the Front-End Electronics (FEE) Assemblies for the Magnetospheric Multiscale (MMS) Project. The FEEs are part of the GPS Navigation System that will be used to fly four identical instrumented observatories in a tetrahedral formation to unambiguously determine the orientation of the Earth's magnetic reconnection layer.

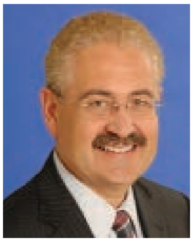
Pulse Electronics Corp., a provider of electronic components, announced that its laser direct structuring (LDS) process was selected by **Samsung Electronics Co. Ltd.** for producing three-dimensional antennas to be incorporated into future Samsung products that use an antenna. Pulse's LDS process creates an antenna pattern in three dimensions on a plastic part, giving Samsung's mobile device product designers an almost unlimited ability to put the antenna anywhere and use almost zero volume.

NEW MARKET ENTRY

SW Tech Equipment sells and services advanced parallel gap welding machines. The SMAPRO series gap welders are based upon resistance or ohmic spot welding principles. The most salient feature of its products is that, in addition to welding gold and silver ribbons, SW Tech can also weld enameled wire directly to welding pads of PC boards without the stripping process.

PERSONNEL

▲ Steven Laub



▲ Tunc Doluca

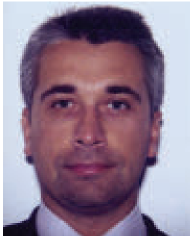
The **Semiconductor Industry Association** (SIA), representing US leadership in semiconductor manufacturing and design, announced that **Steven Laub**, President and CEO of Atmel Corp., and **Tunc Doluca**, President and CEO of Maxim Integrated Products Inc., have joined the SIA Board of Directors. Laub and Doluca join a distinguished group of industry executives from Advanced Micro Devices (AMD), Altera Corp., Analog Devices, Fairchild Semiconductor, Freescale Semiconductor, GLOBALFOUNDRIES, IBM Corp., Intel Corp., Intersil Corp, Linear Technology Corp., LSI Corp., Micron Technology, ON Semiconductor, PMC-Sierra, Qualcomm CDMA Technologies and Texas Instruments Inc.

▲ Glen Fields

M/A-COM Technology Solutions announced the appointment of **Glen Fields** as Director, Aerospace and Defense. A 10-year veteran at M/A-COM Tech, Fields received a B.S. in Systems Engineering from the U.S. Merchant Marine Academy, and also an MBA from University of San Diego. He is also a Commander in the U.S. Naval Reserve, with 17 years of distinguished service.

▲ Susan Munyon

Centerline Technologies LLC appointed **Susan Munyon** to the position of Senior Sales Engineer. Having a bachelor's degree in Ceramic Engineering from Alfred University gave her the materials background. And her extensive experience, including 11 years at Kyocera America and five years at CoorsTek, has expanded her knowledge in the microelectronics area. She has been awarded a Fellow of IMAPS where she remains active as well as with the American Ceramic Society.



▲ Carlo Rizzo

ORBIT Communication Systems Ltd. has appointed **Carlo Rizzo** as Director of Sales and Business Development to head the company's Telemetry and Earth Observation business operations in Europe. Most recently, he served as Director of European Operations for a major U.S.-based antenna measurement system supplier.

REP APPOINTMENTS

Richardson RFPD announced three global distribution agreements. It has been selected by **Amercian Technical Ceramics** as the global exclusive distributor for the new 506WLC series of ultra-broadband inductors. Also, Richardson has been selected by **W. L. Gore & Associates** as the global distributor for its new 18 GHz GORE® PHASEFLEX® RF/microwave test assemblies. In addition, Richardson RFPD has entered into a global distribution agreement with **Kendeil S.r.l**, a manufacturer of screw terminal and snap-in type aluminum electrolytic capacitors headquartered in Gallarate (VA), Italy.

Microwave Components and Systems of Northborough, MA, announced the appointments of representatives for the company's waveguide products. **Disman-Bakner** for northern CA; **RT Associates** for southern CA; **SunTech Marketing** for AZ, New Mexico and NV, and **Trionic Associates** for NY, NJ and PA.

Reactel Inc., a manufacturer of RF and microwave filters, multiplexers and multifunction assemblies to the commercial, military, industrial and medical industries, appointed **El Technology** as the company's exclusive representative in southern NJ, eastern PA and Delaware.

PEI-Genesis Inc. announced an agreement with **Emerson Network Power**, in which PEI-Genesis will distribute and add value to power supply products from the Embedded Power business of Emerson Network Power for customers in North and South America. PEI-Genesis now has the ability to help design engineers solve their power challenges using power supplies from Emerson Network Power.

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GaN HEMT Technologies for Space and Radio Applications

GaN HEMTs have been considered to be the best option for realizing high performance in high power amplifiers (HPA), and now amplifiers based on GaN technology have started to become widely deployed in various applications. This article describes some development activities and performance results of GaN HPAs. The development of a high power added efficiency (PAE) process with a subsequent high output power amplifier for C-band space applications employing GaN HEMT technology is described. In this work, to boost the PAE, a newly introduced on-chip harmonic tuning for FETs is adopted. The 100 W HPA achieves a 67 percent PAE (72.4 percent drain efficiency) at 3.7 GHz, under CW operating conditions. To the best of the author's knowledge, this is the highest reported efficiency of C-band HPAs with over 100 W of output power. In other areas of development at other frequency bands, a 360 W L-band HPA having 65 percent PAE, and a 60 W X-band amplifier with 43 percent PAE are briefly described. The technologies, which have been developed for the 360 W L-band HPA, are particularly applicable for use in base station amplifiers suitable for the cellular phone network.

The GaN-based high electron mobility transistor (GaN HEMT) is generally considered to be the best choice in order to meet the requirements for many current HPA designs. HPAs have recently become desirable for high linearity and wider bandwidth operation at lower power consumption. While GaAs HEMT or LDMOS have traditionally been widely used as the HPA devices, GaN HEMT offers the following advantages:

- Higher PAE, which not only saves electrical power usage (OPEX), but also can reduce the size and cost of HPAs, due to the lower amount of heat dissipated (CAPEX).
- High operating voltage – GaN HEMT operates with a power supply voltage of up to 50 V, similar to the range of the power feeder voltage of 48 V, which is commonly used for communication equipment. Furthermore, for any given output power and supply voltage, the operating current can be reduced, when compared to other technologies.

In general, the amplifier design becomes more challenging as the transistor impedances become lower. GaN HEMT devices have a higher impedance than other technologies. Hence, the HPA design engineer can use the benefits of GaN to enhance HPA performance, such as wider frequency band coverage and higher PAE, depending on the required performance of the HPA.

In space applications, the vacuum tube based traveling wave tube amplifier (TWTA) is still used, because of a high PAE. However, because a TWTA needs an extremely high voltage, of the order of several thousands of volts, and reliability is considered not ideal due to the hot electrons in the vacuum tube, the solid-state power amplifier (SSPA) is often considered to be the favored solution. GaN based SSPAs are now in development, in order to replace TWTAs in many space applications and plans are in place to soon launch GaN SSPAs into space. In this article, a 67 percent PAE, 100 W GaN HEMT for C-band space use is described in detail.

GaN HEMT

Although the GaN HEMT was originally expected to be an ideal device for HPAs, early transistor designs raised the issue that the drain

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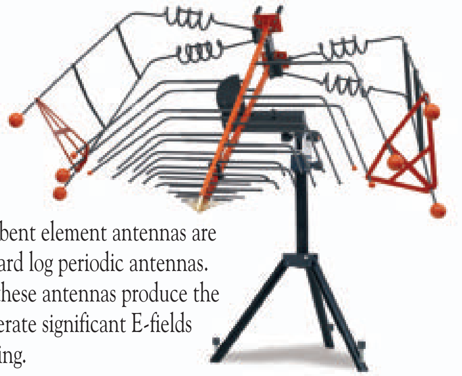

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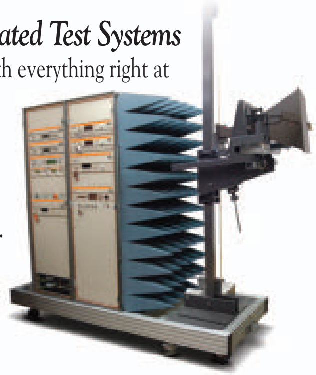

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current measured under pulsed conditions was smaller than that observed under CW conditions. The phenomenon is called current collapse, and leads to a lower PAE and reduced output power. This was due to a less effective knee voltage, which reduced the maximum drain current. In order to suppress this current collapse, a SiN passivation film is deposited with a Cat-CVD process and NH3 treatments.[1] In addition, Si ion implantation under the source and drain electrodes was employed to realize a low ohmic contact resistance.[2] The GaN HEMT device structure employed in this work is shown in ***Figure 1***. The gate-length is 0.6 µm and substrate via holes are used to produce higher power gain in the C-band.

SPACE APPLICATIONS

In space applications, such as satellite communication systems, the RF power amplifier is one of the key components. In the amplifiers, a high PAE is important in order to reduce the launch cost of a satellite.[3] C-band amplifiers, in the frequency range of 3.7 to 4.2 GHz, are often used for satellite downlinks.

In spite of the tremendous merits of SSPAs, GaAs based amplifiers cannot typically offer an acceptable PAE for many satellite applications and the GaN HEMT SSPA, with its higher PAE, is expected to be the best candidate for replacing TWTAs. Many organizations have recently developed GaN HPAs at C-band.[4-8] However, there are very few reports for HPAs with more than 60 percent PAE.[9]

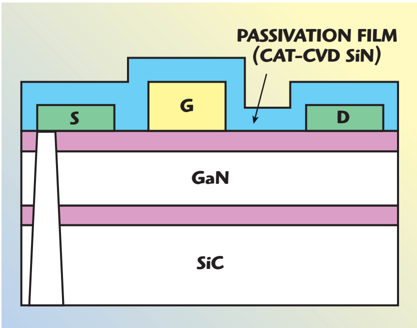
HPA WITH HIGH PAE

Figure 2 shows the second and third harmonic load/source pull measurements of a unit cell of a GaN HEMT (1.2 mm gate-width) with a PAE contour at an operating voltage of 40 V and a frequency of 3.7 GHz. Each measurement was performed while keeping the other fundamental and second and third harmonic impedances fixed for the maximum PAE. The figure shows that not only does the second harmonic output impedance have a substantial impact on PAE improvement, but so does the second harmonic input impedance. Moreover, the second harmonic input impedance region of the highest achieved PAE of more than 82 percent is near a short circuit and is a very small area when compared to the other impedance regions.

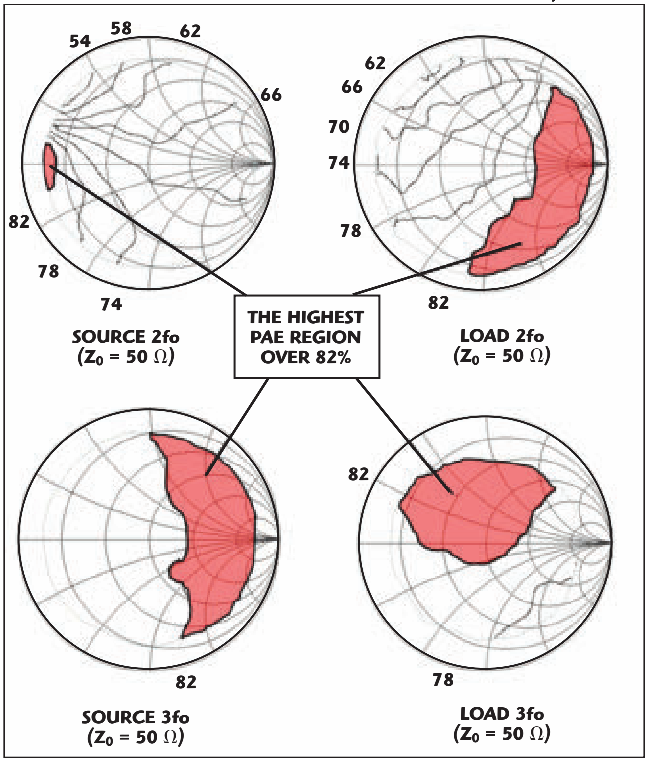
For the third harmonic, the contour of the high PAE is larger than that of the second harmonic. It is, therefore, important to precisely control the second harmonic input impedance to the short region. To achieve the high output power with higher PAE, many GaN-based amplifiers have adopted the harmonic impedance control technique, using resonance circuits such as open stubs formed on external matching circuits.[4,9]

However, this control is not easy to achieve, due to insufficient reflection of harmonic signals from the resonance circuit and the inductance of the bonding wire to the die. Moreover, the bonding wire brings an additional difficulty when trying to precisely control the reflected harmonic phase, because of the fluctuation in the bonding wire length at the second harmonic frequency.

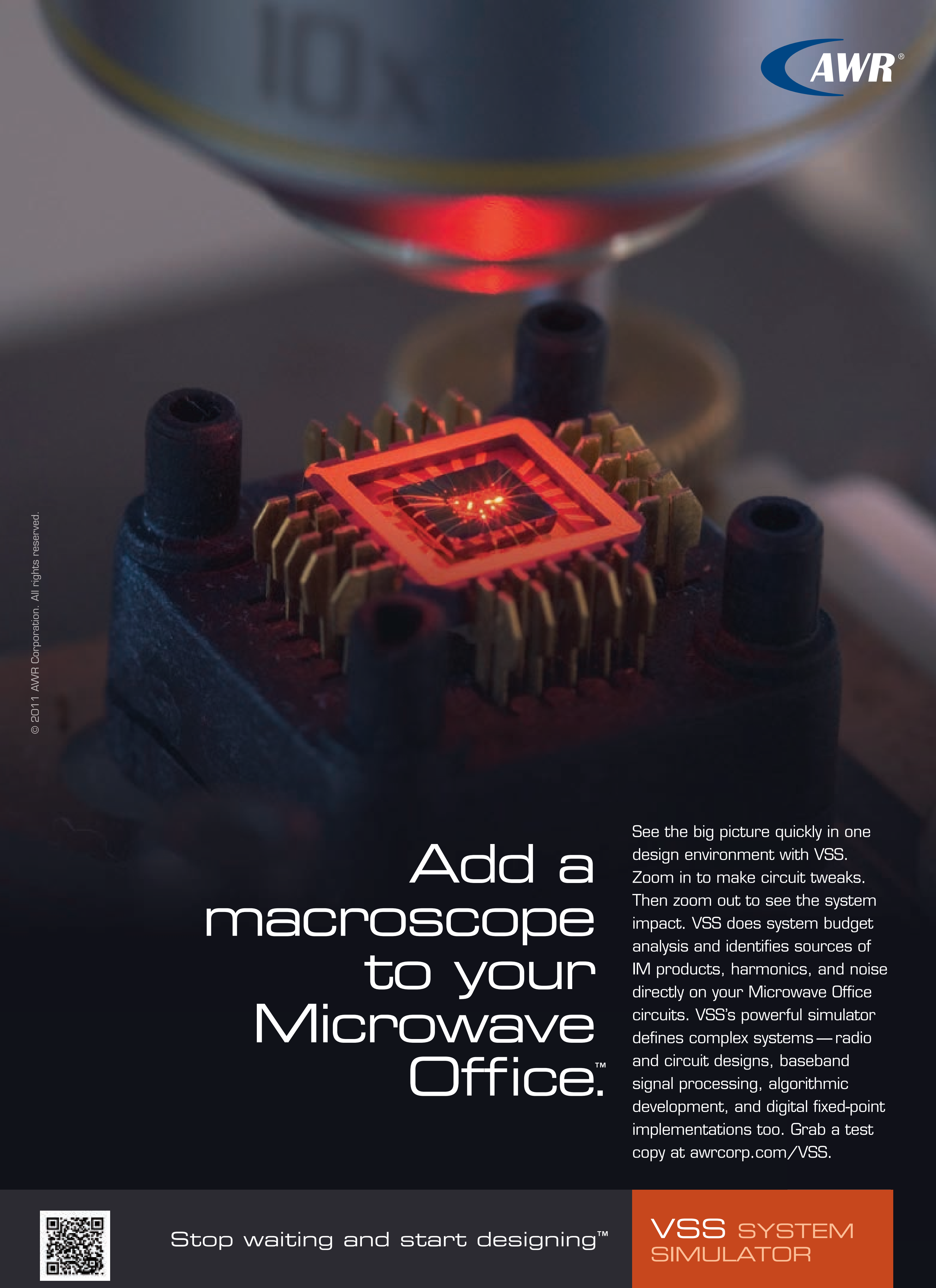
Despite the higher impedance of a GaN HEMT compared to a LDMOS or GaAs HEMT, the above problem is more severe, particularly for a large gate-width FET amplifier, which consists of FETs connected in parallel. For this reason, it is not easy to realize a high PAE with the external harmonic matching circuits. In order to develop a 100 W GaN HPA for C-band space applications, an on-chip input second har-



▲ *Fig. 1 GaN HEMT device structure cross-section.*



▲ *Fig. 2 Second and third harmonic load/source pull measurements of a unit cell GaN HEMT.*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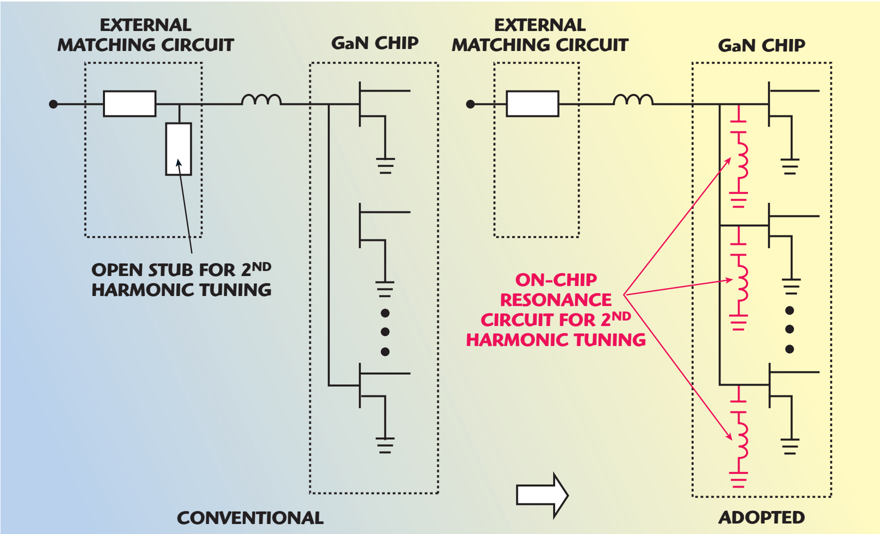


▲ *Fig. 3 Comparison of an adopted and conventional configuration.*

monic tuned FET technology for PAE improvement is introduced.

CIRCUIT DESIGN

The simplified schematic of the adopted configuration, compared to a conventional configuration, is illustrated in ***Figure 3***. In the case of the conventional amplifier, the second harmonic input impedance is controlled by the resonance circuit, such as open stubs, placed in the external matching circuit. As mentioned before, this configuration does not work well. In this study, the resonance circuit used for the second harmonic input impedance control is integrated in each unit cell placed on a GaN chip. The photographs in ***Figure 4*** show the unit cell of a conventional FET and the on-chip harmonic tuned FET, respectively. In Figure 4b, the harmonic resonance circuit consists of a MIM capacitor and a spiral inductor, which are connected to the gate of the FET.

In ***Figure 5***, the PAE dependence on harmonic impedance is shown. The measurement conditions are the same as the conditions of Figure 2. When comparing performances of (a) the conventional FET and (b) the on-chip harmonic tuned FET, the on-chip harmonic tuned FET achieves the highest PAE of more than 82 percent at almost all second harmonic input impedances. Thus, this architecture is very effective for improving PAE, even in large gate-width FETs.

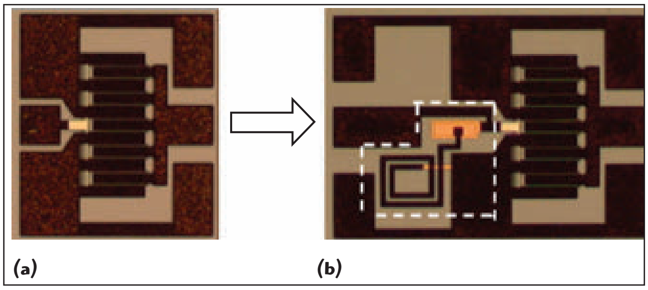
FABRICATED AMPLIFIER PERFORMANCE

A 100 W amplifier was fabricated, using an on-chip harmonic tuned FET. The amplifier and FET chip are shown in ***Figure 6***. The total gate-width of a single chip is 9.6 mm, and the chip size is 2.90 by 0.78 mm. The package size is 15.2 by 14.3 mm. The output characteristics versus input power are shown in ***Figure 7***. For comparison, the performance of the highest PAE amplifier ever reported at C-band is also plotted. Both amplifiers were measured at 3.7 GHz under CW operation. The drain voltage and the quiescent drain current were 40 V and 2 A, respectively. As shown in the figure, a 67 percent PAE (72.4 percent drain efficiency) and a 107.6 W output power were obtained. The PAE is increased by more than five percent, when compared to the conventional amplifier,[9] by using an on-chip harmonic tuned FET. Over the frequency range 3.65 to 4 GHz, this amplifier achieves a high PAE, greater than 60 percent, and a high output power greater than 100 W.

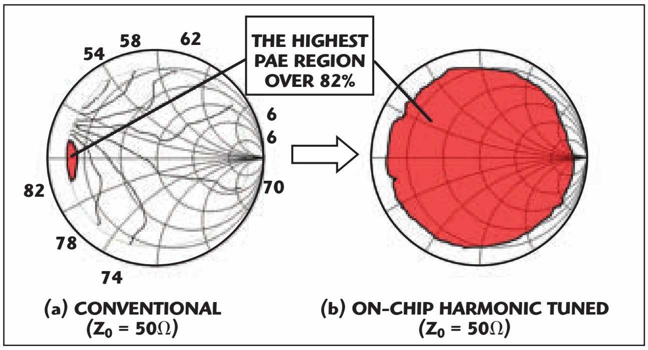
But because of the lower PAE of GaAs-based SSPAs, satellites continue to be launched into space using TWTAs. The new generation of GaN devices eliminates the issue of low PAE in SSPAs. GaN HEMT technology based SSPAs can now accelerate the replacement of the TWTA with the SSPA in these power ranges.

L-BAND GaN HEMT HPA

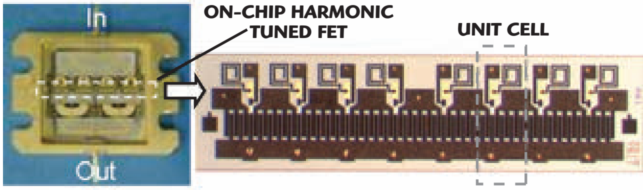
Considering other applications of GaN HEMTs, the HPA used in the



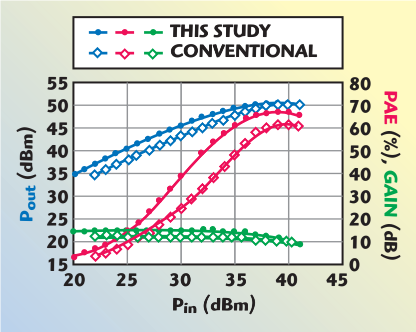
▲ *Fig. 4 Comparison between a conventional FET (a) and an on-chip harmonic tuned FET (b).*



▲ *Fig. 5 Comparison of PAE dependence with harmonic impedance.*



▲ *Fig. 6 100 W GaN amplifier and FET chip.*



▲ *Fig. 7 Output characteristics vs. input power (Vds = 40 V, 3.7 GHz, CW).*

applied to enhance the performance of the main amplifier in a Doherty configuration for cellular phone base station amplifiers. A higher PAE is also important for the efficient performance of a remote radio head (RRH) scheme for base station architecture.

Among the high PAE HPA designs, Class E operation is the most popular approach for L- or S-band.[10] In Class E amplifier design, the parasitic capacitance (Cp) of a transistor is used as the tank capacitance, which consists of an output matching network to achieve high efficiency. From theoretical analysis, the product of operation frequency and output power is inversely proportional to the Cp. In other words, the transistor technology with a smaller Cp can operate at a higher power or frequency.

As shown in ***Table 1***, the Cp of a GaN HEMT is 23.6 times smaller than that of a LDMOS. Considering the current density and the capability of high voltage operation, the advantage of GaN HEMT over LDMOS is very attractive. Employing a modified Class E amplifier design, a 360 W L-band partially impedance matched GaN HEMT has been successfully developed. The load impedance for maximum PAE is shown in ***Table 2***. A partially matched GaN HEMT and an external matching circuit for the 360 W L-band HPA were designed according to the best PAE points shown in the table. ***Figure 8*** shows the GaN device and the external matching circuit. A packaged GaN HEMT with a partially matched circuit was attached to a heat sink by two screws. The GaN HEMT package can be seen between the external input and output matching circuits. The output characteristic of the L-band HPA is shown in ***Figure 9***. The performance

base stations of the cellular phone network is well suited for the adoption of GaN. Currently, to improve the linearity of a HPA, Class AB operation is widely used, but Class AB results in less PAE and, therefore, consumes more power. Many studies using saturated amplifier designs have been carried out recently.[10]

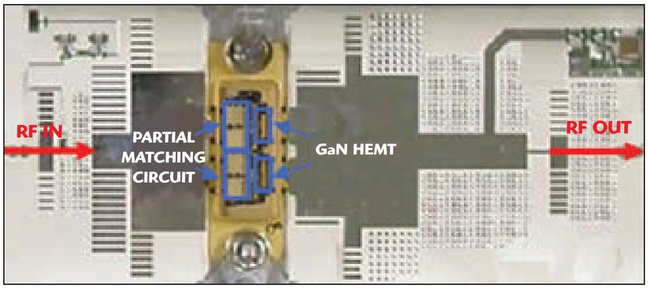
The development results of a 65 percent PAE, 360 W, L-band saturation amplifier will now be covered. The technologies, which enable an increase in the output power and PAE, can be

TABLE I
PERFORMANCE COMPARISON OF HIGH FREQUENCY, HIGH POWER TRANSISTORS

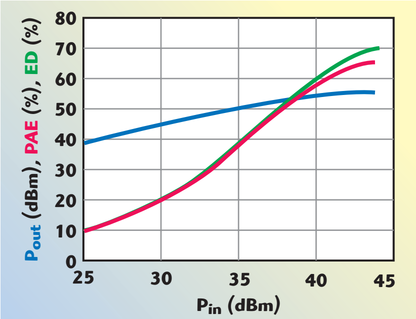
Transistor	Current Density (mA/mm)	Cp (pF/mm)	Breakdown Voltage (V)
Si LDMOS	400	3.3	50
GaAs HFET	300	0.185	15
GaN HEMT	600	0.14	200

TABLE II
LOAD IMPEDANCE FOR MAXIMUM PAE CONDITIONS

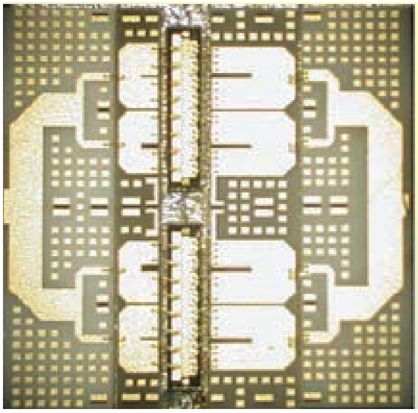
	Real part (Ω)	Imaginary part (Ω)
Z1(f0)	42.3	9.0
Z1(2f0)	2.8	-0.7
Z1(3f0)	3.67	18.2



▲ *Fig. 8 GaN device and external matching circuit.*



▲ *Fig. 9 Output characteristics of the L-band HPA.*



▲ *Fig. 10 X-band HPA.*

was evaluated with Vd = 56 V under pulse operation. The maximum output (Pout) was 360 W, with a PAE of 65 percent, or with a drain efficiency of 70 percent. Extending this developed technology, a 160 W partially matched GaN HEMT for CW operation has been developed, which is suitable for base station applications.

This technology is applicable to modern linear amplifier design, which is needed in order to meet the high peak to average ratio (PAR) required by LTE. In satisfying the linearity requirement, GaN HEMT technology can offer a contribution toward increasing the PAE as well as reducing the amplifier size and cost. This is due to a lower heat dissipation, which is strongly required by the RRH configuration.

GaN HEMT HPA FOR X-BAND

A high PAE HPA employing GaN HEMT is also desired for X-band. Therefore, an X-band amplifier has been designed and fabricated using a shorter gate length and narrow gate width in order to operate at a higher frequency. For X-band, the optimization of higher order harmonic frequencies is important, as it is for the lower bands. One advantage in designing for X-band is that harmonics are in the millimeter-wave region. Therefore, the harmonics have less influence on the PAE than for lower frequency bands, due to a relatively low emission output from GaN HEMT. However, due to the shorter wavelength, the difference in the path length between the matching circuit and the unit cells of the transistor does become a problem. This difference disturbs the equal distribution or combination of input/output power to/from each unit cell. The non-uniformity of power does not only result in a loss of power, but also necessitates an optimized unit cell impedance value. To overcome the problem, input/output matching circuits were designed in an asymmetrical manner in order to keep the uniformity of the power distribution/combination as shown in ***Figure 10***. ***Figure 11*** shows the output characteristics of the X-band HPA. The saturated output power reaches 60 W

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SPDT (R)	0.02–3.0	0.40	23.0	43	30	AS179-92LF
SPDT (R)	0.02–6.0	0.35	24.0	50	30 (0.5 dB)	SKY13351-378LF
SPDT (R)	0.10–2.5	0.55	17.0	56	37	AS193-73LF
SPDT (A)	0.50–6.0	0.6–1.0	27–24	52	37	SKY13348-374LF
SPDT (A)	0.50–6.0	0.7–1.15	31–24	55	39	SKY13370-374LF
SP3T (R)	0.02–6.0	0.60	25.0	50	29	SKY13317-373LF
SP3T (R)	0.10–3.5	0.5–0.6	39–25	57	33	SKY13385-460LF
SP4T (R)	0.02–6.0	0.60	26.0	51	30	SKY13322-375LF
DPDT (R)	LF–6.0	0.95	22.0	60	34	SKY13318-321LF
DPDT (R)	0.10–6.0	0.60	23.5	55	33	SKY13355-374LF
DPDT (R)	0.10–6.0	0.60	22.0	62	37	SKY13381-374LF

Smart Energy, Broadband, Cellular Infrastructure, Test & Measurement, Military (COTS)

Description	Frequency (GHz)	Insertion Loss (dB)	Isolation (dB)	Input IP3 (dBm)	Input $P_{1\,dB}$ (dBm)	Part Number
SPDT (R)	0.0003–2.5	0.3–0.4	25–24	48	30	AS169-73LF
SPDT (R)	0.1–2.5	0.3–0.55	30–17	56	37 (0.1 dB)	SKY13270-92LF
SPDT (A)	0.1–6.0	0.8–1.5	62–42	46	30	SKY13286-359LF
SPDT (R)	3.0–8.0	0.7–0.9	25–22	47	26	SKY13298-360LF
SP3T (A)	0.5–2.5	0.9–1.2	62–55	43	30	SKY13277-355LF
SP4T (A)	0.5–3.0	0.4–0.9	45–25	40	26	AS204-80LF

DBS/LNB 4 x 2 Matrix Switch

Description	Frequency (GHz)	Insertion Loss (dB)	Isolation (dB)	Input $P_{1\,dB}$ (dBm)	Part Number
LNB/DBS (A)	0.25–2.15	7.5–8.5	40–31	15	SKY13272-340LF

UHF/VHF (48–1000 MHz)

Description	Insertion Loss f = 48 MHz (dB)	Isolation f = 48 MHz (dB)	Input $P_{1\,dB}$ f = 48 MHz (dBm)	Insertion Loss f = 1 GHz (dB)	Isolation f = 1 GHz (dB)	Input $P_{1\,dB}$ f = 1 GHz (dBm)	Part Number
SPDT (R)	0.15	56	29	0.3	25	34	AS179-92LF
SPDT (R)	0.2	55	28	0.35	24	30 (0.5 dB)	SKY13351-378LF
SPDT (R)	0.3	42	38.5 (0.1 dB)	0.4	29	38.5 (0.1 dB)	SKY13299-321LF
SPDT (R)	0.3	44	39.8 (0.8 dB)	0.45	23	40.5 (0.1 dB)	SKY13290-313LF
SP3T (R)	0.3	49	26	0.45	27	29	SKY13317-373LF
SP4T (R)	0.3	49	26	0.6	28	30	SKY13322-375LF
SP4T (R)	0.3	54	41	0.45	24	38 (0.1 dB)	SKY14151-350LF

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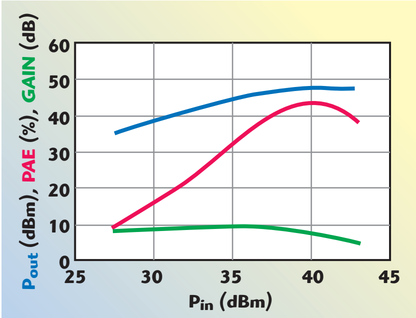
with a high PAE of 43.4 percent. These development results show that GaN HEMT is also well suited to operation at higher frequency bands.

CONCLUSION

GaN HEMT is the best transistor technology for producing high performance HPAs in many applications, so it can satisfy the market demands for high power, high PAE devices. For space applications, an HPA was developed, which offers 100 W output power, together with a very high efficiency of 67 percent. The performance improvements achieved in this development will help to accelerate the replacement of TWTA amplifiers with GaN based SSPAs in this power range.

At L-band, a 65 percent PAE, 360 W amplifier has been successfully developed. In this development, a modified Class E-amplifier technology has been applied for use in modern linear amplifier designs, such as in the main path of Doherty amplifiers. The use of GaN HEMT will encourage amplifier designers of RRH base stations, as used in the cellular phone network, to enhance amplifier performance in order to meet LTE requirements. The successful development of an X-band, 43 percent efficiency, 60 W HPA, shows the capability of GaN HEMT at high frequency bands. ■



▲ *Fig. 11 Output characteristics of the X-band HPA.*

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NEW LZY-22+	0.1-200	43	+42.0	+45.0	8.9	+52	24	6.0	1495	1470
LZY-1+	20-512	43	+45.7	+47.0	8.6	+54	26	7.3	1995	1895
LZY-2+	500-1000	46	+45.0	+45.8	8.0	+54	28	8.0	1995	1895
ZHL-5W-1	5-500	44	+39.5	+40.5	4.0	+49	25	3.3	995	970
ZHL-5W-2G+	800-2000	45	+37.0	+38.0	8.0	+44	24	2.0	995	945
ZHL-10W-2G	800-2000	43	+40.0	+41.0	7.0	+50	24	5.0	1295	1220
ZHL-16W-43+	1800-4000	45	+41.0	+42.0	6.0	+47	28	4.3	1595	1545
• ZHL-20W-13+	20-1000	50	+41.0	+43.0	3.5	+50	24	2.8	1395	1320
ZHL-30W-252+	700-2500	50	+44.0	+46.0	5.5	+52	28	6.3	2995	2920
ZHL-30W-262+	2300-2550	50	+43.0	+45.0	7.0	+50	28	4.3	1995	1920
• ZHL-50W-52	50-500	50	+46.0	+48.0	6.0	+55	24	9.3	1395	1320
• ZHL-100W-52	50-500	50	+47.0	+48.5	6.5	+57	24	10.5	1995	1920
• ZHL-100W-GAN+	20-500	42	+49.0	+50.0	7.0	+60	30	9.5	2395	2320
ZVE-3W-183+	5900-18000	35	+34.0	+35.0	5.5	+44	15	2.2	1295	1220
ZVE-3W-83+	2000-8000	36	+33.0	+35.0	5.8	+42	15	1.5	1295	1220

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*For models without heat sink, add **X suffix** to model No.(Example: LZY-1+, LZY-1X+)*

IEEE MTT-S IMS2011: Busy in Baltimore

The energy and activity levels of a large crowd are hard to quantify, but by the accounts of most observers, there was plenty of both at the International Microwave Symposium 2011 in Baltimore, MD, June 5-10. Event managers said the official attendance was more than 8600 participants. This number is larger than the previous year in Anaheim, CA. "Final attendance was actually 7981 after all the numbers were in…lower than the preliminary estimate of 9500," IMS2010 organizers reported.

This year, technical registration was 2491 and preliminary exhibit-only registration numbers showed 1882 participants. These numbers combined and subtracted from the total indicates that the exhibition staff itself probably accounted for about half of all the attendees. If the health of the industry is based on the number of companies in attendance, this year showed impressive growth with 601 individual exhibiting companies compared to 556 companies in 2010. If you did not submit an accepted technical paper to the conference or you were assigned to work in your company's booth or you traveled to the show at your own expense or your company's expense in the past few years, then you may be wondering what kind of companies are representing the industry these days at IMS.

This year, the Journal produced a series of Microwave Flash Focus: IMS Exhibitor Preview newsletters to help attendees get a jump on what they would see in Baltimore. We divided this list of exhibitors (select advertisers from our May IMS show issue) into several major product categories, namely Components, Semiconductors, Subassemblies/Materials, Cables/Connectors and Test Equipment/Design Software. These are the bulk of companies at IMS. The companies that are missing from IMS are the major commercial and defense system integrators and consumer electronics giants – Raytheon, BAE, Lockheed Martin, Alcatel Lucent, Ericsson, Huawei, Nokia, etc. Those companies are to be found at shows such as MILCOM, CTIA, Mobile World Congress or electronica. IMS is a completely different show – for and about microwave semiconductors and components.

Test equipment and design software vendors sell the bulk of their RF products to all other categories represented in the MWJ exhibitor preview list, so they are generally among the largest exhibitors (based on booth size and staffing). Year after year, semiconductor vendors also tend to make their presence known with the largest booths and staff on the exhibition floor. The remaining small to mid-size companies, those that design and manufacture passive components, materials, cables, connectors, subassemblies and related services, make up the bulk of the exhibition floor space. This is the fabric (and strength) of our industry, an impressive number of innovators and entrepreneurs developing new and creative solutions – forming start-ups, growing organically or through mergers and acquisitions, being acquired and/or spun-off.

In our annual wrap-up article of past IMS exhibitions, we attempted to summarize the major product news. As the show and the number of exhibitors and released products have grown, this task is becoming increasingly challenging to do in a single article. Our main coverage is now addressed online (www.mwjournal.com/ims2011), with show related articles, product releases, news, Twitter feed, videos, pictures and through our Microwave Flash: IMS Show Daily newsletter. This article will instead focus on industry trends and offer data and perspectives on the conference and exhibition.

CONFERENCES

IMS or Microwave Week actually combines three conferences (IMS, RFIC and ARFTG).

MICROWAVE JOURNAL *STAFF*


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The technical program is comprised of more than 165 technical sessions, workshops and panel sessions covering wireless communication, radar, RF technologies, high frequency semiconductors and electromagnetics for a variety of commercial and military applications.

The IMS2011 Technical Program Committee, under the leadership of TPC Chair Ramesh Gupta, increased the number of IMS2011 topic areas from 31 to 35, dividing the conference into four focus tracks including: 1. Microwave Fields and Circuit Techniques 2. Passive RF and Microwave Components 3. Active RF Components and Systems and 4. RF Microwave Systems and Applications. New topics in current technical areas, such as RFID Technologies, Industrial Applications of High Power Microwaves, RF Nanotechnologies, and Emerging Technologies, were added to the program.

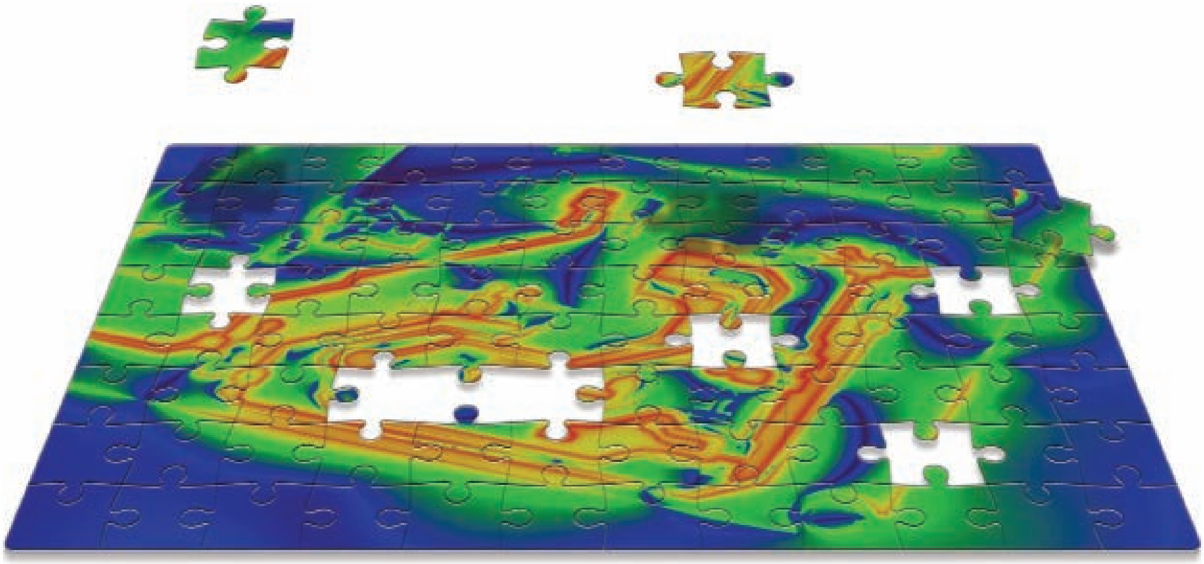
This year, the steering committee implemented a "double-blind" review process for submitted papers, meaning that the authors' names and affiliations were kept from reviewers. This new policy was designed to eliminate any conflicts of interest or bias in the review process. It is unclear if the policy had an impact on the quality of the chosen papers, although there was a sizeable increase this year. The Technical Paper Review Committee selected 444 papers out of 841 submitted, with 348 podium presented papers and 96 interactive forum papers. In addition, the program was supplemented by 33 workshops, six short courses, four panel sessions, one rump session and seven student design competitions, plus a graduate student challenge. By comparison, the 2010 IMS program included 250 technical papers presented orally and 122 papers presented in an interactive forum, so there was a net gain in presented material this year (444 vs. 372). Altogether, the conferences were well attended (2491) however, they were somewhat down from the numbers reported in 2010 (2793). This could be a reflection of tighter travel budgets more than a reflection on the technical program itself.

COMPANY AND PRODUCT HIGHLIGHTS

The acquisitions of AWR and Phase Matrix by National Instruments, API Technologies' acquisition of Spectrum Control and Skyworks' acquisition of SiGe and Advanced Analogic Technologies in the weeks before IMS, created a pre-show buzz for the industry and no doubt attracted the media and attendees to visit these exhibitors. A number of companies announced interesting milestones, expanded product lines and portfolios via press

releases and booth demos throughout the week including:

- MMICs, RFICs and Discrete Semiconductors from RFMD (Narrowband VCOs, VCAs, GaN devices/foundry processes), OMMIC (10 new MMICS), UMS (X-band chip set, GaN power transistors), Hittite (33 new products), Skyworks (low power LNAs), Avago (mobile FEMs), TriQuint (base station RFICs, K-band amps), M/A-COM Tech (50 new products including high power GaN devices), NXP (GaN and LDMOS transistors and related products, RF DACs), Peregrine (digitally tuned capacitors, UltraCMOS™ switches), ADI (differential RF/IF amp, RF driver amps), Cree (GaN PAs), Aeroflex-Metelics (100 W SP3T switches), Freescale (77 GHz chip sets, improved LDMOS), Infineon (LDMOS, LNA modules for GPS/GLNOSS), Mitsubishi (GaN Amps), Ciao Wireless (ultra low noise amps), Endwave (mixers and upconverters), Linear Technology (RF mixers), Murata (Bluetooth FEMs), APA Wireless (VCOs), Valpey Fisher (Hi-Rel/COTS oscillators, passive CMOS discretes), and TowerJazz (SOI switch process).
- Components from K&L (low PIM filters), Synergy (wideband, low noise VCOs), AVX (High Q inductors), MDL (WR90 rotary joints), Sangshin (WiMAX filter), IMS (thin film attenuators, couplers, chip resistors), RLC (adjustable delay lines), Florida RF (high power terminations), Gowanda (conical inductors), Reactel (discrete filters), AMC (switch matrix), Anaren (new Xinger), Crystek (SAW bandpass filters), JFW (variable attenuators), AML (GaN amps), and Crane (switch matrix, POL converters, filters, MultiMix Technology).
- Cables and Connectors from W. L. Gore (18 GHz rugged cable assembly), P1dB (coax adaptors), Delta (cable assemblies), Corning Gilbert (push-on connector), Frontlynk (cables up to 110 GHz), GigaLane (SMA type switch), San-tron (eSeries connectors), Rosenberger (high density interconnects), Southwest Microwave (miniature treaded coupling coax assemblies), SPINNER (rotary joints, calibration kits), Times (TFlex cable), and TRU (high performance connectors).
- Materials and PCB Processing from Rogers (RT/duroid 6035HTC, RO4360), Dielectric Labs (high Q substrates), A.T. Wall (waveguide tubing), Laser Services (cutting EMI/bonding materials), T-Tech (mill path generation), LPKF (laser PCB prototyping), UltraSource (prototyping software), Arlon (ceramic-filled composite materials), RJR Polymers (liquid crystal polymer packages), Transline (fusion bonding of PTFE), and Westbond (bonders of all types).
- Subassemblies, Modules from Pascall (low noise sources), Telemakus (mm-wave synthesized source), EM Power (GaN amp modules), Herotek (harmonic generators), IMST (FRAC-N synthesizer), Power Module Technology (SSPAs), Scintera (linearizer modules), Micro Lambda (synthesizers), Mini-Circuits (you name it, they have it), Phase Matrix (high performance



synthesizers), Teledyne MEC (new SSPA line).

- Test Equipment from Agilent (ENA/PNA network analyzers,) Aeroflex (SGA signal generators for avionics, LTE digital radio test set), Anritsu (broadband VNA, DRM test for LMR Master), NMDG (DC pulsers, pulsed DC receivers), Hittite (20 GHz signal genrerators), AMCAD (load-pull), Holzworth (non-PLL synthesizers), Planar LLC (vector reflectometer), Tektronix (signal analyzers, AWGs), Heuermann and Rosenberger (full vector PIM tester), Rohde & Schwarz (two new VNAs), Wireless Telecom Group (Amplifier Test bench software), Maury (noise measurement, load-pull), Modelithics (X-parameter measurement services), and SPEAG (SEMCAD X Microwave).
- Design Software from Agilent (EMPro, SystemVue), CST (HPC to Studio 2011), Sonnet (v13), AWR (2011 Design suite), ANSYS (HFSS/Designer updates), Remcom (EM software), SPEAG (SEMCAD X), Integrated (CHRONOS), Mician (μWave Wizard), and MIG (WASP-NET).

For detailed product news go to www.mwjournal.com/ims2011.

OTHER HIGHLIGHTS FROM THE EXHIBITION

Over the past few years, organizers and several key exhibitors have been giving the MicroApps sessions a "face-lift" in order to draw larger crowds, thus making them more attractive to potential participants. MicroApps are generally mini-tutorials on a variety of applications. The short talks (typically 20 minutes) are reviewed and approved by the MicroApps steering committee (made up of IMS volunteers) and representatives from the exhibitor community. This event-within-an-event takes place in a sectioned off area of the exhibition floor with speaker presenting to an audience seated in an area for up to 100 attendees. This year, the event was sponsored by Agilent, with additional support (distribution of program CDs) from AWR and organizers from K&L Microwave. The Journal also participated as the organizer of the MicroApps keynote panel on Wednesday. The Nonlinear Characterization Forum drew a standing-room only crowd and had more than 200 people off-site join via a webinar simulcast.

Other show floor attractions included a grand prize award ceremony for NXP's first high performance RF design challenge, on-site training courses at Sonnet and CST (with bonus massage station), design demonstrations for the new digitally tunable capacitors at Peregrine, the many partnering companies on display along Agilent Avenue, and Cobham displaying its Ku-band UAS (drone) lightweight gimbal assembly. One hidden jewel was wearable antennas by Octane Wireless that fit about any form factor using flexible antenna technology. Another jewel was DaisyRF's wireless portable power meters featuring a wireless interface between the remote power meter and handheld display unit. With more than 600 exhibitors, it has become impossible to see them all, especially if one gets into a deep technical discussion. It was precisely the kind of engagement a trade show like the IMS exhibition was designed to be. ■

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MTT-STORIES
AND THE ADVENTURES CONTINUE...
WELCOME TO BALTIMORE!
Volunteer? Wait a minute We're not getting paid for this?
FOLLOWING THE TECHNICAL SESSIONS, WHICH BEGAN SUNDAY, SPECTACULAR FANFARE KICKS OFF THE PLENARY SESSION.....
Baltimore, MD Welcomes IMS2011
NEARLY 9000 PEOPLE "SAILED" INTO BALTIMORE'S INNER HARBOR TO PARTICIPATE IN MICROWAVE WEEK
Which way to registration?
ARRRGH! It be at the Convention Center, matey.
CHESAPEAKE
Microwaves for the World
IMS2011 Baltimore
WAAAAEEEWAA
This is NOT helping the hangover
AS THE CONFERENCE CONTINUES, MARKETING STAFF ARE PREPARING FOR TUESDAY MORNING "SHOW TIME"
EXHIBITS & INTERACTIVE FORUM
IT TAKES A FULL DAY, LOTS OF SWEAT AND A MIRACLE OR TWO TO "PRETTY UP" THE INDUSTRY FOR SHOW TIME. BUT IN THE END...
... AND THE IMS RECEPTION ON MONDAY NIGHT
Ramesh is the mastermind behind this year's technical program.
and George is the "George Hamilton" of the MTT-S.
Hey the booth looks great. Thank goodness for duct tape.


ABOUT 600 EXHIBITORS ARE READY TO DEMO THEIR LATEST RF/MICROWAVE PRODUCTS AND ANSWER CUSTOMER QUESTIONS
"CMOS is Boss, GaAs can kiss my grits."
If someone covers me, I'll go grab some competitive product information.
He really means lunch!
This means they really like me
I'd like to present the winners of our very first RF design contest.
PROFESSIONAL EDUCATION HAS EXPANDED FROM THE TECHNICAL SESSIONS ONTO THE SHOW FLOOR
THERE'S A PACKED RECEPTION AS WOMEN OF MICROWAVES GATHER TO NETWORK AND RELAX
True, he's not a woman, but I'll vouch for him none-the-less.
And Maxwell said, "let there be a relativistic formulation in terms of covariant field tensors" and there was and he saw that it was good.
Today's MicroApps Nonlinear Characterization Expert Panel is also being webcast to a global audience.
PLAYING OFF THE LOCAL CUISINE, MANY VENDORS ADOPTED CRAB-THEMES IN THEIR MARKETING
Is this guy clawing at me?
I'm the San-Tron crab hat. This week at IMS, I'm considered respectable headgear.
Animal Shelter
C'mon now. Crab cakes, filters & paper tablecloths on our heads, that's what Maryland does!
I took mine.. out to the ball game!!!!
HEY, DOWN IN FRONT!!
Feels like there's a crab in my shoes.
And mine smell like Old Bay.
MTT-Shirt
Used to be diamonds were a girl's best friend.
No really. I promised my wife I would get her a Microwave Journal MTT-Shirt.
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G/T FOR A SATELLITE-TERRESTRIAL HANDSET WITH INTERNAL AND EXTERNAL ANTENNAS

In this paper, the figures of merit for a satellite-terrestrial handset with internal and external antennas are extracted, based on the antenna measurements with the handset mechanics in free space. The gain statistics are derived from the measured antenna patterns. The antenna noise temperature is calculated from the sky brightness, the antenna efficiency and loss, and a few critical conclusions are obtained.

The figure of merit (G/T) for a satellite-terrestrial handset is a critical parameter for the link budget calculations, where G is antenna gain, which varies with elevation and azimuth angles, and T is the system noise temperature, which is the sum of the handset receiver and its antenna noise temperatures. For the Terrestar GENUS smart phone, an internal Planar Inverse F Antenna (PIFA) is used[1] for satellite communication in the primary service area. In addition, a novel external helix-octafilar antenna has also been designed as the accessory to support secondary service areas.

In the GMR-1 3G Specification,[2] the figures of merit for several types of satellite receivers are available with only external antennas. The G/T ratio of the various packet data terminals in the direction of the peak antenna gain under clear sky conditions, with the antenna fully deployed and with no conducting objects in the vicinity of the unit, at 20°C, will exceed the tabulated G/T values at elevations over 20°. For a similar terminal as the GENUS™ smart phone with external antenna (terminal E), the given G/T is –30 dB/K in which the given antenna gain is –1 dB, the antenna noise temperature is 150 K, and the receiver noise figure is 5 dB. The G/T definition[2] has caused ambiguity when deriving it using the actual antenna measurements with the handset mechanics, especially about how to define the antenna gain G. It appears that G is a peak antenna gain, but it is unclear which elevation to use, because the peak gain varies with the pointing elevation. If the peak gain is taken at a 20° elevation, the G/T is underestimated, while if the peak gain is taken at a 90° elevation, then the G/T is over estimated. For an internal PIFA, the gain pattern and noise temperature are affected more by the other components around the antenna.

In the following section, it can be found that the PIFA radiation pattern is more random in the preferred elevations, that is 20° to 90° and in the whole azimuth plane. In the GMR-1 3G Specification,[2] no terminals with an internal antenna are available and it is hard to determine the antenna gain and noise temperature to derive the corresponding G/T. In this article, the work is based on free space antenna measurements with approximately 3° angular steps for both the internal PIFA and the external helix-octafilar antenna. The gain G in G/T is proposed to be a statistical value derived in the preferred elevations from 20° to 90°. The antenna noise temperature is derived by considering the antenna efficiency, loss and the brightness seen by the antenna. Then some proposals are offered, regarding the derivation of the G/T.

ANTENNA GAIN MEASUREMENTS AND GAIN STATISTICS

In the GENUS smart phone, the internal PIFA is located in the upper right corner seen

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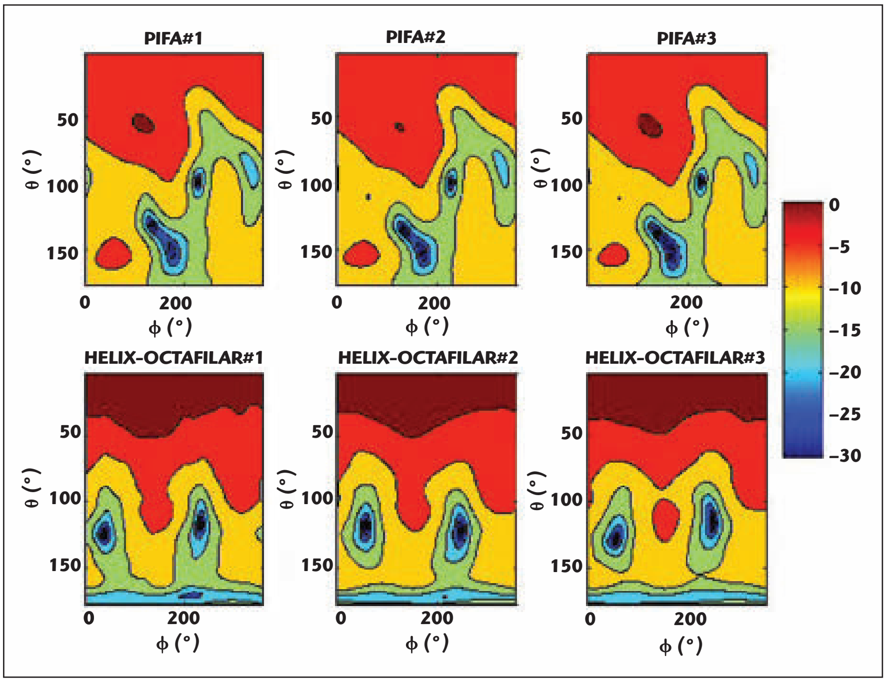
▲ *Fig. 1 Measurement coordinate system.*

from the back cover. There is an RF port available in the upper right corner as well for using an external antenna. Only one of the antenna ports is available at a time. A user must select the preferred antenna from the handset operating system menus. The gain measurements are done using the coordinates shown in ***Figure 1***.

Figure 2 shows the gain patterns (θ = 90°– elevation°) in free space for the forward link (from the satellite to handset) with the left hand circular polarization (LHCP). The first row shows the PIFA patterns, while the second row is for the helix-octafilar prototypes. For both the internal and external antennas, the design objective is to have a good and stable gain pattern in the preferred elevations and also in the azimuth plane. Obviously, the helix-octafilar (being a larger antenna) has better gains in 20° to 90° elevations. ***Figure 3*** shows the gain pattern cuts for Antenna #1 in specific elevations for the PIFA and the helix-octafilar. From the figures, it can be seen that the PIFA gain varies considerably, especially at low elevations. The gain for the helix-octafilar is more stable for a fixed elevation, but the instant gains show a big difference at the low and high elevations. Therefore, from the random PIFA gains, a statistical gain is extracted and listed in ***Table 1***. Then, a reasonable gain is chosen for use in its G/T calculation. For the helix-octafilar, the statistical gain is also extracted and shown in ***Table 2***. From Table 1, it can be seen that the gain repeatability is extremely good for the three PIFA and octafilar prototypes, respectively. The helix-octafilar has better gain statistics than the PIFA, especially in a small Cumulative Distribution Function (CDF), that is approximately 8.6 and 4.7 dB more gain at 1 and 10 percent CDF, respectively.

THE SYSTEM NOISE TEMPERATURE AND G/T

The G/T (dB/K) can be calculated from G -10 log (T), where G is the antenna gain and T is the noise temperature of the system, which is the sum of the antenna and the handset noise temperatures. The antenna noise temperature is derived by considering the antenna efficiency, loss and the brightness seen by the antenna. The sky brightness and how it is seen by the



▲ *Fig. 2 Gain patterns for the PIFA and helix-octafilar prototypes, forward link (LHCP at 2190 MHz).*

TABLE I

PIFA GAIN STATISTICS AND G/Ts

PIFA	Gain Statistics (LHCP)(elev. 20~90 degree)						
	Min.	*CDF 1%*	*CDF 10%*	*Mean*	*Median*	*CDF 90%*	*Max.*
Ant#1	-14.2	-13.3	-7.2	-3.1	-2.1	-0.6	0.1
Ant#2	-14.7	-13.6	-7.7	-3.3	-2.2	-0.7	0.0
Ant#3	-15.0	-13.8	-7.7	-3.3	-2.2	-0.6	0.2
Mininum gain	-15.0	-13.8	-7.7	-3.3	-2.2	-0.7	0.0
G/T (dB/K)	-50.0	-42.8	-36.7	-32.3	-31.2	-29.7	-29.0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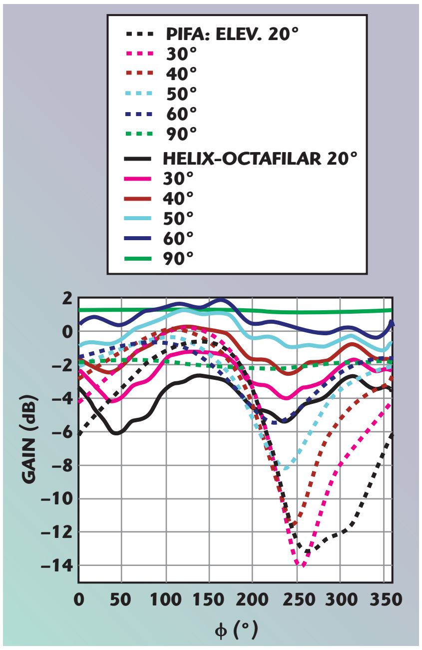

▲ *Fig. 3 Gain patterns for the PIFA #1 and the helix-octafilar #1 at specific elevations, forward link (LHCP at 2190 MHz).*

antenna are based on the following assumptions and equations.

- Calculation of the sky brightness (T_{sky}) by considering:
  - Temperature of atmosphere emission: 270 K
  - Cosmic background noise: 3 K
  - Atmosphere attenuation:
    - Oxygen absorption: 0.007 dB/km at 2 GHz
    - Height of atmosphere: 10 km.
    - Vapor and cloud attenuation are not significant.
- Sky brightness seen by the antenna:[3]

$$T_B = \frac{\int_{4\pi} G_{meas}(\phi,\theta)T_{sky}(\phi,\theta)\partial\Omega}{\int_{4\pi} G_{meas}(\phi,\theta)\partial\Omega} \qquad (1)$$

Where G_{meas} is the measured total gain pattern. Finally, the antenna noise temperature can be calculated from:

$$T_A = T_0\left(\eta_{refl} - \eta_{tot}\right) + T_B\eta_{tot} \qquad (2)$$

Where T_0 is the physical temperature, which is 290 K. η_{tot} is the measured antenna total radiation efficiency (total power). $\eta_{refl} = 1-|\Gamma|^2$ is the reflection efficiency, where Γ is the reflection coefficient, which is calculated by the measured return loss. The total radiation efficiencies[4] of the antenna prototypes are calculated and listed in ***Table 3***, from which very good repeatability of the efficiencies for the PIFA and helix-octafilar prototypes can be observed. The total efficiencies for the internal and external antennas are very close. ***Figures 4*** and ***5*** show the measured return loss of the three PIFA and helix-octafilar prototypes, respectively, used in the calculation of η_{refl}. The frequency ranges are 2000 to 2020 MHz and 2180 to 2200 MHz for the return link and forward link, respectively. From Figures 4 and 5, the return losses are very low in the frequency range of the forward link. The return loss at the middle frequency 2190 MHz is selected in the calculations. The final antenna noise temperatures for the prototypes are extracted and shown in Table 3. In the

TABLE II

HELIX-OCTAFILAR GAIN STATISTICS AND G/Ts

Helix-octafilar	Gain Statistics (LHCP)(elev. 20~90 degree)						
	Min.	CDF 1%	CDF 10%	Mean	Median	CDF 90%	Max.
Ant#1	-5.7	-4.8	-3.0	-0.3	0.3	1.4	2.0
Ant#2	-6.1	-5.2	-2.9	-0.4	0.2	1.2	1.7
Ant#3	-6.2	-5.2	-2.9	-0.4	0.3	1.0	1.4
Mininum gain	-6.2	-5.2	-3.0	-0.4	0.2	1.0	1.4
G/T (dB/K)	-35.4	-34.4	-32.1	-29.6	-29.0	-28.2	-27.8

TABLE III

ANTENNA EFFICIENCY AND NOISE TEMPERATURE

	PIFA		Helix-octafilar	
	Total Efficiency	Ant. Noise Temp. (K)	Total Efficiency	Ant. Noise Temp. (K)
Ant#1	0.575	166.60	0.569	201.40
Ant#2	0.581	167.10	0.577	200.70
Ant#3	0.590	165.50	0.562	202.70
		max: 167.1		max: 202.7

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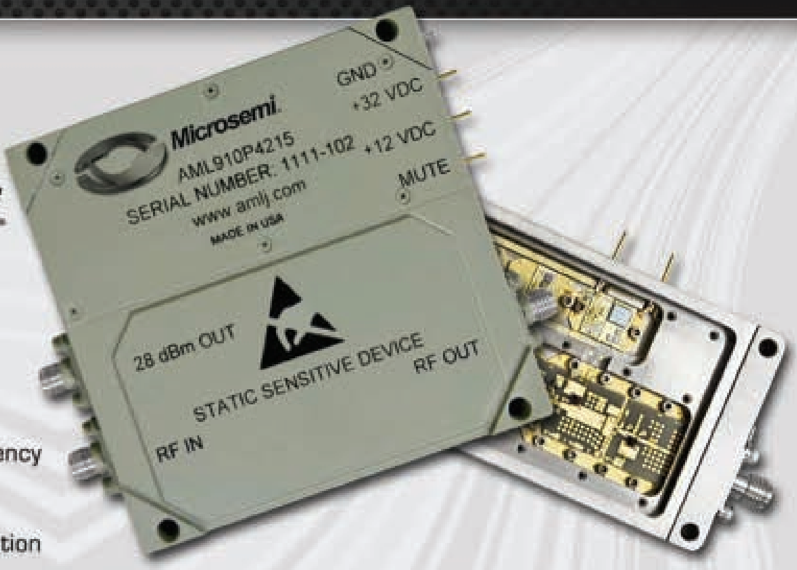

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AML056P4014	0.5 - 6.0	40	37	38	6	28V, 1.0A	20%	EAR99
AML056P4511	0.5 - 6.0	45	39	40	10	28V, 1.3A	25%	EAR99
AML056P4512	0.5 - 6.0	45	43	44	25	40V, 2.7A	23%	EAR99
AML26P4011	2.0 - 6.0	40	40	41	12	28V, 1.0A	30%	EAR99
AML26P4012	2.0 - 6.0	45	43	44	25	28V, 2.5A	30%	EAR99
AML26P4013	2.0 - 6.0	45	46	47	50	28V, 6 A	30%	EAR99
AML59P4512	5.5 - 9.0	45	45	46	40	28V, 3.6A	35%	3A001.b.4.b
AML59P4513	5.5 - 9.0	45	48	49	80	28V, 7.2A	35%	3A001.b.4.b
AML910P4213	9.9 - 10.7	43	37	38	6	32V, 0.5A	30%	EAR99
AML910P4214	9.9 - 10.7	43	39	40	10	32V, 0.8A	30%	EAR99
AML910P4215	9.9 - 10.7	46	41.5	42	15	32V, 1.3A	30%	EAR99
AML910P4216	9.9 - 10.7	46	42	43	20	32V, 1.3A	30%	3A001.b.4.b
AML811P5011	7.8 - 11.0	45	43	44	25	28V, 2.8A	30%	3A001.b.4.b
AML811P5012	7.8 - 11.0	50	46	47	50	28V, 5.5A	30%	3A001.b.4.b
AML811P5013	7.8 - 11.0	50	49	50	100	28V, 11A	30%	3A001.b.4.b
AML618P4014	6.0 - 18.0	40	39	40	10	32V, 2.75A	12%	ITAR
AML618P4015	6.0 - 18.0	40	42	43	20	32V, 4.9A	12%	ITAR
AML218P4012	2.0 - 18.0	40	37	38	6	32V, 1.5A	13%	ITAR
AML218P4011	2.0 - 18.0	35	39	40	10	32V, 2.75A	12%	ITAR
AML218P4013	2.0 - 18.0	38	42	43	20	32V, 4.9A	12%	ITAR

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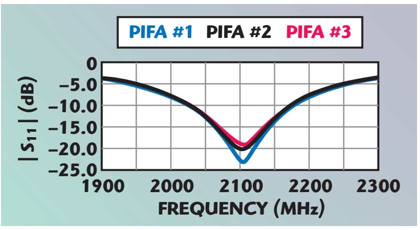
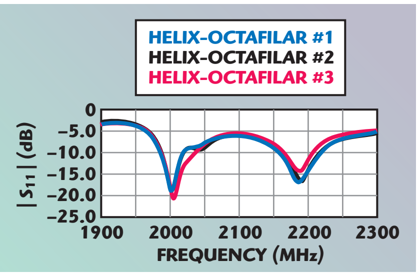


▲ *Fig. 4 Measured return loss for the PIFA prototypes.*



▲ *Fig. 5 Measured return loss for the helix-octafilar prototypes.*

following calculations, the worst 167.1 K and 202.7 K antenna noise temperatures are taken for the PIFA and the helix-octafilar, respectively. The handset receiver noise temperature is 627.06 K using a 5 dB noise figure. The system noise temperatures are therefore 794.16 K and 829.76 K, respectively, for the handset with the PIFA and the helix. In Table 1, the minimum gain G at each column is taken and the final statistical G/Ts are derived and listed in the last row of the tables for the internal and external antennas. The system G/T depends strongly on the antenna gain. The receiver NF is slightly better than 5 dB, based on the measurements conducted on the handset; here a 5 dB NF is taken as proposed.[2] From Figures 2 and 3 and Table 1, it is seen that the antenna gains vary with the elevations and the azimuth angles for both the PIFA and the helix-octafilar. For the helix-octafilar, the average G/T (-29.6 dB/K) might be more meaningful, in which the mean antenna gain is -0.4 dB and the antenna noise temperature is 202.7 K.

The G/T is proposed to be analyzed statistically as shown in Table 1. It is good to say, for instance, what are the minimum, average, and maximum G/Ts, what is the G/T for a specific CDF point according to the system reliability requirement. However, in practice, one can always ask what is the G/T for the handset, and then the average G/T might be a good value. It should be noted that the G/Ts listed in Table 1 are taken directly from the gain measurements of the three antenna prototypes.

CONCLUSION

The method and steps for extracting the G/Ts of a satellite handset, with both internal and external antennas, are introduced in this article. The receiver G/Ts, with both an internal and external antennas, were analyzed statistically, while the G/T of the receiver with the external antenna was compared with the result for a similar type of terminal,[2] where the -30 dB/K G/T is recommended but with vague definition about how to get this value. In the case of the satellite smart phone with the external antennas, the average G/T is –29.6 dB/K, which is very close to what is suggested.[2] For the handset with internal PIFAs, the average G/T is –32.3 dB/K, which is a reasonable value compared to the case with the external antennas. Therefore, the average G/Ts in the preferred elevations can give the better estimations. However, it is good to show the other G/Ts at different CDF points to meet with different system reliabilities. Note that a linear gain should be taken into account in the sky brightness calculations, due to random noise. The suggested antenna noise only has the average sense in the whole 3D space. ■

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IF/RF MICROWAVE COMPONENTS

Design of a Fifth-order Analog Predistorter for Base Station HPA of Cellular Mobile Systems

This article presents the design of a fifth-order analog predistorter for use in base station high power amplifiers (HPA). The predistorter employs two intermodulation (IM) signal generators with identical configuration, to individually generate the third- and fifth-order (IM3 and IM5) signals. The amplitudes and phases of the two IM signals generated are adjusted separately for cancellation of the third- and fifth-order intermodulation distortion products (IMDP3 and IMDP5) at the HPA output, making the tuning process of predistortion much easier. The predistorter is designed and studied by computer simulation, using two-tone and π/4-DQPSK signals, centered at 2.2 GHz in a practical base station 100 W HPA. For verification of the design, measurements are carried out on a prototyped-predistorter. Both simulation and measurement results show that very good agreement and excellent linearity improvement of the HPA can be achieved at an output power of 65.6 W.

The high power amplifier is an important building block in wireless communication systems, but is inherently nonlinear. The nonlinearity results in intermodulation of the input signals, causing intermodulation distortion products at the output of the HPA and hence adjacent channel interference.[1] Thus, linearization methods are usually employed in base station HPAs of wireless communications systems to minimize the IMDPs. Many analog predistortion methods have been reported in recent years.[2-12] Analog predistortion (APD), with the merits of simple structure and acceptable linearity improvement, is one of the popular linearization techniques used. Generally, in analog predistortion, a predistorted signal (which could be the difference-frequency signals, the harmonic-frequency signals and the in-band intermodulation (IM) signals of the fundamental signals) is generated and then, together with the fundamental signal, fed to the HPA to reduce the IMDPs at the output.[6-12] The difference-frequency and harmonic-frequency signals are at much lower and higher frequencies, respectively, from the fundamental signal and so are likely to be blocked by the limited bandwidths of the HPAs. Thus, the method using the in-band IM signals for suppressing the IMDPs is more practical and realistic.

In this article, the design of a fifth-order analog predistorter is proposed, which employs the in-band IM signals for the predistortion of

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the HPA. Two IM signal generators with identical configuration are designed to generate the third- and fifth-order intermodulation (IM3 and IM5) signals. In the previous design of a third-order analog predistorter,[8,9] the IM3 signal and fundamental signal had to be adjusted together, making the tuning process to suppress the IMDP3 very difficult to do. In this proposed design, the IM3 and IM5 signals are generated individually and can be adjusted independently to suppress the IMDP3 and IMDP5, respectively, making the tuning process much easier to do. The fifth-order analog predistorter is designed by computer simulation and studied using a two-tone and π/4-DQPSK signals centered at 2.2 GHz in a practical base station 100 W HPA, HPA2100-085-SW01, manufactured by Bravotech Inc., China, for use in cellular mobile systems. The final design of the predistorter is implemented and the performance is measured for verification. The simulation and measured results show very good agreement, and excellent performance on predistortion of the HPA at an output power of 65.5 W.

THEORY AND CONFIGURATION OF THE PREDISTORTER

Predistortion Principle

The nonlinear characteristic of a HPA can be represented in the form of a power series expression:[1]

$$v_o = a_1 v_i + a_2 v_i^2 + a_3 v_i^3 + a_4 v_i^4 + a_5 v_i^5 + \ldots + a_n v_i^n \qquad (1)$$

where v_o and v_i are the output and input signals, respectively, and $a_1, \ldots, a_n$ are the coefficients used to curve-fit the actual HPA characteristic. Consider an input signal consisting of two tones with equal amplitude and small frequency spacing:

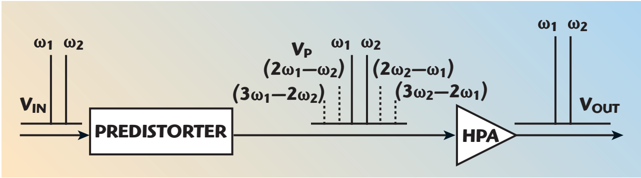
$$v_i = A\cos(\omega_1 t) + A\cos(\omega_2 t) \qquad (2)$$

The output signal from the HPA is:

$$v_o = a_1\left[A\cos(\omega_1 t) + A\cos(\omega_2 t)\right] + a_2\left[A\cos(\omega_1 t) + A\cos(\omega_2 t)\right]^2 + a_3\left[A\cos(\omega_1 t) + A\cos(\omega_2 t)\right]^3 + \ldots + a_n\left[A\cos(\omega_1 t) + A\cos(\omega_2 t)\right]^n \qquad (3)$$

Each of the terms, except the first-order term, in Equation 3 will generate a number of distortion products. For example, the second-order term generates the second-order distortion products at frequencies $2\omega_1$, $2\omega_2$ and $\omega_1 \pm \omega_2$; the third-order term generates the third-order distortion products at frequencies ω_1, ω_2, $3\omega_1$, $3\omega_2$, $2\omega_1 \pm \omega_2$ and $2\omega_2 \pm \omega_1$. It can be shown that the even-order terms in Equation 3 generate the distortion products that are out of band, so the distortion products of most concern are the ones close to the two-tone signal, such as the IMDP3 at frequencies $2\omega_1 - \omega_2$ and $2\omega_2 - \omega_1$ generated in the third-order term of Equation 3.

Figure 1 shows the basic principle of the proposed fifth-order predistorter. To simplify the description, as-



▲ *Fig. 1 Block diagram of the fifth-order distortion using in-band IM signals.*

sume the input signal, v_{in}, to the predistorter is a two-tone signal and the HPA can be modeled using only the first three odd-number terms in Equation 3. Assume that the IM3 and IM5 signals are generated and add them to the two-tone signal in the predistorter to produce an HPA input signal v_p:

$$\begin{aligned} v_p = {} & A_1\left[\cos(\omega_1 t + \varphi_1) + \cos(\omega_2 t + \varphi_1)\right] + \\ & A_3\left[\cos(2\omega_1 t - \omega_2 t + \varphi_3) + \cos(2\omega_2 t - \omega_1 t + \varphi_3)\right] + \\ & A_5\left[\cos(3\omega_1 t - 2\omega_2 t + \varphi_5) + \cos(3\omega_2 t - 2\omega_1 t + \varphi_5\right] \end{aligned} \qquad (4)$$

where A_1, A_3, A_5 and φ_1, φ_3, φ_5 are the amplitudes and phases of the fundamental (two-tone) signals, IM3 and IM5 signals, respectively. The amplitudes and phases of the IM3 and IM5 signals are adjustable in the predistorter. The output signal from the HPA is:

$$v_{out} = a_1 v_p + a_3 v_p^3 + a_5 v_p^5 \qquad (5)$$

Expansions of the third- and fifth-order terms of Equation 5 are very difficult and complicated. To simplify the expansions, consider only the IMDP3 and IMDP5, which have the most power. It can be readily shown that the IMDP3 and IMDP5, respectively, are given by:

$$\begin{aligned} v_{IMDP3} = {} & a_1 A_3\left[\cos(2\omega_1 t - \omega_2 t + \varphi_3) + \cos(2\omega_2 t - \omega_1 t + \varphi_3)\right] \\ & + \frac{3}{4} a_3 A_1^3\left[\cos(2\omega_1 t - \omega_2 t + \varphi_1) + \cos(2\omega_2 t - \omega_1 t + \varphi_1)\right] \end{aligned} \qquad (6)$$

and

$$\begin{aligned} v_{IMDP5} = {} & \left(\frac{5}{8} a_5 A_1^5 + \frac{3}{2} a_3 A_1 A_3^2\right)\left[\cos(3\omega_1 t - 2\omega_2 t + \varphi_1)\right. \\ & \left. + \cos(3\omega_2 t - 2\omega_1 t + \varphi_1)\right] \\ & + a_1 A_5\left[\cos(3\omega_1 t - 2\omega_2 t + \varphi_5) + \cos(3\omega_2 t - 2\omega_1 t + \varphi_5)\right] \\ & + \frac{3}{2} a_3 A_1^2 A_3\left[\cos(3\omega_1 t - 2\omega_2 t + \varphi_3)\right. \\ & \left. + \cos(3\omega_2 t - 2\omega_1 t + \varphi_3)\right] \\ & + \frac{3}{4} a_3 A_1^2 A_3\left[\cos(3\omega_1 t - 2\omega_2 t + 2\varphi_1 - \varphi_3)\right. \\ & \left. + \cos(3\omega_2 t - 2\omega_1 t + 2\varphi_1 - \varphi_3)\right] \\ & + \frac{3}{4} a_3 A_1 A_3^2\left[\cos(3\omega_1 t - 2\omega_2 t - \varphi_1 + 2\varphi_3)\right. \\ & \left. + \cos(3\omega_2 t - 2\omega_1 t - \varphi_1 + 2\varphi_3)\right] \end{aligned} \qquad (7)$$

Note that, in general, adjacent coefficients in the odd-number terms of Equation 1 have opposite signs.[7] Taking this into account and setting $V_{IMDP3} = 0$ in Equation 6, the condition for cancelling off the IMDP3 is

$$\varphi_1 = \varphi_3 \text{ and } A_3 = \frac{-3a_3}{4a_1} A_1^{\,3}$$

which can be achieved by adjusting the signals in Equation 4. Under this condition, the IMDP5 of Equation 7 becomes:

$$v_{IMDP5} = \left(\frac{5}{8}a_5 A_1^{\,5} - \frac{27}{16}\frac{a_3^{\,2}}{a_1}A_1^{\,5} + \frac{81}{64}\frac{a_3^{\,3}}{a_1^{\,2}}A_1^{\,7}\right)\cdot \quad (8)$$
$$\left[\cos(3\omega_1 t - 2\omega_2 t + \varphi_1) + \cos(3\omega_2 t - 2\omega_1 t + \varphi_1)\right]$$
$$+a_1 A_5\left[\cos(3\omega_1 t - 2\omega_2 t + \varphi_5) + \cos(3\omega_2 t - 2\omega_1 t + \varphi_5)\right]$$

which indicates that the IMDP5 can also be cancelled off by adjusting the magnitude A_5 and phase φ_5 of the input IM5 signal in Equation 4.

The Fifth-order Predistorter

Figure 2 shows the block diagram of the proposed fifth-order predistorter. Three π-resistive attenuators Aπ #1, Aπ #2 and Aπ #3 are used to control the power levels of the input signals in Path #1, Path #2 and Path #3. Among these three paths, Path #1 has a much higher signal power to the HPA and so the voltage-variable-attenuator A #1, together with the linear low power amplifier Amp #1 in Path #1, are used to determine the HPA operating point. The input signal in Path #2 is fed to the IM3 signal generator to generate the IM3 signal, which is then amplified by Amp #2 and split into two paths. One of the IM3 signals is adjusted in amplitude and phase using the voltage-variable attenuator A #2 and the phase shifter PS #2, respectively, for predistortion. The other IM3 signal is adjusted by Aπ #4 and Amp #4 to obtain a proper power level, combined with the input signal in Path #3, which is adjusted by Aπ #3 and PS #1 and then fed to the IM5 signal generator to produce the IM5 signal. The amplitude of the IM5 signal is adjusted using Amp #3 and A #3 and the phase is adjusted using PS #3. The resultant signals in Paths #1, #2 and #3 are combined together and fed to the HPA for suppression of the IMDP3 and IMDP5 at the HPA output.

The configuration of the IM3 and IM5 signal generators used in the predistorter is shown in ***Figure 3***. It consists of a 3 dB, 90° hybrid coupler, a pair of anti-parallel Schottky diodes, a λ/4-length transmission line at the frequency of 2.2 GHz, two varactors (D1 and D2), an RF choke inductor L and a resistor. Ports #1 and #4 of the 3 dB, 90° hybrid coupler are used as the input and output ports, RF_{in} and RF_{out}, respectively, of the generator. The DC voltage V_c applied to D1 and D2 through the RF choke inductor L is used to control their reactances and hence the phase shift of the reflected signal. The anti-parallel Schottky diodes circuit is basically a mixer with its current flow given by:[1]

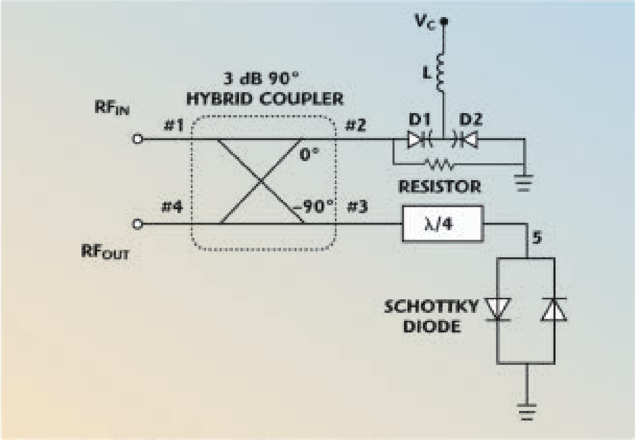


Fig. 3 Block diagram of the IM signal generator.

$$I(t) = I_s\{\exp[kV(t)] - 1\} - I_s\{\exp[-kV(t)] - 1\} =$$
$$I_s\{2kV(t) + \frac{[kV(t)]^3}{6} + \ldots + \frac{[kV(t)]^{2n+1}}{(2n+1)!} + \cdots\} \quad (9)$$

Where V(t) is the signal across the anti-parallel Schottky diodes, k is a constant and I_s is the saturation current of the diodes.

In Equation 9, at low signal level of V(t), the first- and third-order terms are dominant and other higher-order terms can be neglected. Then the current can be approximated by:

$$I(t) \approx I_s\{2kV(t) + \frac{[kV(t)]^3}{6}\} \quad (10)$$

IM3 Generation

Let the input signal to the IM signal generator of Figure 3 be a two-tone signal with same magnitude and a small frequency separation:

$$V_1(t) = a_1 \cos\omega_1 t + a_1 \cos\omega_2 t \quad (11)$$

This input signal is split equally into Ports #2 and #3 of the coupler. The signal from Port #3 is intermodulated in the anti-parallel Schottky diode circuit through Equation 10 and produces a mixing product consisting of the IM3 signal and the fundamental signal. This mixing product is reflected to Port #4, where the fundamental signal in Port #2 is also reflected into the coupler. By appropriately adjusting the resistor and the DC voltage V_c at Port #4, the fundamental signal reflected from Port #2 can have equal amplitude but 180° phase difference with the fundamental signal

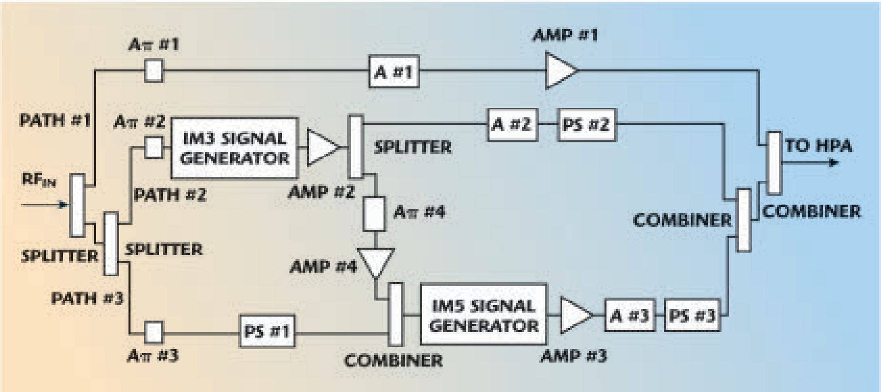


Fig. 2 Block diagram of the fifth-order predistorter.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reflected from the anti-parallel Schottky diode circuit, thus cancelling each other at the Port #4 and leaving only a strong IM3 signal.

IM5 Generation

The same configuration in Figure 3 can be used as an IM5 signal generator. Here, the IM3 signals generated from the IM3 generator is combined with the fundamental signal to produce an input signal:

$$V_2(t) = a\left[\cos(\omega_1 t) + \cos(\omega_2 t)\right] + b\left[\cos(2\omega_1 - \omega_2)t + \cos(2\omega_2 - \omega_1)t\right] \quad (12)$$

At port #3 of the coupler, the signal across the anti-parallel Schottky-diode circuit has only half of the power in Equation 12 and can be written as:

$$V_3(t) = c\{a\left[\cos(\omega_1 t) + \cos(\omega_2 t)\right] + b\left[\cos(2\omega_1 - \omega_2)t + \cos(2\omega_2 - \omega_1)t\right]\} \quad (13)$$

Substituting Equation 13 into Equation 10 yields the mixing product consisting of the fundamental signal, IM3, IM5, IM7 and IM9 signals given, respectively, by:

$$\frac{I_s k^3}{6}\left(\frac{9}{4}a^3c^3 + \frac{9}{4}a^2bc^3 + \frac{9}{2}ab^2c^3 + \frac{12}{k^2}ac\right) \cdot \left(\cos\omega_1 t + \cos\omega_2 t\right) \quad (14)$$

$$\frac{I_s k^3}{6}\left(\frac{9}{4}b^3c^3 + \frac{3}{4}a^3c^3 + \frac{9}{2}a^2bc^3 + \frac{12}{k^2}bc\right) \cdot \left[\cos\left(2\omega_1 - \omega_2\right)t + \cos\left(2\omega_2 - \omega_1\right)t\right] \quad (15)$$

$$\frac{I_s k^3 c^3}{6}\left[\frac{9}{4}(a^2b + ab^2)\right] \cdot \left[\cos\left(3\omega_1 - 2\omega_2\right)t + \cos\left(3\omega_2 - 2\omega_1\right)t\right] \quad (16)$$

$$\frac{I_s k^3 c^3}{6}\left(\frac{9}{4}ab^2\right)\{\cos\left[\left(4\omega_1 - 3\omega_2\right)t\right] + \cos\left[\left(4\omega_2 - 3\omega_1\right)t\right]\} \quad (17)$$

$$\frac{I_s k^3 c^3}{6}\left(\frac{3}{4}b^3\right)\{\cos\left[\left(5\omega_1 - 4\omega_2\right)t\right] + \cos\left[\left(5\omega_2 - 4\omega_1\right)t\right]\} \quad (18)$$

From Equations 16 to 18, it can be seen that, if a is much larger than b, say 5 dB, the IM5 signal in Equation 16 will be much larger than the IM7 signal and the IM9 signal, which therefore can be neglected. Same as in the IM3 signal generator, where the resistor and the DC voltage V_c can be adjusted to cancel either the fundamental in Equation 14 or the IM3 signal in Equation 15 at Port RF_{out}. Note that both the fundamental and IM3 signals cannot be cancelled simultaneously because these two conditions have different requirements to satisfy. In this design, the IM3 signal is chosen to be cancelled, leaving the fundamental signal uncancelled at Port #4. In fact, as explained here, there is no need to cancel the fundamental signal, because the output signal from the IM5 generator is eventually combined with a much stronger fundamental signal from Path #1 (see Figure 2) and then fed to the HPA for predistortion. Thus, as far as the design is concerned, the generator in Figure 3 can be used as an IM5 signal generator.

EXPERIMENTAL RESULTS

The fifth-order predistorter of Figure 2 has been studied and designed using the computer simulation tool ADS2009 and the final design has been implemented on a Roger's RO4005C substrate with an area of 16×12 cm, as shown in ***Figure 4***. In the implementation, the linear low power amplifiers Amp #1 to Amp #4 used are RFMD's SBB5089, the attenuators A #1 to A #3 are Skyworks' AV103, the phase shifters PS #1 to PS #3 are Skyworks' PS214-315, the two-

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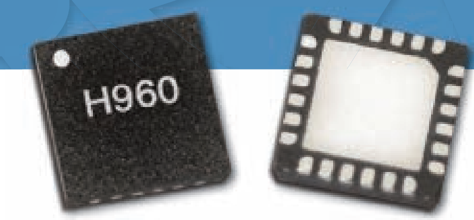

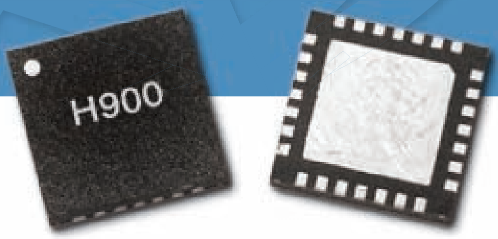

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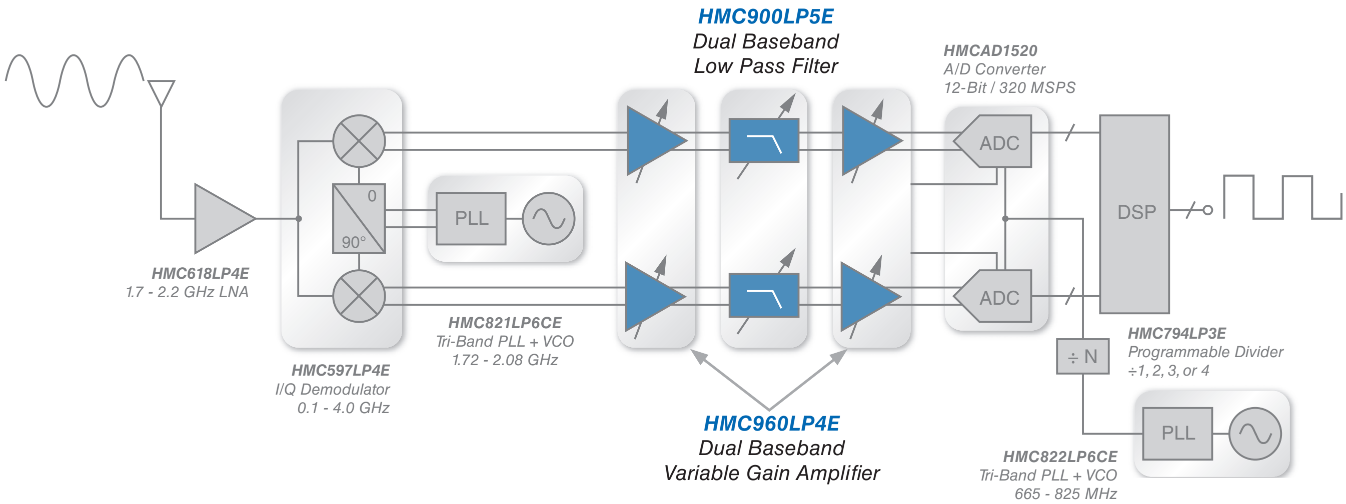

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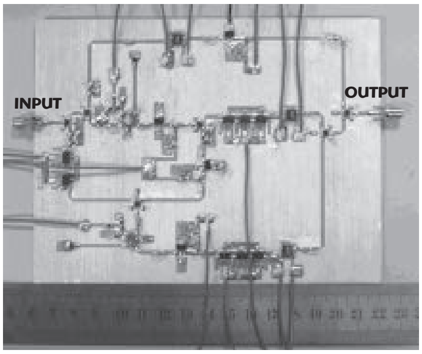
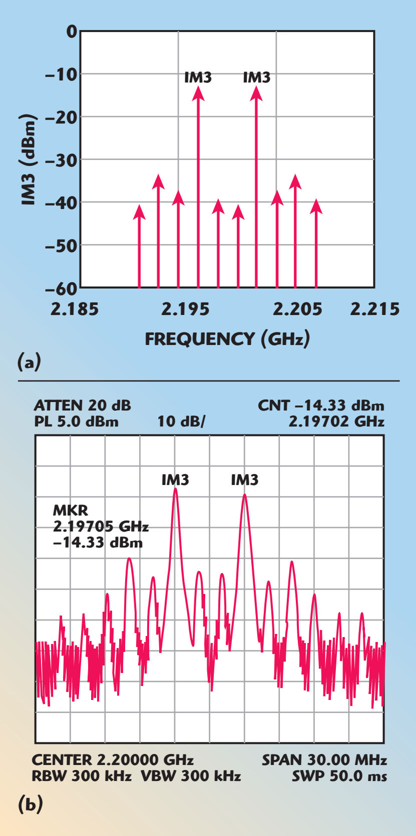
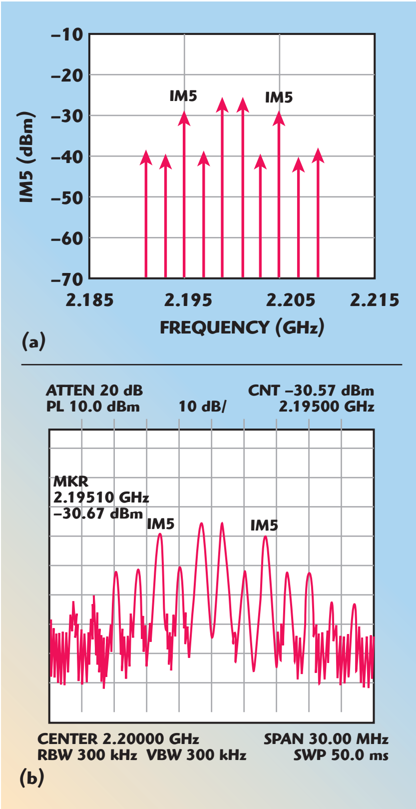


▲ *Fig. 4 Photograph of the fifth-order predistorter.*



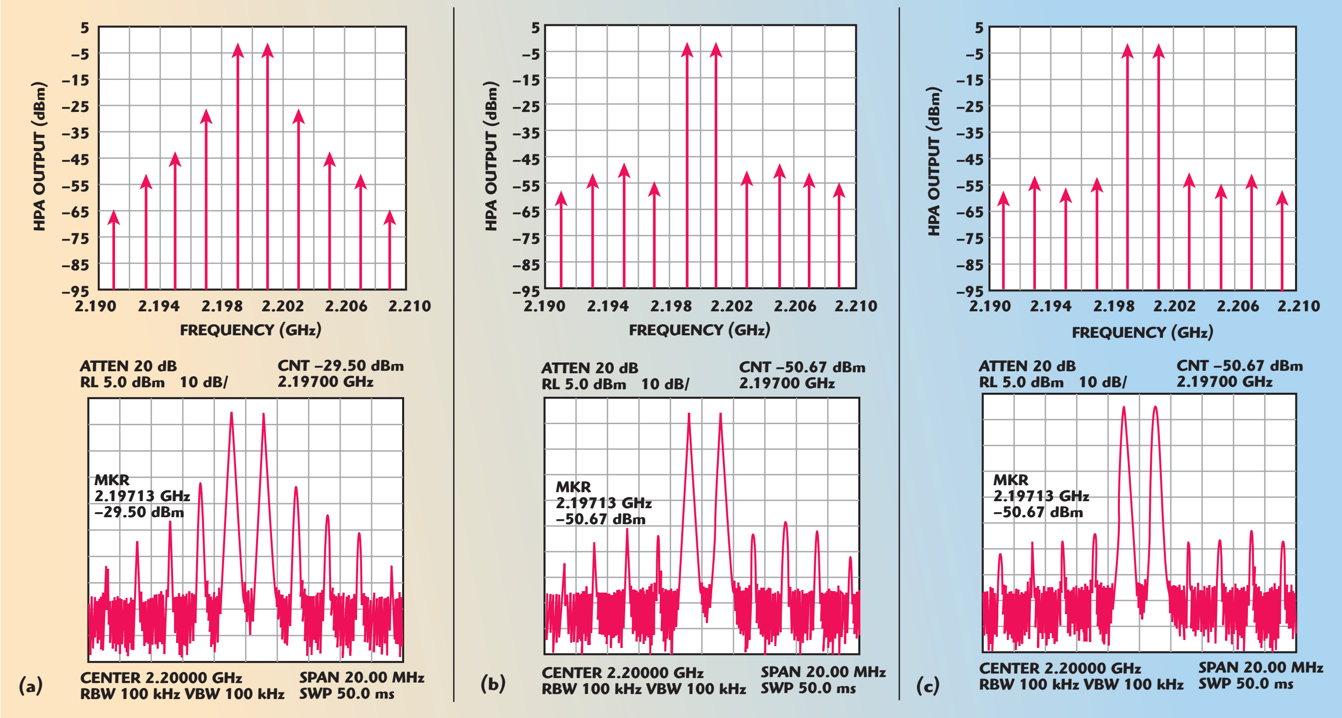
▲ *Fig. 5 Output signal spectra from the IM3 signal generator: (a) simulated and (b) measured.*



▲ *Fig. 6 Output signal spectra from the IM5 signal generator: (a) simulated and (b) measured.*

way splitters and combiners are Skyworks' PD-22 and the resistors in the π-resistive attenuators Aπ #1 to Aπ #4 are 0603 mounting resistors. The IM3 and IM5 signal generators have the same configuration as shown in Figure 3, where the 3 dB, 90° hybrid couplers are Anaren's JP503, the Schottky diodes are Avago's HSMS 282X, the varactors are Skyworks' SMV1245-011, and the resistors and inductor are 0603 mounting components.

To study the performances of the IM3 and IM5 signal generators, a two-tone signal, centered at 2.2 GHz and having a 2 MHz spacing has been used as the input signal. The simulated and measured results of the IM3 and IM5 generator are shown in ***Figures 5*** and ***6***, respectively. It can be seen that the simulated and measured results agree very well. Figure 5 shows that the IM3 signal is more than 20 dB larger than the fundamental signal and the other IM signals. Figure 6 shows that the IM5 signal is more than 10 dB larger than the other IM signals and slightly smaller than the fundamental signal for the reason described previously. However, measurement results have shown that, in normal operation of the predistorter, the required level for the fundamental signal in the main path (that is Path #1 of Figure 2) is more than 20 dB higher than that of the fundamental signal from the IM5 generator, thus the fundamental signal generated by the IM5 generator can be neglected and need not be cancelled.



▲ *Fig. 7 Simulated (left) and measured (right) two-tone spectra for an HPA output power of 65.6 W: (a) without predistortion, (b) with third-order predistortion and (c) with fifth-order predistortion.*

It should be noted that, in the proposed predistorter, the IM3 and IM5 signals are generated by using two separate IM signal generators and their amplitudes and phases are adjusted independently to reduce the IMDP3 and IMDP5 at the HPA output. As a result, the adjusting process in the predistorer is much easier, which is a significant advantage of this design.

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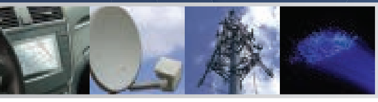

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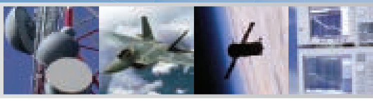

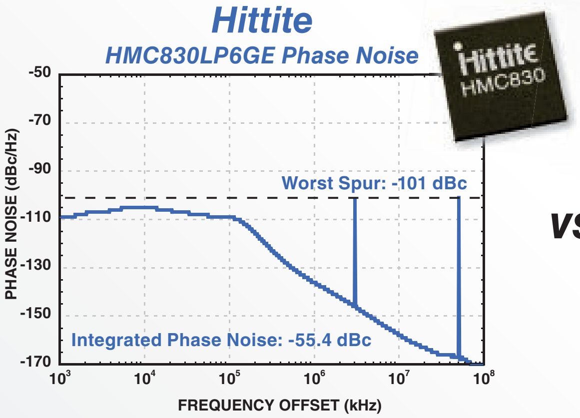

2646.96 MHz, PFD= 50 MHz, Channel Spacing = 240 kHz, Jitter = 144fs

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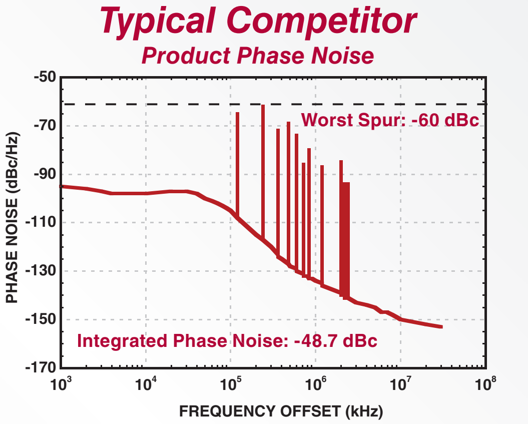

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NEW!	45 - 1050 Fo/N 1400 - 2100 Fo/2 2800 - 4200 Fo	Wideband RF VCO	-108 dBc/Hz @ 4 GHz	-134 dBc/Hz @ 4 GHz	4	112	0.229 @ 4 GHz	HMC829LP6GE
fo/2								
	665 - 825	Tri-Band RF VCO	-118 dBc/Hz	-148 dBc/Hz	11	180	0.05	HMC822LP6CE
	795 - 945	Tri-Band RF VCO	-123 dBc/Hz	-148 dBc/Hz	10	180	0.06	HMC838LP6CE
	860 - 1040	Tri-Band RF VCO	-118 dBc/Hz	-147 dBc/Hz	10	180	0.07	HMC821LP6CE
	1025 - 1150	Tri-Band RF VCO	-123 dBc/Hz	-147 dBc/Hz	12	180	0.07	HMC837LP6CE
	1050 - 1205	Tri-Band RF VCO	-121 dBc/Hz	-146 dBc/Hz	10	180	0.08	HMC839LP6CE
	1095 - 1275	Tri-Band RF VCO	-118 dBc/Hz	-147 dBc/Hz	10	180	0.08	HMC820LP6CE
	1310 - 1415	Tri-Band RF VCO	-121 dBc/Hz	-145 dBc/Hz	10	180	0.09	HMC840LP6CE
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	1330 - 1650	Tri-Band RF VCO	-112 dBc/Hz	-142 dBc/Hz	6.5	180	0.11	HMC822LP6CE
	1590 - 1890	Tri-Band RF VCO	-118 dBc/Hz	-143 dBc/Hz	7.5	180	0.12	HMC838LP6CE
	1720 - 2080	Tri-Band RF VCO	-112 dBc/Hz	-141 dBc/Hz	6.5	180	0.13	HMC821LP6CE
	2050 - 2300	Tri-Band RF VCO	-117 dBc/Hz	-141 dBc/Hz	10.5	180	0.15	HMC837LP6CE
	2100 - 2410	Tri-Band RF VCO	-115 dBc/Hz	-140 dBc/Hz	7.5	180	0.16	HMC839LP6CE
	2190 - 2550	Tri-Band RF VCO	-112 dBc/Hz	-141 dBc/Hz	6.5	180	0.17	HMC820LP6CE
	2620 - 2830	Tri-Band RF VCO	-115 dBc/Hz	-139 dBc/Hz	9	180	0.18	HMC840LP6CE
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	2660 - 3300	Tri-Band RF VCO	-106 dBc/Hz	-136 dBc/Hz	-4	180	0.21	HMC822LP6CE
	3180 - 3780	Tri-Band RF VCO	-112 dBc/Hz	-135 dBc/Hz	-4	180	0.24	HMC838LP6CE
	3440 - 4160	Tri-Band RF VCO	-106 dBc/Hz	-135 dBc/Hz	-4	180	0.27	HMC821LP6CE
	4100 - 4600	Tri-Band RF VCO	-111 dBc/Hz	-135 dBc/Hz	-0.5	180	0.30	HMC837LP6CE
	4200 - 4820	Tri-Band RF VCO	-108 dBc/Hz	-135 dBc/Hz	-4	180	0.31	HMC839LP6CE
	4380 - 5100	Tri-Band RF VCO	-106 dBc/Hz	-135 dBc/Hz	-4	180	0.33	HMC820LP6CE
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A practical base station 100 W HPA, HPA2100-085-SW01, manufactured by Bravotech Inc., China, for cellular mobile systems was used to study the performance of the fifth-order predistorter. In the simulation studies, a complex polynomial was used to approximate the measured data of the HPA and hence model the characteristic. To study the improvements of fifth-order predistortion over third-order predistortion, studies on the performance of third-order predistortion were also carried out. In these studies, the attenuator A #3 in Figure 2 was set to maximum to stop any IM5 signal from going through and then the attenuator A #2 and phase shifter PS #2 at the output of IM3 generator were adjusted to reduce the regrowth of the signal spectrum.

When the predistorter was tested using a two-tone signal centered at 2.2 GHz with 2 MHz spacing as the input signal, the simulated and measured spectra at an HPA output power of 65.6 W are shown in ***Figure 7***. The signal spectrum from the HPA was obtained via a 45 dB coupler in the HPA module. It can be seen that the simulated and measured results agree very well. Without predistortion, the measured power levels of the IMD3 and IMD5 are -29.5 dBm and -41.67 dBm, respectively. With third-order predistortion, the measured power levels of the IMD3 and IMD5 are reduced to -50.67 and -45.5 dBm, respectively. The use of fifth-order predistortion can further reduce the IMD3 and IMD5 to -50.67 and -52.33 dBm, achieving total reductions of 21.17 and 10.66 dB, respectively. Results have also shown that the power levels of the IMD3 and IMD5 could be reduced to the noise level by increasing the amplitudes and adjusting the phases of the IM3 and IM5 signals from the generators. However, by doing this, the IM3 and IM5 signals would intermodulate with the strong fundamental signal from Path #1 in the HPA, producing other high-order IMDPs, such as IMDP7, IMDP9…etc., with increased power levels. Thus, a compromise of minimizing all IMDPs has to be reached in adjusting the predistorter.

Figure 8 shows the simulated and measured spectra at the HPA output power of 65.6 W, when the predistorter was tested with a π/4-DQPSK signal centered at 2.2 GHz. Simulation and measurement results agree quite well. Without predistortion, the measured adjacent channel leakage ratio (ACLR) at ± 20 kHz from the center frequency is -48.67 dBm. With third-order predistortion, the ACLR at the same frequency is reduced to -56.5 dBm, leading to a reduction of 7.83 dB. With fifth-order predistortion, the measured ACLR is further reduced to -63.83 dBm, achieving a reduction of 15.16 dB.

CONCLUSION

A fifth-order analog predistorter using the in-band IM signals for predistortion of base station HPAs has been designed. Two IM signal generators, using identical configuration to generate the IM3 and IM5 signals, have been proposed. The amplitudes and phases of the IM3 and IM5 signals can be adjusted independently to reduce the IMPD3 and IMPD5, making the adjusting process of the predistorter much easier. A two-tone and π/4-DQPSK signals have been used to study the

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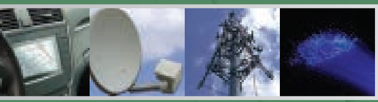

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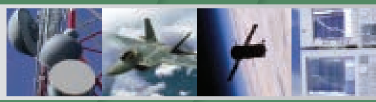

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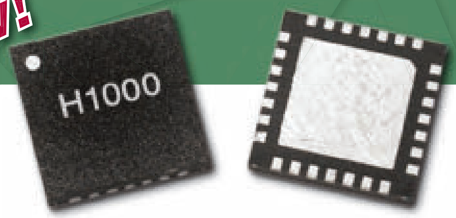

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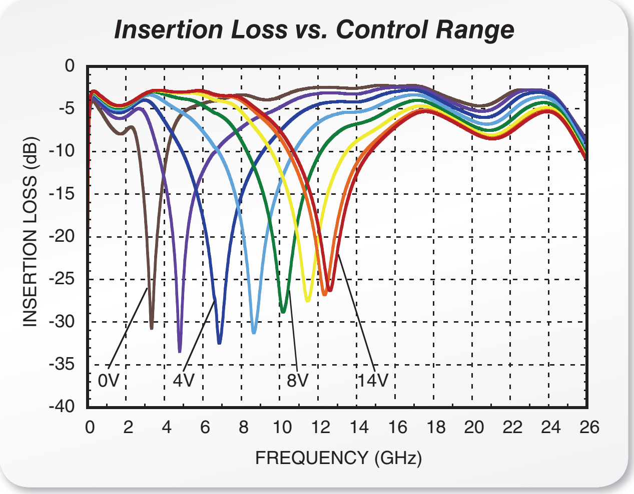

BAND PASS

	Freq. Range (GHz)	Return Loss (dB)	3 dB Bandwidth (%)	Low Side Rejection Frequency (Rej. >20 dB)	High Side Rejection Frequency (Rej. >20 dB)	Tuning Response (ns)	Part Number
	1 - 2	10	11	0.8 x Fcenter	1.2 x Fcenter	200	**HMC890LP5E**
	2 - 3.9	10	9	0.9 x Fcenter	1.15 x Fcenter	200	**HMC891LP5E**
	4 - 7.7	15	9	0.9 x Fcenter	1.13 x Fcenter	200	**HMC892LP5E**
	4.8 - 9.5	7	6.5	0.9 x Fcenter	1.1 x Fcenter	200	**HMC893LP5E**
	5.9 - 11.2	7.5	6	0.92 x Fcenter	1.08 x Fcenter	200	**HMC894LP5E**
	9 - 19	9.5	18	0.81 x Fcenter	1.17 x Fcenter	200	**HMC897LP4E**
NEW!	10 - 18	11	9	0.89 x Fcenter	1.1 x Fcenter	200	**HMC896LP4E**
NEW!	11.5 - 21.5	9	17	0.81 x Fcenter	1.16 x Fcenter	200	**HMC898LP4E**
	18.5 - 37.0	10	18	0.81 x Fcenter	1.20 x Fcenter	200	**HMC899LP4E**

BAND REJECT

	Passband Freq. Range (GHz)	Rejection Band Tuning Freq. (GHz)	Pass Band Insertion Loss (dB)	Stop Band Rejection (dB)	20 dB Bandwidth (%)	Tuning Response (ns)	Part Number
NEW!	0.1 - 25	3.6 - 12.2	3	25	8	200	**HMC1000LP5E**

LOW PASS

Freq. Range (GHz)	Return Loss (dB)	Cutoff Frequency Range (GHz)	Stopband Frequency (Rej. >20 dB)	Tuning Response (ns)	Part Number
DC - 4.0	10	2.2 - 4.0	1.25 x Fcutoff	150	**HMC881LP5E**
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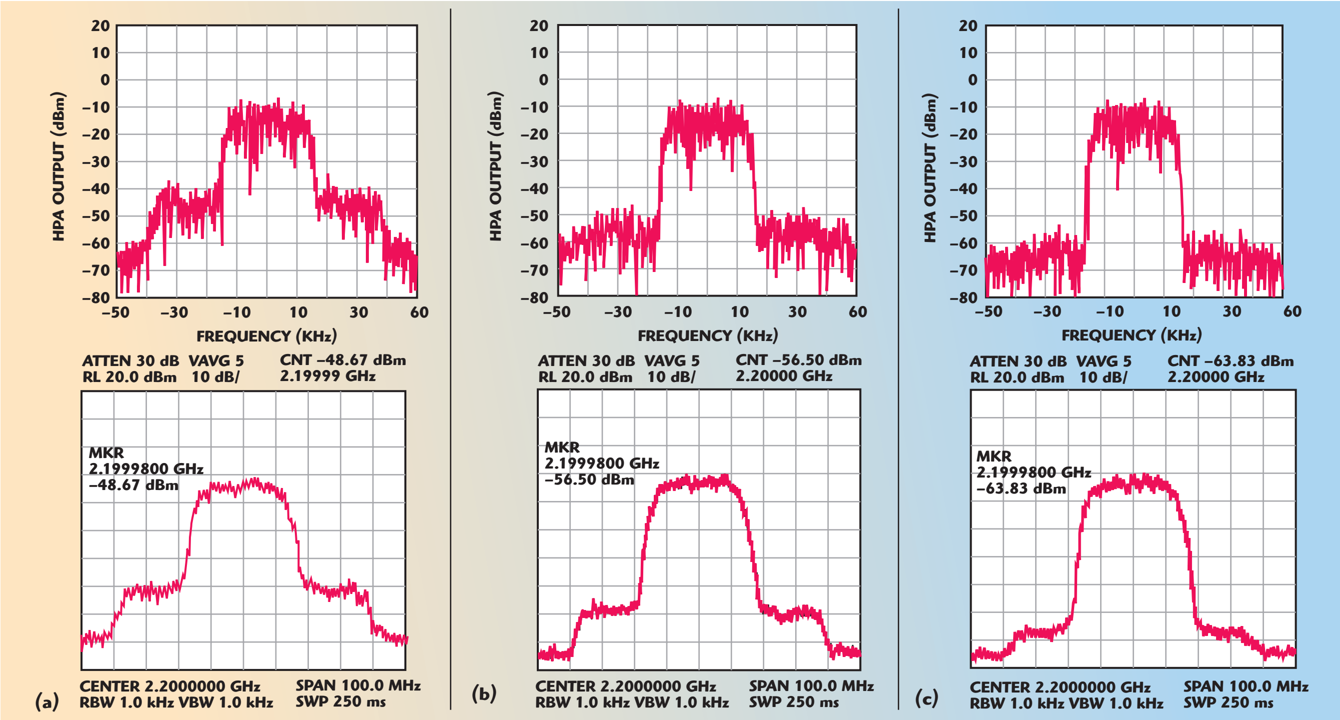

Fig. 8 Simulated (left) and measured (right) π/4 - DQPSK spectra at one HPA output power of 65.6 W: (a) without predistortion, (b) with third-order predistortion and (c) with fifth-order predistortion.

performance of the predistorter in a practical base station 100 W HPA at an output power of 65.6 W. Both the simulated and measured results have shown excellent performances on suppressing the IMPD3 and IMPD5 for the two-tone signal and ACLR for the π/4-DQPSK signal. ■

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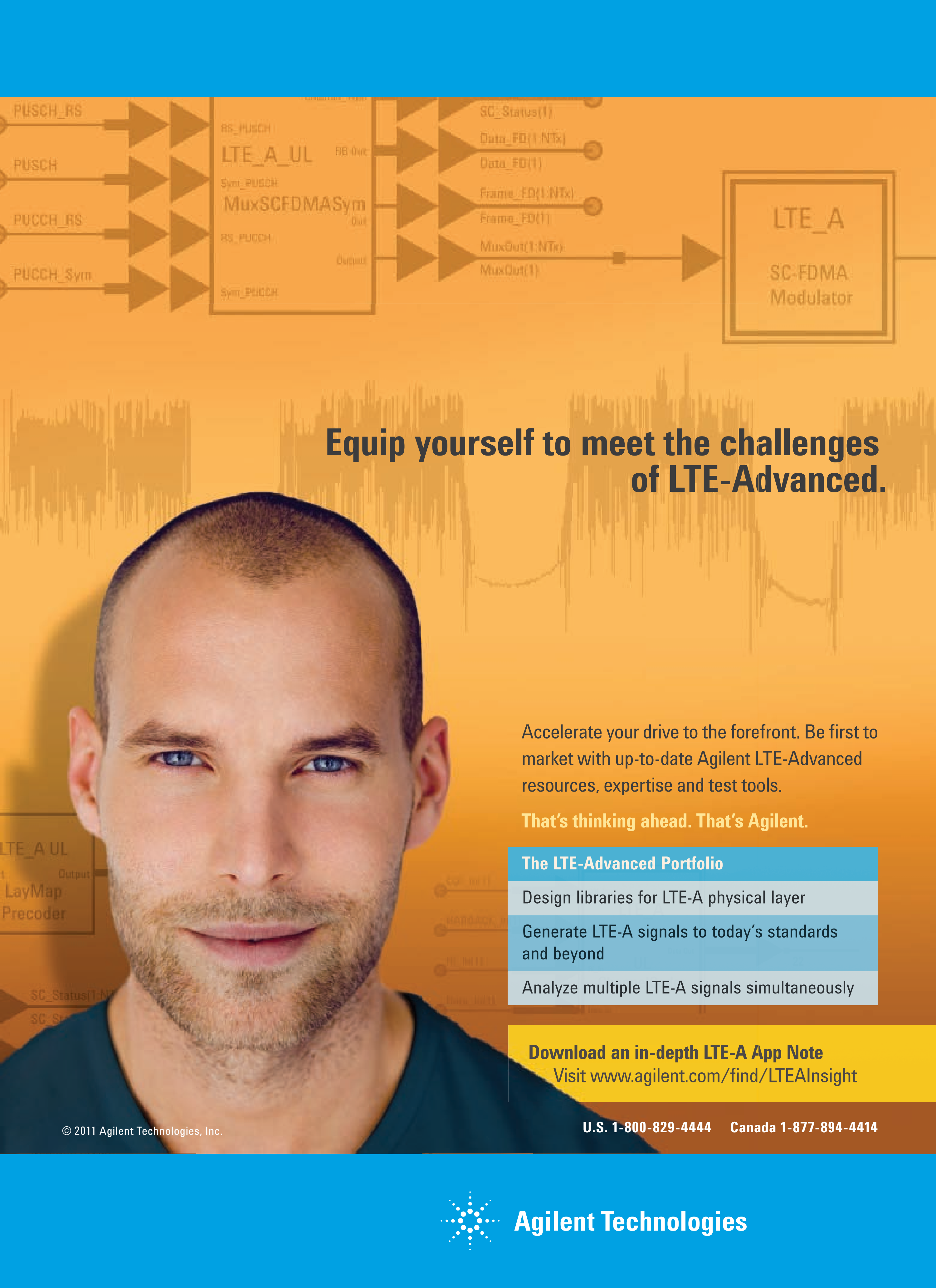
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COMPACT CPW-FED UWB ANTENNA WITH A NOTCHED BAND CHARACTERISTIC

A CPW-fed, ultra-wideband, antenna with a band-notch characteristic is presented. The antenna consists of a CPW ground with a wide slot, a fork-like radiation patch, a tuning stub and a 50 Ω CPW-fed structure. The notched band frequency is obtained by inserting a tuning stub in the middle of the fork-like patch. The notched band frequency can be controlled by adjusting the length of the stub. Experimental and numerical results show that the proposed antenna, with a compact size of 21×28 mm, has an impedance bandwidth range from 3.1 to 10.9 GHz for a VSWR less than 2, with the expected notch band frequency of 5 to 6 GHz for WLAN.

With the development of modern wireless communications, the ultra-wideband (UWB) systems have attracted much attention recently because of their advantages, including high speed data, small size, low cost and low complexity. The antenna of the ultra-wideband systems plays an important role in the receiving and transmitting of ultra-wideband radiation. Many types of UWB antennas have been presented for these applications, such as a spline-shaped antenna,[1] diamond antennas,[2,3] annular ring antenna,[4] bow-tie antennas,[5,6] triangular patch antennas[7] and wide slot antennas.[8,9] However, a narrow band used by WLAN operating at 5 to 6 GHz coexists within the required UWB bandwidth. A UWB antenna, with a notched band in the 5 to 6 GHz range is desired to reduce the potential interference. Recently, several UWB antennas with frequency band-rejection function have been proposed.[10-12] Most of the proposed antennas have a complex structure and the notched bands are not tunable. In another design, a small square monopole antenna, with two inverted U-shaped slots in the radiation patch and an H-shaped slot in the ground plane,[13] is realized with a dual notched band characteristic. However, the structure is complex and is difficult to design. A good design of the notched band characteristic with a stub[14] is investigated, with an operating bandwidth range from 3.1 GHz to more than 10.6 GHz for a voltage standing-wave ratio (VSWR) less than 2, and a notch band at the expected frequency of 5.12 to 6.08 GHz for WLAN applications. The dimension of the antenna is large and has a non-tunable rejection band. In addition, the previously proposed antenna has always various slots cut in the radiation patch or the ground.

In this article, a CPW-fed ultra-wideband antenna with a tunable band-notch and good characteristics is proposed and investigated in

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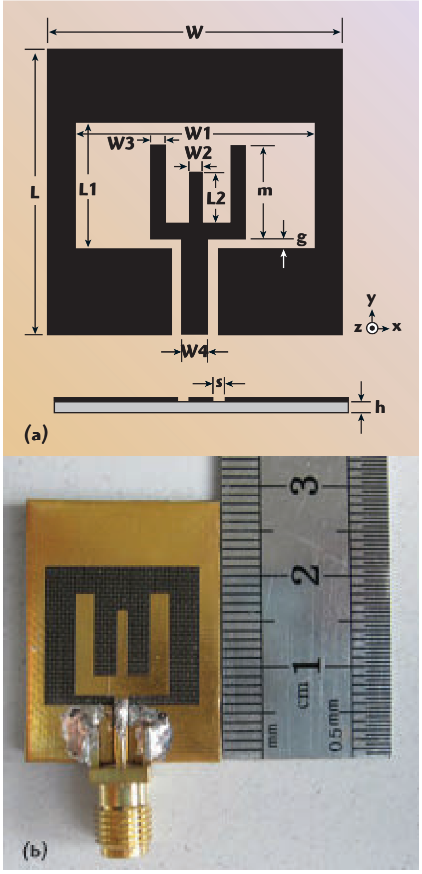
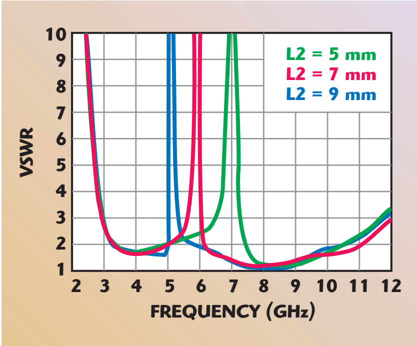


▲ *Fig. 1 Geometry of the proposed antenna (a) and photograph of the antenna (b).*

detail. The antenna consists of a CPW ground with a wide slot, a fork-like radiation patch, a stub and the 50 Ω CPW-fed structure. By inserting a stub between the two branches of the fork-like radiation patch, a notched band, which is variable with frequency, is achieved. The proposed antenna has an impedance bandwidth of 111.4 percent range from 3.06 to 10.9 GHz with good impedance matching and an approximately constant gain is achieved. It also has a notch band frequency of 5 to 6 GHz for WLAN applications. The proposed antenna has been manufactured and measured. Numerical and experimental results for the frequency characteristics, current distributions, radiation patterns and gain of the proposed UWB antenna are also presented and discussed.

ANTENNA DESIGN

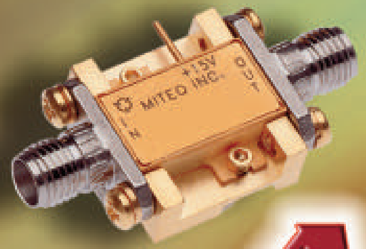
Figure 1 illustrates the geometry and the configuration of the proposed band notch antenna with a fork-like radiation patch and a tuning stub. The antenna is printed on a substrate with a relative permittivity of 2.65, a loss tangent of 0.002 and a thickness of 1.6 mm. The size of the antenna is 21×28 mm, and a 50 Ω CPW feeding structure is employed. It consists of a CPW ground with a wide slot, which has a length L1 = 15 mm and width W1 = 16.8 mm, a fork-like radiation element where the distance between the two branches of the fork is 8 mm, a stub with a length L2 = 7 mm and width W2 = 1 mm and a 50 Ω CPW feeding structure. The 50 Ω CPW feeding structure consists of a microstrip signal strip with a width W4 = 1.4 mm and the CPW ground, which has a gap s = 0.3 mm from the microstrip signal strip. All the dimensions have been obtained using Ansoft High Frequency Structure Simulator (HFSS) v.11.0 based on the finite element method (FEM).



▲ *Fig. 2 VSWR vs. frequency as a function of L2.*

PARAMETERS STUDY

In the design, the distance between the CPW ground and the fork-like radiation element and the dimension of the stub play an important role in the notched band frequency and the impedance. Then, the length L2 and the width W2 of the stub and the distance between the CPW ground and the fork-like radiation element g are considered to optimize the proposed UWB antenna. ***Figure 2*** shows the simulated results of VSWR vs. frequency with various values of L2. The length L2 of stub has an obvious effect on the center frequency of the notch band. By increasing the length of the stub, the center of the resonance frequency moves to a lower frequency. The bandwidth of the notched band is also broadened by increasing the length of the stub. This is due to the coupling between the fork-like radiation element and the stub and the resonance of the stub. In this design, the resonance frequency can be pos-



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AFS3-00120025-09-10P-4	0.12-.25	38	0.50	0.9	2.0:1	2.0:1	+10	125
AFS3-00250050-08-10P-4	0.25-0.5	38	0.50	0.8	2.0:1	2.0:1	+10	125
AFS3-00500100-06-10P-6	0.5-1	38	0.75	0.6	2.0:1	1.5:1	+10	150
AFS3-01000200-05-10P-6	1-2	38	1.00	0.5	2.0:1	2.0:1	+10	150
AFS3-01200240-06-10P-6	1.2-2.4	34	1.00	0.6	2.0:1	2.0:1	+10	150
AFS3-02000400-06-10P-4	2-4	32	1.00	0.6	2.0:1	2.0:1	+10	125
AFS3-02600520-10-10P-4	2.6-5.2	28	1.00	1.0	2.0:1	2.0:1	+10	125
AFS3-04000800-07-10P-4	4-8	32	1.00	0.7	2.0:1	2.0:1	+10	125
AFS3-08001200-09-10P-4	8-12	28	1.00	0.9	2.0:1	2.0:1	+10	125
AFS3-08001600-15-8P-4	8-16	28	1.00	1.5	2.0:1	2.0:1	+8	100
AFS4-12001800-18-10P-4	12-18	28	1.50	1.8	2.0:1	2.0:1	+10	125
AFS4-12002400-30-10P-4	12-24	24	2.00	3.0	2.0:1	2.0:1	+10	85
AFS3-18002650-30-8P-4	18-26.5	18	1.75	3.0	2.2:1	2.2:1	+8	125
MULTIOCTAVE BAND AMPLIFIERS								
AFS3-00300140-09-10P-4	0.3-1.4	38	1.00	0.9	2.0:1	2.0:1	+10	125
AFS2-00400350-12-10P-4	0.4-3.5	22	1.50	1.2	2.0:1	2.0:1	+10	80
AFS3-00500200-08-15P-4	0.5-2	38	1.00	0.8	2.0:1	2.0:1	+15	125
AFS3-01000400-10-10P-4	1-4	30	1.50	1.0	2.0:1	2.0:1	+10	125
AFS3-02000800-09-10P-4	2-8	26	1.00	0.9	2.0:1	2.0:1	+10	125
AFS4-02001800-24-10P-4	2-18	35	2.00	2.4	2.5:1	2.5:1	+10	175
AFS4-06001800-22-10P-4	6-18	25	2.00	2.2	2.0:1	2.0:1	+10	125
AFS4-08001800-22-10P-4	8-18	28	2.00	2.2	2.0:1	2.0:1	+10	125
ULTRA WIDEBAND AMPLIFIERS								
AFS3-00100100-09-10P-4	0.1-1	38	1.00	0.9	2.0:1	2.0:1	+10	125
AFS3-00100200-10-15P-4	0.1-2	38	1.00	1.0	2.0:1	2.0:1	+15	150
AFS1-00040200-12-10P-4	0.04-2	15	1.50	1.2	2.0:1	2.0:1	+10	50
AFS3-00100300-12-10P-4	0.1-3	32	1.00	1.2	2.0:1	2.0:1	+10	125
AFS3-00100400-13-10P-4	0.1-4	30	1.00	1.3	2.0:1	2.0:1	+10	125
AFS3-00100600-13-10P-4	0.1-6	30	1.25	1.3	2.0:1	2.0:1	+10	125
AFS3-00100800-14-10P-4	0.1-8	28	1.50	1.4	2.0:1	2.0:1	+10	125
AFS4-00101200-22-10P-4	0.1-12	34	1.50	2.2	2.0:1	2.0:1	+10	150
AFS4-00101400-23-10P-4	0.1-14	24	2.00	2.3	2.5:1	2.5:1	+10	200
AFS4-00101800-25-S-4	0.1-18	25	2.00	2.5	2.5:1	2.5:1	+10	175
AFS4-00102000-30-10P-4	0.1-20	20	2.50	3.0	2.5:1	2.5:1	+10	125
AFS4-00102650-42-8P-4	0.1-26.5	24	2.50	4.2	2.5:1	2.5:1	+8	135

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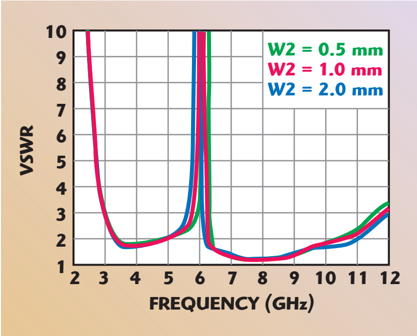
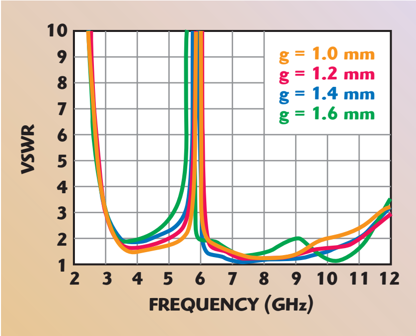
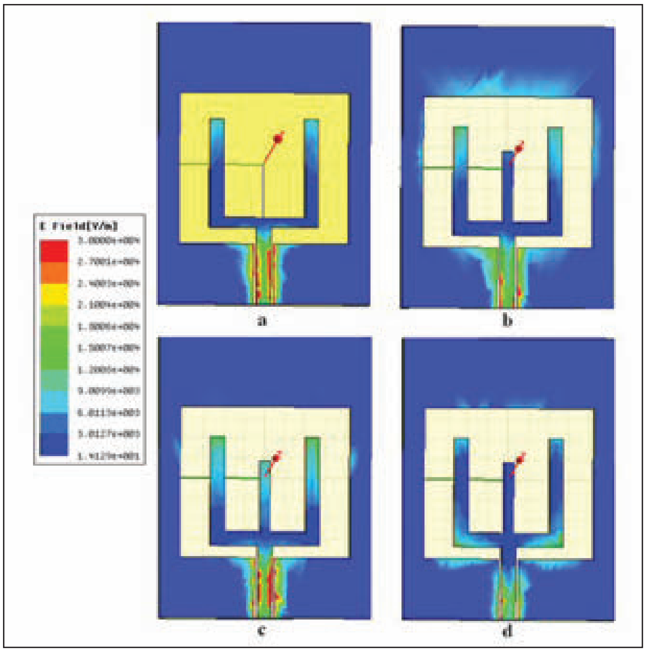


▲ *Fig. 3 VSWR vs. frequency as a function of W2.*



▲ *Fig. 4 VSWR vs. frequency as a function of g.*



▲ *Fig. 5 Current distribution in the proposed antenna.*

tulated from Equation 1:[13]

$$f_{notch} = \frac{c}{2L\sqrt{\varepsilon_{re}}} \quad (1)$$

Where L is the total length of the stub, which here is described as L2, ε_{re} is the effective dielectric constant, and c is the speed of light. Taking Equation 1 into consideration, the length of the stub at the beginning of the design is determined and then later adjusted for the final design.

The effect of the width W2 of the stub is illustrated in ***Figure 3***. With the width of the stub increasing, the center of the notched band frequency is moved slightly and the bandwidth of the notched band is almost invariable, while the impedance bandwidth of the antenna is increased, which is caused by the capacitive and inductive changes between the fork-like radiation patch and the stub.

Figure 4 shows the effect of the distance g between the CPW ground and the fork-like radiation element. The impedance of the antenna is getting wider and the bandwidth of the notched band is broadened, while center of the notched band is changed slightly. This is due to the coupling effect and the capacitive and inductive changes between the CPW ground and the fork-like radiation element.

The simulated current distribution of the proposed antenna without the tuning stub at 5.5 GHz and with the tuning stub at 3.5, 5.5 and 9 GHz are calculated and shown in ***Figures 5a, 5b, 5c*** and ***5d***, respectively. It can be seen from Figure 5a that the current flows mainly on the CPW-fed structure and the fork-like patch, while around the ground it is small. The current distribution at 3.5 and 9 GHz, shown in Figures 5b and d, is mainly along the wide slot in the CPW ground, CPW-fed structure and the fork-like radiation patch. On the contrary, in Figure 5c, the current distribution around the tuning stub and the CPW-fed structure is obtained. Therefore, the surface current can excite the notch band frequency.

RESULTS AND DISCUSSIONS

In order to estimate the design antenna, the proposed antenna is optimized. The optimized parameters are

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TM2-1	1 - 600	2:1	
TM1-6	5 - 3000	1:1	
TM2-GT	5 - 1500	2:1	
TM4-GT	5 - 1000	4:1	
TM8-GT	5 - 1000	8:1	
TM4-1	10 - 1000	1:4	
TM4-4	10 - 2500	1:4	
TM1-2	20 - 1200	1:1	
TM1-9	100 - 5000	1:1	
TM1-8	800 - 4000	1:1	

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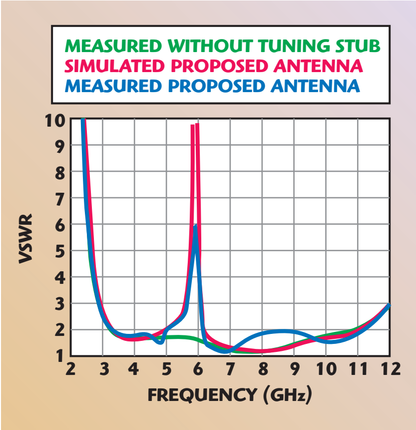
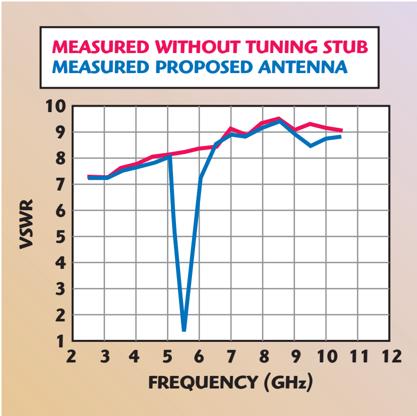
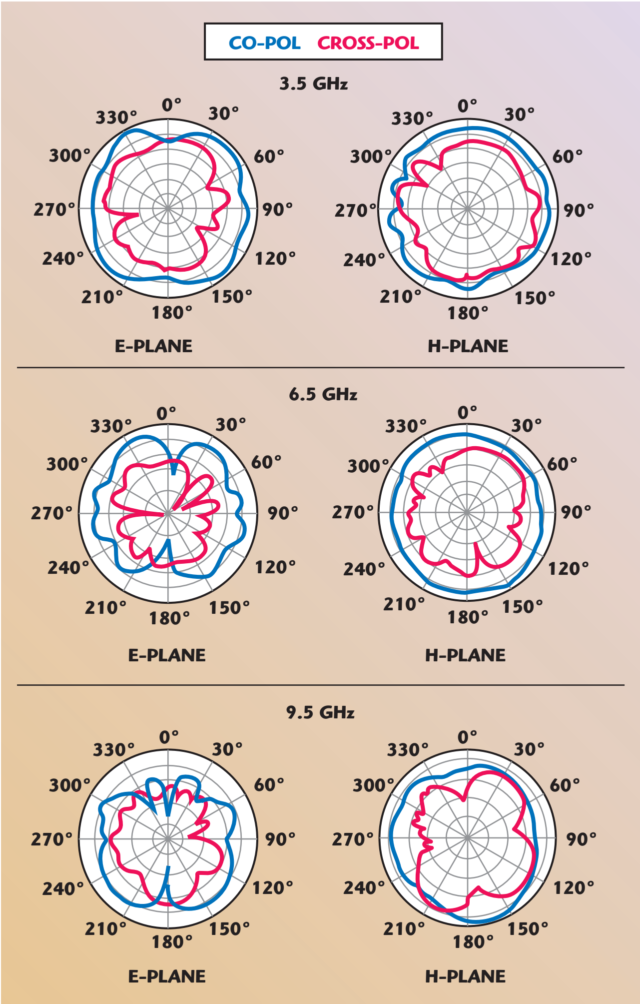


▲ *Fig. 6 VSWR vs. frequency for the proposed antenna.*



▲ *Fig. 8 Gain of the proposed antenna vs. frequency.*



▲ *Fig. 7 Radiation patterns of the proposed antennas.*

as follows: L = 28 mm, W = 21 mm, L1 = 15 mm, W1 = 16.8 mm, L2 = 7 mm, W2 = 1 mm, W3 = 1.4 mm, m = 10.8 mm, g = 1.2 mm, W4 = 1.4 mm, s = 0.3 mm, h = 1.6 mm and the distance between the two branches of the fork is 8 mm. The proposed antenna has been manufactured and tested, using the above parameters. The measured results were obtained with an HP8757D network analyzer with the antenna placed in an anechoic chamber. The VSWR of the proposed antenna with and without the tuning stub is shown in ***Figure 6***. The proposed antenna can cover the whole UWB band without the tuning stub. It also appears that the antenna can satisfy the UWB (3.1 to 10.6 GHz) applications for a VSWR < 2, while rejecting the 5 to 6 GHz used in WLAN applications. The differences between the simulated and measured values may be due to dimensional errors in the manufactured antenna and the SMA connector to the CPW-fed transition, which is included in the measurements but not taken into account in the calculated results. The measured radiation patterns at 3.5, 6.5 and 9.5 GHz are shown in ***Figure 7***. It shows that the antenna can give a nearly omni-directional characteristic in the H-plane and quasi omni-directional pattern in the E-plane. The gain of the pro-

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posed antenna, with and without the tuning stub, is shown in ***Figure 8***. As desired, the gain sharply decreases in the vicinity of 5.5 GHz and the gain of the notch band drops to -4.6 dBi.

CONCLUSION

A CPW-fed ultra-wideband antenna with a band-notch characteristic is proposed for UWB applications. The band notch frequency is obtained by using a tuning stub in the middle of the fork-like radiation patch. The antenna is successfully optimized, fabricated and tested. The results show that the antenna not only has a band notch characteristic, but also has a good radiation pattern. The antenna also has compact dimensions of 28 × 21 × 1.6 mm, which makes it attractive for UWB applications. ■

ACKNOWLEDGMENT

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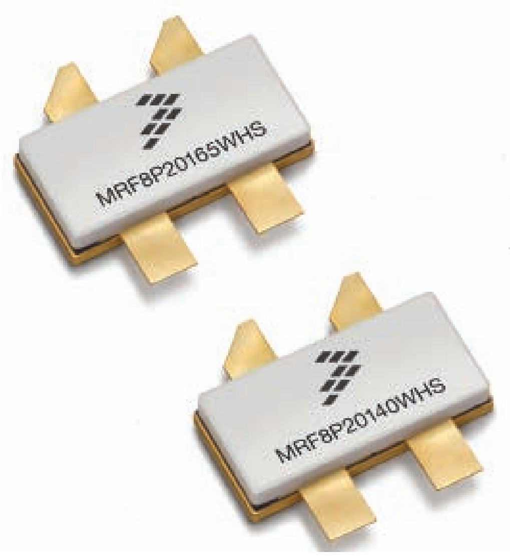

NEW WIDE INSTANTANEOUS BANDWIDTH RF POWER DEVICES FOR WIRELESS INFRASTRUCTURE

The RF power market possesses a healthy share of competitive suppliers, all eager to grab market share from one another. In order to lead the market, one must constantly innovate to offer the best-in-class products, optimized for the cellular infrastructure market space. In the past, customers were content to utilize devices that achieved the highest basic RF performance numbers based on gain, efficiency and linearity. Now customers are demanding those basic RF performance requirements and the ability of the devices to be easily Digital Pre-Distortion (DPD) error corrected.

One of the latest innovations for improved DPD capability is the concept of improved instantaneous bandwidth. By improving the in-package output matching structure and adding DC bias decoupling inside of the RF power device itself, one can significantly improve the ability of the device to amplify very wide bandwidth signals or multiple wideband modulated signals.

The instantaneous bandwidth capability of a device is limited by two controlling factors. One is the internal resonant frequency of the internal device output matching structure. This is easily controlled and set to very high frequencies, well above the 100 MHz range. The other limiting factor is the ability of the external circuit DC bias decoupling capacitors to supply enough current to the device at the high peak power demand of in phase, multiple carrier signals. The problem is that most of the decoupling capacitance is on the DC side of the RF blocking choke and that RF choke inductance limits the current delivery capability of the capacitors. The solution is to place some of that decoupling capacitance inside of the device on the RF side of the circuits' RF choke. Enhanced video bandwidth parts, or eVBW devices, have this technology installed and are capable of instantaneous bandwidths in the 100 to 140 MHz range.

Two of the newest enhanced video bandwidth devices released from Freescale are the MRF8P20140WH and the MRF8P20165WH. Both of these devices are presented in the symmetrical Doherty configuration in a NI780-4 air cavity ceramic package and are designed for the 2000 MHz LTE market space.

The MRF8P20165WH has approximately 16 dB gain, 46 percent efficiency and –33 dBc adjacent channel power ratio at the 37 W output level with a single carrier wideband CDMA test signal at 1995 MHz. Its video bandwidth capability is on the order of 100 MHz, which is a 50 percent greater improvement over conventional designs.

The MRF8P20140WH has approximately 16 dB gain, 43 percent efficiency and –31 dBc adjacent channel power

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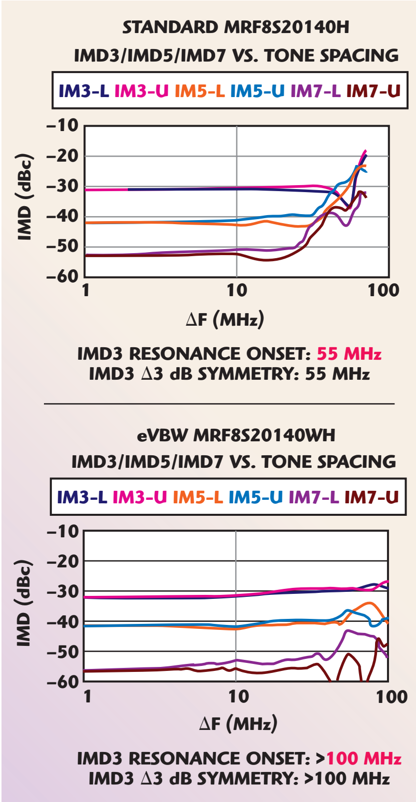

▲ *Fig. 1 Two-tone IMD comparison between standard and eVBW devices.*

ratio at the 24 W output level with a single carrier wideband CDMA test signal at 1995 MHz. Its video bandwidth capability is on the order of 140 MHz, which is a 2× greater improvement over conventional designs.

Figure 1 shows a comparison of the two-tone intermodulation distortion products across various tone spacings for both a conventional device and an enhanced VBW capable part. With the conventional design, the third order intermodulation product tends to start falling apart at about 55 MHz. The same devices with the patented Freescale matching structure are capable of maintaining good IMD numbers at tone spacings greater than 100 MHz.

These are just the latest improvements in a series of innovations that continuously add value for customers. The existence of multiple suppliers incentivizes competition. This forces a healthy amount of continuous innovation and development, which of course, always benefits the designer of cellular infrastructure power amplifiers.

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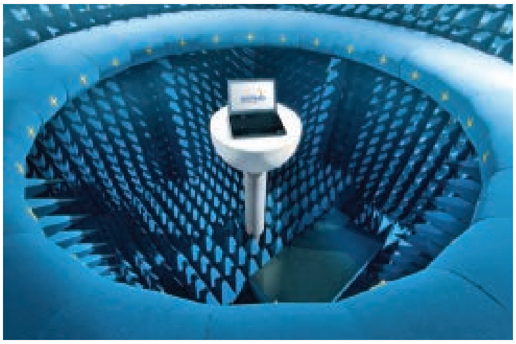

LTE MEASUREMENT SOLUTION IMPROVES MEASUREMENT TEST TIMES

SATIMO has integrated the Anritsu MT8820C One-Box Tester into its OTA measurement systems for LTE measurements (see ***Figure 1***). The combination of SATIMO multi-probe measurement technology with Anritsu LTE measurement solutions enables device developers and manufacturers to perform LTE OTA measurements in both single input, single output (SISO) and multiple-input, multiple-output (MIMO) modes in record times (up to 10 times faster, depending on measurements).

Multiple antenna techniques are a central concept to LTE, and they are used to increase coverage and system capacity (see ***Table 1***). LTE Over-The-Air (OTA) testing can be split into SISO and MIMO testing. The former uses Total Radiated Power (TRP) and Total Isotropic Sensitivity (TIS) as figures of merit (FOM), in order to characterize a transmitter and receiver, respectively. This methodology is not suitable for MIMO testing, creating the need for a new testing methodology.

TABLE I

PEAK DATA RATE (20 MHz BANDWIDTH) FOR UE CATEGORIES

UE Category	Peak Downlink Data Rate [Mbps]	Antenna Configuration [eNodeB TX x UE RX]	Peak Uplink Data Rate [Mbps]
1	10.296	1×2	5.16
2	51.024	2×2	25.456
3	102.048	2×2	51.024
4	150.752	2×2	51.024
5	302.752	4×2	75.376

The SATIMO StarMIMO is a commercial solution based on the Spatial Fading Emulation (Technique Alessandro Scannavini, et. al. "OTA Throughput Measurement by Using Spatial Fading Emulation Technique," EuCap 2010, Barcelona 2010) in which a spatial-temporal characteristics environment (multipath plus fading) is simulated at the device location.

LTE SISO TRP AND TIS TESTING

SATIMO has offered traditional SISO OTA testing with its SG64, 32, 24 series, as well as its compact StarLab, which are suitable for 2G, 2.5G and 3G SISO OTA testing. With the recent interest in LTE OTA testing, SATIMO worked with Anritsu to integrate the MT8820C into its SW package. SATIMO's automated software SAM 2 for OTA measurement (latest software release SAM 2.17.2) is now compatible with Anritsu's MT8820C One-Box Tester, which supports measurement of transmit power and receive throughput for multimode LTE devices when incorporated into the SATIMO system. Additional capabilities provided by the MT8820C include high speed RF calibration; RF parametric tests in either signaling

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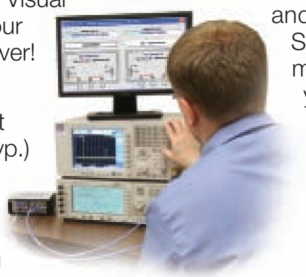

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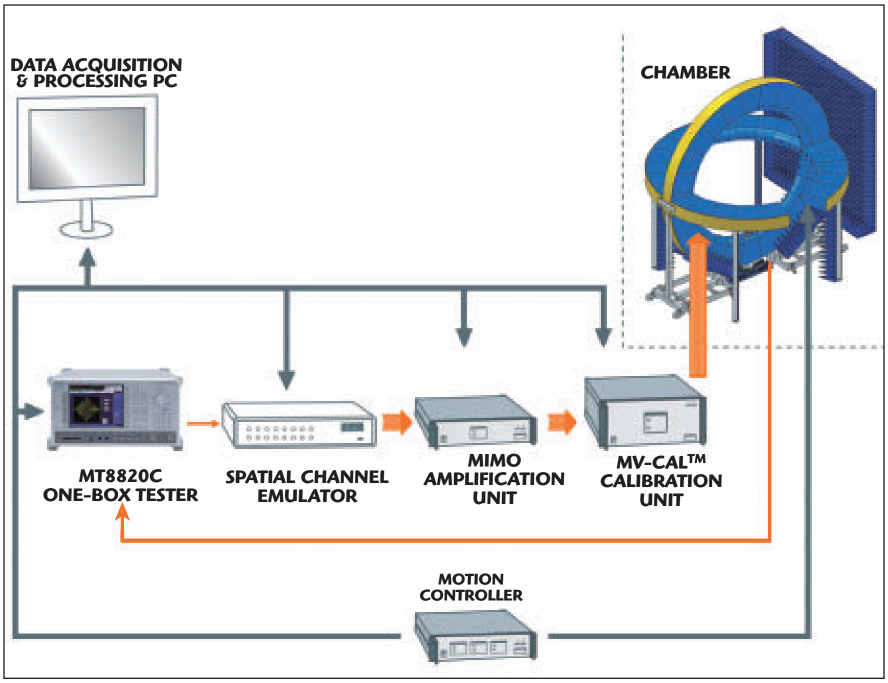


▲ *Fig. 1 Standard LTE MIMO testing solution with Anritsu One-Box Tester.*

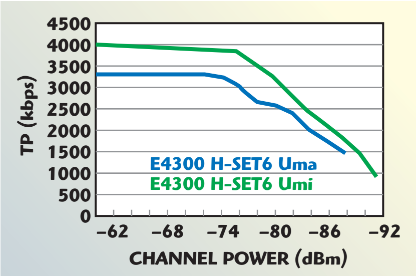
or non-signaling mode; and functional tests, including voice calls, video calls, end-to-end throughput and current consumption.

The integration of the MT8820C enables the SATIMO solution to conduct OTA measurements for two recent protocols: LTE and the TD-SCDMA/HSPA. The MT8820C One-Box Tester also includes additional 2G/3G protocols, such as W-CDMA/HSPA and HSPA Evolved, CDMA2K to 1xEV-DO rel. A, TD-SCDMA and GSM/GPRS/E-GPRS. OTA-tested performances include all declination of TRP and TIS measurements (upper hemisphere, near-horizon, total and effective, intermediate channel).

The MT8820C makes the testing of LTE physical layer parameters quick and simple, including the measurement of both TX and RX parameters in accordance with 3GPP test standards. Parameter setups and pass/fail limits for tests defined in 3GPP 36.521-1 are pre-programmed, including automatic setup of uplink and downlink Resource Block (RB) allocations. Further improving test times and efficiency is the Parallel Phone Measurement (PPM) function of the MT8820C, which allows two UEs to be tested simultaneously and independently (see ***Figure 2***).

LTE MIMO OTA TESTING

Testing the performance of LTE MIMO capable devices Over-The-Air is fundamental for manufacturers. MIMO OTA testing is designed for receiver performance testing such as downlink



▲ *Fig. 2 Throughput as a function of channel model power in two environments–Urban Micro (Umi) and Urban Macro (Uma).*

data rate. Manufacturers are designing optimization algorithms into their devices' chipset to improve performances in low signal, high interference and other challenging environments.

With multiple antennas, improvement of performance is made by clustering signal paths in the most effective way. Indeed, even if the chip is working properly – for instance two receiving antennas – the same signal can be received twice. The diversity of the received signals (Rx diversity testing) can be used to improve the sensitivity of the device in challenging conditions. With SATIMO's multi-probe approach, 4-32 probes can be selected to form clusters of direct signals, scatterers and interferers. Using SATIMO's MV-Cal™ technology, calibration of all the emulated channels can be performed almost instantaneously, drastically reducing the measurement time by 15 to 20 percent.

With SATIMO's MIMO testing solution and Anritsu's MT8820C One-Box Tester, measurement of multiple antennas terminals can be performed in a fully RF controlled environment. The MT8820C supports a 2×2 MIMO mode, so it can generate two data streams in downlink mode. The generated signals are then transformed, and mapped to eight dual polarized probes (16 outputs) in the channel emulator in order to emulate specific propagation models at the device location. The emulations of multi-path signal include Cross Polar Ratio (XPR), delay spread, fading profiles and Doppler shift. They are compliant with 3GPP standardized Channel Propagation Models for conformance testing of HSPA and LTE MIMO capable devices.

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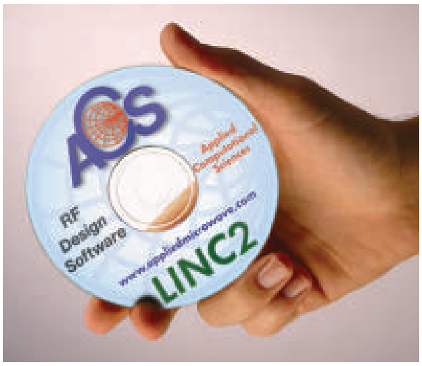

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ACS says its LINC2 Pro RF and microwave circuit design and analysis software suite is the industry's price-performance leader. Now with the new Visual System Architect (VSA) as an integral part of the LINC2 software suite, performance over cost has been extensively multiplied. The LINC2 VSA adds system-level simulation while LINC2 Pro adds circuit synthesis and circuit-level simulation to the LINC2 software suite. The latest version of the LINC2 VSA and LINC2 Pro (V2.72 release K) both offer enhanced support for multiple project data folders. The LINC2 simulator will now automatically search for project data within the user specified project folder or across different project folders for shared component data files as needed.

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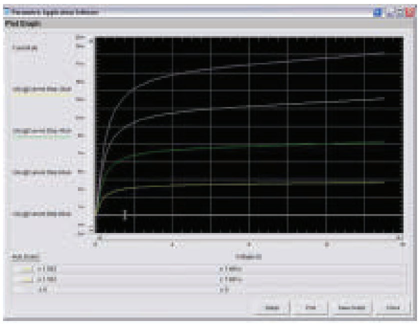

SOFTWARE FOR DC PARAMETRIC TESTING

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Agilent U2942A Parametric Measurement Manager Pro is designed for DC parametric testing on component devices. The software works with Agilent U2722A and U2723A USB modular source measure units to analyze discrete semiconductor devices, without the need for prior programming experience. It also lets users define and customize test profiles and includes built-in math functions to reduce testing time. PMM Pro provides high measurement sensitivity of 100 pA and four-quadrant operation on a three-channel unit. PMM Pro also gives users the ability to make parametric measurements with automated test sequencing and predefined test profiles for diode, bipolar junction transistors and field-effect transistors. After taking the required parametric measurement, the software plots, displays and logs the results in an IV curve.

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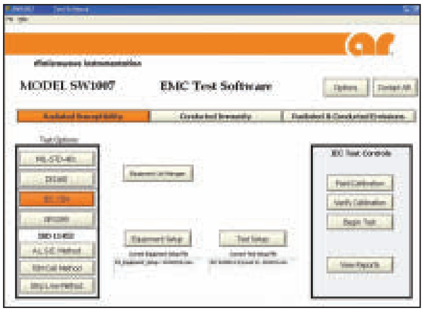

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AR's SW1007 software is a standalone program that combines conducted immunity test software and radiated susceptibility test software into one user-friendly package suitable for corporate to professional test lab users. The software automatically performs both calibration and immunity testing in full compliance with IEC 61000-4-3, 4-6; MIL STD 461/462 RS103, CS114 and RTCA/DO160 Section 20 specifications. The new version has an updated user interface, including a tab system, and organizes all the features for quick, easy access and makes selecting test standards much easier. The SW1007 also has the ability to control more equipment and the report-generating feature has been enhanced to offer more control and customization.

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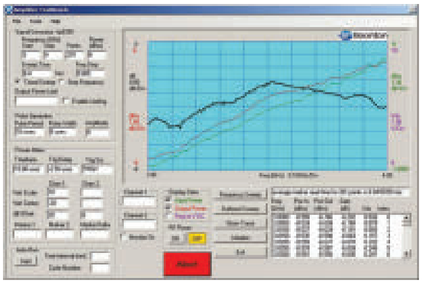

AMPLIFIER TEST BENCH

Amplifier Test Bench supports analysis of pulsed and linear amplifiers. It also measures gain over frequency and gain over input power. The software supports both fast Boonton peak power meters 4540 and 4500B and a variety of standard generators. No programming knowledge is required. Amplifier Test Bench also has the capability to measure VSWR and return loss over time. With this feature, it is a powerful tool for measuring long-term stability of RF systems. Analyzing the quality and wear of rotating radar joints is just one example. For this application, the shaft position pulse provides the 0 degree starting point, which triggers repeating measurement cycles of Amplifier Test Bench. Time is correlated to angle and based on that, the software plots return loss over angle. Possible problems that are related to the position angle of the radar system can now be pinpointed easily. Amplifier Test Bench is offered as single user package, with the option of obtaining multi-user licenses.

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EuMC	£350.00	£87.00	£455.00	£113.00
EuMIC	£268.00	£78.00	£348.00	£101.00
EuRAD	£209.00	£76.00	£271.00	£98.00
2 Conferences				
EuMC + EuMIC	£556.00	£165.00	£723.00	£214.00
EuMC + EuRAD	£503.00	£163.00	£654.00	£211.00
EuMIC + EuRAD	£429.00	£154.00	£558.00	£199.00
3 Conferences				
EuMC + EuMIC + EuRAD	£661.00	£241.00	£860.00	£312.00

STANDARD REGISTRATION CONFERENCE FEES (AFTER 9 SEPT AND ONSITE)

CONFERENCE FEES	ADVANCE DISCOUNTED RATE			
	Society Member (*any of above)		Non-member	
1 Conference	Standard	Student/Sr.	Standard	Student/Sr.
EuMC	£455.00	£113.00	£591.00	£146.00
EuMIC	£348.00	£101.00	£452.00	£131.00
EuRAD	£271.00	£98.00	£352.00	£127.00
2 Conferences				
EuMC + EuMIC	£722.00	£214.00	£939.00	£277.00
EuMC + EuRAD	£653.00	£211.00	£849.00	£273.00
EuMIC + EuRAD	£557.00	£199.00	£724.00	£258.00
3 Conferences				
EuMC + EuMIC + EuRAD	£859.00	£312.00	£1,116.00	£404.00

WORKSHOP AND SHORT COURSE FEES (ONE STANDARD RATE THROUGHOUT)

For full details & titles of Workshops & Short Courses, visit www.eumweek.com

FEES	ADVANCE DISCOUNTED RATE			
	Society Member (*any of above)		Non-member	
	Standard	Student/Sr.	Standard	Student/Sr.
1/2 day WITH Conference registration	£70.00	£50.00	£95.00	£70.00
1/2 day WITHOUT Conference registration	£95.00	£70.00	£125.00	£95.00
Full day WITH Conference registration	£100.00	£75.00	£135.00	£95.00
Full day WITHOUT Conference registration	£135.00	£100.00	£175.00	£125.00

Other Items

Proceedings on CD-ROM

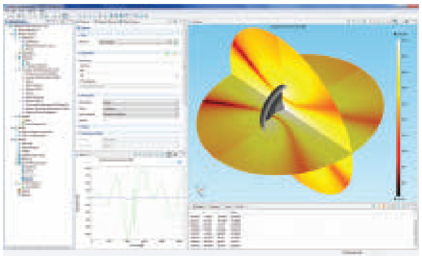
All papers published for presentation at each conference will be on a CD-ROM, given out FREE with the delegate bags to those attending conferences. For additional CD-ROMS the cost is £42

DVD Archive EuMC	Eu*M*A Members	Non Eu*M*A Members
DVD Archive EuMC 1969-2003	£8.00	£34.00
DVD Archive EuMC 2004-2008	£30.00	£106.00

Partner Programme and Social Events

For information on and registration to any of these events, please visit www.hotelzon.com/en/uk/events-eumw-pp or email: sally.garland@hotelzon.co.uk.

FREE SPECIAL FORUMS & SESSIONS			
Date	Time	Title	Location
Weds 12th	09:00 - 19:00	The 2011 Defence & Security Forum	Charter 1
Thurs 13 & Fri 14th	08:30 - 17:00	Doctoral School of Microwaves	Central Meeting Rm 8



SOFTWARE EXPANDS MULTIPHYSICS APPLICATIONS

VENDORVIEW

Comsol Inc. has released the latest version of COMSOL Multiphysics, its award-winning simulation environment. Version 4.2, which expands the scope of applications covered by COMSOL, is now available and will be shipped to all customers with current subscriptions. Version 4.2 expands the applications covered by COMSOL with three new application modules – Microfluidics, Geomechanics, and Electrodeposition – and new LiveLink interfaces for AutoCAD® and SpaceClaim®.

Comsol Inc.,
Burlington, MA (781) 273-3322,
www.comsol.com.

ADC EVALUATION KIT

VENDORVIEW

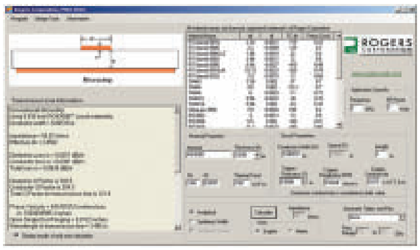
Hittite's ADC Evaluation Kit features EasySuite™ software, allowing users to configure Hittite ADC Evaluation Boards, and capture & analyze data. It consists of a Xilinx© Spartan-6 development kit, an FMC evaluation board with Hittite's ADC mounted, and a software tool for configuring the ADC and analyzing the resultant data. EasySuite™ also includes EasyStack™ FPGA firmware for capturing data from the ADC and parsing configuration commands to the ADC, including all control functionality.

Hittite Microwave Corp.,
Chelmsford, MA (978) 250-3343,
www.hittite.com.

TIME DOMAIN SOLVER AND HIGH FREQUENCY TOOL

Integrated Engineering Software has released CHRONOS, its new time domain solver and high frequency tool for modeling and simulating 3D RF and microwave applications. The software has been introduced to address the challenge of the modeling and simulation of many RF applications and antennas in terms of speed, required memory, and accuracy. CHRONOS is ideal for the analysis and design of RF and antenna applications, including near field and far field applications; planar microwave and antenna structures; wire antennas; UWB antennas; and microwave circuits, waveguides and coaxial structures.

Integrated Engineering Software,
Winnipeg, Manitoba, Canada
(204) 632-5636,
www.integratedsoft.com.



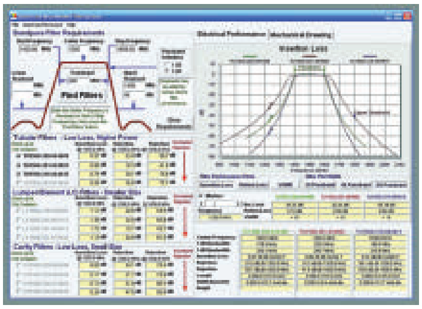
IMPEDANCE CALCULATOR

VENDORVIEW

Rogers Corp. is offering its MWI-2010 Microwave Impedance Calculator software free to RF/microwave designers. The utility program calculates transmission-line parameters for a variety of high frequency circuits, including microstrip and stripline, based on conductor dimensions and substrate characteristics. The easy-to-use software runs on Windows-based computers. Users enter parameters specific to their circuit application, including target frequency and RF power level, and generate transmission-line parameters, such as conductor width and spacing for a desired impedance. Results can be saved and reused in other programs. A free 22-page user manual is available on the Rogers site in PDF form.

Rogers Corp.
Chandler, AZ (480) 961-1382,
www.rogerscorp.com.

Software Update



FAST BANDPASS FILTER DESIGNS

FilterXpress from Spectrum Microwave is a free software program that delivers thousands of real bandpass filter designs, real fast. FilterXpress does not deliver simulated filters like other programs. Spectrum Microwave's database of thousands of cavity, lumped element and coaxial-tubular filters lays the groundwork for matching a company's unique requirements with a real bandpass filter design. By entering specific filter requirements, including the passband and rejection points, FilterXpress responds with up to 12 designs from Spectrum Microwave's huge library of filters.

Spectrum Microwave,
Philadelphia, PA (888) 553-7531,
www.spectrummicrowave.com.

CAD EDITING SOFTWARE

T-Tech Inc. has released IsoPro® 3.1, Mill Path Generation and CAD editing software for Quick Circuit users. IsoPro® 3.1 newly added features include: CheckByTouch® broken bit detection, ContactByTouch® automatic depth sensing, Automatic Tool Change, Tool Management, including Linking, Improved mill/drill path optimization, Multilingual help files with graphics, Live Machine Status Bar, Windows 2000 - Windows 7 and Mac 10.X compatible, 32/64 bit compatibility, Layer tool list options, Tool Pod dialogue bar, Select entities options.

T-Tech Inc.
Norcross, GA
(770) 455-0676,
www.t-tech.com.

Components

X-band Tx and Rx Filters

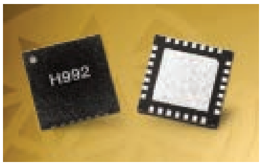
The company claims to have released the world's smallest waveguide X-band Tx and Rx filters for military SATCOM applications. The filters have less than 0.3 dB insertion loss and have greater than 90 dB rejection in the complementary frequency bands. They are said to be shorter and lighter than equivalent filters, which makes them suitable for portable solutions.
A1 Microwave Ltd.,
Pickering, UK +44 (0)1751 476600,
www.a1microwave.com.

110 GHz 1.0 mm Connectors

The new 1.0 mm connector series is designed for semi-rigid and low-loss flexible cable and adaptors for custom applications. They are designed for 50 Ω and are said to exhibit excellent performance up to 110 GHz. The connector's outer conductor ID is 1.0 mm; the interface is air dielectric and the contact is supported by a short dielectric bead. The connectors can operate in a temperature range from -55°C to 125°C and other features include low insertion loss, low reflection loss and good VSWR performance.
Frontlynk Technologies Inc.,
Tainan, Taiwan +886 6 356 2626,
www.frontlynk.com.

Automatic Gain Control Product Line

VENDORVIEW



Hittite's first IF automatic gain controller, HMC992LP5E, is composed of two identical voltage variable attenuators in combination with an InGaP HBT gain block MMIC amplifier and operates from 0.1 to 0.8 GHz. The HMC992LP5E features superior gain control range from -10 to +38 dB, and delivers noise figure of 6 dB in its maximum gain state, with output IP3 up to +40 dBm. Housed in a RoHS compliant 5 × 5 mm QFN leadless package, the HMC992LP5E requires no external matching components.
Hittite Microwave Corp.,
Chelmsford, MA (978) 250-3343,
www.hittite.com.

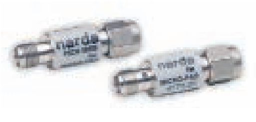
Wideband KABUC-ODUs

Jersey Microwave introduces its new outdoor package for its high performance, production Ka-band phase-locked block up converters (KABUC). These outdoor units (ODU) translate L-band signals (950 to 2450 MHz) to Ka-band (24 to 31 GHz in up to 1500 MHz band segments). Features include phase-locked to an external (5 MHz/10 MHz) or an internal reference (auto-switchover when external reference is removed). Superior performance over temperature, excellent phase noise (exceeds IESS 308/309 and MIL-STD-188-164A), low output spurious, LO leakage, output power up to 4 W, operates from 90 to 260 VAC, 25 dB gain adjustment, full M&C functionality via Ethernet, and RS485/422 are available. Block down converters are also available. Multiband solutions are available in C-, X-, Ku- and Ka-bands.

Jersey Microwave,
Flanders, NJ (908) 684-2390,
www.jerseymicrowave.com.

Miniature Fixed 3 dB Attenuator

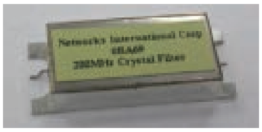
VENDORVIEW



Model 4772-3 miniature fixed 3 dB attenuator has flat frequency response, low VSWR, and meets environmental requirements for MIL-A-3933. The attenuator measures only 1.24" × 0.38" and weighs 0.5 oz. It handles 2 W average and 200 W peak RF input power, has a VSWR of 1.4:1 or less, and attenuation deviation of ± 0.3 dB or less. Connectors are stainless steel SMA female. The model 4772-3 attenuator is in stock for immediate delivery.
Narda Microwave-East,
Hauppauge, NY (631) 231-1700,
www.nardamicrowave.com/east.

200 MHz Crystal Filter

VENDORVIEW



NIC introduces a 200 MHz fundamental frequency Crystal filter used to achieve spectral purity and noise reduction in clock/timing chain applications. Some of the features include a hermetically-sealed package, low insertion loss of < 6 dB, rejection of > 40 dB at Fc ±100 KHz and ultimate rejection of > 75 dB, built in a small package size of 1.0" × 0.5" × 0.28." Custom designs are available up to 250 MHz.
Networks International Corp.,
Overland Park, KS (913) 685-3400,
www.nickc.com.

Solid-state Attenuator

VENDORVIEW

The PMI model DTA-50M2D5G-CD-SFF is a solid-state attenuator that operates in a frequency range from 50 MHz to 2.5 GHz. Features include mean attenuation range of 60 dB; insertion loss of 4.5 dB maximum; VSWR of 2.0:1 maximum, minimum attentuation step of 0.06 dB; switching time of 1.0 usec maximum; control is 10-bit TTL; DC voltage is ±15 VDC; connectors are SMA(F)×2 and 15 Pin D-Sub. Size is 2.0"L × 1.81"W × 0.88"H.
Planar Monolithics Industries Inc.,
Frederick, MD (301) 662-5019,
www.pmi-rf.com.

30 W Switch

Pulsar model PS4-52-452/13S covers the frequency range of 15 to 40 GHz with 12 dB minimum isolation, 2 dB maximum insertion loss and 1.90:1 maximum VSWR. Amplitude and phase balance are, respectively, 0.8 and 12 degrees maximum input power is 30 W maximun.
Pulsar Microwave Corp.,
Clifton, NJ (973) 779-6262,
www.pulsarmicrowave.com.

Low Frequency, High Power Notch Filter

VENDORVIEW

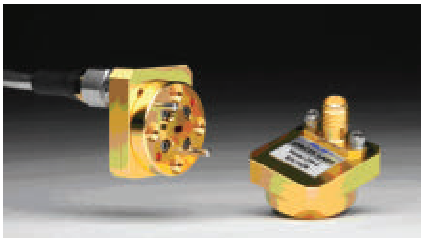
6R10-434-X7N11 is a low frequency, high power notch filter perfect for co-site interference applications. While this unit is centered at 434 MHz, there are many other center frequency and passband configurations available. Please contact the factory with your exact requirement.
Reactel Inc.,
Gaithersburg, MD (301) 519-3660,
www.reactel.com.

Universal Adapter Kit

RF Connectors is offering its 30-piece Unidapt™ kit with white bronze plating, RFA-4024-WB. White bronze provides a tarnish-free, non-magnetic solution with electrical performance rivaling silver plated products. In addition, white bronze is corrosion resistant, lead-free, and has low intermodulation distortion. Unidapt™ system adapters come with gold-plated contacts and DuPont Teflon™ insulation. Simply mix or match any male-to-male, female-to-female, or male-to-female adapter components. Literally hundreds of different adapters can be made instantly using the N, BNC, TNC, SMA, UHF or M-UHF components contained within the RFA-4024 Unidapt™ kit. The universal center adapter is the key.
RF Industries,
San Diego, CA (800) 233-1728,
www.rfindustries.com.

DW-2 Broadband Detector

Spacek Labs model DW-2 is a full-band, 75 to 110 GHz detector. This detector is a very cost-



effective way of measuring power in the W-band spectrum. The RF input is WR-10 (UG387/UM) and the output is SMA (F). These detectors can be used as fast data rate receivers, with up to 3 GHz bandwidth at the 3 dB point into a 50 Ω load. Typical input sensitivity is 1500 mV/mW at -20 dBm input power. Using a 10 megohm load the sensitivity is 1500 mV/mW at -20 dBm input power. Flatness across the band is ±2 dB with a typical tangential sensitivity of -45 dBm in a 1 MHz video bandwidth. Maximum input power is +18 dBm. This detector is available with positive (P) or negative (N) output polarity.
Spacek Labs Inc.,
Santa Barbara, CA (805) 564-4404,
www.spaceklabs.com.

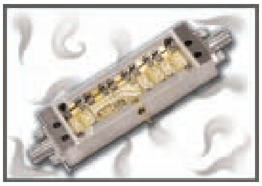
Two-way Combiner, 20 to 1000 MHz

VENDORVIEW

The model D8682 is a high power combiner designed specifically for multi-octave, commercial and military solid-state amplifier applications. This model is only one of several Werlatone combiners available with full 20 to 1000 MHz bandwidth, at power levels ranging from 25 to 500 W CW. D8682 is rated at 500 W CW and will tolerate a full input failure at rated power with forced air cooling and 300 W CW without forced air cooling.
Werlatone Inc.,
Patterson, NY (845) 278-2220,
www.werlatone.com.

Amplifiers

X-Band Amplifier



AML announces the availability of a low noise X-band amplifier, model number AML812L3003. This LNA operates in the frequency range of 8 to 12 GHz with small signal gain over 30 dB and a noise figure of 1.1 dB typical. Output P1dB is +10 dBm minimum. This amplifier is available in a SMA connectorized housing with internal voltage regulation and reverse voltage protection.
AML Communications,
Santa Clara, CA (408) 727-6666,
www.amlj.com.

Dual-band Solid-state Amplifiers

VENDORVIEW

With AR's dual-band amplifiers, you have freedom like never before. You pick the power from 5 to 80 W. You pick the bandwidth from 0.8 to 8 GHz, 0.8 to 10.6 GHz or 0.8 to 18 GHz. AR RF/Microwave puts it together for you in one package that costs less, weighs less, and takes less space than two separate amplifiers.
AR RF/Microwave Instrumentation,
Souderton, PA (215) 723-8181,
www.arworld.us.

400 W Ku-Band TWTA

The XTD-400KHE high power amplifier (HPA) is a compact, antenna mountable TWTA designed for high linear power with high efficiency. The new amplifier is in a compact, rugged package weighing only 32 pounds. Drawing only 960 W at 200 W of linear RF output power, the amplifier is ideal for transportable applications where high efficiency, light weight, and high ambient temperature operation are required. The high efficiency 400 W Ku-band traveling wave tube amplifier (TWTA) has the size, weight and prime-power requirements of traditional 200 W products.
Comtech Xicom Technology Inc.,
Santa Clara, CA (408) 213-3300,
www.xicomtech.com.

L-Band Power Amplifier

VENDORVIEW

The GCM5C5DHO (SKU 3114) is a 2110 to 2170 MHz, 47 dBm, GaN, multi-function, microprocessor controlled amplifier. This amplifier is small (2" × 6") and lightweight (< 0.5 pounds) providing 50 W over the entire -40° to +85°C temperature range. Efficiency is > 50 percent and is designed for rugged operating conditions. It operates unconditionally stable into open and short circuits. The amplifier Enable On/Off is ultrafast < 5 µsec and has a low standby power consumption of < 5 W. This compact, fully integrated amplifier module is designed for high volume manufacturing.
Empower RF Systems Inc.,
Inglewood, CA (310) 412-8100,
www.empowerrf.com.

GaN Broadband PA

The new broadband power amplifiers – models KUPABB322A and KUPABB325A – based on GaN-technology are claimed to provide excellent gain flatness and constant output

power over the specified frequency range. Compact size (124 × 80 × 25 mm) and low supply voltage (+28 V DC) make the modules suitable for any broadband application including, CW/pulsed systems, laboratory equipment and radar.

Kuhne electronic GmbH,
Berg, Germany +49 (0) 9293 800 939,
www.kuhne-electronic.de.

Low Noise Amplifiers

VENDORVIEW

The MAAL-010705 and MAAL-010706 are highly linear LNAs with low noise figure, high gain and excellent input and output return loss designed for operation from 0.5 to 1.6 GHz and 1.4 to 4 GHz, respectively. These two amplifiers share the same pin out and are packaged in an RoHS compliant leadless 2 × 2 mm DFN package. The bias current and gain can be set with external resistors allowing the user to customize the current consumption and gain value to fit the application. The MAAL-010704 is a versatile broadband LNA that operates in the frequency range of 0.1 to 3.5 GHz and is packaged in SOT-363. Its bias current can also be set externally via the use of a resistor. The LNAs all feature an integrated active bias circuit allowing direct connection to 3 V voltage supply while minimizing variation over temperature and process.

M/A-COM Technology Solutions Inc.,
Lowell, MA (800) 366-2266,
www.macomtech.com.

Coaxial High Power Amplifier

VENDORVIEW

The LZY-22+ is a ruggedized high power amplifier capable of delivering 30 W output signals across its entire operating bandwidth, from 0.1 to 200 MHz. Extensive safety features to prevent amplifier damage include over-temperature protection and the ability to handle short and open loads. It offers digitally controlled blanking, isolation of 70 dB typical, and high gain, 43 dB typical. The LZY-22+, including heat-sink and cooling fan, is designed for a 24 V/5.5A DC power supply.

Mini-Circuits,
Brooklyn, NY (718) 934-4500,
www.minicircuits.com.

High Power Linear Ku-Band PA

VENDORVIEW

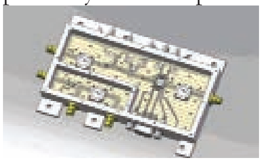
The AMF-6B-14001535-50-40P is a connectorized Ku-band high power linear amplifier/module, covering 14 to 15.35 GHz and delivering over 10 W at P1dB. The connectorized aluminum housing is 1" high, including the top fins, 2.8" wide × 4.6" long, excluding the connectors, heatsink with fan pack and the standard field replaceable isolator in addition to the 28 V option shown in the picture. It is intended for bolting to a flat cooling surface. This module has internal regulation, over voltage, temperature and reverse polarity protection. Single +12 to +15 V supply is required and 28 V is optional. The power amplifier is fully compliant over a base temperature range of -30° to +60°C. Nominal small-signal gain is near 40 dB with a gain flatness of less than ±1.5 dB. RF port VSWRs are less than 1:1.5 at input and 1:2 at output and noise figure is less than 5 dB. Output IP3 is typically 47 dBm. Current draw from +15 V is nominally 7A and 7.5A at P1dB.

MITEQ Inc.,
Hauppauge, NY (631) 439-9469,
www.miteq.com.

Power Amplifier

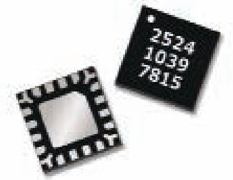
VENDORVIEW

The HRAD6.5-005 power amplifier/upconverter covers the frequency range from 5.5 to 7 GHz and is usable to 7.2 GHz. MMIC technology is used to achieve high reliability and repeatability. An output level of 3.5 W saturated has been achieved. The SSG is 40 dB at 6.5 GHz. Multiple devices buffered by ferrite junctions used to achieve the best circuitry allowing the use of a single bias to power the amplifier. This component can be integrated with the onboard DSB upconverters and other components to form custom subassemblies for specific applications. The upconverter is housed in a separate enclosure to prevent leakage and so that external filters can be used. The amplifier/upconverter can be used in transmitters for communication and radar systems and also as part of test equipment suites.



Renaissance Electronics,
Harvard, MA (978) 772-7774,
www.rec-usa.com.

PtP Power Solution



TriQuint has released the TGA2524-SM (12 to 16 GHz) amplifier for point-to-point microwave radio and Ku-band VSAT applications. TriQuint's TGA2524-SM offers 35 percent lower power consumption and surface-mount convenience in a 3 × 3 mm-QFN package. TGA2524-SM allows for gain regulation with gate and voltage adjustment; it requires no external PCB matching and typically provides 26.5 dBm of saturated output power with 23 dB of small signal gain.

TriQuint Semiconductor,
Hillsboro, OR (503) 615-9000,
www.triquint.com.

Sources

IEEE 1588 OCXO

Connor-Winfield's new high stability SMD OH300 series of OCXOs provide an excellent capability to support IEEE 1588 system requirements. This SC crystal based design maximizes short term stability, frequency stability over temperature and extremely low aging rates. Offering standard frequencies like 5M, 10M, 12.8M, 13M, 19.44M, 20M and 20.48M, this model can be configured to provide exceptional performance for short term stability to the level 5×10^{-12}, stability over temperature of 1×10^{-9} and daily aging rates of 5×10^{-10}. Package size is 22 × 25 × 12.7 mm.

Connor-Winfield Corp., Aurora, IL (630) 851-4722, www.conwin.com.

Phase-locked Clock Oscillator

The XLT-129 ultra-miniature, low noise clock oscillator operates at a fixed frequency of 129 MHz as reference clocks in military and commercial RF/microwave systems. Locked to an external frequency reference, the XLT-129 features instantaneous turn-on, excellent phase noise (Fout = 129 MHz, < -130 dBc/Hz at 10 KHz, typical), high vibration tolerance (12 g's RMS, operating) and low power consumption at +3.3, +5, +8 or +12 VDC. The XLT is housed in a miniature connectorized package (1.3" × 1.1" × 0.4") to withstand harsh environments, and operates over the standard temperature range of -30° to +70°C. Optionally available features include operating over the MIL-SPEC temperature range (-40° to +85°C) and optional hermetic sealing per MIL-STD-883.

EM Research Inc., Reno, NV (775) 345-2411, www.emresearch.com.

Four-channel Oscilloscope

The four-channel PicoScope 6404 PC Oscilloscope has an analog bandwidth of 500 MHz, matched by a real-time sampling rate of 5 GS/s, which guarantees accurate representation of signals up to the full bandwidth. The scope features an ultra-deep 1 gigasample buffer memory that allows capture and analysis of complex waveforms, even when sampling at full speed. It connects to any Windows XP, Vista or Windows 7 computer with a USB 2.0 port and also offers a built-in function generator, arbitrary waveform generator, mask limit testing, switchable bandwidth limiting on each channel, and switchable 1 megohm and 50 Ω inputs.

Pico Technology, St. Neots, UK +44 (0) 1480 396 395, www.picotech.com.

Surface-mount XOs and VCXOs

Rakon has launched two new 7 × 5 mm surface-mount XO and VCXO products. The RXO7050R (XO) and RVX7050R (VCXO) offer high performance at low cost, with fast lead times. The RXO7050R and RVX7050R offer wide frequency ranges from 10 MHz to 1500 MHz and CMOS, LVPECL or LVDS output options. The series is available with 2.5 or 3.3 V operation and <1 ps RMS phase jitter integrated from 12 kHz to 20 MHz for the XO. The RVX7050R offers excellent close-in phase noise. A distinct feature for both the XO and VCXO products is an optional "frequency select" pin enabling the output frequency to be selected from two or four pre-defined alternatives. The pin enables maximum design flexibility while reducing design time and lowering inventory costs. Sample turnaround is less than two weeks on more than 200 of the most commonly used frequencies. The RXO/RVX7050R series is ideally suited for many high speed serial data communications, networking and telecom applications.

Rakon Ltd., Auckland, New Zealand +64 9 571 9216, www.rakon.com.

VCO with Low Phase Noise

Z-Communications Inc. announces a new RoHS compliant voltage-controlled oscillator (VCO) model CRO3262B-LF in S-band. The CRO3262B-LF operates at 3261 to 3263 MHz with a tuning voltage range of 0.5 to 4.5 VDC. This VCO features a typical phase noise of -113 dBc/Hz at 10 KHz offset and a typical tuning sensitivity of 5 MHz/V. The CRO3262B-LF is designed to deliver a typical output power of 8 dBm at 5 VDC supply while drawing 25 mA (typical) over the temperature range of -40° to 85°C. This VCO features typical second harmonic suppression of -15 dBc and comes in Z-Comm's standard MINI-16-SM package measuring 0.5" × 0.5" × 0.22." It is available in tape and reel packaging for production requirements. The CRO3262B-LF is also ideal for automated surface-mount assembly and reflow. CRO3262B-LF is well suited for fixed wireless applications that require ultra low phase noise performance.

Z-Communications Inc., Poway, CA (858) 621-2700, www.zcomm.com.

Processing Equipment

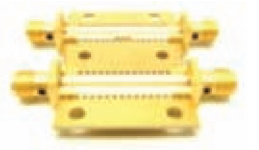
Parallel Gap Welder

Resistance or ohmic welding is widely used in the automotive, electronics, medical, aerospace, RF and microwave industries. The model SMAPRO100 parallel gap welding machine cannot only weld gold and silver ribbons, but also enameled wires without additional coating layer stripping steps. Thus, it eliminates the expensive and difficult stripping process and produces more reliable joints. Welded products are inherently RoHS-compliant because there is no toxic soldering material involved. The flagship SMAPRO100 can weld ribbon sizes up to 40 × 2 mils and enameled wire up to gage #26. Two output power levels, 400 W and 800 W, are offered as Type S and Type L models. Various electrodes and optical devices are offered for selection. The control unit measures 13"(W) × 7.0"(H) × 8"(D) and weighs 35 lbs.

SW Tech Equipment Inc.,
Torrance, CA (424) 757-0117,
www.swtechequipment.com.

Test Equipment

DC to 14 GHz Evaluation Board



Electro-Photonics LLC is expanding its product offerings, and announces the availability of a high performance RF/microwave evaluation (eval) board for easy characterization of SMT attenuators. It can accommodate many SMT attenuators with chip sizes 0.150" × 0.125" (.XXX ± 0.010). Optimized end launches and through line is included for quick de-embedding. Everything you need to evaluate attenuators in minutes on one easy-to-use board with excellent performance up to 14 GHz.

Electro-Photonics LLC,
Palm City, FL (772) 485-0927,
www.electro-photonics.com.

IWX Analyzers

The Invisible Waves X™ capitalizes on the successes of its predecessor by adding a suite of controls providing "world-first" RF analysis. Highlighting the array of new features are Alert Unidentified Frequency Objects (UFO) to warn of rogue interference, Click to Listen™ (listen-in to all RF space) and RF Coordinator™ to identify usable open RF space. Also included are RF Congestion Scale™ to gauge the severity of local RF and RF Level Alert™ to warn when any cataloged signals fall below assigned thresholds. Other new features are an RF Event/Alarm Recorder™ and Logger, and insta-save and recall custom profiles and screen images. The IWX analyzers are sold as complete kits, which include AC adaptor/charger, multiple antennas and a quick USB to PC connection, all enclosed in a pre-configured, laptop-sized, high-impact carrying case. The analyzers also have very intuitive and easy to use sweep analysis display for simultaneous broad span sweeps and docking on-screen control panels.

Kaltman Creations LLC,
Suwanee, GA
(678) 714-2000,
www.kaltmancreationsllc.com.

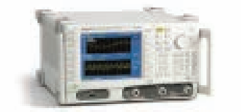
Compact Signal Generator

VENDORVIEW

The R&S SGS100A signal generator has been optimized for use in automated test. It offers a very high output level of typically +22 dBm as standard and has an electronic step attenuator covering the entire frequency range. Its low non-harmonics of –76 dBc up to 1.5 GHz make the generator a suitable signal source for converter tests. Two versions are available. The CW model generates frequencies up to 12.75 GHz and can be used as a local oscillator as well as for interference testing against mobile radio standards. The vector signal generator version with integrated I/Q modulator offers a maximum frequency of 6 GHz and covers the most important frequency bands for digital communications standards. The R&S SGS100A's compact size enables it to fit in one-half the width of a 19" rack as a single height unit, so that four RF sources can be installed in the space previously needed for one.

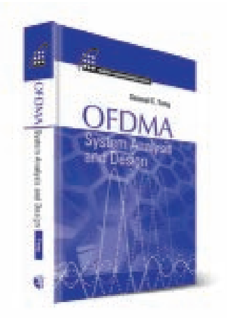
Rohde & Schwarz,
Munich, Germany
+49 89 4129 12345,
www.rohde-schwarz.com.

Cross Domain Analyzer Series



Advantest Corp. announced the availability of its new Cross Domain Analyzer™ family, the U3800 series. The U3800 is the industry's first metrology tool to offer phase measurement of two high-frequency signals in a single instrument, allowing operators to determine the phase difference. This new functionality enables quick and accurate detection of reception problems caused by inter-circuit interference or radio wave reflection, making the U3800 ideal for applications ranging from electromagnetic interference (EMI) challenges, to broadcasting and communications. The U3800 series utilizes a new "X math" function for comparative analysis of inputs from two channels. This function displays the waveforms of both signals on a single coordinate plain, enabling operators to see the phase difference between the signals at a glance. The U3800 is available in three configurations with varying frequency ranges and price points.

Advantest Corp.,
Tokyo, Japan +81-3-3214-7502,
www.advantest.com.



OFDMA System Analysis and Design

Samuel C. Yang

Most of us today cannot imagine working (and living) without 802.11-based wireless networks, popularly known as Wi-Fi. Traveling professionals who really needed to send an e-mail and who had to drive around town looking for a hot spot can attest to the technology's importance. People have become used to high speed wireless networking in the local area (i.e., hot spots) and soon we will become used to high speed mobile networking in the wide area.

This book is designed as a broad examination of orthogonal frequency division multiplexing (OFDM) and orthogonal frequency division multiple access (OFDMA), which are fast becoming the de facto methods of transmission at the physical layer in broadband mobile systems. The associated functions necessary to support OFDM and OFDMA at layer 2 are also addressed. This book focuses on system analysis, design and engineering of an OFDMA-based system. It also deals with both the theory and the application of OFDMA in the context of a broadband mobile wireless network. Based on the analysis of OFDMA, this book tries to develop and present applicable design frameworks in different areas of treatment.

This book uses the case of the IEEE 802.16 standard to exemplify the general concepts of OFDMA. It does not attempt to encompass all details of the standard, but covers those points that are important to a system-level understanding of the technology. Given that IEEE 802.16 is a well-understood implementation of OFDMA, it serves as a solid foundation from which to investigate the relevant subject matters.

Instead of making the chapters modular so that they can be considered individually, the author structured this book so that the best result can be obtained when a reader proceeds through the chapters sequentially. This organization is due to the intertwined nature of OFDMA and IEEE 802.16 standard, so it is recommended that it be read in its arranged sequence of chapters. The book is appropriate for practicing engineers, students and anyone interested in OFDMA.

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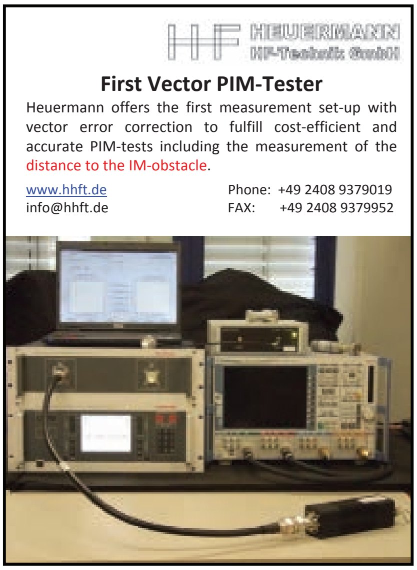
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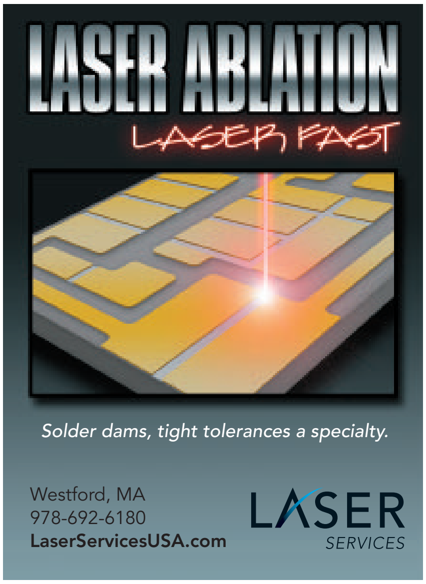
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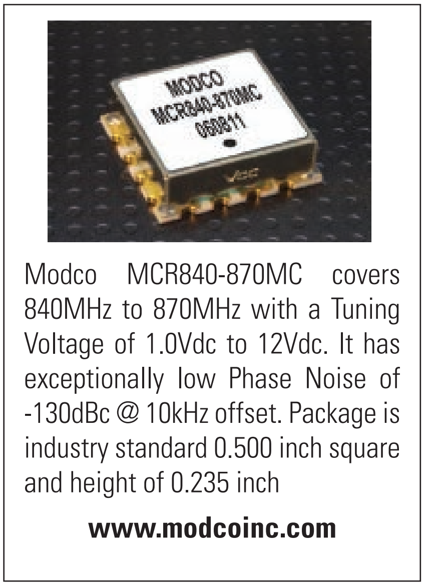
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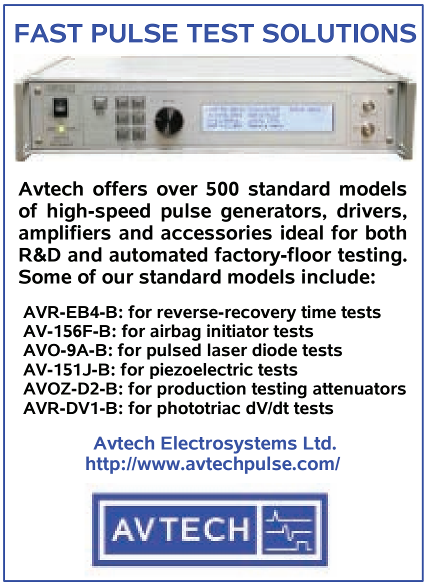
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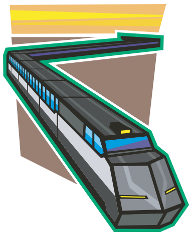
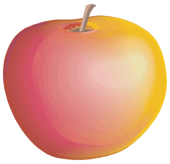


The Smith Jones Robinson Riddle

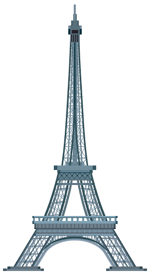
On a train, Smith, Robinson and Jones are the fireman, brakeman and the engineer, but NOT respectively. Also aboard the train are three businessmen who have the same names: a Mr. Smith, a Mr. Robinson and a Mr. Jones. Using the clues below, determine the identity of the engineer.

1. Mr. Robinson lives in Detroit.
2. The brakeman lives exactly halfway between Chicago and Detroit.
3. Mr. Jones earns exactly $20,000 per year.
4. The brakeman's nearest neighbor, one of the passengers, earns exactly three times as much as the brakeman.
5. Smith beats the fireman in billiards.
6. The passenger whose name is the same as the brakeman's lives in Chicago.



Apple

Eric has a perfect spherical shaped apple. With a cylindrically shaped drill bit, he removes the core of the apple. A cylindrically shaped hole remains — the center of this hole is exactly at the center of the apple. Eric measures the length of the hole with a piece of rope. It turns out to be exactly 8 cm. What is the volume of the remaining apple?



Eiffel Tower

The Eiffel tower in Paris, has including the TV antenna, a height of 321 meters. It is made out of 7 million kg steel. Somebody would like to build a scale model of this tower with a weight of 1 kg. How tall will this scale model be?

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U.S. Export Control Reform: Getting It Right This Time

OVERHAUL OF U.S. EXPORT CONTROL

The Obama Administration has launched a very comprehensive and well thought-out game plan to modernize the complex and often confusing United States Export Control System's set of Rules and Regulations. The administration's plan for Export Control Reform (ECR) — to make the system work for us as part of our national security strategy, not against us – is indeed a visionary approach for those of us who have been involved in this bureaucratic nightmare for many years. The administration's effort is to create an export control system that is responsive to the national security, technology and commercial imperatives of the 21st century. The goal is also to be better able to monitor and enforce controls on technology transfers with real security implications while helping to speed the provision of equipment to allies and partners who fight alongside us in coalition operations.

THE GAME HAS CHANGED

The Cold War is over and so are most of the assumptions that led us to this point in the evolution of Export Control Laws and Regulations. We now have to look at Export Controls in the context of a new reality and recast them to support how we globally engage our enemies and our friends. Today, we fight in "cyberspace domains at the speed of light." And our Export Control Systems must be brought up to new standards and be re-evaluated in that context. It should reflect how we deal with our closest allies internationally, both as close friends and as military coalition partners. We must protect the critical technology in the U.S. in the proper fashion from all the "bad guys." But our Export Control laws must reflect the world we live in today. The context for this discussion is clear – our laws need to keep pace with advancing technology in a globally connected world economy. U.S. military supremacy depends on our warfighters having a clear technological advantage. Technology is the critical factor that determines support for our national military strategy, and most importantly, is the key underpinning used to protect and support our warfighters on the battlefield.

Jim Fallon
Fallon and Associates LLC,
Hingham, MA

THE ADMINISTRATION'S EXPORT CONTROL REFORM (ECR)

Let's explore some of the critical issues surrounding Export Control Reform, focus on some of the real problems companies face every day and take a closer look at what's being proposed to fix Export Control by our government leaders. What are President Obama, the Administration, Secretary of Defense Gates and others doing to attack this problem? The good news is that they have been at this task for more than a year. The better news is I think they are making significant progress and are on the right track. The not so good news is the toughest part of the work still lies ahead. This whole discussion is really all about one thing – "a big reset" that is coming – on how we will come together and implement Export Control Reform. And this issue is very serious for all of us in the microwave industry, and we need to understand what is happening. Make no mistake about it, dismissing this issue as "not your problem and somebody else's to worry about" is not good. This is a critical business issue that has direct implications on our business plans.

THE PLAYERS, PLAYGROUNDS AND PROBLEMS

Responsibility for U.S. Technology Export Controls are scattered across four major agencies and several lesser ones. The Department of Commerce's Bureau of Industry and Security (BIS) is responsible for implementing and enforcing Export Administration regulations, which pertain to the export and re-export of "dual use" commercial items. There are also several lists associated with this effort. The U.S. Munitions List (USML) and the Commerce Control/Critical Commodities List (CCL) are the most prominent ones. The Department of State is technically responsible for approving military sales. It enforces the ITAR sales, which are governed by the Arms Export Control Act (22 U.S.C. 2778). Items governed by ITAR relate to the USML. These two agencies (and how these two lists are used) are the main players involved with regulating American technology and military exports. And the DoD, along with Department of Homeland Security (DHS), the U.S. Treasury and other departments, are involved in most of

The U.S. Takes Violations Seriously – BAE Systems and ITT

Recently the U.K.-based military contractor BAE Systems PLC recently agreed to pay $79 M, the largest fine in the history of the U.S. Department of State, to settle civil allegations of export control violations, a year after the company pled guilty in related criminal cases. This was reported in the press and covered in several news releases from the company. According to the U.S. State Department, BAE, the largest military contractor in Europe, committed more than 2591 violations of the Arms Export Control Act and the International Traffic in Arms Regulations (ITAR), including unauthorized brokering of U.S. defense articles and failure to maintain proper records. It ends a long-running corruption investigation into the company, Europe's biggest arms maker by sales, on both sides of the Atlantic. The department cleared BAE's fast-growing U.S. unit and its subsidiaries of all charges against the parent company, based in Farnborough, outside London. But it said a lack of full cooperation from the parent had left it "unable to assess fully the potential harm to U.S. national security" from the unauthorized resale of U.S. weapons and technology know-how to more than a dozen countries.

The U.S. subsidiary, BAE Systems Inc., accounts for about 52 percent of the company's worldwide sales and is among the Pentagon's top 10 suppliers. It operates a separate export compliance program under a special security pact that governs its dealings inside and outside the U.S. BAE also failed to cooperate fully for the 14 months since the criminal pleadings set the stage for the parallel civil investigation, the department said. It followed the global settlement announced in February 2010 of criminal cases brought by the U.S. Department of Justice and Britain's Serious Fraud Office. Under its agreement last year with the Justice Department, the company pleaded guilty to one charge of conspiring to make false statements to the U.S. government and paid a fine of $400 M.

In London, BAE pleaded guilty to one charge of failing to keep records of payments made to a marketing advisor in Tanzania and paid about $50 M. The cases grew from criminal investigations into arms deals in Saudi Arabia, Tanzania, Sweden, the Czech Republic and Hungary. The State Department said it is releasing an administrative hold it imposed, after the criminal conviction, on license applications by the parent company to export U.S.-origin arms and services. But it declared a policy of presumptive denial on three BAE subsidiaries "because of their substantial involvement in activities related to the conviction." The units' export license requests would be approved only if they were determined to be in the U.S. national interest.

ITT Corp. several years ago revealed in a news release that it had agreed to a final settlement relating to an investigation that began in 2001 regarding ITT Night Vision's compliance with ITAR. As part of the agreement, the company paid a $50 M fine and pleaded guilty to one ITAR violation relating to the improper handling of sensitive documents, and one ITAR violation of making misleading statements. The government has agreed to defer action regarding a third count of ITAR violations pending ITT's implementation of remedial actions. ITT agreed to cooperate with the government to continue to invest in research and development and capital improvements for its Night Vision products so it can continue to provide the most advanced night vision technology to the U.S. military and its allies.

The value of these investments is $50 M over the next five years. In addition, the company has been engaged in a comprehensive review of its policies, practices, training programs and procedures, including complete audits of all business units. New monitoring approaches, communications and training initiatives have already begun as a result of this review and more are expected. ITT's CEO said at the time, "We have been cooperating with the government in this investigation and we have voluntarily disclosed all discrepancies that our internal reviews revealed." And, he said, "while this settlement relates to the actions of a few individuals in one of our 15 business units, we regret very much that these serious violations occurred." He added, "Our renewed commitment to a culture of integrity and compliance applies to the entire company. ITT has a long track record as a trusted employer, supplier and partner, and we are firmly committed to ensuring that this will not happen again. These violations have made it clear that we had gaps in our compliance programs. The steps we are taking now will address these issues in a comprehensive way." The company has already begun implementing stricter new measures such as: Insuring that all personnel understand and follow applicable regulations governing the export of critical technology, naming a new compliance officer, instituting a required ethics and compliance training program for all employees worldwide, developing a comprehensive computer tracking program to monitor all packages sent from ITT facilities and working with independent experts to refine and enhance the effectiveness of these measures. In a related action, the Department of State has placed restrictions on certain exports of night vision equipment and technical data and ITT Night Vision will not be allowed to ship devices to specific parties for a period of not less than one year.

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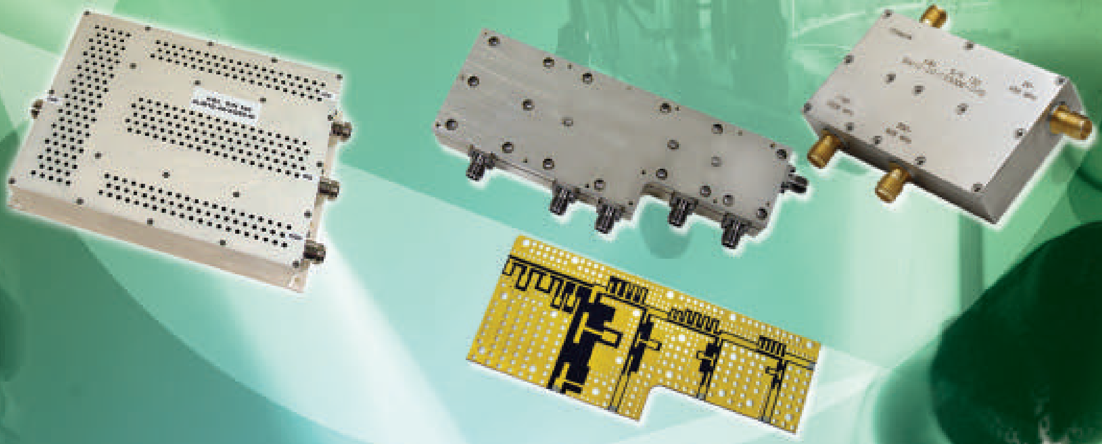
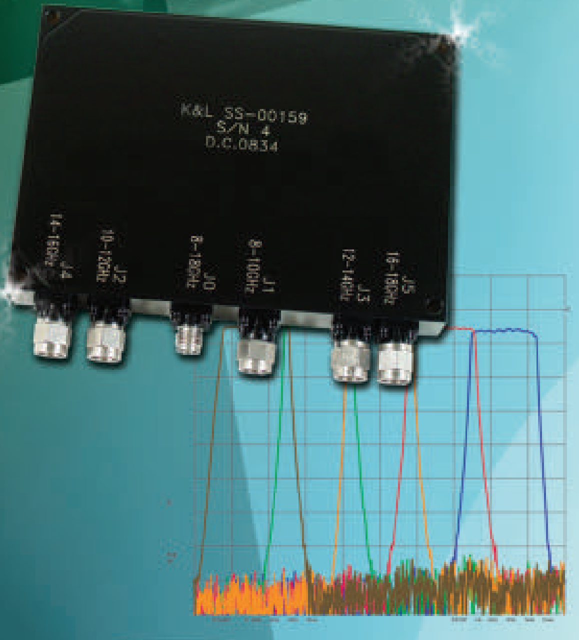


Product Spotlight



8-18 GHz Multiplexer with Overlapping Bands

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these activities. As you see and may surmise, there are "way too many cooks" in this Export Control kitchen.

HOW THE SYSTEM IS SUPPOSED TO WORK AND DOES

The idea behind the existing organizational approach to Export Controls was that various agencies with their different agendas and perspectives would create a system of "checks and balances" that would be more difficult to defeat by those trying to game the system. However, it has not worked out that way, and the associated costs of all these redundant activities are very high and are becoming administratively prohibitive. There were several obvious problems with these arrangements and some that are not so obvious. The most obvious one involves overlapping jurisdictions. It is not always clear for example where a specific item falls on one of these "lists" or to which agencies that should possibly be involved in an Export License application.

For example, a company that wants to act ethically may not be clear about where to submit its export license application, or may end up going to one agency to be subsequently told they must now go to a different agency. Yet, no agency has the legal authority (nor will they formally or informally) to actually interpret the Export Control laws and regulations. You are responsible for any action taken, and are criminally liable if you proceed in an illegal fashion. You can see the "Catch 22" situation.

It has been reported that some export license applications can be approved by one agency and denied by another. The flip side is that savvy companies can "shop their applications" by picking the regulator they believe is most likely to say yes. The problem of multiple forms to multiple agencies is made worse by long processing times. These departments have limited funds from which to support staff to review applications, and the State Department is reportedly still mostly paper based. Commerce is only slightly ahead with an IT system that needs to be updated. The net effect for industry is potentially long processing times – four to six months is not unusual for an application. In that time frame it is very possible for the American company to find that the foreign bid competition that it was trying to enter is now closed and the order placed with a competitor.

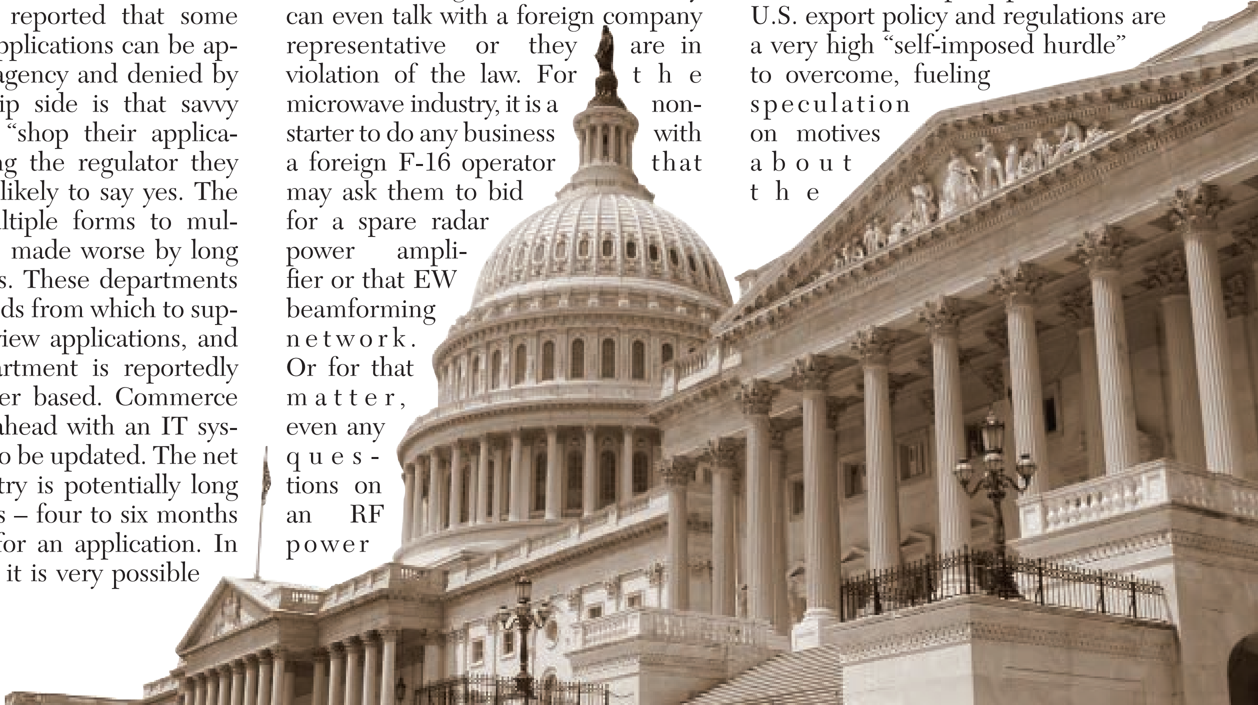
HAVING A SYSTEM EXPORT LICENSE DOES NOT EQUAL HAVING A LICENSE FOR THE SUM OF ITS PARTS

The next difficulty builds on the others, and is a vexing problem for the microwave industry. The U.S. Export Control system makes more work for itself by requiring approval at the level of individual components. Think about how many parts are in a Fighter with all its avionics and associated equipment. In addition, it has Radar Guided Missiles, Electronic Warfare Suites, and RF Communication Systems, among many other systems. It is absurd to control things at that low a component level.

For example, a foreign country was approved to buy an F-16 Fighter Aircraft from Lockheed Martin without having any apparent difficulty in obtaining the license through appropriately filling out all the required export paperwork. Now, according to U.S. Export Control Policy, that does not mean that suppliers to that weapons platform or system are approved to export anything that they supply to it. In addition, suppliers are not authorized under US Export Control Laws to respond even when asked to bid parts to that foreign country to help maintain that F-16 Fighter Aircraft. And as a supplier, one must apply for a Marketing License before they can even talk with a foreign company representative or they are in violation of the law. For the microwave industry, it is a non-starter to do any business with a foreign F-16 operator that may ask them to bid for a spare radar power amplifier or that EW beamforming network. Or for that matter, even any questions on an RF power transistor requires approval. It is controlled at that level, right down to the performance characteristics of the transistor. We are now letting government regulators into controlling access via the S-parameter data. And, it gets worse. Suppliers are not allowed to transfer parts to another U.S. ally whose F-16s are operating from the same base to support an American-led operation. This makes the problem more complex. Bottom line – component suppliers are not covered by the platform's OEM export license.

PROTECTIONISM AND POLITICS

Export control regulations are even affecting weapons development programs around the world, which is of great concern to many American defense firms. The ITAR processes make it difficult for firms like Raytheon, Northrop Grumman, General Dynamics, Boeing and many others to share information around the world with their own international subsidiaries. This inhibits the inclusion of American technology into bids for foreign contracts in foreign countries or to even explore collaboration with foreign firms in allied nations. And, they cannot talk to their own company employees outside the U.S. without first getting a Marketing or Technical License for the U.S. government to approve the contact. This can shut American firms out of foreign weapons programs at the earliest stages, which is not good. What is even more troubling is that many people outside the U.S. have a perception that the U.S. export policy and regulations are a very high "self-imposed hurdle" to overcome, fueling speculation on motives about the



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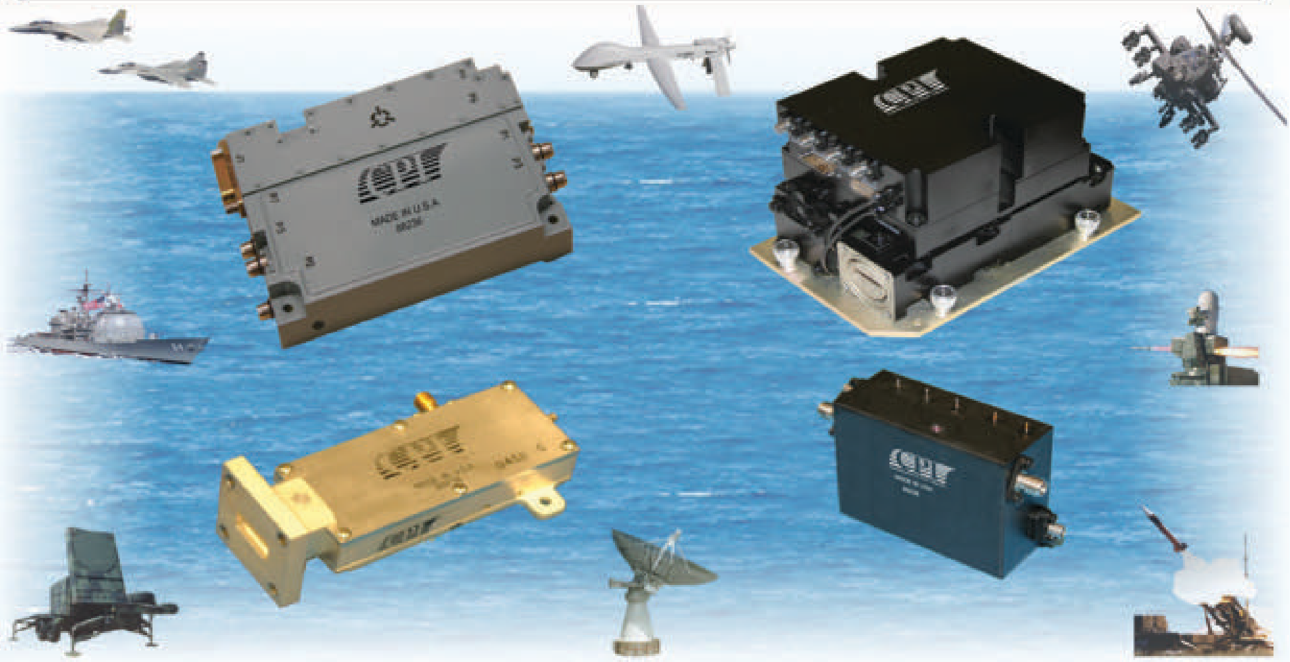

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U.S. government hiding behind "the rules," and acting very protectionist and partisan in defense of U.S. technology and product dealings. In some instances, foreign governments and countries have accused the U.S. of trying to stop foreign business competitors, and this activity has actually encouraged these negative perceptions. The current system encourages multinational companies to move research, development and production offshore, "eroding our defense industrial base" as well as "undermining our control regimes."

THE EXPORT CONTROL/ITAR CONUNDRUM ON THE INDIAN FIGHTER COMPETITION

It was no surprise to some of us that all U.S. Fighter entries in the ongoing Indian Fighter competition were down-selected out of the Tender to supply advanced fighter aircraft to India. It had been reported in the press that the love affair with the Indian Air Force and the Russian Fighter community was becoming a strained relationship at best. And the Indians were requiring that industry in their country participate fully as partners in all technology and hardware manufacture. This implied direct manufacture of critical electronic subsystems, including Advanced Electronic Warfare Self-Protection suites, Electronically Scanned Active Arrays (including all transmit receive modules) and covert RF communications systems. It has been reported in the Defense press that the U.S. government would not approve the license to allow that to happen. So while the U.S. political and Administrative levels of government said they would support the sale, the cold hard facts when it got to the regulators of ITAR/Export Controls was they said absolutely not. There would not be any export on the "jewels of defense electronics" on board these advanced Indian fighters. So the two remaining contenders still in the competition are the Eurofighter and the Rafelle, who have reported "full and complete cooperation" with Indian industry on the local manufacture of their fighter aircraft with the U.S. losing out on a chance to win these large contracts.

THE BASICS OF REFORM

Fundamental reform needs to be carried out in a half dozen government agencies and the final set of updated Export Control rules will need to 1) achieve consistency of purpose and direction, 2) have a well thought-out strategy on the various technologies and approaches to controls that are realistic and 3) put in place specific regulations that will have clear and unambiguous objectives. The government needs to fix all the conflicts and put in place crisp guidance to be followed by everyone. The government's intent on what technology needs to be protected must be crystal clear. And the Export Control Regulations should support those findings. Export Control rules need to be an enabler for national security, not used as a gatekeeper to hold back on everything. And once they have vetted these new rules and effectively challenged themselves that they have done it correctly, they will then need to roll it out and plan to implement it. It now has to stand on its

own as an effective U.S. government policy directive, specifically designed for protecting critical technology for the warfighter. The government must transform this process into a unified business-like methodology. And it has to communicate it clearly to the stakeholders – our citizens, the business and government community and our global allies. Make no bones about this task, it will be arduous, painful and time consuming to upgrade and make common sense of all these disparate agency rules and regulations. Mistakes will be made and lessons will be learned in this effort. But the old system is broken, and needs to be upgraded to today's standards of coalition warfare and global alliances.

GETTING TO THE ECR FINAL OUTCOME — IS IT EVEN POSSIBLE?

To achieve this goal will be a monumental task given how many different entrenched government bureaucracies play in the game of Export Controls, ITAR and the licensing process. Government organizations have a unique ability to "wrap themselves in a warm and fuzzy blanket" of agency and procedural "do's and don'ts" that are derived solely from their own agency's perspective. When operating in this fashion, a specific agency's procedural approach is somehow called upon and used ceremoniously to justify their specific regulatory or decision process. But this logic confounds the average business person who has to deal with the many agencies involved – each seeming to have their own rules, laws and regulations. And business folks have to also fill out application forms and, as such, need to be accountable to their shareholders – who expect lawful behavior tied to good business practices. To deal with a group of government agencies that each have their own point of view, which sometimes are contradictory, at best, and indeed not even understandable, at worst, is not good. The business person is caught in the middle of this, with the added burden that they are legally bound to comply with all regulations under the penalty of law.

HIGHLIGHTS OF THE ADMINISTRATION'S PLANS FOR ECR

Last spring, Defense Secretary Gates set out the Administration's conclusion that fundamental reform is needed. "If the application of controls on key items and technologies is to have any meaning," he said, "we need a system that dispenses with 95 percent of 'easy' cases and lets us concentrate our resources on the remaining five percent. By doing so, we will be better able to monitor and enforce controls on technology transfers with real security implications while helping to speed the provision of equipment to allies and partners who fight alongside us in coalition operations." The President, Secretary of Commerce Locke and others discussed how the end result of addressing these critical questions would be a single control list administered by a single licensing agency operating on a single information technology platform and enforced by a single primary export enforcement coordination agency. The structural reforms require congressional action for a single control list and a single IT


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system. This past December, the Departments of State and Commerce issued proposed regulations to achieve two fundamental reform objectives: controlling items based on transparent technical parameters, which translates in export control parlance to "positive lists" that do not overlap; and separating items by tier, to focus controls on the most sensitive items while allowing for more flexible authorizations for relatively mature technologies that are more widely available.

THE U.S. MUNITIONS LIST (USML) AND THE COMMERCE CONTROL LIST (CCL)

The most important aspect of control list reform may be making the USML a "positive" list. Currently, the USML controls many defense articles based on "design intent," in part because, at one time, the majority of items used by the military were produced specifically for the military. Today, however, many technologies used by the military are developed and manufactured by the commercial sector. Moreover, the design-intent nature of the USML is inconsistent with a predictable and transparent regulatory process – one where industry and government alike readily and objectively can determine what is controlled. The existing setup has fueled an increase in commodity jurisdiction disputes. This has resulted in many commercial systems being ruled subject to ITAR control or jurisdictional decisions being delayed, thereby impeding the competitiveness of U.S. items or, even worse, resulting in their being "designed out" of foreign end products.

This "design intent" approach would focus the category's controls on truly significant military items, while moving less significant items – particularly parts and components that do not serve an inherently military function to the Commerce Control List. For many of the low level parts, widely available items will be transferred from the USML to the CCL; Commerce jurisdiction will provide greater flexibility and a simpler structure of controls. First, ITAR registration would be eliminated for many small and medium-sized exporters if their sole ITAR items are minor elements of Defense products. Second, the change in jurisdiction should eliminate many problems associated with the "see through" rule, which make certain items manufactured offshore subject to U.S. re-export control requirements if they incorporate U.S. origin ITAR parts and components, regardless of value or importance. Third, there would be far fewer transactions requiring U.S. exporters to enter into and obtain complex Manufacturing Licensing Agreements or Technical Assistance Agreement to share data and services. Finally, there could be a significant reduction in the time required to determine the jurisdiction of parts and components.

The USML is not the only focus of the Administration's attention. The existing CCL is largely a "positive" list that describes items using objective criteria, but it is not wholly so. The Administration will seek to make it sufficiently positive, clear and precise so that someone who is not an expert on U.S. export controls, but understands the technical characteristics and capabilities of an item, can accurately determine its jurisdictional status and classification.

THE PARALLEL-TIERED CONTROL LISTS

The government's plan involves converting the USML and CCL into parallel constructed, three-tiered lists that allow the U.S. government to focus control on the most sensitive items while establishing cascading controls on more mature and widely available items. The government would then apply licensing policies associated with the tiers. To implement this tiered construct, the U.S. government has developed control list criteria:

1) Tier 1 items are weapons of mass destruction or are almost exclusively available from the U.S. that provide a critical military or intelligence advantage. These are what Secretary Gates has termed our "crown jewels."

2) Tier 2 items are almost exclusively available from regime partners or adherents and provide a substantial military or intelligence advantage, or make a substantial contribution to the indigenous development, production, use, or enhancement of a Tier 1 or Tier 2 item. These are what the U.S. government has termed "precious metals."

3) Tier 3 items are more broadly available and provide a significant military or intelligence advantage or make a significant contribution to the indigenous development, production, use, or enhancement of a Tier 1, 2, or 3 item, or are other items controlled for national security, foreign policy, or human rights reasons.

COMPLIANCE AND ENFORCEMENT

Enforcement activities have a high priority in the Administrations reform program in at least three important respects. The government will establish an Export Enforcement Coordination Center comprising representatives from Department of Commerce/BIS, the Federal Bureau of Investigation, Immigration and Customs Enforcement, the Intelligence Community, and military security agencies. Agencies will share information and leverage their resources to enhance compliance with export control laws and regulations. To enhance coordination among export control enforcement agencies, Commerce/BIS will continue to make use of specific compliance tools to prevent the unauthorized export of technologies to end users of concern. Third, BIS is adjusting how we penalize those who violate U.S. export controls. In the past, BIS typically has imposed penalties on companies involved in export violations. Going forward, where a violation is the deliberate action of an individual, the Administration will consider seeking penalties against that individual including heavy fines, imprisonment and the denial of export privileges – as well as against the company. The same will be true for supervisors who are complicit in deliberate violations by their subordinates.

At the same time, the Administration will recognize that even companies that have good intentions can make mistakes. The Administration promotes the submission of voluntary self-disclosures (VSD) in these and other instances. And the Administration views VSDs, along with robust internal compliance programs, as important mitigating factors. Given the volume of exports and re-exports that are subject to the EAR-BIS (more than 20,000 license applications during 2010), we rely on industry for the bulk of compliance as their knowledge of the products, their end users, and their customers makes them the front line troops in this important effort.

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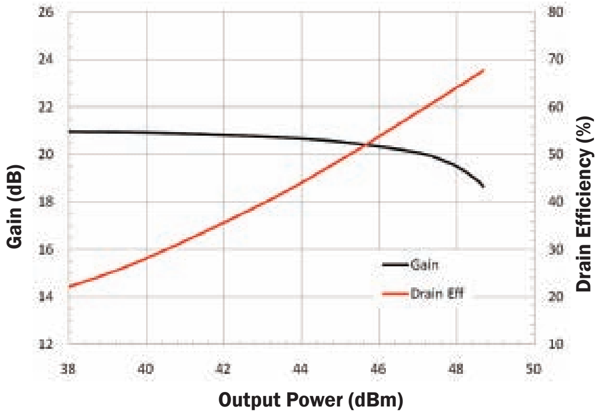
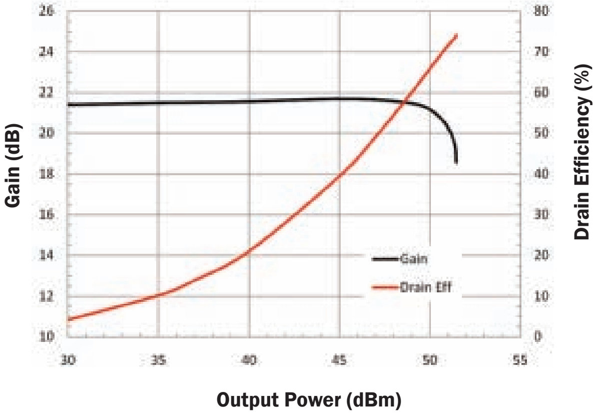


RF3934 Performance

Gain/Efficiency versus P_{OUT}, f = 900MHz
(CW, V_D = 48V, I_{DQ} = 440mA)



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INFORMATION TECHNOLOGY SYSTEMS FOR ECR

The government has a plan in place to upgrade its IT systems to make them more user-friendly for exporters and to leverage the resources and information of agencies across the U.S. government. One of the first steps it will take to improve customer service through expansion of IT capabilities is to establish online registration for the export licensing system. This allows an exporter to go online to file and quickly obtain a personal or corporate information number that allows the exporter to file licenses and other requests. This approach also transfers to the exporter the responsibility to manage its account and add or remove persons authorized to have access to the system. This move will eliminate the manual and sometimes untimely processing of more than 6500 annual requests for access to the licensing system.

THE OUTCOME: GETTING IT RIGHT THIS TIME

- When the Administration has implemented these actions, its goal will be what they call the three greater efficiencies. It will control and investigate those items that are the most significant in terms of providing the United States with a military or intelligence advantage, while facilitating exports to coalition partners in order to improve our interoperability.
- Increased education to ensure that everyone subject to our regulations knows of their existence and requirements. The effort also will help exporters understand how the changes will affect their compliance responsibilities. The Administration will also be emphasizing the adoption of internal export management and compliance programs.
- Enhanced enforcement to ensure that exporters, re-exporters and end users comply with our regulations and use U.S.-origin items responsibly. Administration compliance personnel will evaluate exports made under license or license exception to ensure they comply with the Export Regulations. Government agents are increasing their presence domestically and abroad. They will have new export control officers in China and Singapore, and will leverage the resources of the FBI and Immigration, Customs Enforcement (ICE) as participants in the Export Enforcement Coordination Center. ■

Jim Fallon *is President and CEO of Fallon and Associates LLC, a management and consulting firm that focuses on corporate strategy, marketing and business development, capture planning and proposal leadership. A 38-year veteran of the microwave industry, Fallon has held senior executive positions in numerous organizations, focused on defense electronics subsystems in electronic warfare, missiles and munitions, radar, and military communications markets. He has lobbied in Washington and represented many companies' interests in the defense budget deliberations on Capitol Hill. He has been a speaker at many national technology conferences and symposia, ran the Electronic Industries Association's (EIA) Microwave Division as Chairman representing the Industry, and authored many technical articles in professional journals. He has run a national technical conference on electronic warfare and been involved in many professional organizations, such as AFCEA, AUSA, AOC, Navy League and AFA. He has won numerous industry awards recognizing his contributions to protecting the Warfighters, including a Lifetime Achievement Award (LAA) from the Association of Old Crows (AOC), the Electronic Warfare Professionals Association for a career of achievements in protecting the Warfighter and winner of the Business Development Award from AOC.*

Addressing the Challenges of Wideband Waveform Generation and Analysis

Satellite and radio waveforms can utilize custom/proprietary formats with modulation bandwidths beyond 1 GHz for increased data rates. Generating custom waveforms with wide modulation bandwidths can present challenges, especially when excellent signal fidelity is required and when distortions must be kept to a minimum. Traditional signal generators can provide the required signal purity, but are limited in modulation bandwidths. In addition, wide bandwidth signal analysis requires a new approach for waveform demodulation relative to a traditional RF signal analyzer approach.

These challenges highlight the need for an improved wideband waveform generation and analysis methodology. This article will show a new waveform generation solution, using a wide bandwidth, high precision arbitrary waveform generator (AWG), combined with a vector RF/microwave signal generator with wideband IQ inputs to generate a 16QAM waveform at X-band with a 1.76 GHz symbol rate. Simulation will provide the flexibility needed to create custom/proprietary AWG waveforms. A 32 GHz high performance digital oscilloscope with vector signal analysis (VSA) software will be used to demodulate the waveform to measure the error vector magnitude (EVM).

A PARADIGM SHIFT FOR WIDE BANDWIDTH APPLICATIONS

RF signal generators have traditionally been used for wireless applications. They typically offer good signal purity and performance and the convenience of software applications, which can be used to generate parameterized and pre-configured waveforms, such as Mobile WiMAX™ and LTE. However, RF signal generator AWG modulation bandwidths are typically limited to approximately 100 MHz, which can limit their ability to address emerging applications, such as wide bandwidth satellite and radio communications. In these communication systems, modulation bandwidths may significantly exceed 100 MHz and possibly even approach 1 to 2 GHz of modulation bandwidth. In addition, military radio applications, such as software defined radio (SDR), may require custom waveforms to be generated, such as a custom orthogonal frequency division multiple access (OFDMA) waveforms. Flexibility is needed in the waveform generation process

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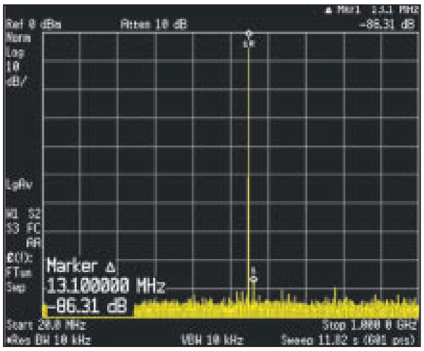


▲ *Fig. 1 Spectral purity of high performance arbitrary waveform generator.*

to facilitate custom proprietary waveform creation, in addition to wide modulation bandwidths.

A similar situation exists for RF signal analysis. Today's RF signal analyzers have IF bandwidths of approximately 140 MHz, which can limit modulation domain analysis, or waveform demodulation, to applications where the modulation bandwidth is within 140 MHz. A new approach is needed for RF/microwave modulation domain signal analysis applications, which exceed 1 to 2 GHz of modulation bandwidth at X-, Ku- and Ka-band carrier frequencies.

High performance commercial-off-the-shelf (COTS) AWGs and digital oscilloscopes are an enabler for wide bandwidth RF/microwave applications. Recent breakthroughs in their performance present a paradigm shift in the way RF engineers think about creating and analyzing wideband satellite and radio waveforms over traditional approaches.

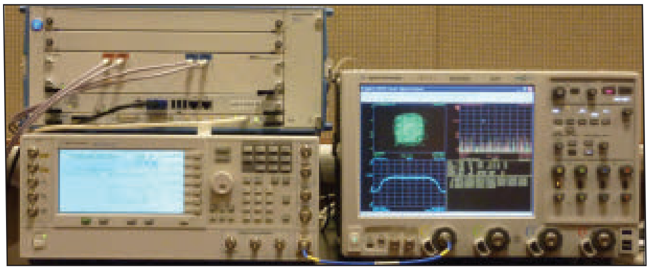
For example, take the spectral purity of a high performance AWG, as shown in ***Figure 1***. The AWG is used to generate a simple single tone at 555 MHz with a sampling rate of 7.2 giga samples per second (GSa/s). The spectral purity is clean, with spurious down to approximately –86 dB. Of course, although this CW case shows the performance that can be achieved with a wideband AWG, it is not representative of the modulated signal formats used for satellite and radio applications.

The next section of this article will show the waveform creation and analysis of a 16QAM waveform at X-band with a 1.76 GHz modulation bandwidth. The residual error vector magnitude (EVM) will be used as the metric, to show the high performance that can be achieved with today's AWG and oscilloscope COTS technology.

A 16QAM EXAMPLE USING A WIDE BANDWIDTH COTS TEST SETUP

Figure 2 shows the high performance wide bandwidth COTS test equipment used to generate and analyze a 16QAM waveform at X-band with a 1.76 GHz modulation bandwidth. The upper left is a precision wide bandwidth AWG with a DAC resolution of 14 bits up to 8 GSa/s, or 12 bits up to 12 GSa/s. The AWG has 2 GSa of arbitrary waveform memory per channel and 5 GHz of analog bandwidth per channel. This is the AWG used to generate the CW tone in Figure 1, but here it is being used to generate a wideband 16QAM waveform. A vector signal generator with wideband IQ inputs is shown on the lower left. This is used to modulate the IQ waveform on an X-band carrier centered at 10 GHz.

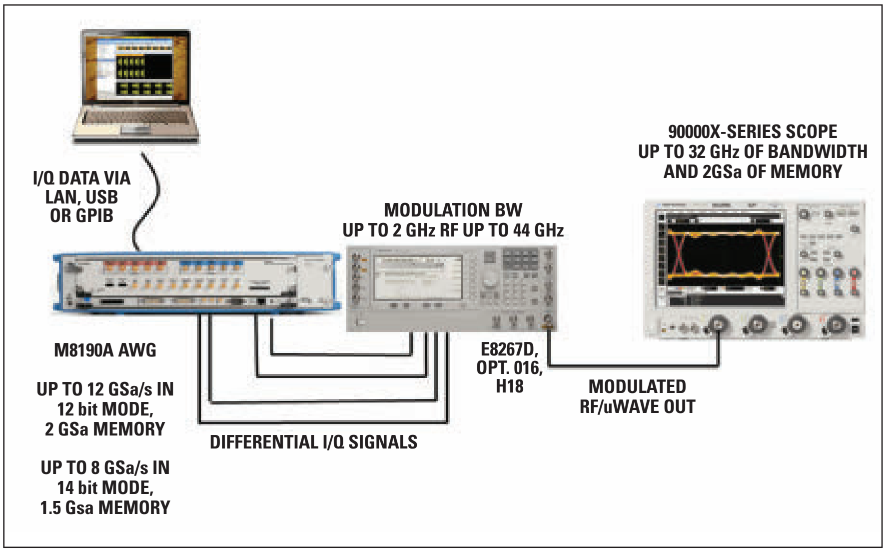
A high performance 32 GHz digital oscilloscope, with VSA software, is connected to the signal generator output to demodulate the wideband 16QAM waveform at the RF/microwave carrier frequency. Although oscilloscopes are traditionally used for time-domain measurements, here it is being used for RF/microwave frequency modulation domain analysis.



▲ *Fig. 2 COTS test equipment setup to generate and analyze wideband satellite communications and radio waveforms.*

Figure 3 shows the setup diagram of the test equipment shown in Figure 2. Waveform creation software or simulation software, such as MATLAB™, can reside on an external PC and downloaded to the AWG. However, in this example, it is installed in the oscilloscope and downloaded from the oscilloscope to the AWG via LAN.

The differential analog IQ outputs of the AWG are fed into a vector RF/microwave signal generator with external wideband IQ inputs, to modulate the IQ waveforms onto a 10 GHz carrier. The output of the vector signal generator is connected to channel 1 on the high performance digital oscilloscope to demodulate the waveform. However, before generating the 16QAM waveform, a MATLAB utility is first used in the digital oscilloscope to create and download a wideband multi-tone waveform for flatness corrections (see ***Figure 4***). The complex frequency response (magnitude and phase) of the AWG output path, in combination with the I/Q modulator in the vector PSG, are analyzed using the VSA software in the oscilloscope. This information is fed back into the MATLAB script,

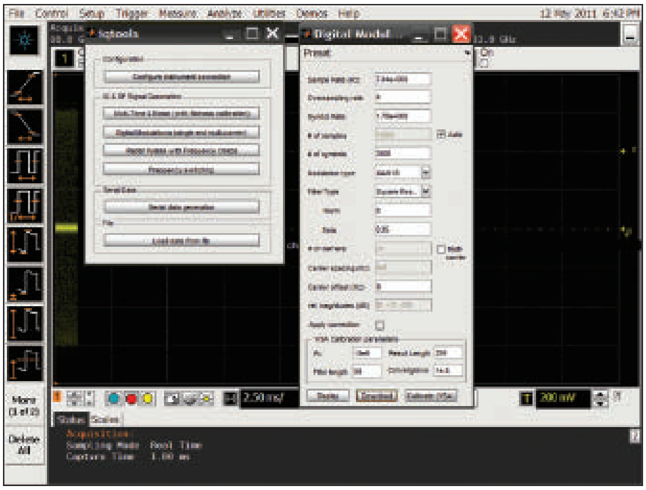


▲ *Fig. 3 Diagram of the test equipment setup.*

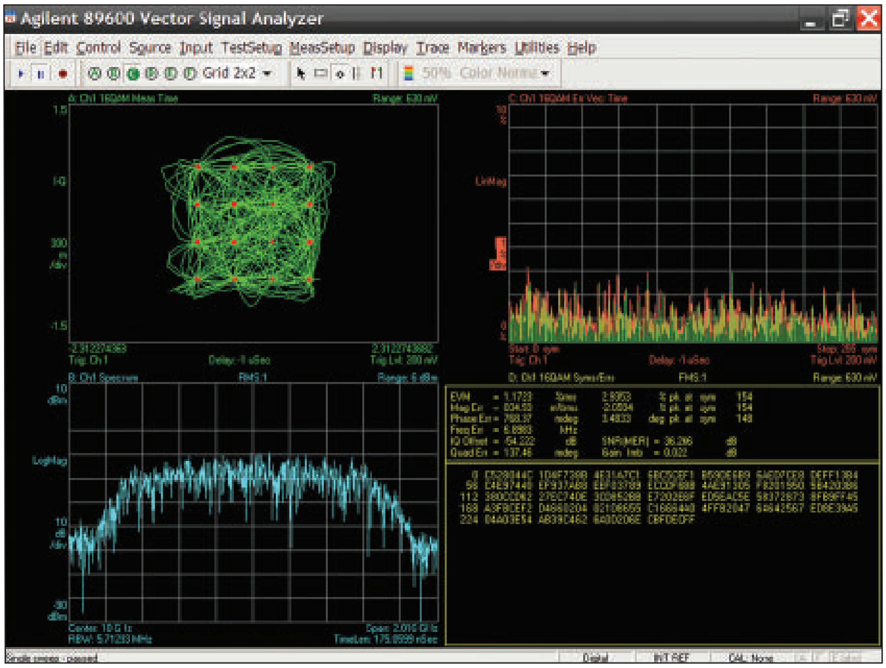
which calculates a pre-distorted waveform and downloads it into the AWG.

Once flatness corrections have been performed, a MATLAB utility is then used to create and download the 16QAM waveform from the oscilloscope to the AWG via LAN. The digital modulation dialog box is configured for a 16QAM waveform with a 1.76 GHz symbol (modulation) rate and 4× oversampling (7.04 GSa/s sample rate). A 0.35 alpha root raised-cosine filter is applied. The high performance digital oscilloscope with VSA software is then used to demodulate the resulting RF/microwave wideband waveform as shown in ***Figure 5***.

The 16QAM constellation is shown on the upper left of the VSA display, the RF modulated spectrum centered at 10 GHz is shown on the lower left, the EVM vs. symbol (time) is shown on the upper right, and the EVM summary table is shown on the lower right. The residual EVM is measured at approximately 1.17 percent, which is quite impressive for a modulation bandwidth of 1.76 GHz at a 10 GHz carrier frequency. Using the VSA software with wide bandwidth high performance digital oscilloscopes enables RF engineers to analyze wide bandwidth modulated waveforms at X-, Ku- and Ka-band (up to 32 GHz) directly, without the need for external down-conversion. In addition, multiple phase coherent inputs enable multiple-input multiple-output (MIMO) OFDMA waveforms to be analyzed and demodulated,[1] using the digital oscilloscope with VSA software. Although not shown in this example, MATLAB can also be used as a custom user defined function (UDF) in digital oscilloscopes.[2]



▲ *Fig. 4 Configuring a MATLAB utility to generate and download a 1.76 GHz 16 QAM waveform to an M8190A AWG.*



▲ *Fig. 5 Measurement results for a 1.76 GHz 16 QAM waveform at 10 GHz.*

SUMMARY

An improved approach for generating and analyzing wide bandwidth waveforms for satellite and radio applications was shown. High performance precision AWGs, combined with RF/microwave vector signal generators with external wideband IQ inputs, enable RF engineers to generate wideband waveforms with excellent signal fidelity. Simulation tools, such as MATLAB, facilitate creating and downloading custom/proprietary waveforms using COTS equipment. High performance digital oscilloscopes, combined with VSA software, enable wide bandwidth RF/microwave waveforms to be analyzed at X-, Ku- and Ka-band, up to 32 GHz, without the need for external down-conversion. Exceptional residual EVM performance was demonstrated with the AWG, vector signal generator and digital oscilloscope on a 10 GHz X-band waveform modulated at a 1.76 GHz symbol rate. ■

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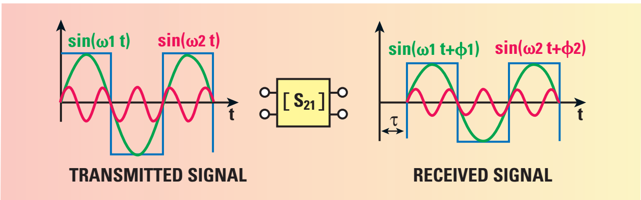
New Group Delay and Phase Measurement Method for Long Distance Transmission

The demands placed on modern communications systems for transmitting wideband signals at high quality are growing in both the civil and military sectors. The performance of such systems crucially depends on achieving constant magnitude and linear phase versus frequency of the transmission coefficient within the useful band. Measuring the phase linearity and the group delay of such systems is vital. This applies in particular to microwave communications systems that include components such as satellites or satellite base stations. With systems of this kind, a baseband signal of large bandwidth is up-converted to a high frequency signal at the transmitter end, and the high frequency signal is down-converted to the baseband at the receiver end. Applications like this require group delay to be measured even on frequency-converting devices.

Relative group delay can be determined using the reference mixer method. This measurement method, however, requires access to the mixer's local oscillator (LO) or at least to a reference frequency. Given that numerous aerospace and defense applications do not allow access to either, a different approach is needed. In addition, the reference mixer method reaches its limits when used to perform free-space measurements on transmission systems. With this method, a system's input and output are connected to a network analyzer via RF cables. If distances of more than a hundred meters have to be bridged, cable losses will deteriorate the signal-to-noise ratio (SNR) significantly.



▲ *Fig. 1 Example of a transmitted and received signal.*

To solve this problem, a new, two-tone method has been developed that allows users to measure relative group delay on converters and mixers with high precision. This method requires no access to the local oscillator or a reference signal, and places only modest requirements on the frequency and phase stability of the local oscillator(s) involved. The method also enables group delay measurements on a transmission system by means of two network analyzers spaced apart from each other. This eliminates the need for RF cable connections, avoiding the typical problems resulting from the use of long cables.

TRANSMISSION QUALITY

For correct information transmission, the signal shape at the transmission system output must be identical to the shape at its input. The amplitudes of the output and the input signal may differ, as the signal may undergo amplification or attenuation to match its amplitude to the conditions prevailing at the receiver end. Also, there is no impact on signal quality if the signal arrives at the receiver with a delay.

THILO BEDNORZ AND
JOCHEN WOLLE
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However, for correct transmission all frequency components within a transmission channel or the transmission bandwidth must undergo identical attenuation or amplification and have an identical delay, relative to the input signal. ***Figure 1*** offers an example of a transmitted and received signal.

For two signals with the frequencies ω1 and ω2 to have an identical delay within a transmission channel, the following must be fulfilled:

$$\varphi = -\omega\tau \qquad (1)$$

$$\varphi_1 = -\omega_1\tau$$

$$\varphi_2 = -\omega_2\tau$$

$$\varphi_2 - \varphi_1 = -\tau\left(\omega_2 - \omega_1\right)$$

$$-\frac{\Delta\varphi}{\Delta\omega} = \tau$$

where $\Delta\varphi = \varphi_2 - \varphi_1$ and $\Delta\omega = \omega_2 - \omega_1$

To obtain a constant delay for all frequencies, the phase of the transmission coefficient S_{21} must be a linear function of frequency. Starting from equation (1), changing the unit of Δφ from radians to degrees, substituting Δω with 2πΔf and reducing the step size to infinitesimal values, the following relationship is obtained:

$$\tau = -\frac{1}{360°} \bullet \frac{d\varphi}{df}$$

The delay, τ, is referred to as the group delay, which is defined as the negative derivative of the phase versus frequency.[1] For a transmission channel to be distortion-free, its transmission coefficient, S_{21}, must have constant magnitude and linear phase versus frequency. By contrast, the absolute values of phase and phase slope versus frequency (the latter can be expressed as the group delay) do not impact transmission quality.

S-PARAMETERS

Rather than determining the derivative of the phase (S_{21}) versus frequency, which is based on infinitesimal deltas, vector network analyzers calculate the difference quotient.

$$\tau = -\frac{1}{360°} \bullet \frac{\Delta\varphi}{\Delta f} \qquad (2)$$

This yields a good approximation of the required group delay. Δf is referred to as frequency aperture. From ***Figure 2*** Δφ = φ2 − φ1 and Δf = f2 − f1 are used for calculating group delay.

Determining the group delay based on the phase measurement of S-parameters delivers precise results as the measurement accuracy of the network analyzer is very high and can be increased further by applying suitable calibration methods. This approach is ideal for non-frequency-converting DUTs, such as amplifiers and filters.

However, in the case of frequency-converting DUTs such as satellite base station converters, the phase of the transmission coefficient S_{21} cannot be measured directly because the input and the output signal have different frequencies. Moreover, the phase of the output signal is influenced, not only by the DUT, but also by the frequency and phase drift of its local oscillator.

REFERENCE MIXER METHOD

Phase and group delay measurements on mixers with an accessible LO are performed using the reference mixer method.[2] The reference mixer uses the LO of the mixer under test in order to convert the reference signal from the network analyzer to the frequency of the IF signal output by the mixer under test. Sharing the same LO compensates for the effects of frequency and phase fluctuations of the LO of the mixer under test. ***Figure 3*** shows a test setup for mixer measurements using the reference mixer method.

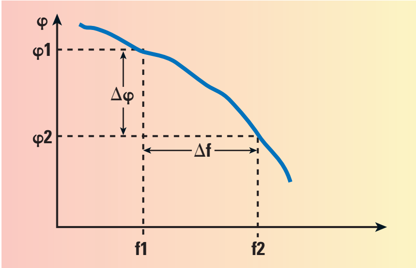


Fig. 2 The terms Δφ = φ2 – φ1 and Δf = f2 – f1 for calculating group delay.

The measurement yields the mixer's phase and group delay relative to a reference mixer that was used in place of the mixer under test in order to calibrate the test setup. The reference mixer is often assumed to have ideal characteristics, so the phase and group delay of the mixer under test are measured relative to the reference mixer. With many mixers, the assumption that they have ideal characteristics is justified, as they exhibit a group delay variation of less than 1 ns, which corresponds to a rather linear phase versus frequency.

As has been mentioned, correct information transmission does not depend on absolute group delay, but on the deviation of the group delay from a constant value within the relevant frequency range. The reference mixer method is, therefore, sufficient in most cases. However, this measurement technique cannot be used with DUTs whose LO cannot be accessed.

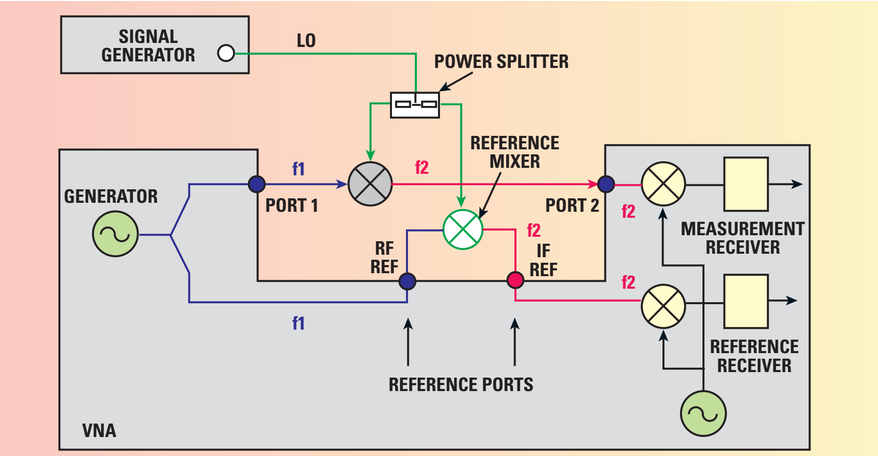


Fig. 3 Test setup for mixer meaurements using the reference mixer method.

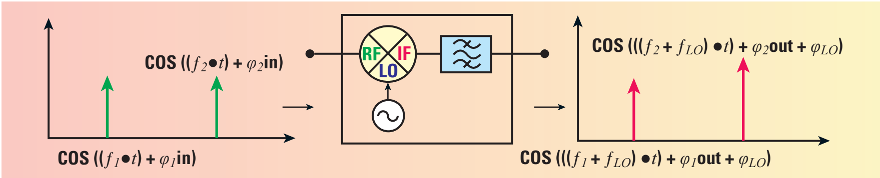
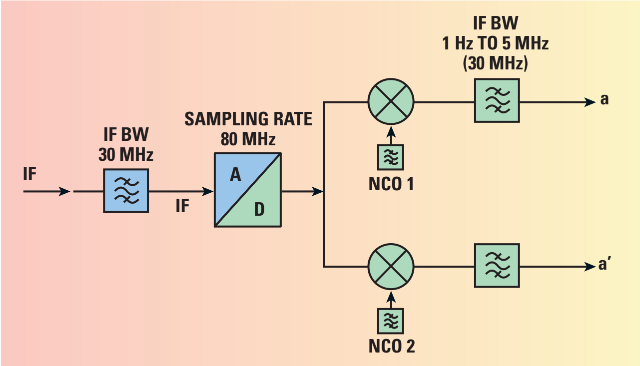


Fig. 4 Group-delay measurement using the two-tone method.

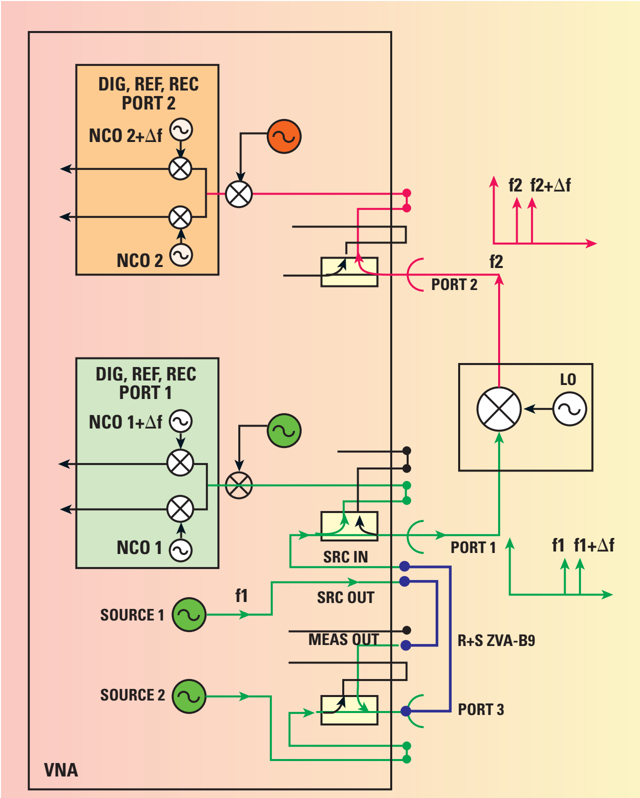
One possible approach in such cases would be to provide the reference mixer LO by means of an external generator, and set the LO's frequency as closely as possible to that of the DUT's internal LO. In most cases, though, this approach does not yield sufficiently stable results. However, the new two-tone method delivers reliable results, regardless of the stability of the DUT's LO.



▲ *Fig. 5 Digital front-end with two digital downconversion stages.*

THE TWO-TONE METHOD

This method stimulates the DUT with a two-tone signal, whereby the network analyzer measures the phase difference between the two carriers, both at the input and the output of the DUT. From the resulting phase differences and the carrier frequency offset, the analyzer calculates the group delay in the same way as in the classic S-parameter measurement.



▲ *Fig. 6 Block diagram of test setup for group delay measurement using the two-tone method.*

Figure 4 illustrates group delay measurement using the two-tone method. The frequency offset, Δf, between the two carriers corresponds to the frequency aperture in S-parameter measurement.

$$\tau = -\frac{1}{360^\circ} \bullet \frac{\Delta\varphi}{\Delta f} \qquad (3)$$

$$\Delta\varphi = (\varphi 2out + \varphi LO - \varphi 1out - \varphi LO) - (\varphi 2in - \varphi 1in)$$

$$\Delta f = f2 - f1$$

To measure the phase between two signals with different frequencies, the signal is down-converted to the IF and digitized. In the digital signaling processing (DSP) stage, the signal is down-converted to DC by means of a numerically controlled oscillator (NCO) and filtered. For the two-tone method, each receiver of the network analyzer requires two digital mixer and filter stages with two independent NCOs. This allows the magnitude and phase relationships of two carrier signals to be determined simultaneously in each receiver and used to calculate the group delay. This is shown in ***Figure 5***.

The signal paths within the network analyzer contribute to the measured group delay. This effect can be

removed by a calibration that is based on a mixer with known group delay.

The two-tone method is particularly suitable for measurements on frequency-converting DUTs because the frequency and phase fluctuations of the DUT's internal LO cancel each other out when the phase differences between the carriers are determined. In addition to group delay, the relative phase as well as deviation from linear phase can be calculated by integrating the group delay and the derivative of the group delay by differentiating it. Together with scalar conversion loss, this method delivers all parameters necessary to characterize a DUT to determine transmission quality.

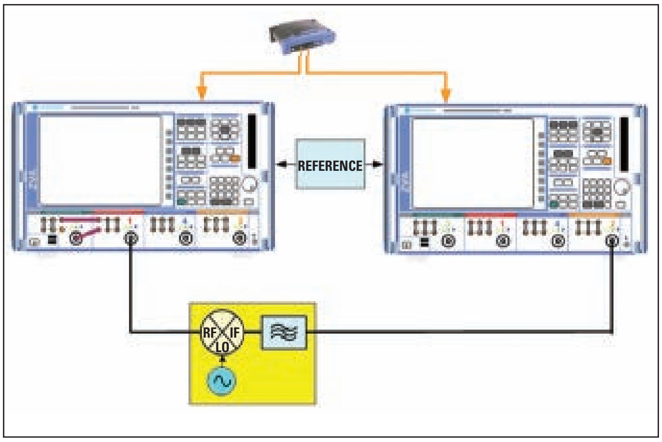
TEST SETUP

To obtain accurate results, the two-tone signal must be generated with a defined frequency offset. The ideal approach is to use the two internal sources of a four-port network analyzer. This ensures an identical frequency offset between the two RF carriers of the two-tone stimulating signal and the two digital oscillators (NCO). Using one of the network analyzer's couplers, the two carriers are combined into a two-tone signal and fed back into the source path. The reference receiver measures the phase difference between the two input signals, which are then applied to the DUT. The DUT output signals are measured by the receivers at port 2 (see ***Figure 6***).

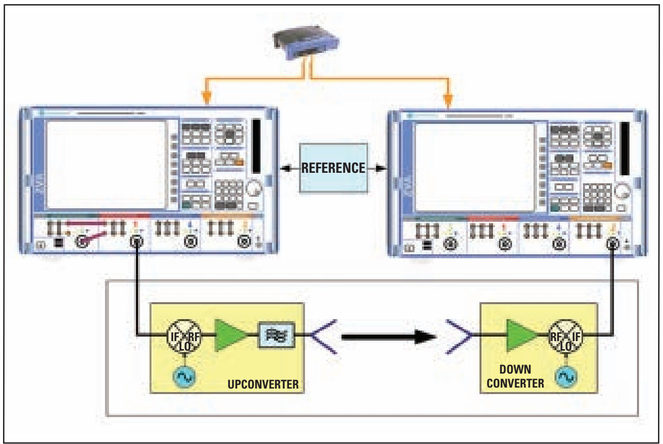
MEASURING USING TWO VNAS AT SEPARATE LOCATIONS

If the input and output of a transmission system are located far apart (as in free-space measurements), the group delay and phase are very difficult to measure. Long cables are required to transport the RF signals from the DUT to the network analyzer, but they can result in significant losses, deteriorating the signal-to-noise ratio. In addition, phase errors will occur when the cables are moved as they have only limited phase stability.

These difficulties are avoided by measuring the group delay and relative phase using the two-tone method with two spatially separated network analyzers, which both need to be aware of the precise frequency offset of the two-tone signal. The frequencies of the two NCOs are then set accordingly and the individual frequency points read synchronously by the two analyzers. This solution makes it possible to measure the magnitude, group delay and phase of the transmission coefficient without a coaxial connection. All that is required is a common reference frequency for the two network analyzers, which can be



▲ *Fig. 7 Test setup with two network analyzers installed at separate locations.*



▲ *Fig. 8 Test setup for measuring group delay and conversion loss on a microwave link.*

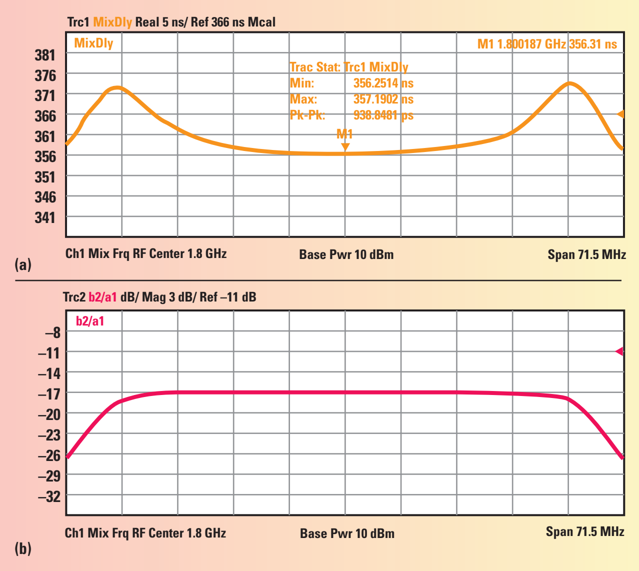
provided by means of radio-based modules, for example.

Figure 7 shows such a test setup where one network analyzer acts as a master, the other one as a slave. The master controls the slave via a LAN connection and processes and displays results. The two analyzers communicate with each other using LAN messages in line with the LXI standard. They are connected to one another via a LAN router with an integrated DHCP server that assigns the IP addresses to the devices. Alternatively, the devices can use fixed IP addresses. The two analyzers can communicate over a distance of 2 × 100 meters. This is the maximum possible length of a LAN segment. For larger distances, a WLAN connection can be used.

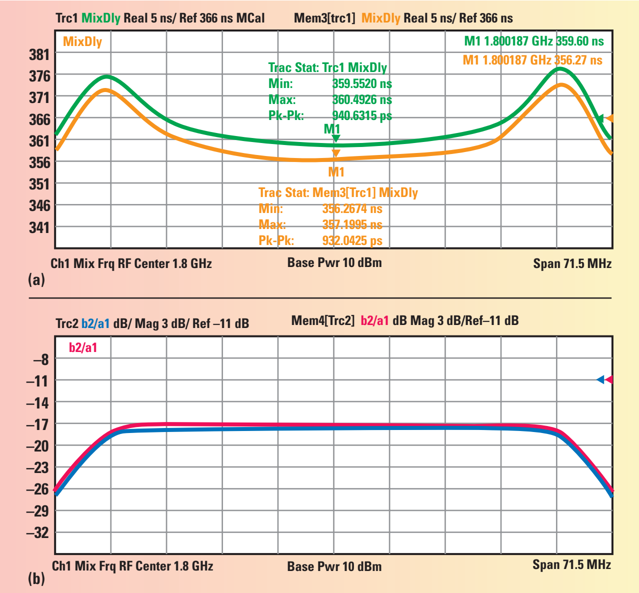
In operation, the master generates the two-tone signal to be applied to the DUT and measures the phase difference between the two signals at the DUT input. It sets the receiver of the slave to the DUT's output frequency. In the case of a frequency-converting DUT, the output frequency differs from the input frequency. The slave measures the phase difference between the two carriers at the DUT output and sends the data to the master, which calculates the conversion loss and the group delay from the data received. This procedure is repeated for each frequency point.

The master sets the two-tone signal and its own receiver to the frequency to be measured, and also sets the slave to the corresponding frequency. This test setup can be used to measure the conversion loss magnitude as well as the absolute and relative group delay.

After installation, the analyzers are connected to the LAN/LXI network and to a common reference frequency. The master displays the magnitude and the relative group delay of the transmission coefficient. If the analyzers are switched off after calibration, the displayed group delay will be shifted by a constant value relative to the actual group delay. If the analyzers remain switched on and connected to the reference frequency between the



▲ *Fig. 9 Relative group delay (a) and conversion loss (b) measured on a microwave link.*



▲ *Fig. 10 Relative group delay (a) and conversion loss (b) after increasing the distance between the transmitter and the receiver by one meter.*

calibration and the measurement, the master will also display the correct absolute group delay.

As has been mentioned, constant magnitude and group delay of the transmission coefficient are crucial to correct information transmission, whereas the absolute values of these quantities are not relevant to transmission quality. It is, therefore, sufficient to calibrate the master and slave together once before they are installed at their respective sites.

MEASURING A MICROWAVE LINK

The following example describes the process of measuring a microwave link based on an up-converter and a down-converter with inaccessible internal LOs. The input frequencies are different from the output frequencies. The magnitude of the conversion loss and the relative group delay are to be measured. ***Figure 8*** shows the test setup.

For this application, it is sufficient to measure relative group delay, or group delay deviation from a constant value, respectively. This means that a mixer with a constant group delay is sufficient for calibration. The LO of the calibration mixer offsets the input frequency relative to the output frequency by the same delta as the DUT does during signal up-conversion and down-conversion. For applications with identical input and output frequencies, a non-frequency-converting through connection is sufficient for calibration. ***Figure 9*** shows the relative group delay and the conversion loss.

In a subsequent measurement, the distance between the transmit and receive antenna is increased by about one meter. ***Figure 10*** shows that the relative group delay, or group delay response, remains the same, which was to be expected. The absolute group delay, however, increases by 3.3 nanoseconds, which corresponds approximately to the electrical length of one meter.

SUMMARY

The two-tone signal method is ideal for measuring group delay on frequency-converting devices that do not allow access to their internal LO. It accommodates measurements on test ports spaced a large distance apart, requiring two vector network analyzers; a coaxial connection between the two analyzers is not needed and the analyzers communicate with each other via a LAN/LXI interface. ■

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2.45 GHz High Gain Self-Oscillating Mixer for Simple Short-Range Doppler Radar

A high gain self-oscillating mixer (SOM) for short-range Doppler radars, which meets the needs of simplicity, low power and low cost, is accomplished using a new optimization technique based on SOM's constant gain curves similar to those of amplifiers. Using the optimization technique, the maximally optimized value for conversion gain and corresponding circuit parameters can be obtained. The measured conversion gain is up to 21.2 dB with one FET, which is the highest value reported to date. For the SOM, a microstrip slotted-square-patch resonator (SSPR) with a high quality factor is adopted. The SSPR-SOM, which emits a low power of –3.64 dBm with a microstrip patch antenna of 3.8 dB gain at 2.45 GHz band, shows good performance as a proximity motion detector.

Modern microwave communication systems have to comply with hard requirements for small size, low cost and reduced power consumption. In order to obtain a final system with such specifications, a commonly used approach is the combination of some functionalities of the system on a single circuit, reducing the number of components and the final cost of the system.[1]

Doppler radars are widely used for various purposes, including near distance motion detections. Examples include vehicle equipment, measurement of water surface velocity, detection of acoustic vibrations, non-contact cardiopulmonary monitoring and proximity motion detection in which the system's microwave front-end consists of several components. Some examples are one or two antennas, a local oscillator, one or two hybrids and/or an isolator, a frequency mixer and bandpass filters.

In order to reduce the number of components, hence to save on the size and cost of the Doppler radar, a self-oscillating mixer (SOM) could be adopted.[2] There are various advantages related to the self-oscillating mixer technique: cost is reduced, due to a lowered component count and thus higher reliability, the more compact solution offers easier integration into monolithic microwave integrated circuits (MMIC) and the total power consumption is lowered.[3]

The performance limits in Doppler radar sensing depend mainly on mixer conversion loss at baseband, and phase noise of the local oscillator signal in the RF band.[4] Hence, in this

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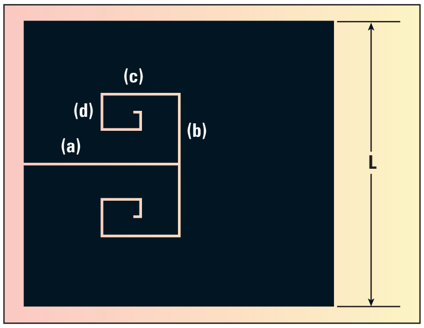

Fig. 1 Layout of the designed SSPR.

work, a Doppler radar is designed, based on SOM, for short-distance motion detections, with simplicity, low cost and low emitting power. For further reducing the cost and complexity with the least degradation of performance related to the SOM's phase noise, dielectric resonator is replaced with a new slotted-square-patch resonator (SSPR), which is easy to fabricate. For maximizing the conversion gain of the SOM, an optimization technique based on constant gain curves is carried out. The high conversion gain is helpful in reducing the emitted power from the Doppler radar.

MICROSTRIP SSPR

Phase noise is one of the most important performance parameters of an oscillator. For a lower phase noise, a dielectric resonator (DR) is most frequently used in microwave frequencies because of its high quality factor. The DR however has higher cost and additional difficulties in properly positioning it on a post with the exact coupling factor.

Figure 1 is the layout of the SSPR, which is a microstrip patch type resonator with the effective wavelength of $n\lambda/2$ and a high Q-factor. The resonator is designed by inserting the successive slot lines of the ratio of r = N/(N1) in the square patch, denoted as (a), (b), (c) and (d) in the figure. Hence, the lengths of (a) to (d) are L×r, L×r^2, L×r^3 and L×r^4, respectively. The slot lines start from the center of one side, L, of the square patch and with the length reduced by the same ratio, r, until it reaches a given slot number or a minimum limited length that can be manufactured.

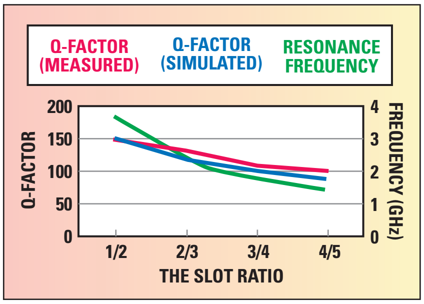

Fig. 2 Resonance frequency and quality factor of the SSPRs, according to the slot ratio $r = \frac{N}{N+1}$.

Here, only four successive slots are used.

According to the chosen integer N, from 1 to 4 for L = λ/5, four resonators with one λ electrical length were designed. ***Figure 2*** depicts the results of simulations and measurements. The total slot length increases and the line microstrip width decreases with N increasing, hence the resonance frequency decreases and the Q-factor decreases. The measured unloaded Q-factor was 154.1 for N = 1, which is approximately a 13.6 percent improved value, compared to that of the conventional hair-pin resonator.[5] The SSPR's improved Q-factor is due to the adoption of a slotted-patch type resonator, which can inherently maximize use of the circuit space and also to use the wider line width of middle part in length of the resonator in which current flow is maximized. The simulations were performed using a commercial 3D electromagnetic simulator, HFSS™. The substrate used is Teflon with a thickness of 0.762 mm, a relative dielectric constant of 3.48 and loss tangent of 0.003.

SOM DESIGN

The RF-layout for the proposed SOM or SOM Doppler radar circuit is shown in ***Figure 3***. A 50 Ω termination at the left end of the gate transmission line, the self-bias circuit and the IF bandpass filter at the drain transmission line are not shown in the

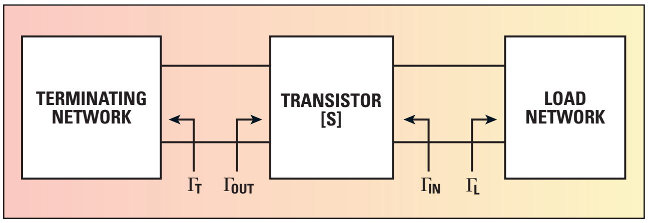

Fig. 4 Circuit model for a two-port transistor oscillator.

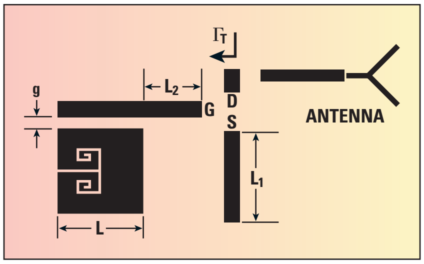

Fig. 3 RF layout of the designed SOM Doppler radar.

figure. The circuit was simulated using a commercial circuit simulator ADS™ with an HB-simulation test bench. A well-known transistor, NE3508M04, was self-biased near the pinch-off region (V_{DD} = 3 V, V_{DS} = 2 V, I_{DS} = 3 mA, V_{GS} = –0.4 V).

A transistor oscillator with a one-port negative-resistance is effectively created by terminating a potentially unstable transistor with an impedance designed to drive the device in an unstable region. In the circuit model for a two-port transistor oscillator of ***Figure 4***, the input and output reflection coefficients are generally given by Equations 1 and 2.[6] Then the input and output stability circles can be drawn as ***Figure 5***, using the conditions of $|\Gamma_{in}| = 1$ and $|\Gamma_{out}| = 1$.[6]

$$\Gamma_{in} = S_{11} + \frac{S_{12}S_{21}\Gamma_T}{1 - S_{22}\Gamma_T} \qquad (1)$$

$$\Gamma_{out} = S_{22} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{11}\Gamma_L} \qquad (2)$$

The source transmission line L_1 in Figure 3 was adjusted for a wider unstable region. The unstable region is inside of the input stability circle and outside of the output stability circle, which is region (b) in Figure 5.

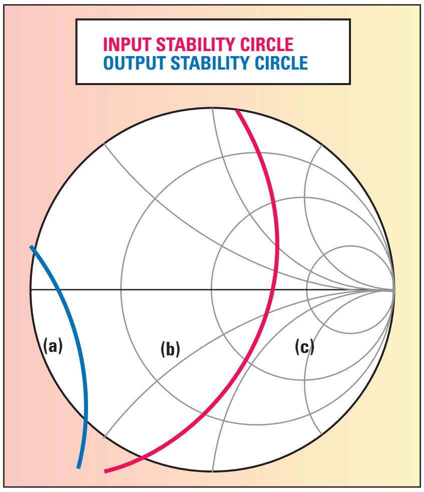

Fig. 5 The input and output stability circles.

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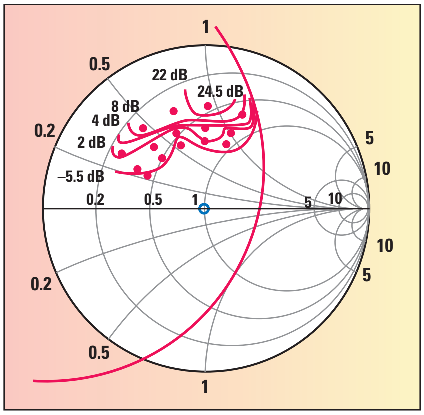
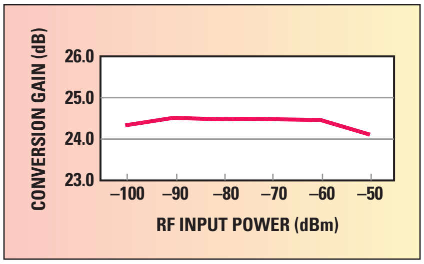


▲ *Fig. 6 Constant conversion gain curves of the designed SOM Doppler radar.*

On the other hand, the conversion gain, G_c, for a mixer is generally defined by Equation 3. Here, P_{RF} and P_{IF} are the powers of the received RF signal and the corresponding IF signal, respectively. In order to obtain the maximally optimized G_c, constant conversion gain circles are drawn, which are similar to those of amplifiers, according to Γ_T.

$$G_c(dB) = 10\log\frac{P_{IF}}{P_{RF}} \quad (3)$$

The gap, g, between the SSPR and the 50 Ω gate transmission lines, and L_2, were changed so that the Γ_T can be moved within the unstable region (b) of ***Figure 6***. Then a conversion gain point for each change of Γ_T can be obtained. A systematic investigation of 15



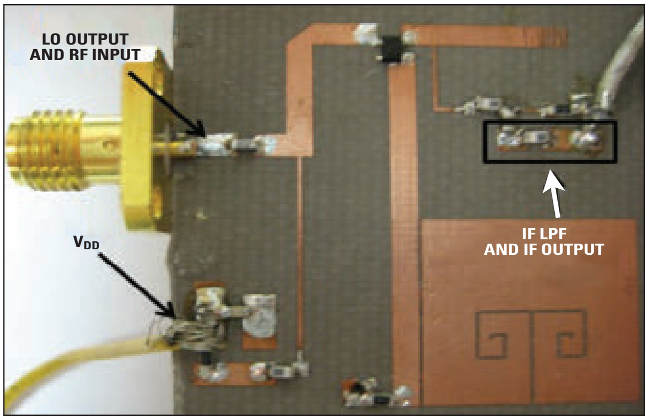
▲ *Fig. 7 Simulated conversion gain as a function of RF input power.*

points for the pairs of Γ_T and conversion gain, G_c, using a circuit simulation with ADS, gives the rough constant conversion gain curves outlined in the figure. For the simulations, the RF input power was assumed to be –50 dBm at the antenna port. The maximum conversion gain can be seen to be approximately 24.5 dB and at this point, the related parameters were g = 0.1 mm and L_2 = 11.0 mm.

The change in the simulated optimum conversion gain of the SOM as a function of the RF input power is shown in ***Figure 7***. The variation of the conversion gain is only 0.9 dB for RF input powers from –50 to –100 dBm, assuming a short distance motion detector.

MEASURED RESULTS

The optimized SOM for Doppler radar with a SSPR was fabricated as shown in ***Figure 8***. The SSPR is 13.8 × 13.8 mm and the total dimensions of the SOM circuit were 32 × 36 mm. The self-oscillated output power of the SOM Doppler radar was measured using a spectrum analyzer (Agilent E4407B). It shows –3.64 dBm LO output power at 2.45 GHz. As shown in ***Figure 9***, the phase noise obtained is –107.86 dBc/Hz at 100 kHz offset, which is comparable to a general

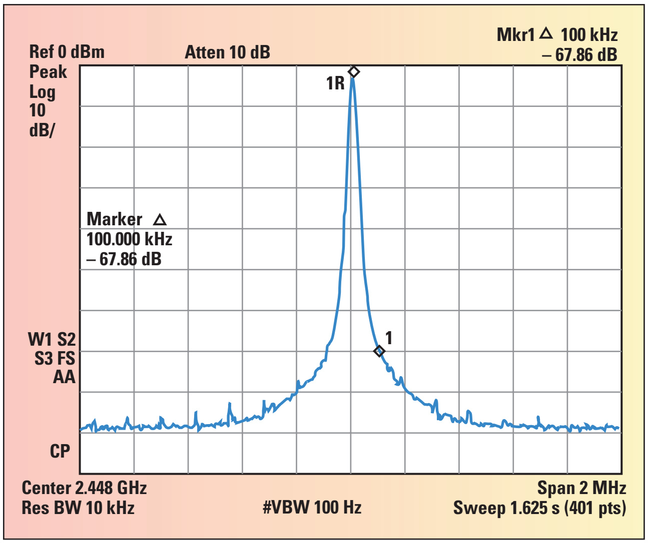


▲ *Fig. 8 Photograph of the fabricated SOM Doppler radar.*

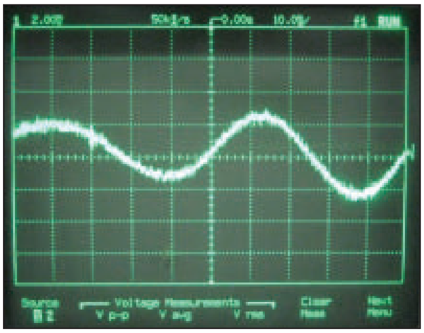
TABLE I

COMPARISON OF CONVERSION GAINS

Ref.	Frequency (GHz)	IF Frequency	Conversion Gain (dB)
[7]	2.5	about 50 MHz	8 to 13
[8]	5 to 6 9.8 to 11.8	about 200 MHz	5 to 12
This work	2.45	about 120 kHz	21.15



▲ *Fig. 9 Measured phase noise of the fabricated SOM Doppler radar.*



▲ *Fig. 10 IF waveform of the proposed SSPR-SOM Doppler radar used as a motion detector.*

oscillator. To measure the conversion gain accurately, –50 dBm RF power was driven, using a signal generator, and an IF power of -28.85 dBm was obtained at the IF port, which means that a 21.15 dB conversion gain was obtained. The measured conversion gain of 21.2 dB of the proposed SSPR-SOM for Doppler radar shows an excellent performance, compared to other high gain SOMs,[7-8] as summarized in ***Table 1***.

To observe the operation of the SOM Doppler radar working as a proximity motion detector, a simple aluminum metal plate target of 30 × 30 cm, moving at a distance of approximately 2.0 m with a velocity of approximately 1.2 m/sec, was used. The detected IF shows a peak-to-peak voltage of approximately 5.0 mV and a Doppler frequency of approximately 19.0 Hz. ***Figure 10*** shows an oscilloscope waveform at the IF port of the SOM Doppler radar when the motion is detected. The antenna used is a microstrip patch antenna with a gain of 3.8 dBi.

CONCLUSION

A simple, low cost and low power SSPR-SOM for Doppler radar is proposed. The proposed SSPR and a very high gain self-oscillating mixer (SOM) can replace the entire DR resonator, LO, mixer and hybrids in a conventional Doppler radar for the purpose of circuit simplicity, low power and low cost. The proposed constant gain curves, according to the Γ_S, give an extremely high constant gain of 21.2 dB, compared to other works that have been reported. The SSPR-SOM of 32 × 36 mm, with a microstrip patch antenna is very simple, but works very well as a Doppler radar for short-distance motion detection. ■

ACKNOWLEDGMENT

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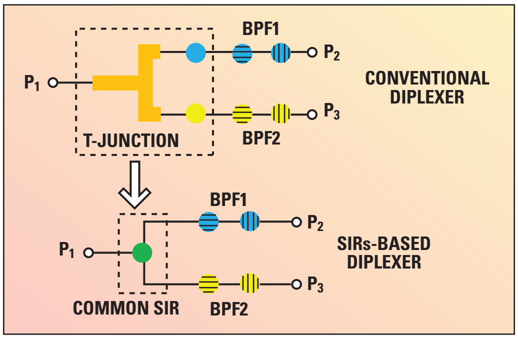
Packaged Microstrip Line Diplexer Using SIRs

A compact microstrip line diplexer is reported, which is integrated into a commercial off-the-shelf package for frequency-division duplex wireless communication systems. This diplexer is designed based on the concept of stepped-impedance resonators (SIR), offering twofold advantages. First, by making use of the first two resonant modes of an SIR, the first resonator in two bandpass filtering channels of the diplexer can be shared, so that the circuit size can be reduced greatly compared to the conventional design. Second, by adjusting the impedance and length ratios of different SIRs, high out-of-band suppression can be achieved over a wide frequency range. The proposed diplexer is then assembled into a commercial package and measured with a customized test fixture. Both simulation and experiment show good results.

A diplexer is an essential component in frequency-division duplex (FDD) wireless communication systems. Typical requirements of modern diplexers are compact size, good return loss, low insertion loss and high isolation between two passbands. Packaged diplexers are usually preferred because they can easily be integrated into transceiver subsystems. Therefore, the aim of this work is to present a complete design procedure of packaged microstrip diplexers suitable for commercial off-the-shelf utilization.

In the proposed diplexer, two passbands are centered at 10 and 15 GHz, respectively, and they have an identical bandwidth of 700 MHz. Some trade-offs have to be made between the circuit size and the electrical performance (such as isolation). The circuit size, however, has high priority in this work due to the limited area of the selected package. In the conventional design of diplexers, the two channels of bandpass filters (BPF) are designed independently and subsequently combined at the common input port for achieving the desired duplexing function through iterative optimization. This design scheme would have two shortcomings if the transmitting and receiving passbands have a large frequency separation: one is the large circuit size occupied by two BPFs and the other one is design complexity due to the T-junction at the common input port P_1. Its transmission response is frequency-dependent, especially over a wide frequency range, so the T-junction would have to be optimized with great effort so that it would not affect the performance of two channel filters.



▲ *Fig. 1 Topology simplification from conventional diplexer to SIR-based diplexer.*

The concept of stepped-impedance resonator (SIR) was proposed to specially arrange the harmonic frequencies of a transmission line resonator by adjusting its impedance and length ratios.[1] Based on this concept, the T-junction and the first resonators in two filtering channels can be replaced by one common SIR,[2] of which the fundamental resonance and first harmonic are allocated at two passbands, respectively. This topology simplification is illustrated in ***Figure 1***. As a result, the T-junction is removed and circuit size is greatly reduced. Furthermore, by using dissimilar resonators with staggered harmonic frequency allocations, it is possible to achieve a high rejection of spurious passbands over a wide frequency range.[3] In the figure, blue and yellow solid nodes represent resonators of lower and upper bands, respectively, while different patterns indicate dissimilar resonators. Therefore, this work will take full advantage of these special features of

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SIR in order to develop a compact packaged diplexer with wideband harmonic suppression.

DESIGN OF THE MICROSTRIP LINE DIPLEXER

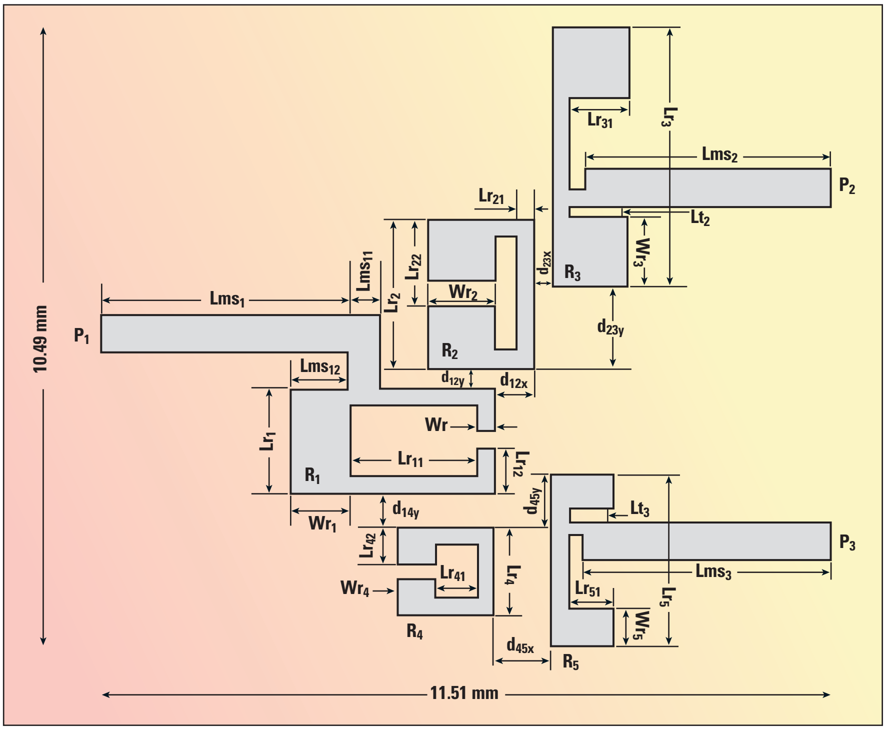
Figure 2 shows the proposed diplexer combining two BPFs with a common resonator R1. The substrate of choice is RT/duroid® 6010.2LM with a substrate thickness of 0.635 mm and a copper thickness of 17 µm. Half-wavelength SIRs are chosen for all the resonators in order to avoid the use of grounding vias. A three-pole Chebyshev response is selected for both BPFs in order to reach 20 dB attenuation at 10±2 GHz and 15±2 GHz. The 10 GHz BPF is composed of SIRs R_1, R_2 and R_3, while the 15 GHz BPF consists of SIRs R_1, R_4 and R_5.

In order to enlarge the stopband, the following frequency allocation scheme is adopted for designing the proposed diplexer. All the results in ***Table 1*** are obtained from full-wave simulations.[4] From the table, it is evident that, on one hand, by introducing an impedance ratio larger than 1, the first two resonances of the common resonator R_1 are allocated at 10 and 15 GHz, respectively. On the other hand, for all the other resonators (R_2 to R_5), their first harmonic frequencies are set higher than twice of the fundamental resonant frequency by adjusting their impedance ratios less than 1. Moreover, their harmonic frequencies are staggered, and as a result, spurious passbands can be suppressed over a wide frequency range. However, it should be noted that even when the impedance ratios are the same for R_2 and R_3 as well as R_4 and R_5, their first harmonic frequencies are different due to different length ratios of SIRs, as well as different parasitic effects of the microstrip bend or step discontinuities.

TABLE I

FREQUENCY ALLOCATION SCHEME OF THE SIRs

	R_1	R_2	R_3	R_4	R_5
Impedance Ratio	1.52	0.53	0.53	0.76	0.76
Fundamental f_0 (GHz)	10.0	10.0	10.0	15.0	15.0
Fundamental f_{h1} (GHz)	15.0	28.0	24.5	>30	>30



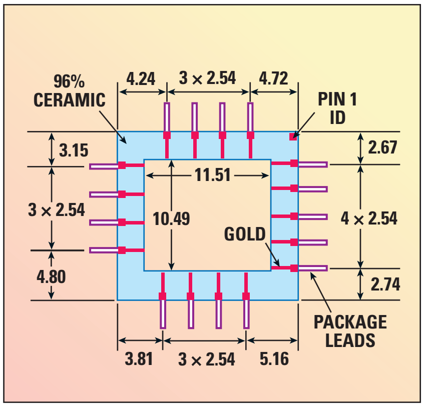
▲ *Fig. 2 Diagram of the microstrip line diplexer.*

According to the design specifications, the following coupling matrices are synthesized for two passbands, respectively.

$$[M]\Big|_{10GHz} = \begin{bmatrix} & S & 1 & 2 & 3 & L \\ S & 0 & 0.0758 & 0 & 0 & 0 \\ 1 & 0.0758 & 0 & 0.0722 & 0 & 0 \\ 2 & 0 & 0.0722 & 0 & 0.0722 & 0 \\ 3 & 0 & 0 & 0.0722 & 0 & 0.0758 \\ L & 0 & 0 & 0 & 0.0758 & 0 \end{bmatrix}$$

$$[M]\Big|_{15GHz} = \begin{bmatrix} & S & 1 & 2 & 3 & L \\ S & 0 & 0.0505 & 0 & 0 & 0 \\ 1 & 0.0505 & 0 & 0.0481 & 0 & 0 \\ 2 & 0 & 0.0481 & 0 & 0.0481 & 0 \\ 3 & 0 & 0 & 0.0481 & 0 & 0.0505 \\ L & 0 & 0 & 0 & 0.0505 & 0 \end{bmatrix}$$

The external quality factor and the coupling coefficients between resonators are subsequently extracted according to the synthesized coupling matrices using the method of Hong and Lancaster.[5] In this procedure, attention must be paid to the following two aspects. The first one is that the diplexer should fit into the available area of the selected commercial package.[6] ***Figure 3*** shows an illustration of the package. It can be seen that the total dimension of the usable area in the package is only 11.51 × 10.49 mm, or 1.02 λ_g × 0.93 λ_g, where λ_g is the guided wavelength of the 50 Ω line at 10 GHz. The second aspect is the input/output of the diplexer should be located at the exact position of the package leads in order to reduce the parasitic effects of the ribbon bond-



▲ *Fig. 3 Illustration of the commercial package.*

TABLE II

DIMENSIONS OF THE MICROSTRIP DIPLEXER

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
Lms_1	3.59	Wr_2	1.00	Lr_{41}	0.57
Lms_{11}	0.51	d_{12x}	0.53	Lr_{42}	0.53
Lms_{12}	0.72	d_{12y}	0.24	Wr_4	0.52
Lr_1	1.52	d_{23x}	1.21	d_{14y}	0.38
Wr_1	0.77	d_{23y}	0.18	d_{45x}	0.64
Lr_{11}	1.79	Lr_{31}	0.81	d_{45y}	0.64
Lr_{12}	0.64	Lr_3	3.76	Lr_5	2.41
Wr	0.25	Wr_3	1.02	Lr_{51}	0.60
Lr_2	2.13	Lms_2	3.63	Wr_5	0.51
Lr_{21}	0.23	Lt_2	0.15	Lms_3	3.71
Lr_{22}	0.89	Lr_4	1.27	Lt_3	0.18

ing. A slight optimization was carried out, based on the initial geometrical dimension, in order to satisfy the design specifications and the final dimensions of the designed diplexer as listed in ***Table 2*** for reference.

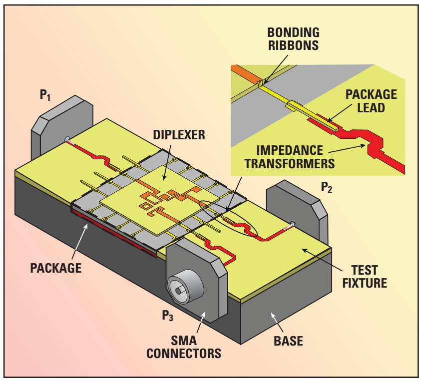
PROTOTYPING AND RESULTS

Figure 4 shows a perspective view of the packaged diplexer together with the test fixture that is designed using the same substrate. The diplexer is assembled inside the commercial ceramic package with the support of two bonding ribbons on each lead.

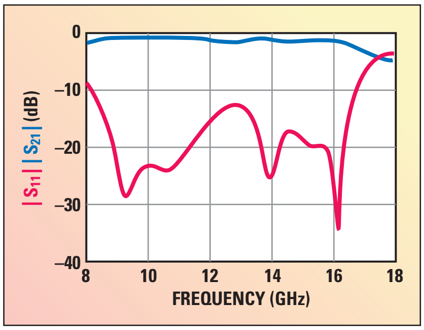
A back-to-back transition between the 50 Ω microstrip line and the package is designed and optimized to achieve a good match between the two passbands. Two stages of impedance transformers are utilized with the second stage meandered for reducing the circuit size. ***Figure 5*** plots the simulated performance of the back-to-back transition, and it shows that the return loss is better than 20 dB for the 10 GHz passband and better than 17 dB for the 15 GHz passband.

After being analyzed in a full-wave simulator, the packaged diplexer together with the test fixture was prototyped and measured with three subminiature version A (SMA) connectors, using a vector network analyzer (Anritsu 37397C). A photograph of the fabricated prototype is given in ***Figure 6***.

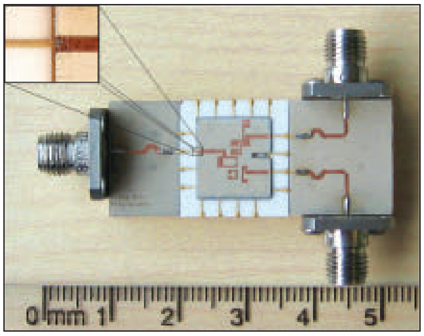
The measured scattering parameters are compared with the simulated ones in ***Figure 7***. Good agreement is observed except for the increased insertion loss at the high edge of the 15 GHz passband,



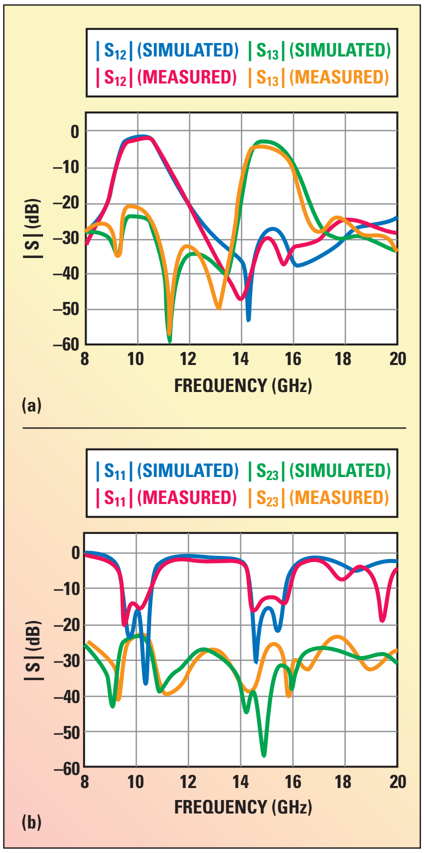
▲ *Fig. 4 Packaged microstrip line diplexer.*



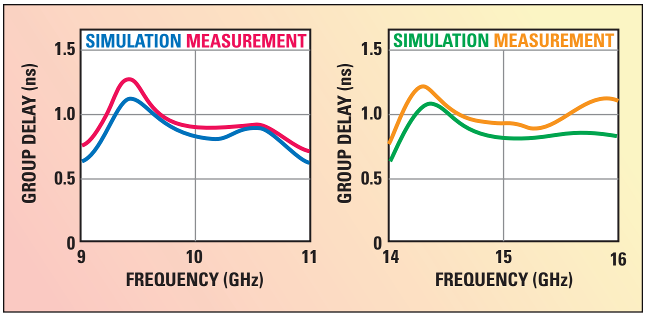
▲ *Fig. 5 Simulation results of the back-to-back transition.*



▲ *Fig. 6 Photograph of the fabricated prototype.*



▲ *Fig. 7 Comparison between simulated and measured S-parameters of the packaged diplexer: (a) S_{12} and S_{13} (b) S_{11} and S_{23}.*



▲ *Fig. 8 Comparison of group delay between simulation and measurement.*

which will be discussed below.

From figure 7a, it can be seen that in the simulation, the maximum in-band insertion losses are 2.0 and 3.4 dB in the 10 and 15 GHz passbands, respectively. However, the measured maximum insertion losses are 2.5 and 4.8 dB in the 10 and 15 GHz passbands, respectively. The additional loss can be partially ascribed to the insertion loss of the SMA connectors, which is not included in the simulations. Furthermore, if the diplexer is encased, the measured maximum insertion loss in the 15 GHz passband is 4.4 dB, which means there is 0.4 dB radiation loss from the circuit itself.

It is shown in figure 7b that the simulated return loss of the common port P1 is better than 15 dB for both passbands while the measured return loss is better than 14.5 dB in the 10 GHz passband and better than 12.5 dB in the 15 GHz passband. In addition, the simulated isolation is higher than 23.5 dB over the entire frequency band of interest with a measured one better than 22 dB. The isolation can be further improved by allocating transmission zeros in the passband of the other filter.

Finally, the measured group delay, shown in ***Figure 8***, tallies well with the simulated one. Both of them present small in-band variation.

CONCLUSION

A compact packaged microstrip line diplexer is reported and good results are obtained in both simulation and measurement. This packaged diplexer is very compact and it can be directly and easily applied to wireless communication systems with frequency-division duplex mode. ■

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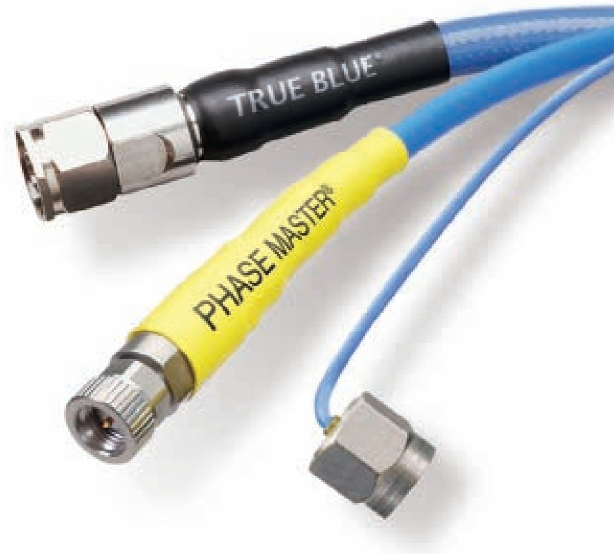

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Defense Market Trends for Microwave Applications in AEW&C

Airborne Early Warning & Control (AEW&C) is a broad term used to describe the airborne capability to detect air, land or water threats and direct a response, typically from a large distance. The radar, control and aircraft platforms are diverse but high performance semiconductor devices and electronic technologies enable them. The rationale behind airborne surveillance is simple: the more you see, the more you know. High altitude aircraft and powerful radars achieve the "more-you-see" capability and sophisticated sensor, onboard processing and communications capabilities satisfy the "more-you-know" dimension.

Earlier versions of these capabilities were called Airborne Warning and Control System (AWACS) or Airborne Early Warning (AEW). In fact, one of the most widely deployed platforms, the E-3 Sentry, has become commonly known as "AWACS." These systems play a major role on the modern battlefield by providing real-time intelligence and the control needed to maintain air superiority over the combat area. These platforms are not solely for wartime use. Several nations devote resources exclusively to enable surveillance of borders in peacetime.

Current airborne surveillance includes, not only detection, tracking and identification of targets, but also execution of actions that result from data derived from its suite of sensors. These actions may be offensive, like the control of other aerial assets (mainly interceptors), or defensive, like initiation of electronic countermeasures. As the processing capabilities on these aircraft have increased, their control capabilities have also improved and expanded to the point where the mission is now exclusively AEW&C.

Airborne Early Warning and Control capabilities provide a fundamental building block of a national defense or combat strategy. Until recently, design and development of AEW&C platforms had been the near-exclusive domain of U.S. military OEMs, but as countries acknowledge the importance of the mission, more

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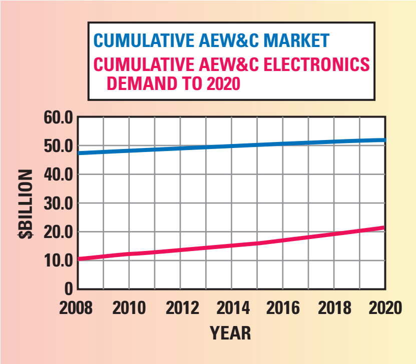
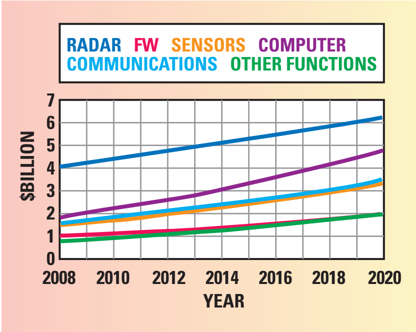


▲ *Fig. 1 Cumulative AEW&C platform market to 2020.*



▲ *Fig. 2 Cumulative AEW&C electronics segmentation.*

AEW&C development effort is being undertaken in other regions and countries, including Europe, Israel, China, India and Russia.

The market is thus growing along two paths: countries with mature capabilities will seek to upgrade to the latest technology to outpace threats, and countries with rudimentary or no capability will purchase new AEW&C platforms. As existing users expand or upgrade their coverage and new countries implement services, Strategy Analytics believes the number of planes in service will see a steady increase with upgrades and retrofits.

Strategy Analytics forecasts a market growing to more than $52 B by 2020 (see ***Figure 1***). The total electronics content for radar, communications, computers, sensors and other related systems will increase over time as technology is upgraded, growing to $22 B.

All AEW&C platforms make extensive use of advanced electronics and component technology for radar, communications, EW, computer, sensor and other related systems. The diversity of AEW&C platforms incorporates a range of technologies including tubes, silicon/GaAs/GaN/other microelectronics and optoelectronics. The basic subsystems found onboard a typical AEW&C platform are as follows:

- Radar
- Data processing
- Displays
- Identification Friend and Foe (IFF)
- Radio & Data Communications
- Navigation
- Electronic Support Measures (ESM)
- Electronic Counter Measures (ECM)

These subsystems require a control system to ensure that all are functioning correctly at the right time. AEW&C aircraft also have individual electronic units for other systems, notably the flight controls and engines. Collectively these represent a substantial opportunity for electronic components and associated hardware.

From an electronics perspective, even though the yearly increase in platforms is relatively small, the deployed base is very large. The attractive aspect of this market is the development time, longevity and expense of the airframe platform, which makes it uniquely suited to the upgrade market (see ***Figure 2***). The most important system aboard the AEW&C platform is the main radar sensor. A typical AEW&C will have at least two radar systems: the main radar for the early warning functions and a smaller nose-mounted unit for general use in situations such as adverse weather alerts. New platform developments and upgrades are typically utilizing some form of phased array radar to perform these functions. There are two basic designations for electronically scanned arrays: passive and active. The phased array concepts are identical for both types, but the implementation is different, with the main difference being the transmit power source. Older AEW&C platforms predominantly use passive arrays utilizing TWT-based power sources with radars in rotating rotodomes, while new platforms are increasingly making use of GaAs-based T/R modules in active arrays.

As an example, the E-3D Sentry, best known as the AWACS, uses an older Passive Electronically Scanned Array (PESA) radar that continues to provide several major air forces with a system well matched to their needs. The main radar antenna is located

inside a rotating rotodome mounted above the spine of the aircraft. This rotodome contains several systems, primarily the Northrop Grumman AN/APY-1/2 search radar on one side of a 30-foot long beam structure and, on the other, a set of aerials for the IFF AN/APX-103 interrogator, supplied by the Telephonics Corp., and data-link fighter-control (TADIL-C) antennas. A dual klystron-based amplifier system inside the fuselage generates the RF power that is sent to the antenna array via waveguides.

There have been several upgrades to this program, but there is no plan to replace the PESA radar with a solid-state Active Electronically Scanned Array (AESA) radar. One of the biggest upgrades for the AWACS was the Radar System Improvement Program (RSIP) that has been referred to as "Sharpening the Eye of the Eagle" and replaces aging original equipment. RSIP was a joint U.S./NATO development program involving major hardware and software-intensive modification and costing $1.2 B for the 32 U.S., 17 NATO and seven UK E-3 aircraft.

At the other end of the spectrum is the U.S. Navy E-2 platform, the most popular AEW&C plane in the world. The U.S. Navy has added incremental improvements, the most recent implemented in the Hawkeye 2000. The Navy is also performing a major platform upgrade with the E-2D Advanced Hawkeye. This variant will revamp the radar and include the Northrop Grumman APY-9 AESA based radar. Its new rotodome, developed by L-3 Communications Randtron Antenna Systems, will provide 360-degree scanning capability in a hybrid mechanical/electrical scanning arrangement.

In an AESA implementation, each element is driven by a transmit/receive (T/R) module. These T/R modules contain solid-state MMICs, typically GaAs for the transmit/receive paths and silicon for the control functions with future trends pointing toward GaN technologies being used in conjunction with SiGe.

Development time, cost, mission and radar performance are just a few of the trade-off characteristics that make platform upgrade such a multi-layered decision process. As described, most of the earliest, most popular aircraft platforms were modified to incorporate rotating rotodomes. A discussion of modifications and trade-offs must often be viewed in the context of the entire AEW&C platform and whether the improved performance and capability of an AESA radar does not offset the cost of retrofitting the rest of the platform.

Changing focus to communications, information must be disseminated quickly and efficiently to all assigned agencies working with the AEW&C aircraft. The users of this information generally fall into two categories: onboard and external staff. In practice, the AEW&C platform is at the center of a three-dimensional network of forces ranging from relay satellites and ground stations to strike aircraft and other assets. Other onboard communications capabilities include secure voice and data communication systems.

- The Erieye has a secure voice and data link communications suite with HF and VHF/UHF links. The VHF/UHF data link operates at 4800 bps.
- The Boeing Wedgetail has a communications suite that includes three HF and eight VHF/UHF communications systems together with Link 4A and Link 11 systems.

AEW&C platforms must ensure that all communications are secure from enemy eavesdropping. To address this issue, the Joint Tactical Information Distribution System (JTIDS) was developed and is now common to most airborne assets. An additional avenue to address this issue is AWACS systems providing anti-jam communication for information distribution, position location and identification capabilities.

As far back as 1989, an improved communication system named HAVE QUICK A-NETS was deployed to address secure communications. This system provides secure, anti-jam contact with other AWACS platforms, friendly aircraft and ground stations. It is also included in French and RAF systems. The AN/ARC-164 HAVE QUICK II radios are used for air-to-air, air-to-ground and ground-to-air communications and are deployed on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all Army rotary wing aircraft. By 2007, nearly all U.S. military aircraft had adopted HAVE QUICK. Improvements include HAVE QUICK II Phase 2, and a "Second generation Anti-Jam Tactical UHF Radio for NATO" called SATURN. The latter features more complex frequency hopping.

Another system called enhanced TADIL-A Link-11 ensures high speed exchange of radar information. Also known as TADIL-J, or Link-16, it requires additional computer memory to anticipate new ESM and future enhancements. The Class 2H JTIDS terminal is a secure digital communications system that allows E-3 crew members to communicate with other participants such as fighter aircraft, Navy units and ground-based units during air battle. It has a capability to identify units using common points of reference.

Looking at the communications systems in general, common trends across the board include a move toward higher frequencies and wideband performance, driven by a need to have multi-mode, multi-band capabilities that will enable these radios to act as nodes in the total battle space. This is coupled with an increasing emphasis on data and efficient spectrum use that will drive linearity requirements as well as the continued development of SDR and cognitive radio capabilities. While Si-based power amplifiers are the incumbent technology, these factors will provide opportunities for other RF technologies that can couple high power outputs with wideband performance, linearity and higher efficiencies.

Electronic Support Measures (ESM) provide for a passive detection, electronic surveillance capability to detect and identify air and surface-based emitters. The ESM system passively detects signals from hostile, neutral, friendly, and unknown emitters and identifies targets, augmenting present on-board sensors. ESM equipment consists of sensitive direction finding radar-warning receivers coupled to an extensive software threat library to permit the calculation of bearing and type tracks. These are made available in a format readable by the data processing software, allowing the operators to passively identify sources of transmission, oftentimes at ranges nearly double those of active radar and with useful receive sensitivity.

Electronic Counter Measures (ECM) are now considered essential for all military and even some chartered civil aircraft. There may be times when high-value platforms, such as AEW&C, will have to rely on self-defense when enemy fighters or missiles get too close. Lacking offensive armament, the AEW&C relies on special ECM and electronic counter-countermeasures (ECCM) to confuse and deflect incoming threats. The concept of Smart Jamming, for example, involves detecting the oncoming missile, classifying it by identifying its seeker signature and then sending a jamming signal in a particular band to break its lock. These types of concepts are leading to what may be described as a "no-channel" concept in which the systems are tasked with looking at a complete frequency

range resulting in multiple channels being handled by one receiver. For jamming applications, this has to be coupled with high power capabilities across the frequency range and this has opened the door for GaN-based systems in this area.

The enabling RF technologies, of which there is a wide range, include Si, SiGe, GaAs, GaN as well as TWTs. Each technology offers specific advantages.

- Si LDMOS/MOSFET technologies provide good saturated power capabilities, but have a relative limited frequency range. While operating along the same frequency ranges, SiC offers higher power.
- SiGe offers broader frequency capabilities, but is limited in power. However, the integration capabilities will see SiGe used in the receive function while SiGe-based ADC and DAC components will see increasing penetration of the radar, EW and communications systems as phased array capabilities are coupled with digital receivers.
- GaAs offers a strong mix of power, frequency and linearity capabilities that have driven the use of this technology but still has limitations compared to TWT capabilities.
- TWTs offer the broadest frequency operation, very high efficiencies and reliability coupled with high power but scaling can be an issue, depending on the platform.
- GaN appears to offer the best solution in terms of power, efficiency, wide frequency operation and reliability though linearity can be an issue.

The AEW&C platform is a good example of the trends in the defense industry that will drive demand for RF technologies. For communications, electronic warfare and radar systems, both in AEW&C as well as in the broader defense sector, capabilities are expanding around specific parameters such as broadband performance, power, linearity and digitization. No one semiconductor technology solution will singularly satisfy every system requirement, and we will see different technologies used side-by-side depending on the requirements of the system and platform. While global economics have forced governments to rethink defense priorities, the desire for technology differentiation will lead to continued opportunities for electronic systems and the enabling of semiconductors in both emerging platforms as well as through upgrade/retrofit channels. ■

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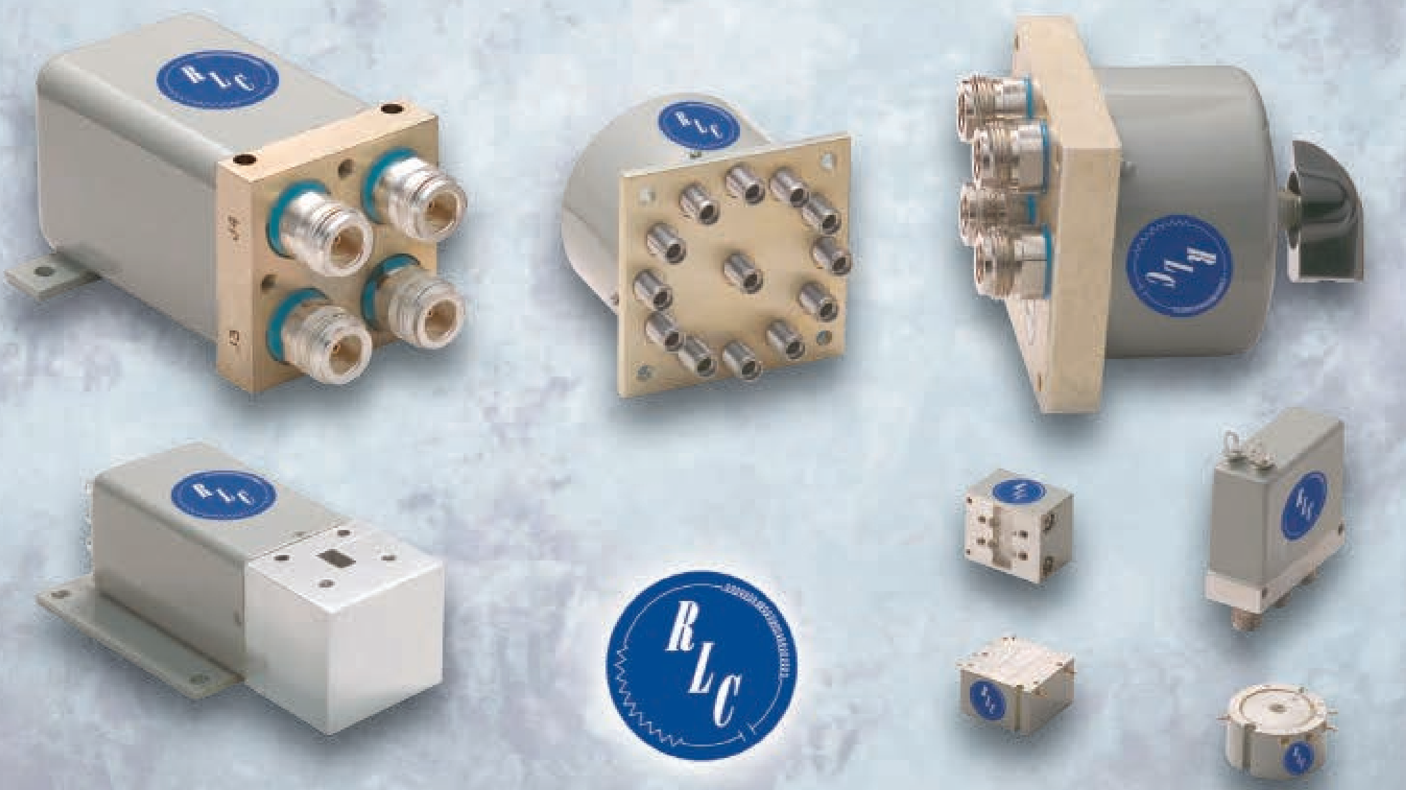

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Extending Millimeter-wave Measurement Systems with Harmonic Mixer Technology

Emerging applications in the millimeter-wave (mm-wave) band, which occupies the 30 to 300 GHz spectrum (wavelengths from 10 to 1 mm), now span radio astronomy, communication, imaging, space research and homeland security. Market forecast and limited available spectrum suggest that attractive growth is just over the horizon. Most engineers extend their existing test equipment into this mm-wave spectrum with frequency extension accessories based on harmonic mixer technology.[1] The purpose of this article is to provide an overview of the low cost harmonic mixer technology (retail pricing is currently between $2,000 and $6,000 USD) and to present practical tips on how to apply this commercially available down conversion technology to spectrum analysis.

HARMONIC MIXER PRIMER

To overcome frequency limitations in available instrumentation, frequency extension accessories based on harmonic mixer technology are used to down convert the mm-wave spectrum into the signal analyzer's bandwidth for analysis. In a typical external mixer setup, the harmonic mixer bridges the gap between the mm-wave output from the DUT and the lower frequency spectrum analyzer input (see ***Figure 1***). In this way, the harmonic mixer provides the enabling technology for mm-wave measurements. This setup functionally relies on an external mixer option in the spectrum analyzer for the necessary LO and IF interconnects to the harmonic mixer and automatically displays the desired signal parameters. Once connected, the nth harmonic of the LO frequency mixes with the mm-wave frequency (RF) to produce the predefined IF frequency. The conversion loss of the harmonic mixer is proportional to the multiplier factor, n. This popular setup depends on a diplexer for signal separation, which can be either external or internal to the spectrum analyzer.

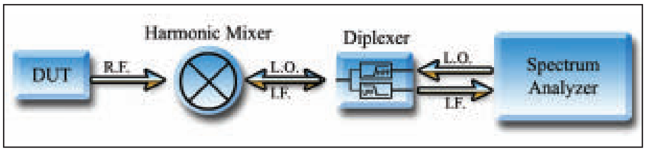

Fig. 1 The harmonic mixer converts the DUT mm-wave (RF) to a predefined IF frequency.

With an external mixer option, the harmonic mixer operation with the spectrum analyzer is transparent to the user. The harmonic mixer with waveguide interface can conveniently connect to the mm-wave output of the DUT or to a waveguide antenna. On the opposite side of the harmonic mixer, a reasonable length coaxial cable (such as 1 meter) offers efficient access to the spectrum analyzer, including the diplexer. After selecting the corresponding waveguide band on the spectrum analyzer, engineers can use their familiar instrument to conduct mm-wave measurements on their DUT. For accurate amplitude measurements, additional offset features are available in the spectrum

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- Frequency range from 60 MHz to 120 MHz
- G-Sensitivity < 0.5 ppb/g
- Designed for harsh environments

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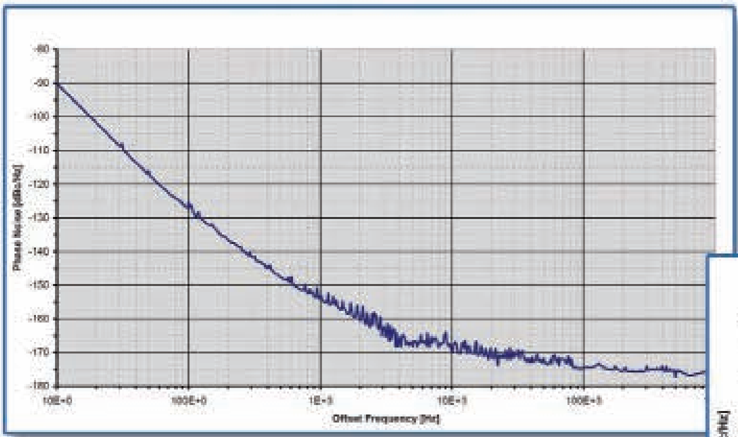
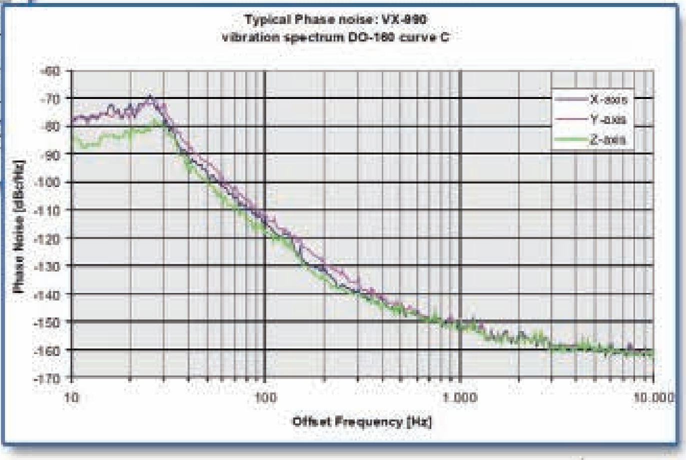


Phase Noise Under Vibration

Frequency: 120 MHz



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- Land based radar

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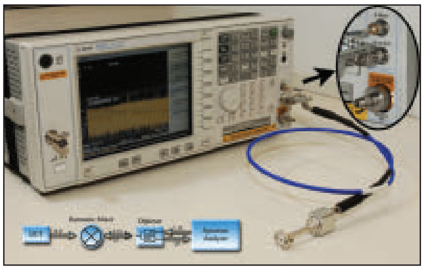
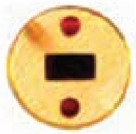
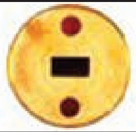
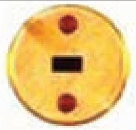
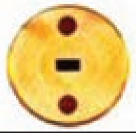
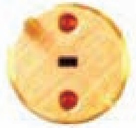
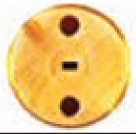
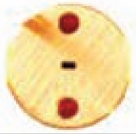
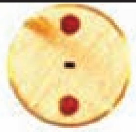


▲ *Fig. 2 A typical mm-wave measurement set-up.*

analyzer to manually compensate for the conversion loss of the harmonic mixer. In this way, this frequency extension accessory offers an attractive value proposition to engineers with mm-wave requirements.

A typical mm-wave measurement setup includes the microwave spectrum analyzer, harmonic mixer and diplexer (see ***Figure 2***). Cabling is efficient and unobtrusive. The inlay shows the close-up interconnects between the diplexer and the IF and LO inputs provided with the external mixer option.

As background, the spectrum analyzer's external mixer option enables substitution of the harmonic mixer for its own RF front-end design to overcome the mm-wave measurement limitation. After substitution, the later stages in the spectrum analyzer's receiver chain are still utilized for the remaining signal analysis capabilities. Harmonic mixer suppliers use spectrum analyzer manufacturer's designated LO, IF, and multiplier factor

WAVEGUIDE SPECTRUM	TE_{10} CUTOFF FREQUENCY (GHz)	RECTANGULAR WAVEGUIDE INTERFACE VIEW	INTERNAL DIMENSIONS (mils)	AGILENT PSA MULTIPLIER FACTOR, n
50 – 75 GHz WR-15 V-BAND	39.9 GHz		148.0 × 74.0	14
60 – 90 GHz WR-12 E-BAND	48.4 GHz		122.0 × 61.0	16
75 – 110 GHz WR-10 W-BAND	59 GHz		100.0 × 50.0	18
90 – 140 GHz WR-08 F-BAND	73.8 GHz		80.0 × 40.0	22
110 – 170 GHz WR-06 D-BAND	90.8 GHz		65.0 × 32.5	26
140 – 220 GHz WR-05 G-BAND	115.7 GHz		51.0 × 25.5	32
170 – 260 GHz WR-04 Y-BAND	137.2 GHz		43.0 × 21.5	38
220 – 325 GHz WR-03 H (J)-BAND	173.6 GHz		34.0 × 17.0	48

▲ *Fig. 3 Popular 50 to 325 GHz mm-wave spectrum by waveguide bands.*

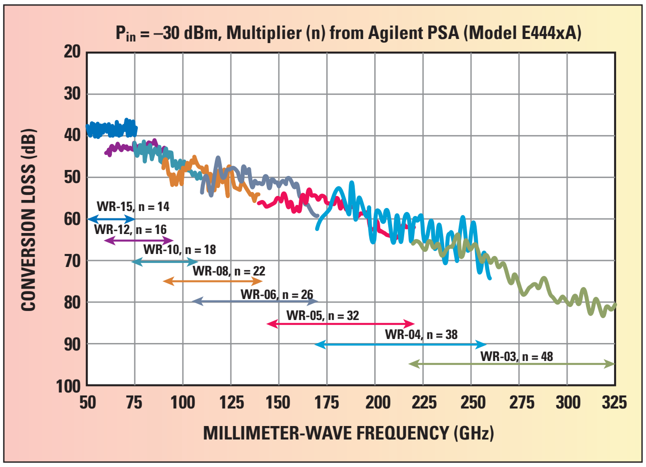
to characterize their harmonic mixers (with bias, if available).[2] The correction process is easy to implement using the supplier's final test data.

Once connected, the harmonic mixer design down converts the RF signal by mixing the nth harmonic of the LO to generate the predefined IF of the existing instrument. The RF input and the harmonics from the LO drive the mixer to produce the IF that satisfies the equation n(LO) – (RF). As an example, the high performance spectrum analyzer with predefined IF of 321.4 MHz has multiplier values that can range from n = 14 for WR-15 to n = 48 for WR-03 (see ***Figure 3***).[3] Typically, firmware automatically handles the multiplier factor so the displayed start and stop frequencies are the desired mm-wave RF spectrum. In addition, offset compensation is possible so displayed amplitude corrects the conversion loss of the harmonic mixer. In a typical measurement scenario, the display readout offers actual results with real-time updates when using the harmonic mixer technology with the spectrum analyzer.

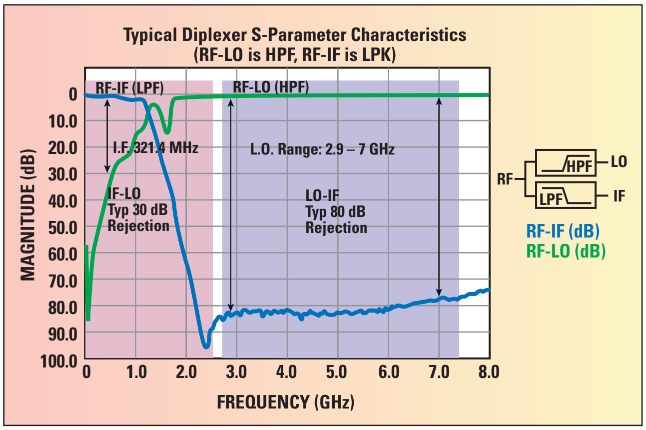
RECTANGULAR WAVEGUIDES

Below 50 GHz, commercially available instrumentation using coaxial connections are available for convenient and affordable signal analysis, as well as reasonable cable losses. Over the 50 GHz threshold, rectangular waveguide is often implemented for its low-loss transmission of mm-wave frequencies. In particular, popular waveguide band segmentation allows engineers to translate their application into the proper frequency extension accessory that is based on these same industry standard waveguide terminologies.

Figure 3 also contains the key rectangular waveguide information for the TE_{10} propagation mode, including the aperture size, both dimensionally and visually, for relative comparisons. The cutoff frequency indicates the frequency above which electromagnetic energy will propagate in the corresponding waveguide. The dimensions are proportional to the wavelengths, which decrease with higher frequencies. The multiplier factor (n) is a harmonic mixer value chosen by the analyzer manufacturer that down converts the millimeter to the microwave spectrum for easier analysis in modern spectrum analyzers.



▲ *Fig. 4 Representative conversion loss of a single unbalanced harmonic mixer.*



▲ *Fig. 5 Diplexer design for external mixing.*

MEASUREMENT EXAMPLE

For most convenient readouts, modern spectrum analyzer features can compensate for the external harmonic mixer attributes, so amplitude and frequency readouts are accurate. For amplitude readouts, the harmonic mixer manufacturer supplies the typical amplitude correction factor (that is conversion loss) value, which is largely influenced by the nth harmonic of the LO signal needed to down convert the RF to the predefined IF for signal analysis. As one might expect, the conversion loss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increases with higher multiplier values. ***Figure 4*** shows the representative conversion loss of a single diode, unbalanced harmonic mixer versus the mm-wave frequency range for the Agilent PSA Signal Analyzer (model E444xA). As predicted, the multiplier factors are overlaid with the typical conversion loss values to show how conversion loss increases with the multiplier value. These results are typical for the predefined LO, IF capabilities of the PSA. Results may vary when using other spectrum analyzers, due to different settings for LO, IF, and multiplier factors. For simplified frequency readouts, the spectrum analyzer contains preset settings, selectable by waveguide band, to compensate for the multiplication factor so the frequency scale reads RF instead of LO or IF.

Independently verifying the operation of the harmonic mixer requires a mm-wave source with a known power level. Simply set the RF source to a value in the harmonic mixer's linear range avoiding input compression. Using Figure 1, apply this "reference" RF signal to the input of the harmonic mixer and complete the LO and IF connections to the spectrum analyzer (an external diplexer may be necessary). After properly configuring the spectrum analyzer for external mixer operation, the readout will display a measured value that includes the reference signal level and the harmonic mixer's conversion loss. By entering the conversion loss as an offset, the spectrum analyzer will display the corrected power level.

MEASUREMENT CONSIDERATIONS

The following factors should be considered by test engineers when using harmonic mixers to extend their measurement system into mm-wave frequencies:

Damage Level: The maximum input power is typically 20 dBm, where nominally +15 dBm is allocated to the LO signal. Maintaining composite power levels below +20 dBm ensures damage will not occur to the harmonic mixer diode(s).

Linearity: Mixers are inherently nonlinear devices, so careful selection of power levels will help optimize the results. Position measurements in the linear input range, which, practically speaking, mean to avoid applying input signals within 10 dB of the 1 dB compression point. Below -30 dBm input power, single diode unbalanced harmonic mixers typically provide both accurate and repeatable measurements when using high performance spectrum analyzers.

Mixer Topology: Balanced mixers are popular for their increased linearity performance. However, they also fundamentally limit harmonic mixing to only even products due to the balanced properties in this topology. This may be a good selection as long as the spectrum analyzer utilizes even harmonic multipliers in their external mixer option. In contrast, the single diode mixer offers more versatility to use both even and odd products with less LO power, which are the reasons for their popularity in mm-wave applications. The single diode topology also requires bias, which can be useful to "peak" responses and further optimize results.

Image Rejection: There will be numerous mathematical intersections occurring where these harmonic cur-

rents, m + n, combine to produce responses within the spectrum analyzer's IF bandwidth. Furthermore, the strongest of these IF responses can, in turn, be combined with other m + n products to produce additional IF responses. Do not be alarmed that the results on a spectral display look like a "picket fence." Instead, most high performance spectrum analyzers offer "image rejection" features to eliminate "false" from the "desired" results, thereby simplifying the signal analysis task.

Conversion Loss and Dynamic Range: Frequency extension using harmonic mixer technology is a valuable tool for measuring fundamental characteristics of mm-wave signals, but not without some trade-offs. As a general observation, the higher conversion loss versus higher frequency behavior reduces measurement dynamic range and might be an obstacle when measuring low-level signals (such as intermodulation distortion products, discrete spurious or noise figure). As a tip, it is important to analyze after external mixing (taking into account the conversion loss) whether sufficient dynamic range (that is signal-to-noise ratio) exists in the spectrum analyzer for accurate measurements. Generally speaking, accurate measurements require greater than 10 dB signal-to-noise ratio.

Diplexer Characteristics: The diplexer is essential to the successful operation of the harmonic mixer, especially in single diode harmonic mixers. Although it is more convenient when the diplexer is integrated into the spectrum analyzer, this is not always the case. For example, the Agilent PSA (model E488xA) requires an external diplexer as part of its external mixer setup. In this case, the predefined IF is 321.4 MHz and the available LO range is 2.9 to 7 GHz. The diplexer design for external mixing is optimized for signal separation and harmonic mixing performance at the predesigned IF and available LO range of 2.9 to 7 GHz and will ensure these frequencies will flow unimpeded and with adequate signal separation to optimize performance for mm-wave spectrum analysis (see ***Figure 5***). The diplexer characteristics are occasionally worthwhile to consider in the setup because they constitute hardware constraints.

SUMMARY

The harmonic mixer technology enables the practical measurement of millimeter-wave signals. This primer describes harmonic mixer technology, including the typical conversion loss versus the millimeter waveguide bands for single diode harmonic mixers. This primer and tips will ensure that engineers can explore the mm-wave frontier using the terminologies and frequency extension accessories as practical tools. This technology is also the foundation for additional frequency extension accessories deployed in mm-wave signal generation, scalar, and vector network analysis. ■

References

1. M. Sayed, "Millimeter Wave Tests and Instrumentation," *65^{th} ARFTG Conference Digest*, June 2005, pp. 28-37.
2. "Using a Millimeter Wave Harmonic Mixer to Extend the Frequency Coverage of a Spectrum Analyzer," OML Inc. Application Note, 42-010124, January, 2001.
3. "External Waveguide Mixing and Millimeter Wave Measurements with Agilent PSA Spectrum Analyzers," Agilent Technologies Application Note #1485, 5988-9414EN, October, 2007.

Spectrally Compliant Waveforms for Wideband Radar

Modern radars often require the use of wideband waveforms to perform high resolution target imaging. In microwave systems, the bandwidth can be on the order of 1.5 GHz, while in UHF systems that typically operate between 200 and 500 MHz, the waveform bandwidth might exceed 200 MHz. A major issue in the operation of such systems is that they often overlap the spectrum used by other radars, and even the spectrum allocated for other types of systems, such as communications and navigation devices.

Thus for the radar to operate using a wideband waveform, spectral notches must be included that suppress the radiated signal by 30 dB or more at frequencies allocated to other systems. One method, for a radar to generate such notches, is to interrupt the sweep of a linear FM (that is a CHIRP) pulse. While this method can be effective, it often results in a significant loss in radiated power as the transmitter is turned off during the notching. The action of turning the transmitter on and off can also cause significant VSWR problems. Additionally, there are systems for which a modulation, such as a phase coded or noise-like modulation, is required.

To address these challenges, Technology Service Corp. (TSC) has developed software for the U.S. Army to generate constant envelope amplitude, spectrally compliant, wideband waveforms. The waveform generation approach is based on constrained optimization theory. Such waveforms are currently being used in a state-of-the-art wideband UHF synthetic aperture radar (SAR). Among the capabilities of the software are the abilities to:

- Generate either constant amplitude pulses, or pulses with controlled leading edge rise times, trailing edge fall times and pulse envelope tapers.

Technology Service Corp.
Fairfax, VA

Components and Integrated Assemblies

Renaissance Electronics Corporation
20th Year
1991-2011

Receiver Multi-Coupler

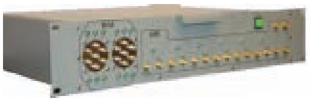
Renaissance Electronics' Receiver Multi-Coupler Model #14A4NH is designed for next generation commercial wireless applications. With a very low noise figure, the signal-to-noise ratio of the system improves significantly. Redundant power supplies require less system maintenance and lower maintenance cost. This unit has been field tested for facilitating site expansion in a cost effective and timely manner.

Multi-Band Combiner

Renaissance Electronics has designed a multi-band combiner Model #18A3BAA for GSM 800/900/1800/1900 & UMTS frequency bands. This is ideal for in-building distributed antenna systems (DAS) where different operators require simultaneous coverage without interference.

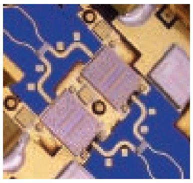
Surface Mount Circulator

Renaissance Electronics has designed an innovative industry first coplanar Surface Mount Circulator in the frequency bands of 4.2 - 4.4 GHz (3SMH6NA) and 5.3 - 5.9 GHz (3SMH6NB) for radio and radar altimeter applications. This design is re-flow compatible and suited for pick and place manufacturing practices. This is a new addition to our surface mount designs.



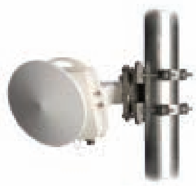
ADC/DAC Switch Matrix

Renaissance Electronics Corporation has released a new DC to 500 MHz Switch Matrix with two inputs and six outputs. The 18A1NA will support the high level of integration required during qualification testing for digital and analog assemblies operating at microwave frequencies.



35 GHz Integrated Transceiver

HXI produces two highly integrated transceivers to support the ground-based and flight units for a UAV landing system application. The program has been in production for 5+ years using our parts. The ground-based unit integrates 17 individual Millimeter Wave and IF circuit functions, including a 3.5W Ka-band power amplifier and a SP4T non-reflective switch matrix.

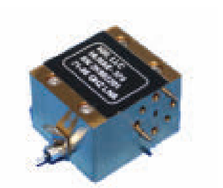


60 GHz & E-Band Radio Links

We have more high-capacity 60 GHz millimeter wave radios commercially deployed than any other manufacturer. Our standard off-the-shelf GigaLink radio links at 60 GHz and in E-Band are now being marketed worldwide. In addition, we have produced a number of variants of these radios for military and government usage, including analog links, custom antenna configurations, HDTV usage, etc. Standard links are full duplex, operate at a data rate of 1.25 Gbps and have near-zero latency. Each link is bench and range tested for dynamic range and bit errors.

HDTV Link System for 3D HD Sports Production

Our GigaLink HD wireless system is the ideal solution for the most challenging temporary deployment applications where studio quality feeds are essential. Dual channel operation supports 3D-HDTV, multiple camera feeds or as a redundant hot standby configuration for absolutely critical real-time acquisition.



Millimeter Wave Components

HXI offers a broad range of standard catalog components for use in prototyping new systems and for production requirements. These components consist of single function modules that can easily be configured into subsystems using waveguide or coax connections. The modules use mature technology such as GaAs MMICs and beam lead semiconductor devices, resulting in well established performance characteristics. The use of many common stocked parts results in low cost and fast delivery. Custom components include variations of many of our catalog products, such as LNAs, power amplifiers, frequency multipliers, mixers, switches and isolators/circulators.

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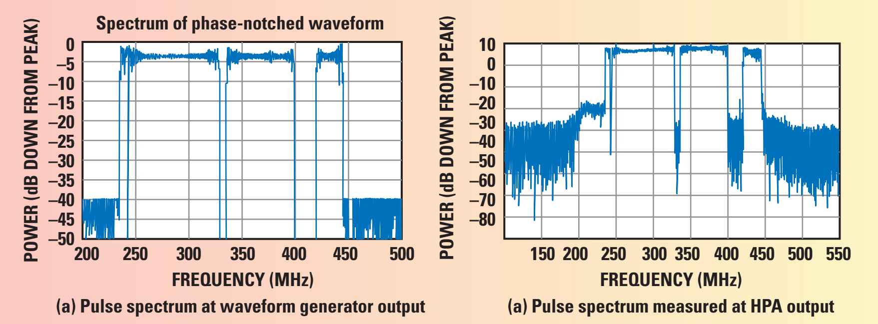


Fig. 1 TRACER waveform.

- Create multiple, narrow and wide spectral notches, both within and outside the radar waveform bandwidth (notching in excess of 15 percent of the signal bandwidth has been demonstrated).
- Pre-distort the signal that is input to the radar's high power amplifier (HPA) to ensure that the requisite notches are preserved in the transmitted signal.
- Generate mismatched pulse compression filters that suppress (typically by 15 dB) the high range sidelobes created by the spectral notching.

The software produces the digital waveform coefficients (currently done offline) that are stored in the radar's digital arbitrary waveform generator within nominally one minute. (This time could be shortened by many orders of magnitude by re-hosting the code in a language such as C++ on an FPGA processor.)

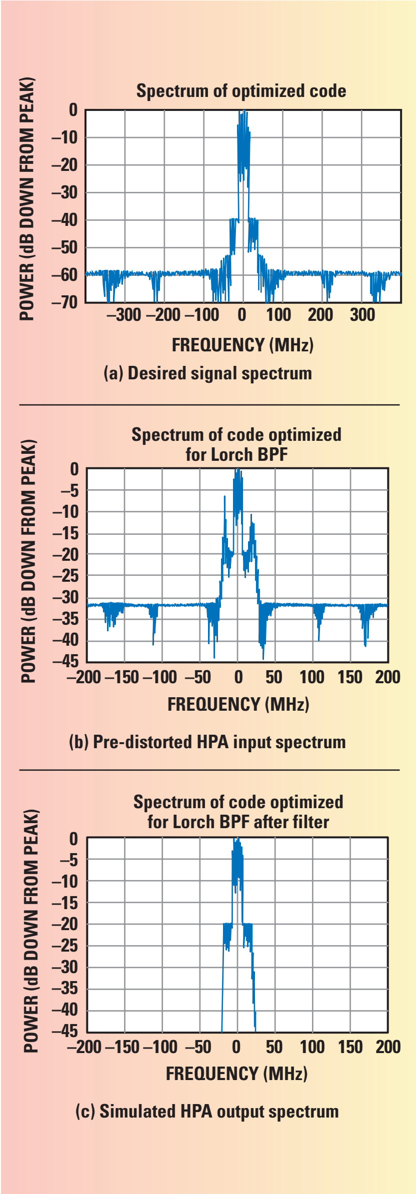
SAR WAVEFORM EXAMPLE

The Tactical Reconnaissance and Counter-concealment Enabled Radar (TRACER) is a UHF SAR that is being developed by Lockheed Martin in Phoenix, AZ, for the U.S. Army CERDEC. For a waveform designed specifically for domestic testing purposes, TRACER was required to incorporate four spectrum notches. There are three in-band notches centered at 243, 332 and 410 MHz with widths of 0.5, 6.8 and 20 MHz, respectively, and one out-of-band notch centered at 452.5 MHz with a width of 5 MHz. ***Figure 1*** shows the notched spectrum of the resulting TRACER domestic testing waveform. The Lockheed measurements have thus confirmed that all of the spectral notches had depths of at least 40 dB when measured at the HPA output. (Note: The pre-distortion techniques described below were not applied to this waveform.)

WAVEFORM PRE-DISTORTION

In some radar systems, the transmitter amplitude and phase characteristics can degrade the spectral notch characteristics. To prevent this from occurring, waveform pre-distortion techniques that compensate for transmitter effects have been developed. The waveform generation software uses the measured transmitter characteristics to pre-distort the signal at the HPA input in a manner that preserves the desired characteristics at the output.

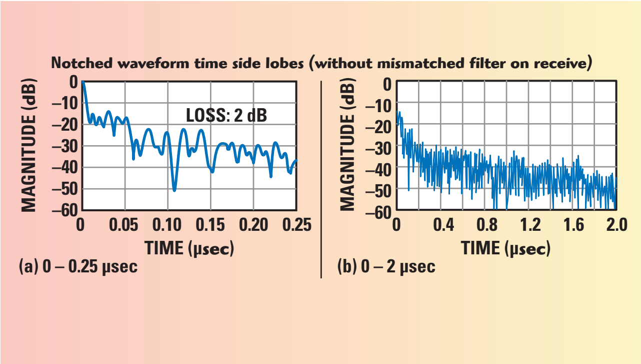
For example, ***Figure 2*** is a simulated case where a transmitter having a steep spectral roll-off and a nonlinear phase characteristic was modeled. Figure 2a shows the spectrum of a desired constant amplitude transmit pulse. Figure 2b shows the spectrum on the pre-distorted signal that was input to the simulated transmitter. Figure 2c shows the resulting spectrum at the HPA output. As can be seen, the spectrum at the simulated transmitter output very closely resembles the ideal spectrum. The output pulse's envelope amplitude ripple was less than 0.1 dB. Thus, the pre-distortion techniques should be effective in preserving the desired pulse amplitude and spectral characteristics. (Note: Although there are no spectral notches in this example, simulated notched waveforms show similar performance.)



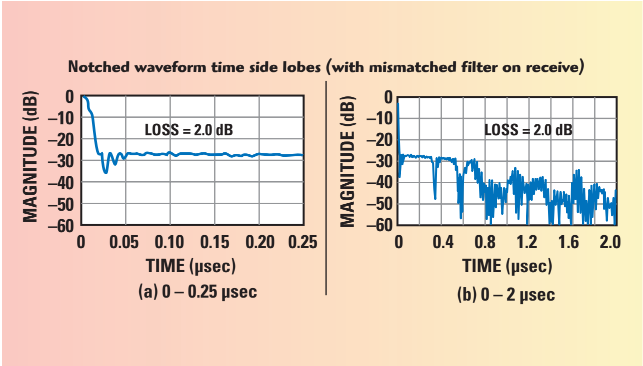
▲ *Fig. 2 Spectrum of desired signal.*

MISMATCHED FILTERING

When a significant fraction of the waveform is notched, high pulse compression sidelobes result. This is shown in ***Figure 3*** for the notched TRACER waveform presented in Figure 1. To reduce the sidelobes, the software also provides a mismatched pulse compression filter (MMF). As shown in ***Figure 4***, the MMF suppresses the high range sidelobes



▲ *Fig. 3 Matched pulse compression filter response for the notched TRACER waveform.*



▲ *Fig. 4 Mismatched pulse compression filter response for the notched TRACER waveforms.*

by nominally 15 dB. The cost for achieving this sidelobe suppression is a 58 percent broadening of the 3 dB compressed pulse width and a 2.0 dB SNR loss. These values are comparable to a weighting function (that is Hamming) that would typically be applied to a radar signal.

SUMMARY

The Spectrally Compliant Waveform Generation Software, which is a licensed TSC product currently being used by the Army's TRACER program, has been used to support several other radar development efforts. The waveform generation software can provide the capability of a wideband system to operate in complex RF environments and to address the requirements of both U.S. and host nation spectrum management organizations.

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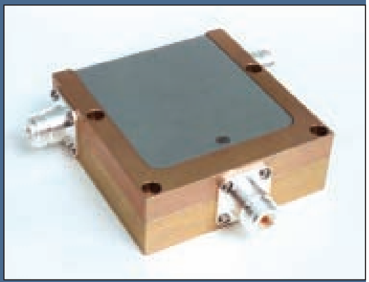

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As one of the leading suppliers of ferrite components in the industry, UTE Microwave has pioneered innovative designs, quality craftsmanship and exceptionally high quality products. Custom designs, standards...many of them off-the-shelf, are the result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

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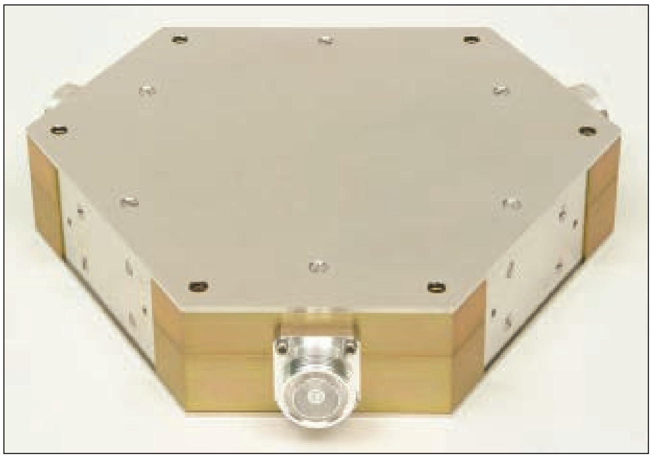

A new HIGH POWER Circulator suitable for FM Broadcast, Scientific and Medical applications is now available. The unit provides 10 MHz bandwidth in the 85–110 MHz spectrum.

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

HIGH POWER Drop-in Series

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

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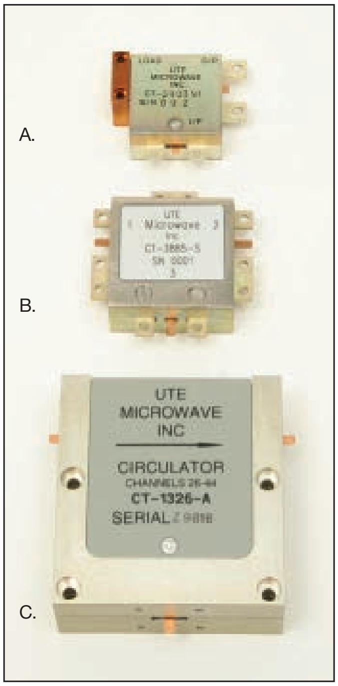

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CT-3838-N	5 Kw Pk 500 W Av	N Conn.	2.7–3.1 GHz
CT-1645-N	250 W Satcom	N Conn.	240–320 MHz
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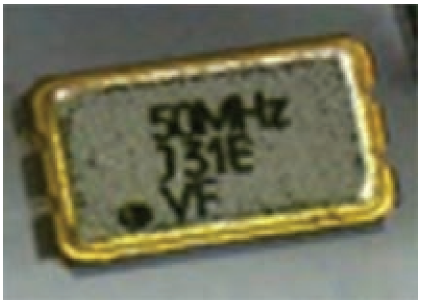


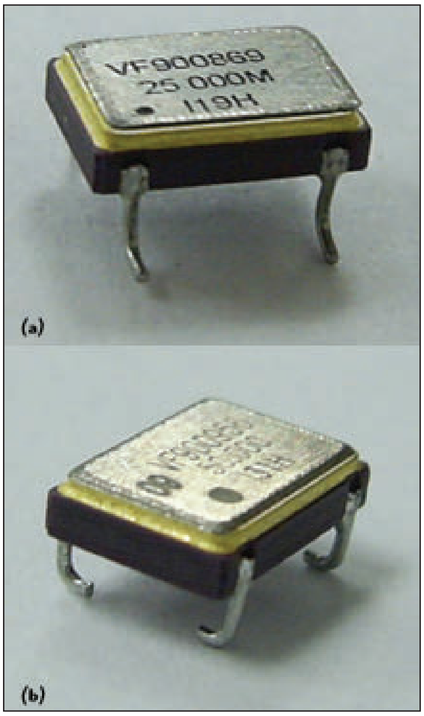
Smaller is Better in Military Applications

In many electronic assemblies today, thermal mismatch between the printed circuit board (PCB) and the ceramic components causes micro cracks in the solder joints. Several factors contribute to these cracks, notably component size, temperature variation, PCB material and solder material. A common result of these cracks is intermittent failures during use. The failures are easy to detect, but hard to repeat. In commercial applications, we have all experienced this when a cell phone call is dropped, there is a skip in a YouTube video, or an Internet application is temporarily interrupted. The impacts of these interruptions are usually trivial. In military applications, a missile loses its location or target, a soldier's tracking device fails (leaving him temporarily "lost" or worse, not identified as "friendly") or radio communication stops. In these applications, intermittent failures can be life threatening.

In the electronic components market, the standard package for an oscillator device is a ceramic surface-mount (SMT) 7 × 5 mm, 4 or 6 pin package. There are tens of millions of these devices sold every year. In the commercial market, where temperature variations are limited to –40° to 85°C, these oscillators are used in every type of application from SONET to LTE to test equipment. Their universal availability and small size make them ideal for most applications.

In military applications, where temperature extremes are much more demanding (–55° to 125°C), the 7 × 5 mm package is "too big." It seems crazy to think a part the size of the word "big" on this page is actually too big for an application. The calculations are complicated, but the reason is simple; over these temperatures, the PCB flexes more than the ceramic package. The weakest part of the assembly is the solder joint. To relieve the pressure of the stress, micro cracks form on the joint. If there is enough flex and enough cracking, the electrical connection in the joint is "opened" and, for a moment or longer, the device stops functioning. Once the temperature is reduced, the

VALPEY FISHER CORP.
Hopkinton, MA

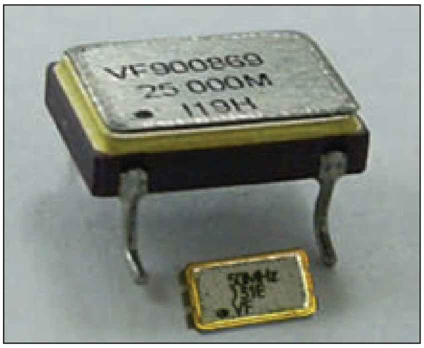


▲ *Fig. 1 Gull wing package (a) and J-lead package (b).*

PCB returns to a normal state, the micro cracks fill in and the device begins working again.

Designers of military-grade systems are well aware of this phenomenon and choose to design using larger packages (14 × 9 mm or greater) with leads on them. The leads "flex," allowing the PCB to move while the more rigid package remains stiff. In applications where a smaller component size is required, manufacturers have been challenged to create new package solutions. Since 7 × 5 mm packages are not available with leads, one accepted solution is to braze or weld leads onto the package. The parts are manufactured using the standard 7 × 5 mm assembly process and then have the leads attached using a brazing process (see ***Figure 1***). The leads are added one at a time and the process is time consuming and tedious. It is also expensive, adding significant cost to the devices. However, it works to relieve the thermal "mismatch" between the PCB and ceramic package.

The Valpey Fisher VFH3225 miniature hi-rel/COTS oscillator represents a significant change for designers of military systems. It takes advantage of the latest package technology, a ceramic SMT 3.2 × 2.5 mm 4 pin package (see ***Figure 2***). At just one



▲ *Fig. 2 Valpey Fisher VFH3225 package compared to traditional 7 × 5 mm package.*

quarter the size of the 7 × 5 mm package, or the size of the "b" in the word big, it is small enough that the thermal mismatch between PCB and ceramic is not significant. In other words, the PCB does not flex enough to cause significant stress on the solder joints to crack them. There is no need to add costly leads and designers are no longer restricted to using the larger packages with leads on them.

In addition to solving the thermal mismatch problem, the VFH3225 is the only military temperature range oscillator available that operates up to 160 MHz while maintaining a temperature stability of 50 ppm. With supply voltages of 3.3, 2.5 and 1.8 V, a low power consumption of 12 mW and available Group A, B or C testing, the VFH3225 is a good fit for applications where the environmental conditions are demanding and the choices are limited.

The VFH3225 represents the latest technology achievement from Valpey Fisher. With more than eight decades of innovation in oscillators (including special recognition in 1945 from General Eisenhower for the company's contribution to the war effort), the company continues to design and deliver hi-rel/COTS products that enable a wide range of applications for military communications, munitions and guidance systems.

VENDORVIEW

Valpey Fisher Corp., Hopkinton, MA (800) 982-5737, www.valpeyfisher.com.

Broadband Combiner Provides Input Failure Protection

Werlatone provides Non-Coherent RF Combiner designs with proven heat dissipation techniques for broadband Non-Coherent Combining applications, such as combining two or more signals of differing power, frequency and/or phase onto a single output. Model D9048 provides a four-way combining solution capable of handling 500 W CW output power while covering a full 20 to 1000 MHz bandwidth. While providing exceptional port-to-port unbalance protection, this unit operates with only 0.65 dB of insertion loss. Measuring just 5" × 4.7" × 1.4", the model D9048 is more efficient and smaller than most 20 to 500 MHz combiners in the marketplace today.

Designed for military and commercial applications, this unit will tolerate a full input failure at rated power and operates over a temperature range of –55° to +85°C. Input failure tolerance insures that remaining transmitter(s) may continue to operate until the amplifier system can be properly shut down for maintenance. This small package size weighs 2.5 pounds and can be supplied with several connector options including: N Female, 7/16 Female and SMA connectors. The model D9048 is also available as a RoHS compliant design.

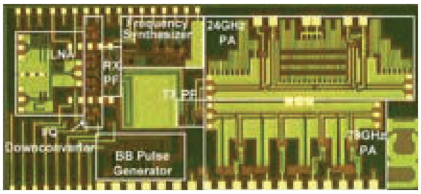
The company offers extensive experience as a supplier to military platforms worldwide, with 0° combiners/dividers, dual directional couplers, 90° hybrid couplers and 180° hybrid combiners/dividers. These components can be used in military communications and EW applications, such as HF, VHF, UHF, S-band ground based, shipboard, aircraft radar as well as commercial communications, such as AM, FM, VHF, UHF, digital UHF and satellite radio.

VENDORVIEW

Werlatone Inc., Patterson, NY (845) 278-2220, sales@werlatone.com, www.werlatone.com.

Third-Gen SiGe Reduces Noise and Power Consumption

TowerJazz recently announced the company's third-generation 0.18 µm SiGe technology, SBC18H3, offering transistors with 240 GHz Ft and 260 GHz Fmax in a cost-effective and analog-friendly 0.18 µm node. The technology is built on the same mature integration platform used for the company's prior two SiGe processes, which are currently in high volume production (SBC18H2 at 200 GHz and SBC18HX at 155 GHz). The technology addresses next-generation needs for high speed interfaces in communication protocols, such as optical fiber, and high data rate wireless, by improving performance with reduced noise and power consumption of key building blocks. SBC18H3 also targets applications



such as automotive collision avoidance systems, millimeter-wave radar and GHz imaging.

Power consumption is dramatically reduced. For example, a 77 GHz amplifier can be made to consume three times less DC power than was possible with older technology. At the same time, noise is improved to levels exceeding those of prior SiGe technologies as well as the results typically reported for III-V materials (minimum noise figure at 20 GHz is measured at less than 1 dB and at 40 GHz at only 2 dB).

For design support, SBC18H3 Process Design Kits (PDK) include mm-wave components such as a transmission-line toolbox, PIN diodes for RF switching, and support for small size MIM capacitors. PDKs are available for Cadence Virtuoso and Agilent ADS. TowerJazz offers a monthly MPW for quick and cost-effective prototyping of designs, and leading customers have already built initial SBC18H3 prototype designs through this MPW service. The IP of high speed components from H2 and HX can be readily ported to the new H3 process since they are all in the same 0.18 µm node.

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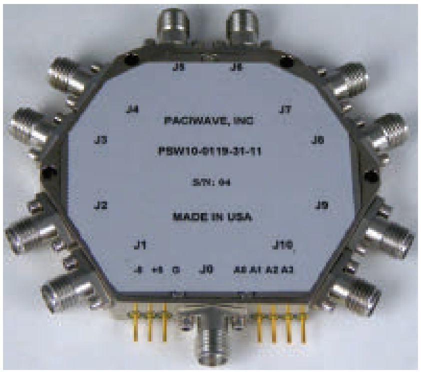
Ultra Low Loss PIN Diode RF Switches

Paciwave has developed a new family of ultra low loss PIN diode RF switches for military and instrumentation applications that feature high switching speed, high isolation and excellent VSWR. The model PSW10-0119-31-11 is a SP10T switch that covers the RF band from 1.5 to 18.5 GHz, is TTL controlled by Paciwave designed integral driver, has insertion loss of 4.0 dB maximum (3.6 dB typical), isolation of 80 dB minimum (85 dB typical), is reflective and has a switching speed of 30 ns typical. Power handling is on the order of +30 dBm CW, +33 dBm peak. Port return loss is 10 dB maximum, 15 dB typical.



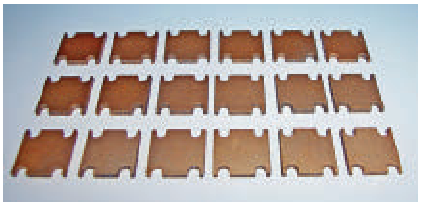
The unit is powered by ±5 VDC. Options include absorptive operation, higher power handling and low video transients. The unit is housed in a compact radial package measuring roughly 2.4 inches in diameter by 0.28 inches thick, which allows for optimally short internal transmission line lengths to optimize port to port phase and amplitude matching. Matching is within ±0.5 dB port to port on amplitude and ±10° on the phase at the high end of the band. Operating temperature range is –40° to +85°C and the unit can be hermetically sealed.

Paciwave has spent the last 16 years optimizing and refining its circuits, materials and processes and now is able to offer customers some of the best-performing switches on the market. Paciwave's ultra low loss switch technology is available throughout the entire line of switches from SP1T to SPNT, covering all the common frequency bands up to 40 GHz. Paciwave's switch-related products, such as matrices, filter banks, calibration modules and integrated microwave assemblies, also feature ultra low loss switch technology.

Paciwave Inc., Sunnyvale, CA (408) 745-0385, sales@paciwave.com, www.paciwave.com.

Aluminum Diamond Heat Spreader Material for GaN Devices

Nano Materials International has introduced aluminum diamond metal matrix composites (MMC) for use as heat spreaders that can reduce GaN junction temperatures by up to 25 percent, has a coefficient of thermal expansion (CTE) close to that of SiC and metallization well suited for die attach. They also have excellent dimensional tolerances and material stability. In addition, they can be economically produced in large quantities while adding a minimal cost to each GaN device.



Polycrystalline diamond has the highest thermal conductivity of any material, ranging from 1200 to 2000 W/mK. When used in an aluminum diamond MMC, the effective conductivity remains over 500 W/mK, far higher than common heat spreader materials such as copper tungsten (200 W/mK), copper molybdenum (250 W/mK) and copper-molybdenum-copper (350 W/mK). The MMC material with nickel-gold electrolytic or electroless plating can be made in the thicknesses required for use as a heat spreader and in virtually any shape and size typical of GaN HEMT or MMIC devices. It is available as a MMC material alone or incorporated within a package, allowing it to accommodate the specific needs of device manufacturers and package suppliers.

The aluminum diamond MMC products have been tested with a variety of GaN devices and are proving well suited for solving the problems created by GaN's extremely high power density. They are likely to be an essential part of the solution for removing heat at the device level from high power RF and microwave amplifiers that will be employed in future generations of military electronic warfare, radar, and communications systems.

Nano Materials International, Tucson, AZ, www.nanomaterials-intl.com.

MILITARY MICROWAVES SUPPLEMENT

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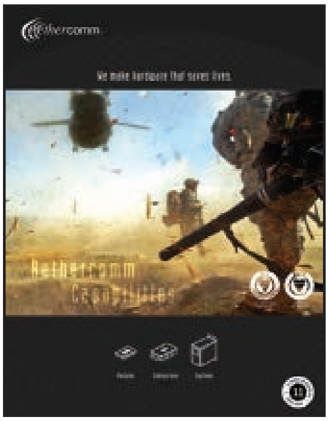
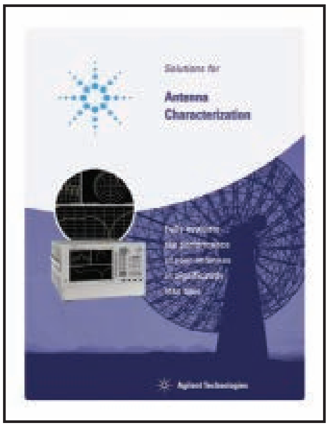


Capabilities Brochure

This capabilities brochure features Aethercomm's three major product lines: RF amplifier modules, RF subsystems and RF systems. The major classes of RF amplifier modules are broadband high power, linear high power and high power pulsed amplifiers. The products are employed in electronic warfare, radar and communication systems and other applications that require high power RF energy. Aethercomm offers automated assembly and test capabilities, hybrid and MIC capabilities, custom product design and is ISO 9001:2008 and AS 9100 certified.

Aethercomm Inc.,
Carlsbad, CA (760) 208-6002, www.aethercomm.com.

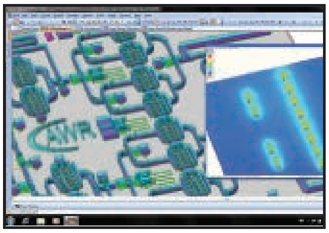


Antenna Test Solutions Brochure

VENDORVIEW

See how to lower antenna test times by as much as 80 percent, significantly improve measurement sensitivity or replace existing 8530A-based solutions with higher performance and code emulation.

Agilent Technologies Inc.,
Santa Clara, CA (800) 829-4444, www.agilent.com.

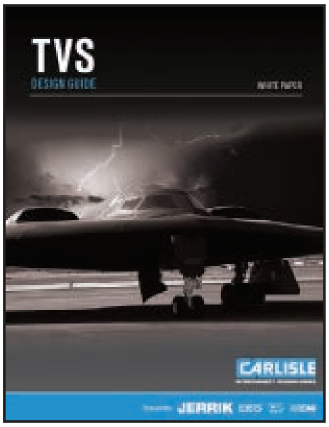


Product Portfolio

VENDORVIEW

AWR Corp. dramatically reduces development time and cost for products employed in wireless, high speed wired, broadband, aerospace and defense, and electro-optical applications. The 2011 version of its product portfolio – Microwave Office™, Visual System Simulator™, AXIEM® and Analog Office® – features electrical-thermal MMIC co-simulation design flow, simulation-state management technology, yield analysis/optimization via a graphical shape-based manipulation approach, envelope simulator and asynchronous electromagnetic (EM) simulation support.

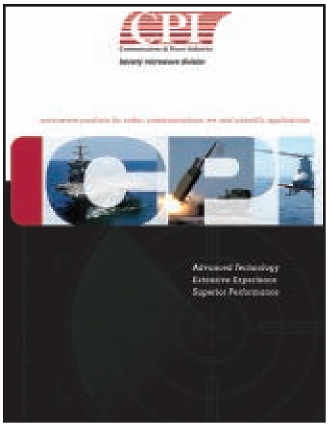
AWR Corp.,
El Segundo, CA (310) 726-3000, www.awrcorp.com.



TVS Design Guide

Lightning strikes aircraft, helicopters, UAVs and ships with a higher frequency than most people would believe. There also is the potential of a nuclear event that would propagate an Electro Magnetic Pulse (EMP) to consider. By using Transient Voltage Suppression (TVS) devices, the company can guard against the destructive energy spikes generated by lightning and EMPs. This guide will explain many of the considerations needed to select the proper device to prevent EMP issues.

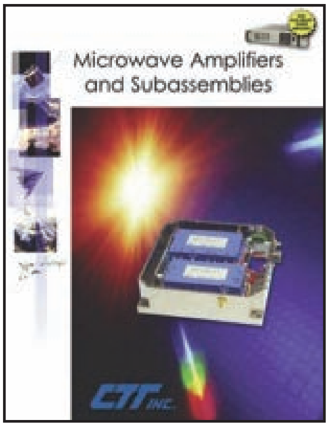
Carlisle Interconnect Technlogies,
St. Augustine, FL (904) 829-5600, www.carlisleit.com.



Product Catalog

CPI's Beverly Microwave Division (BMD) designs and manufactures a broad range of RF and microwave products for radar, communications, electronic warfare and scientific applications. CPI/BMD is the world's largest manufacturer of receiver protectors and related products. Other product lines include magnetrons, TWTs, CFAs, transmitter assemblies, scientific systems, high power solid-state switches and switch assemblies, pressure windows and a wide variety of multifunction components and integrated microwave assemblies.

Communications & Power Industries (CPI),
Beverly Microwave Division, Beverly, MA (978) 922-6004,
www.cpii.com/bmd.



Amplifiers and Subassemblies

This 36-page catalog features more than 175 new amplifier products, including lightweight LNAs with drop-in or connectorized options. CTT's expanded product offerings include gallium-nitride (GaN) monolithic-microwave-integrated-circuit (MMIC) device technology power amplifiers for wideband jammer applications and narrowband radar applications. A new line of rack-mount power amplifiers operates from 0.5 to 31 GHz for wide or narrowband linear applications covering UHF through Ka-Band. Additional solid-state amplifier products have been introduced for use in a wide range of applications.

CTT Inc.,
Sunnyvale, CA (408) 541-0596, www.cttinc.com.

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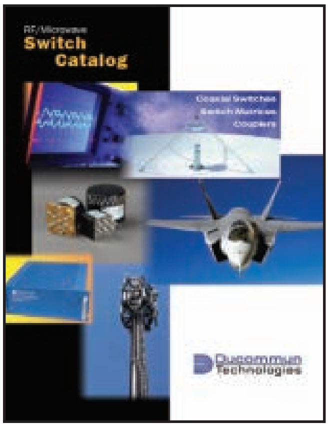
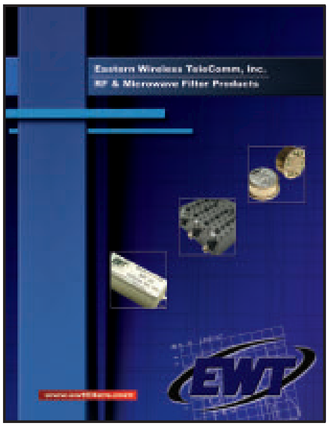


Switch Catalog

Ducommun LaBarge Technologies has served the aerospace, defense, industrial and telecommunications markets for more than 40 years by providing RF components and sub assemblies. Ducommun is a design and manufacturing company specializing in RF products, including coaxial switches. Its heritage includes industry stalwarts as Dynatech (DMT) and DBP Microwave (DBP). It designs and manufactures RF coaxial switches covering the frequency range of DC to 50 GHz. In addition to RF coaxial switches, Ducommun designs switch matrices, millimeter-wave components and integrated subassemblies.

Ducommun LaBarge Inc.,
Carson, CA (310) 513-7256, www.ducommun.com.



Filter Catalog

VENDORVIEW

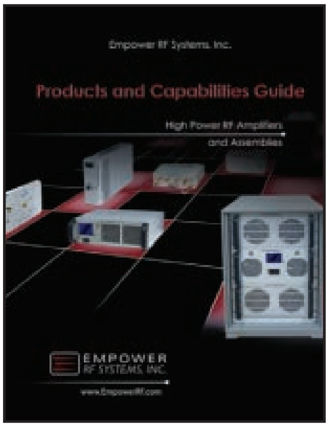
This new short form catalog features a sampling of the company's RF and microwave filter products to 40 GHz utilized in military, commercial and wireless applications. The catalog also highlights some of the company's diverse filter design and manufacturing capabilities.

Eastern Wireless TeleComm Inc.,
Salisbury, MD (410) 749-3800, www.ewtfilters.com.

Connectors Product Catalog

Emerson Connectivity Solutions is a global manufacturer of connectivity products, specifically microwave components and cable assemblies, which support wireline & wireless communications, networking, RF/microwave, test & measurement, broadcast, medical, military and industrial applications. The new kwiQMAte™ branded Johnson® product line catalog of QMA connectors features a push-pull interface allowing for more connectors per application.

Emerson Connectivity Solutions,
Bannockburn, IL (847) 739-0300, www.emersonconnectivity.com.



High Power Broadband RF Amplifiers

VENDORVIEW

Empower's Products and Capabilities Guide is a comprehensive overview of the company's capabilities and a listing of its most popular amplifier products. With products that cover from 150 kHz to 6 GHz and an extensive library of building block designs, there is an array of catalog standard and semi-custom solutions available. This brochure will be especially useful for buyers, sales representatives and engineers.

Empower RF Systems Inc.,
Inglewood, CA (310) 412-8100, www.empowerrf.com.

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LITERATURE SHOWCASE

10 MHz to 67 GHz Components Catalog

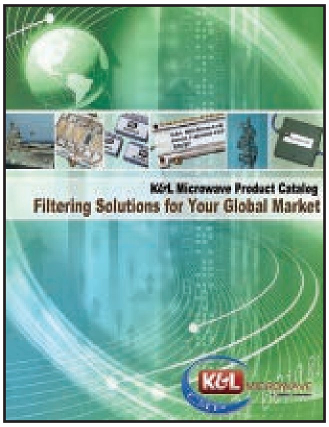
ET Industries is a high technology, leading edge company specializing in the design, development and manufacture of the state-of-the-art radio and microwave frequency, narrowband and wideband subsystems and components. The company was created with the sole purpose of assisting customers to investigate and solve problems that are technologically advanced, and may require critical schedules for completion. ET Industries, therefore, welcomes such programs. The company provides application-specific designs to meet special requirements of its customers. Please contact ET at sales@etiworld.com.

ET Industries,
Boonton, NJ (973) 394-1719, www.etiworld.com.

Microwave Cable Catalog

This short form catalog features the SUCOFLEX 400 microwave cable family that has been specifically developed for high performance electronic warfare applications. Anywhere low insertion loss, best phase stability versus temperature and bending, excellent return loss and mechanical stability are of particular importance, the SUCOFLEX 400 is claimed to be a fitting solution.

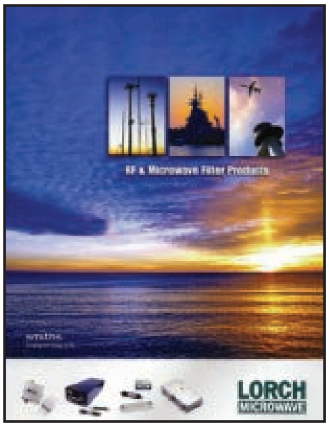
HUBER + SUHNER,
Herisau, Switzerland, info@hubersuhner.com, www.hubersuhner.com.



Product Catalog

K&L Microwave's 128-page catalog can be used as a desktop reference guide that offers details and specifications to help designers and engineers choose products quickly. Integrated assemblies and a wide assortment of lumped component, cavity, ceramic and suspended substrate filters are among the many types of products featured in this catalog.

K&L Microwave,
Salisbury, MD (410) 749-2424, www.klmicrowave.com, www.klfilterwizard.com.



Short Form Product Guide

VENDORVIEW

The Lorch Microwave short form product guide presents the complete product range in a clear and concise format. The products featured are used in a wide range of military and commercial applications. Also included are frequency range of operation, photographs and specific application information, charts and tables.

Lorch Microwave,
Salisbury, MD (410) 860-5100, www.lorch.com.

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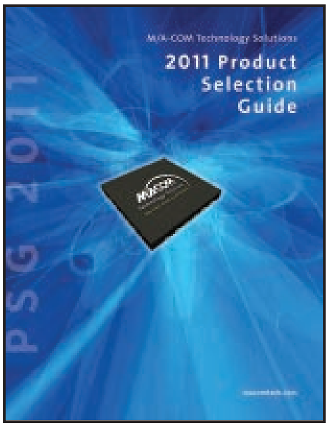
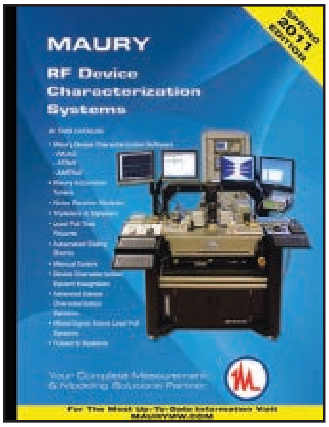


Product Guide

VENDORVIEW

The Product Selection Guide is designed to help engineers select products for commercial, aerospace and defense markets. It contains a listing of products, in addition to packages available, wavelength and frequency information, Decibels-Volts-Watts Conversion Table, Telecommunications Standards, Part Number index, and application block diagrams. Download a copy by going to macomtech.com.

M/A-COM Technology Solutions,
Lowell, MA (978) 656-2546, www.macomtech.com.



Device Characterization Systems Catalog

This catalog covers Maury Microwave's full line of device characterization solutions, including IVCAD software, ATSv5 software, load pull and pulsed IV systems, automated tuners, controllers, manual tuners and test bench accessories. It has everything needed to make Device Characterization measurements with confidence. Get the 84-page PDF download from http://maurymw.com/pdf/1G-003b_sprg2011.pdf.

Maury Microwave Corp.,
Ontario, CA (909) 987-4715, www.maurymw.com.

Components Catalog

VENDORVIEW

Celebrating its 50th anniversary, MECA (Microwave Electronic Components of America) designs and manufactures an array of RF/microwave components with industry leading performance. MECA is recognized worldwide as a primary source of supply for rugged and reliable components to commercial and military OEMs, service providers and installers by only providing products made in the USA.

MECA Electronics Inc.,
Denville, NJ (866) 444-6322, www.e-meca.com.

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IF/RF Microwave Signal Processing Components Guide

VENDORVIEW

Mini-Circuits' new 164-page catalog includes more than 750 new products and the industry's most comprehensive listing of RF/IF and microwave components and subsystems with more than 4100 products and more than 25 product lines, including state-of-the-art amplifiers, mixers, VCOs, synthesizers, filters, test accessories and USB Power Sensors. Mini-Circuits' website provides additional data, application notes, design tools and its powerful YONI search engine, which searches actual test data on thousands of units.

Mini-Circuits,
Brooklyn, NY (718) 934-4500, www.minicircuits.com.

Analyzing Antenna Performance

VENDORVIEW

Successful integration of an antenna onto a vehicle platform poses many challenges, from vehicle features and motion impacting antenna performance to environmental factors, and radiation hazards. This paper provides a variety of examples on how modeling and simulation can be used to analyze antenna performance, identify problems and evaluate potential solutions. Download at www.remcom.com/antenna-platform-integration/.

Remcom,
State College, PA (814) 861-1299, www.remcom.com.

Filters, Multiplexers and Multi-function Assemblies

VENDORVIEW

This catalog features RF and microwave filters, multiplexers and multi-function assemblies. The catalog contains RF and microwave filters, multiplexers and multi-function assemblies for the military, industrial and commercial industries. To request a copy, please e-mail reactel@reactel.com, or visit www.reactel.com.

Reactel Inc.,
Gaithersburg, MD (301) 519-3660, www.reactel.com.

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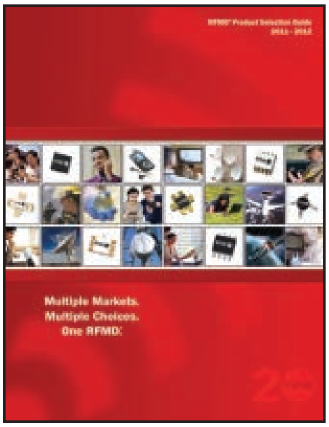


2011 Product Selection Guide

The 2011 Product Selection Guide provides specifications for more than 900 products, including more than 90 recently released products targeting multiple end-market applications. The 64-page guide allows customers to cross-reference and search products using end-market application diagrams. RFMD's Product Selection Guide lists products servicing more than 20 end-market segments, including cellular, Point-to-Point Microwave Radio, WiFi, WiMAX, Smart Energy AMI, Zigbee®, wireless infrastructure, aerospace & defense, broadband transmission, consumer, and others. To download, visit www.rfmd.com/SelectionGuide/default.aspx.

RFMD Inc.,
Greensboro, NC (336) 664-1233, www.rfmd.com.

Product Catalog

RLC Electronics is a leader in the design and manufacturing of RF and microwave components. The company's product range includes coaxial switches up to 65 GHz, power dividers, couplers, variable attenuators, filters and detector diodes up to 40 GHz. Many components are available in surface-mount construction, designed to meet specific customer requests electrically and mechanically. Those products include filters, switches, couplers and power dividers. New products include programmable attenuators, high power broadband couplers, high frequency broadband power dividers and delay lines up to 40 GHz.

RLC Electronics Inc.,
Mount Kisco, NY (914) 241-1334, www.rlcelectronics.com.

Secure Communications Catalog 2011

VENDORVIEW

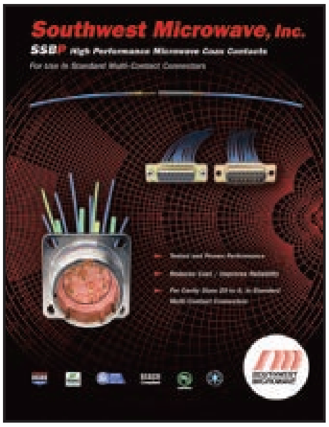
For air force missions, the key to success is the reliability, security, flexibility and future-readiness of communications equipment. This catalog addresses this issue and documents the company's secure communications solutions: mobile and highly mobile airborne radiocommunications, secure information transmission, stationary and mobile ground communications, and test and measurement equipment for radio communications.

Rohde & Schwarz GmbH,
Munich, Germany (Europe): +49 89 4129 12345,
(USA): +1 888 837 8772, www.rohde-schwarz.com.

Product Brochure

RT Logic's product overview brochure summarizes the company's broad line of innovative channel simulation, signal, data and network processing systems for the space and aerospace communications industry. Since RT Logic's founding in 1977, thousands of RT Logic systems have been fielded, with 90 percent of America's space missions utilizing RT's products during their test, launch, or on-orbit phase.

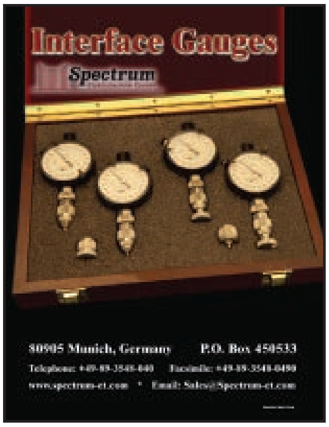
RT Logic,
Colorado Springs, CO (719) 598-2801, www.rtlogic.com.



SSBP Product Catalog

Southwest Microwave's new SSBP product catalog describes a family of microwave contact sizes designed to fit into standard (non-coax) cavities in MIL-DTL-38999 circular, MIL-DTL-24308 D-Sub, and special MIL-DTL-83513 Micro-D connectors. It includes RF/microwave testing to 65 GHz, plus 5000 cycle mating durability plus shock and vibration. SSBP coaxes allow applications to mix microwave signals with DC/digital and fiber optics in one connector. The catalog is available for download online or a printed copy can be requested.

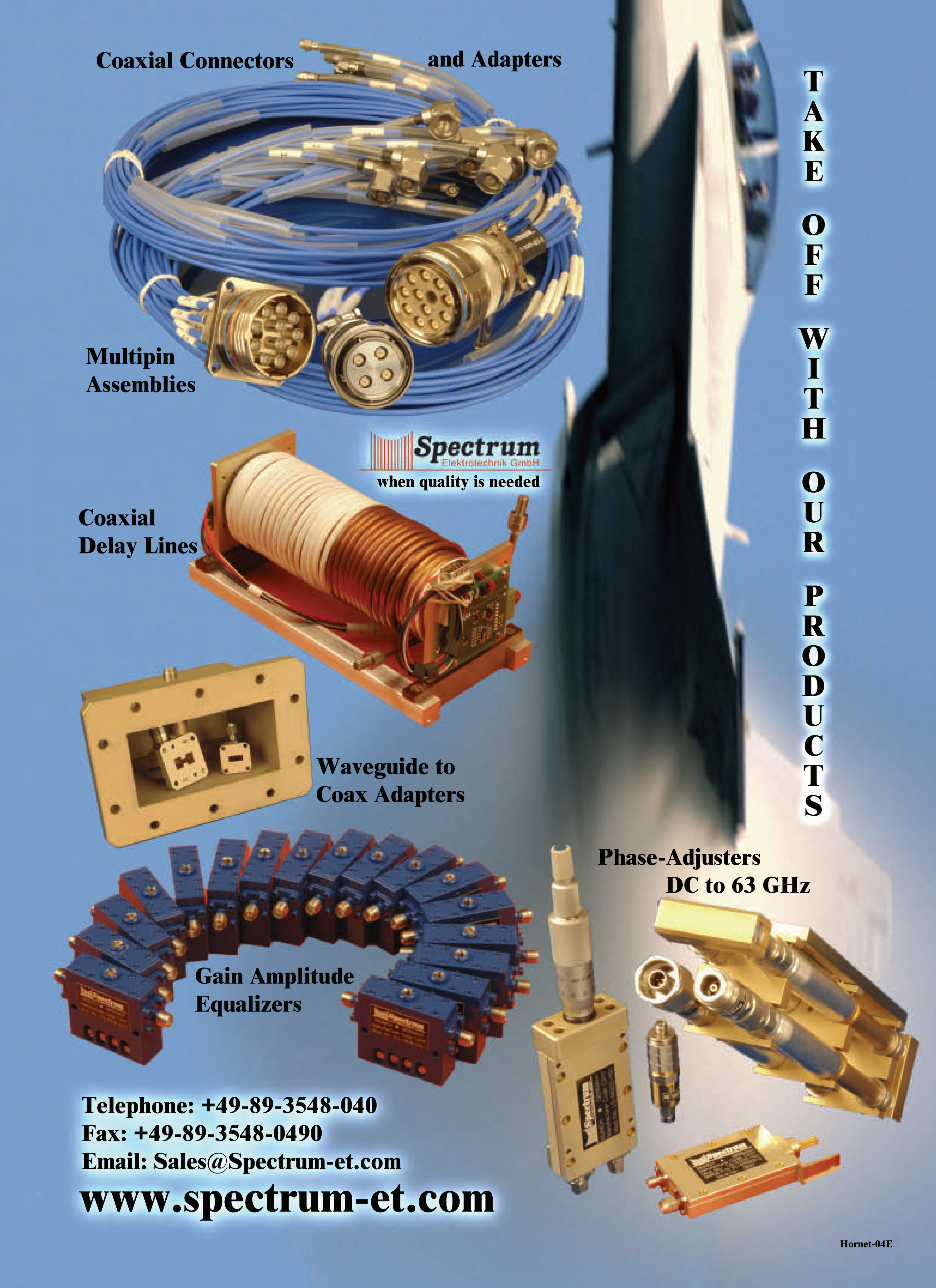
Southwest Microwave Inc.,
Tempe, AZ (480) 783-0201, www.southwestmicrowave.com.



Interface Gauge Catalog

The new short form catalog showcases the manufacturer's full line of connector gauges for checking the critical interface dimensions of most standard coaxial connectors. The sets are supplied in pristine wooden boxes. The catalog outlines the importance of checking the interface dimensions of connectors and adapters as those interfaces not meeting specification will not only lead to the possible degradation of components, but also may damage the connectors of mating components or mating connectors of associated equipment.

Spectrum Elektrotechnik GmbH,
Munich, Germany +49 89 3548 040, www.spectrum-et.org.


Coaxial Connectors and Adapters
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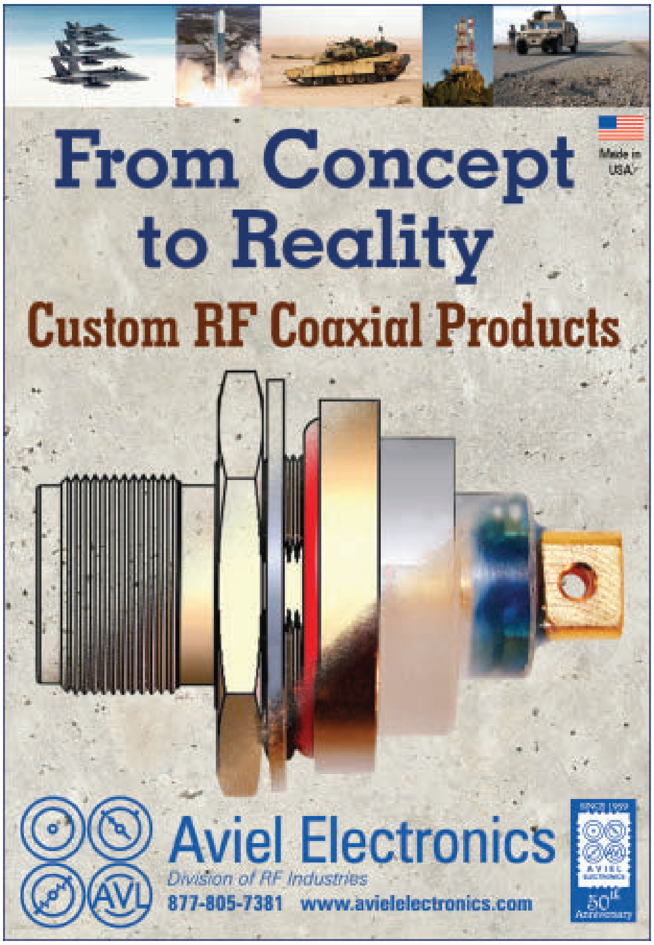

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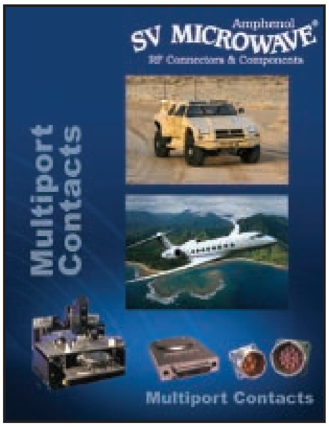
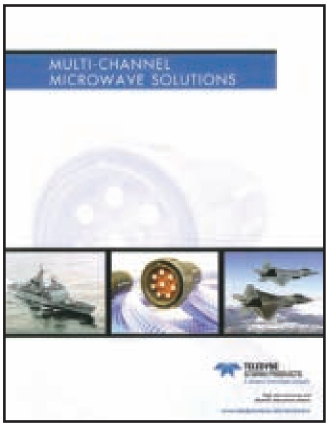


Multiport Contacts Catalog

SV Microwave has released its new Multiport Contacts catalog featuring information on Size 8, 12 and 16 contacts operating to 18 GHz and fitting into M38999, ARINC, Micro-D and SIM connector cavities. These new contacts have enabled SV to combine RF/microwave and DC signals in hybrid harnesses, providing simplified interconnection and smaller package size to aid both designers and operators in the field.

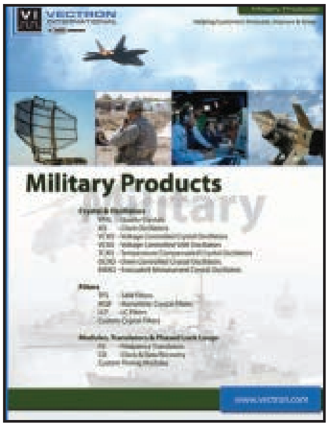
SV Microwave,
West Palm Beach, FL (561) 840-1800, www.svmicro.com.



Harness Capabilities Brochure

Teledyne Storm Products' new Multi-Channel Microwave Solutions brochure details the company's capabilities in the design and manufacture of both standard and custom multi-channel microwave harness assemblies. The harnesses, found in a wide range of airborne, ground and sea-based military and commercial applications, are backed by Teledyne Storm's more than 30 years of microwave cable design and manufacturing expertise. It includes a case study.

Teledyne Storm Products,
Woodridge, IL (630) 754-3300, www.teledynestorm.com.



Military Products Brochure

With more than 50 years experience, Vectron is the leader in providing frequency control and hybrid solutions to customers around the world. Vectron claims its innovative approach to design and manufacture has resulted in the most advanced product offering of any frequency control supplier in the world.

Vectron International,
Hudson, NH (603) 598-0070, www.vectron.com.

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markm@actintl.com.hk

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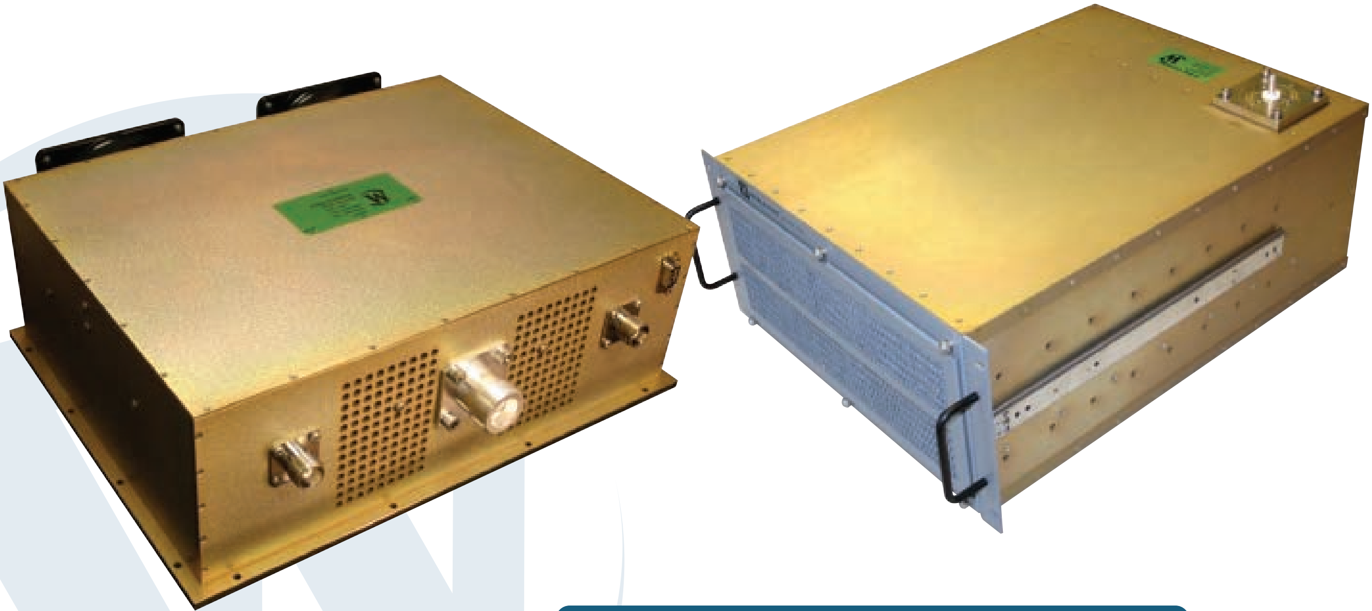
- Coherent and Non-Coherent Combining



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17 Jon Barrett Road
Patterson, New York 12563
T 845.278.2220
F 845.278.3440
sales@werlatone.com
www.werlatone.com

A few of our Customer driven designs.

Model	Type	Frequency (MHz)	Power (W CW)	Insertion Loss (dB)	VSWR	Isolation (dB)	Size (Inches)
D8265	2-Way	1-50	5,000	0.3	1.25	20	15.5 x 15 x 5.25
D2075	2-Way	1.5-30	6,000	0.2	1.25	20	15.5 x 11.75 x 5.25
D8969	2-Way	1.5-30	12,500	0.2	1.25	20	17 x 17 x 8
D6139	4-Way	1.5-32	5,000	0.25	1.25	20	13 x 11 x 5
D6774	4-Way	1.5-32	20,000	0.3	1.20	20	21 x 17.25 x 11
D6846	6-Way	1.5-30	4,000	0.35	1.35	20	3 U, 19" Rack
D8421	8-Way	1.5-30	12,000	0.3	1.30	20	22.5 x 19.5 x 8.75
D7685	4-Way	2-100	2,500	0.5	1.30	20	14.75 x 13 x 7
D2786	4-Way	20-150	4,000	0.5	1.35	20	18 x 17 x 5
D6078	2-Way	100-500	2,000	0.25	1.20	20	13 x 7 x 2.25
H7521	2-Way (180°)	200-400	2,500	0.3	1.30	20	15 x 10 x 2
D7502	2-Way	400-1000	2,500	0.25	1.20	NI*	9.38 x 3.5 x 1.25

*NI = No Isolating Terminations

Our Patented, Low Loss Combiner designs tolerate high unbalanced input powers, while operating into severe Load Mismatch conditions.

Semiconductors | First Response | Medical | In-Building | Military Comm and EW