Vol. 58 • No. 6

June 2015

Microwave Journal .com

MVP
Peregrine
40 GHz
SOI Switch

horizon house®

Founded in 1958

Power Divider/Combiners
MECA offers a variety of Power Divider/Combiners in assorted bands from 20 MHz to 40 GHz with SMA, 2.92mm, QMA, N, TNC, RP-TNC, 4.1/9.5 & 7/16 DIN interfaces. Their rugged construction makes them ideal for both base station, in-building wireless and satellite systems.

Attenuators & Terminations
MECA offers a variety of models capable of operating up to 40 GHz with power handling up to 500 watts with SMA, 2.92mm, QMA, N, TNC, RP-TNC, 4.1/9.5 & 7/16 DIN interfaces. Their rugged construction makes them ideal for both base station, in-building wireless and satellite systems.

Bias Tee & DC Blocks
MECA offers a variety of models capable of handling up to 6 & 18 GHz with SMA, 2.92mm, QMA, N, TNC, RP-TNC & 7/16 DIN interfaces. Their rugged construction makes them ideal for both base station, in-building wireless and satellite systems.

Circulators & Isolators
MECA offers Circulators and Isolators in N, SMA, 2.92mm and 7/16 DIN Female connectors with average power ratings from 2 - 250 watts. The most "popular" frequency bands between 0.698 - 40.0 GHz are readily available and can ship from STOCK.

BETTER BUILDINGS / BETTER NETWORKS

Dr. D.A.S. © Prescribes: MECA Millimeter-Wave Products.

Since 1961 MECA Electronics (Microwave Equipment & Components of America) has served the RF/Microwave industry with equipment and passive components covering Hz to 40 GHz. MECA is a privately held ISO9001:2008 Certified, global designer and manufacturer for the communications industry with products manufactured in the **United States of America**.

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

NEW Catalog Supplement "mmWave Products"

DR. D.A.S. prescribes...

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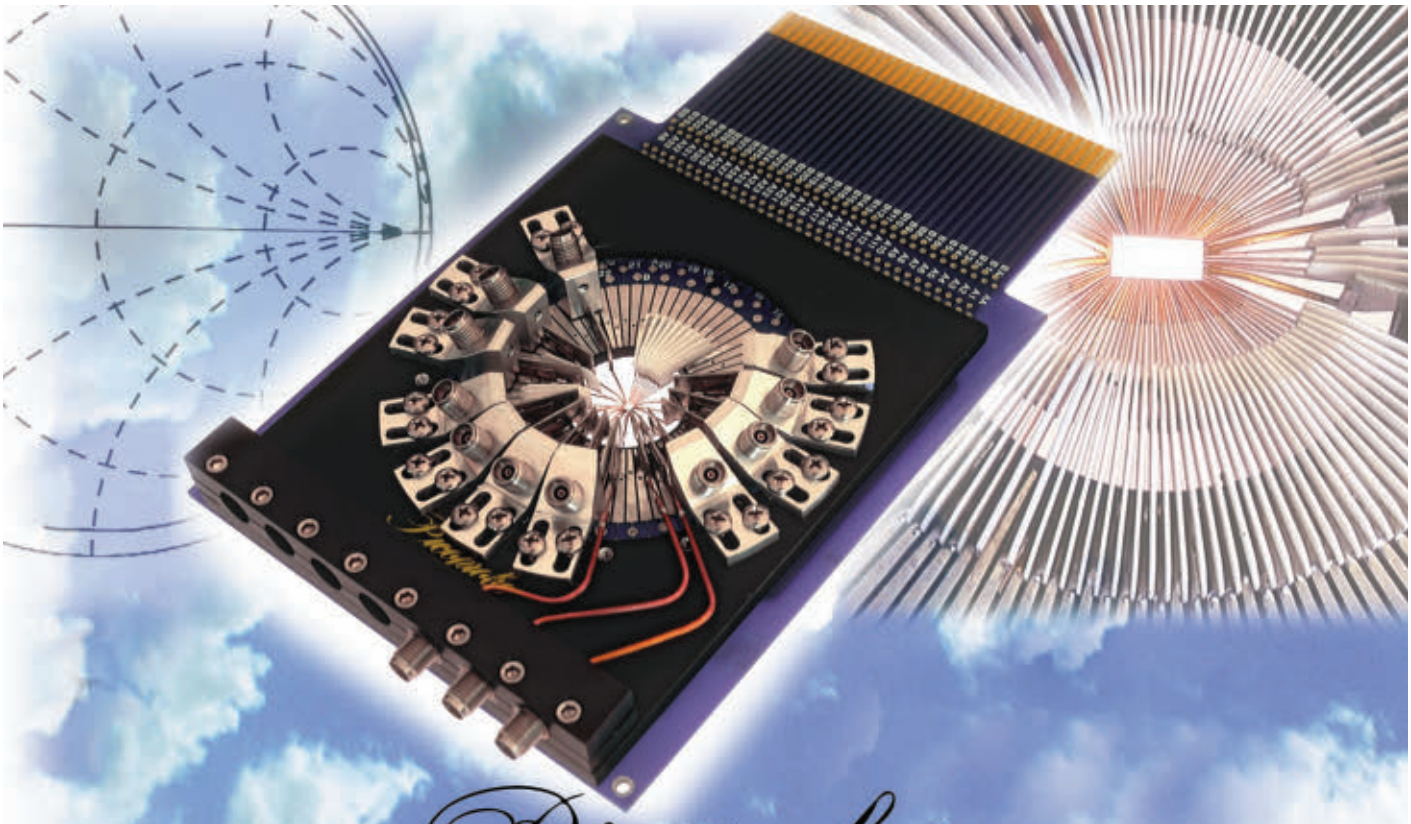

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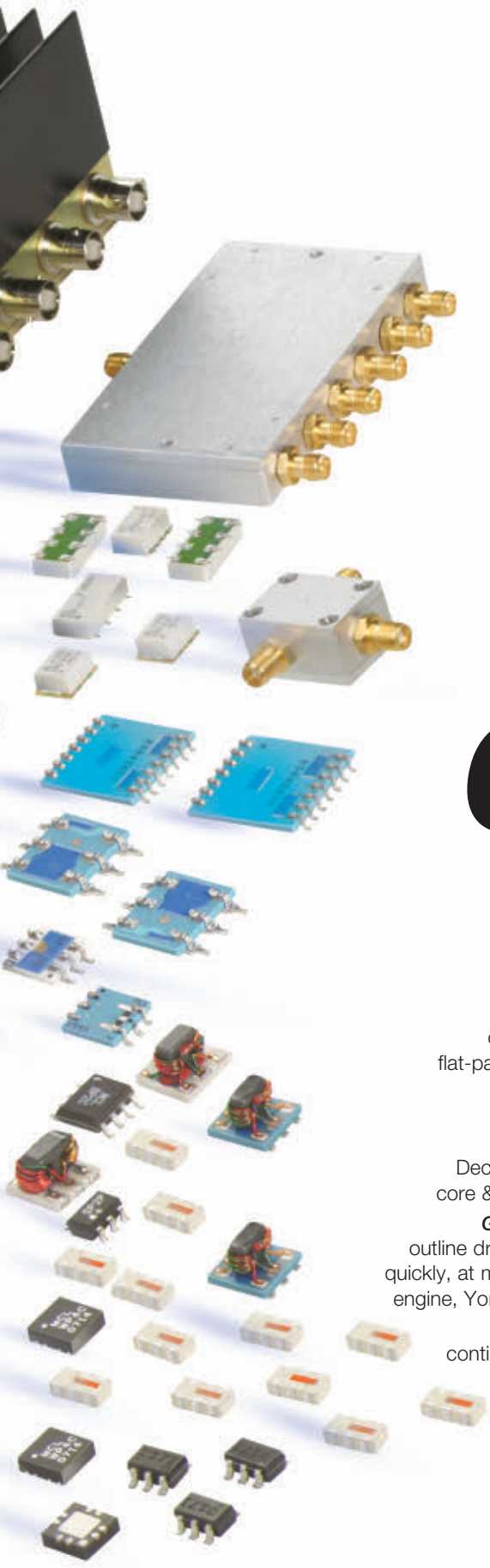

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The Industry's Largest Selection includes THOUSANDS of models, from 2 kHz to 18 GHz, at up to 300 watts power, in coaxial, flat-pack, surface-mount and rack-mount housings for 50 and 75 Ω systems.

From 2-way through 48-way designs, with 0°, 90°, or 180° phase configurations, Mini-Circuits power splitters/combiners offer outstanding performance for insertion loss, isolation, and VSWR. Decades of experience with multiple technologies make it all possible, from core & wire, microstrip, and stripline, to semiconductors and LTCC ceramics.

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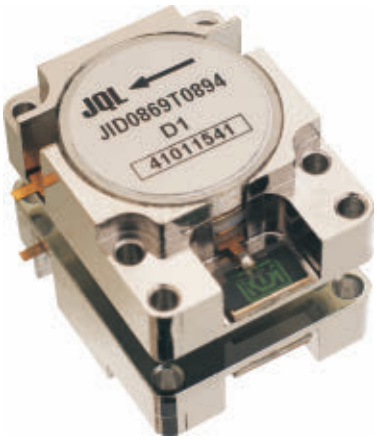

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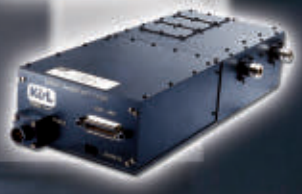

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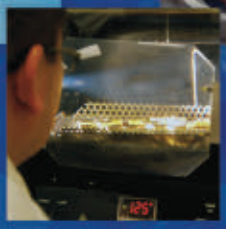

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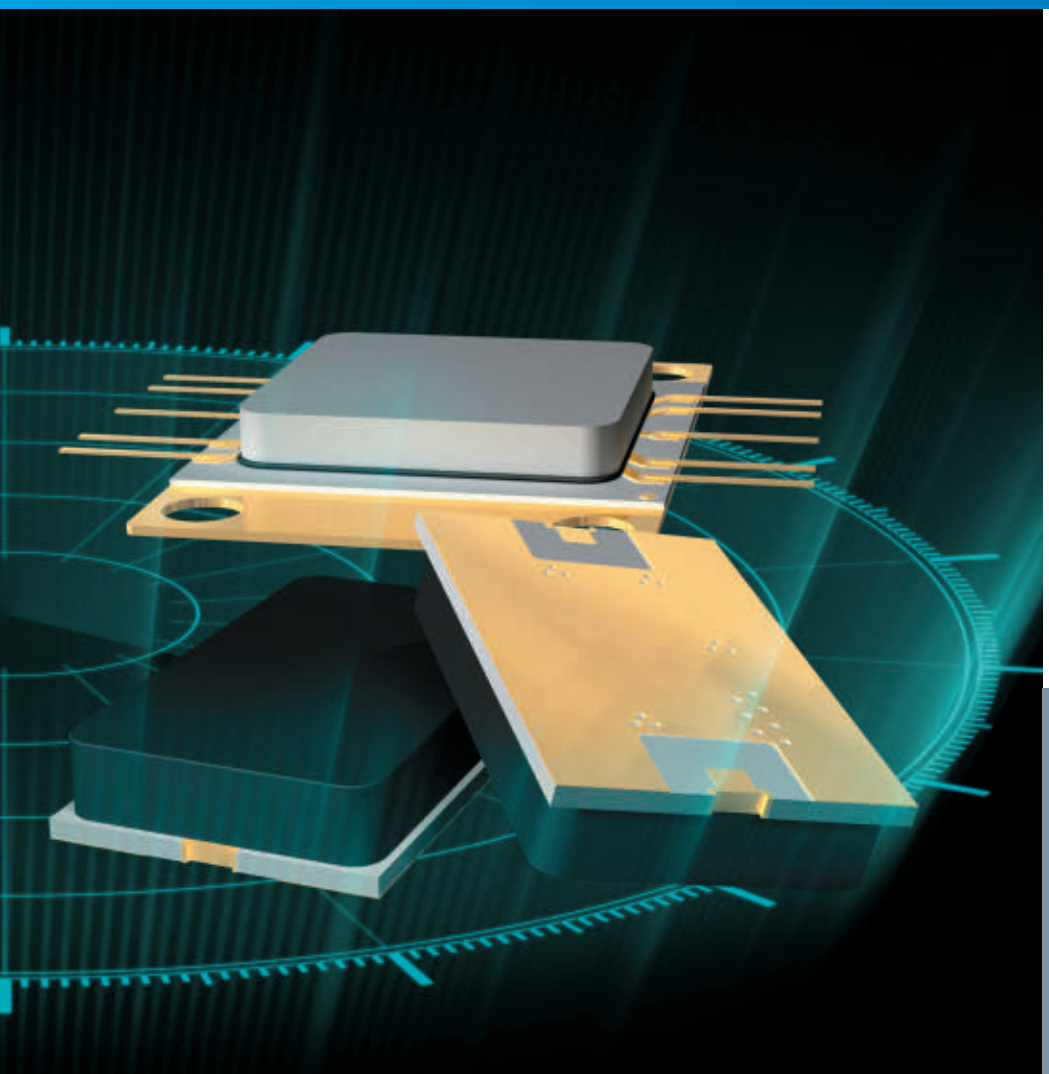

New high power surface mount limiters from Cobham Metelics are making your receiver/protector sections a whole lot easier to design. These drop-in devices include 11 completely integrated components that have been optimized for L, S, and C band radar systems. In comparison to silicon and GaAs MMICs,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

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

High Power Surface Mount Limiters

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

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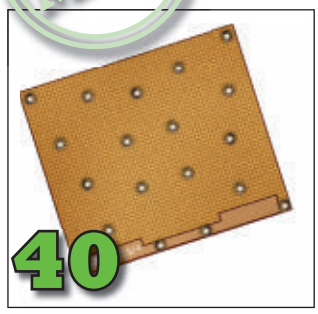
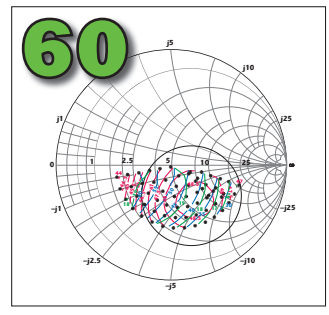
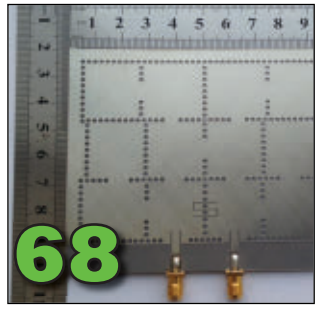
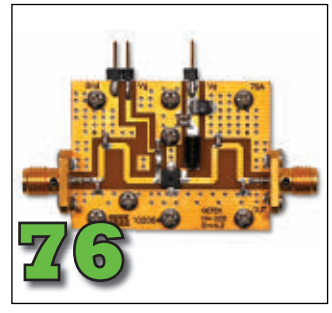








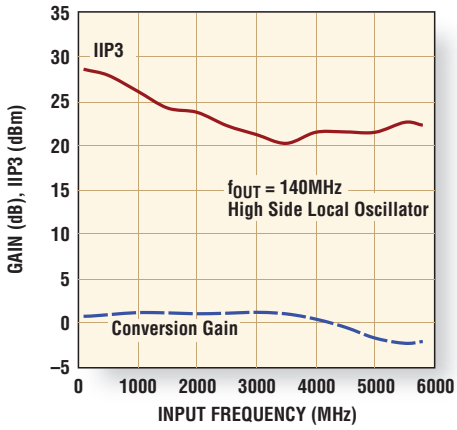
Cover Feature

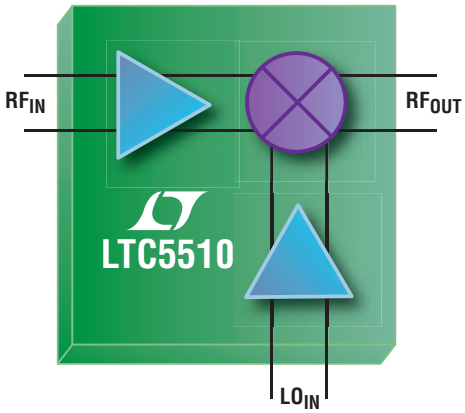
MVP: Most Valuable Product

Technical Features

Special Report

50Ω Matched Input 30MHz to 6GHz Mixer





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The LTC®5510's continuous 50Ω matched inputs and high IIP3 from 30MHz to 6GHz set a new level of performance for ultra-wideband scanning receivers, broadcast radios, VHF and white-space receivers, wireless microphone receivers, public safety radios, cable infrastructure receivers and RF test instrumentation. The device's up or downconversion capability provides flexibility while its excellent isolation performance simplifies your design.

Signal Chain Components

	LTC5567	+26.9dBm IIP3, 1.9dB Gain Mixer	Detector	LTC5582	10GHz, 57dB Dynamic Range RMS Detector
	LTC5569	Dual +26.8dBm IIP3, Low Power Mixer		LTC5587	6GHz 40dB Dynamic Range RMS Detector + ADC
	LTC6430-15	+50dBm OIP3 @240MHz, 15dB Gain Differential Amplifier		LTC6412	31dB Gain Control, Analog VGA with +35dBm OIP3
	LTC6431-15	+47dBm OIP3 @240MHz, 15dB Gain Single-Ended Amplifier		LT®5554	16dB Gain Control, 0.125dB/Step Digital VGA
ADC	LTC2158-14	Dual 14-Bit, 310Msps ADC		LTC6946	Low Phase Noise Integer-N PLL + VCO
	LTC2209	16-Bit, 160Msps ADC		LTC6945	Low Phase Noise Integer-N PLL

Info & Free Samples

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LINEAR TECHNOLOGY

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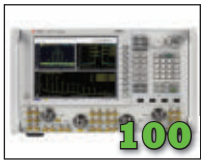

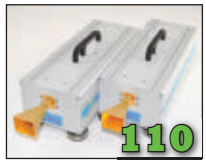

Product Features

Tech Briefs

Departments

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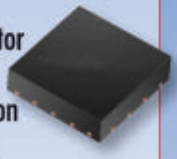
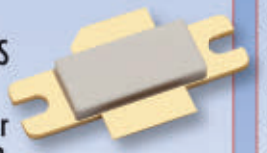


RF AMPLIFIERS
- Gain Blocks
- Coaxial Module
- Low-Noise
- Linear Drivers
- High Power
- Variable Gain

RF TRANSISTORS
- GaN
- LDMOS
- GaAs
- Bipolar
- High Power
- High Frequency



RF FILTERS
- Monoblock
- SAW / BAW
- HP / LP / BP
- Ceramic Resonator
- Duplexer / Diplexer
- Cavity

RF OSCILLATORS
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- VCXO
- TCXO
- PLL Synthesizers
- RF Generators

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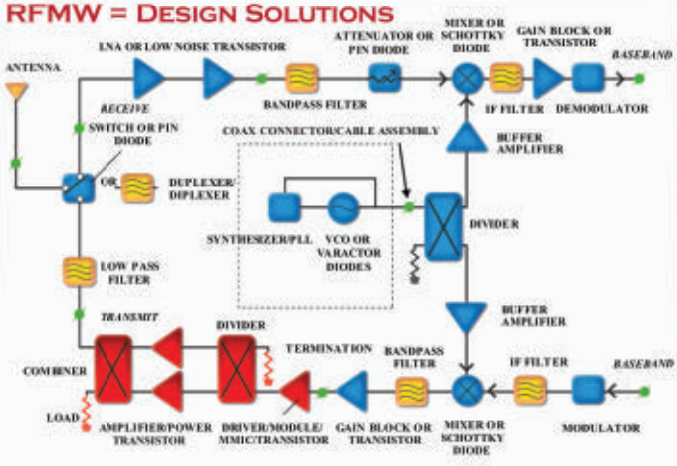
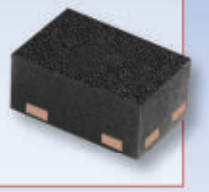
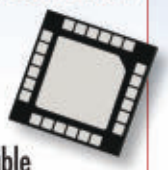


RF DIODES
- PIN
- Schottky
- Varactor
- Limiter
- Gunn



RF ATTENUATORS
- Fixed
- Digital
- Coaxial
- Chip
- Voltage Variable
- Temperature Variable



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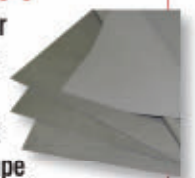

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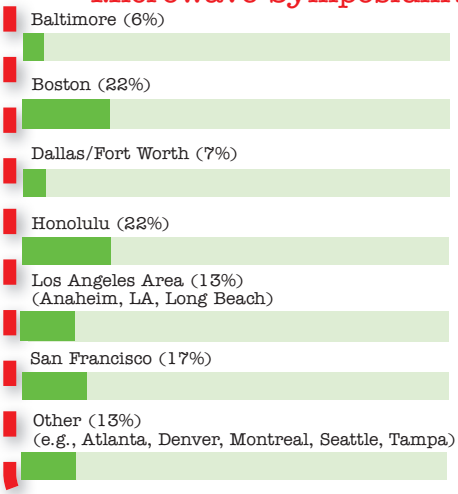
Web Survey

Now that GaN power amplifiers have penetrated the market, what is the next circuit function that will successfully use GaN?

Look for our multiple choice survey online at mwjournal.com

April Survey

What is your favorite city for the MTT-S International Microwave Symposium?



Ray Sharpe, CEO of **Isola Group**, discusses the company's history, global footprint and materials expertise in PCB products and related measurement services.

Executive Interview

WHITE PAPERS

KEYSIGHT TECHNOLOGIES — New Pulse Analysis Techniques for Radar and EW

TEXAS INSTRUMENTS — Why Your High-Speed ADC Can Never Have Enough SNR

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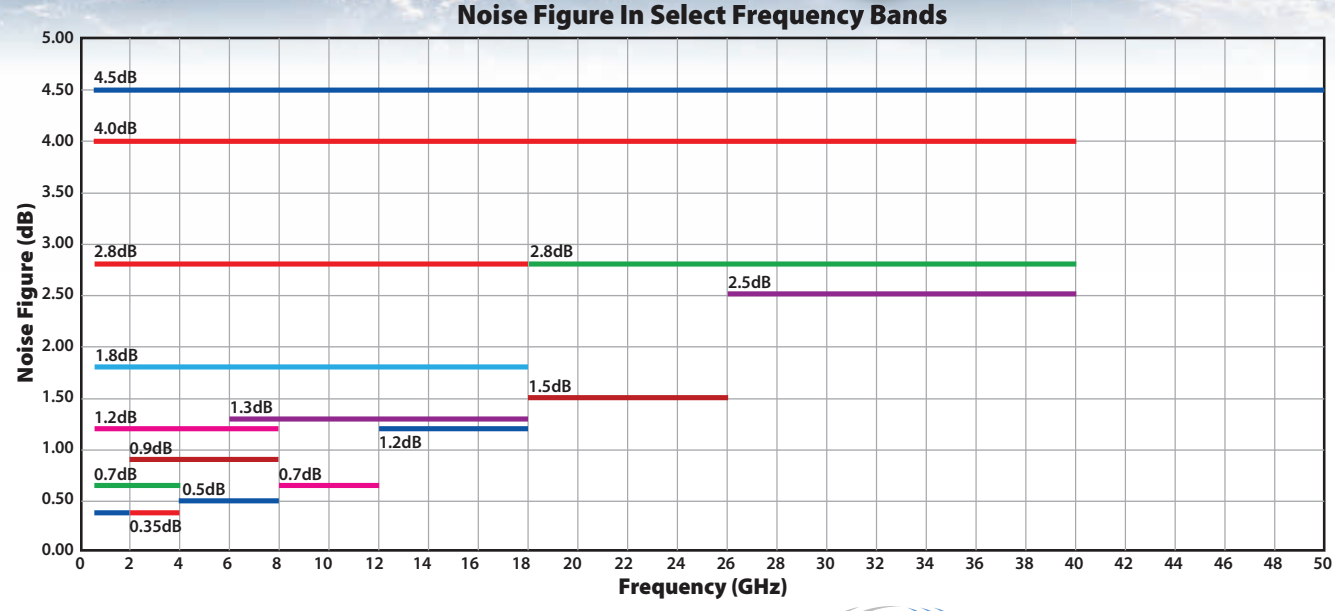
Has Amplifier Performance or Delivery Stalled Your Program?



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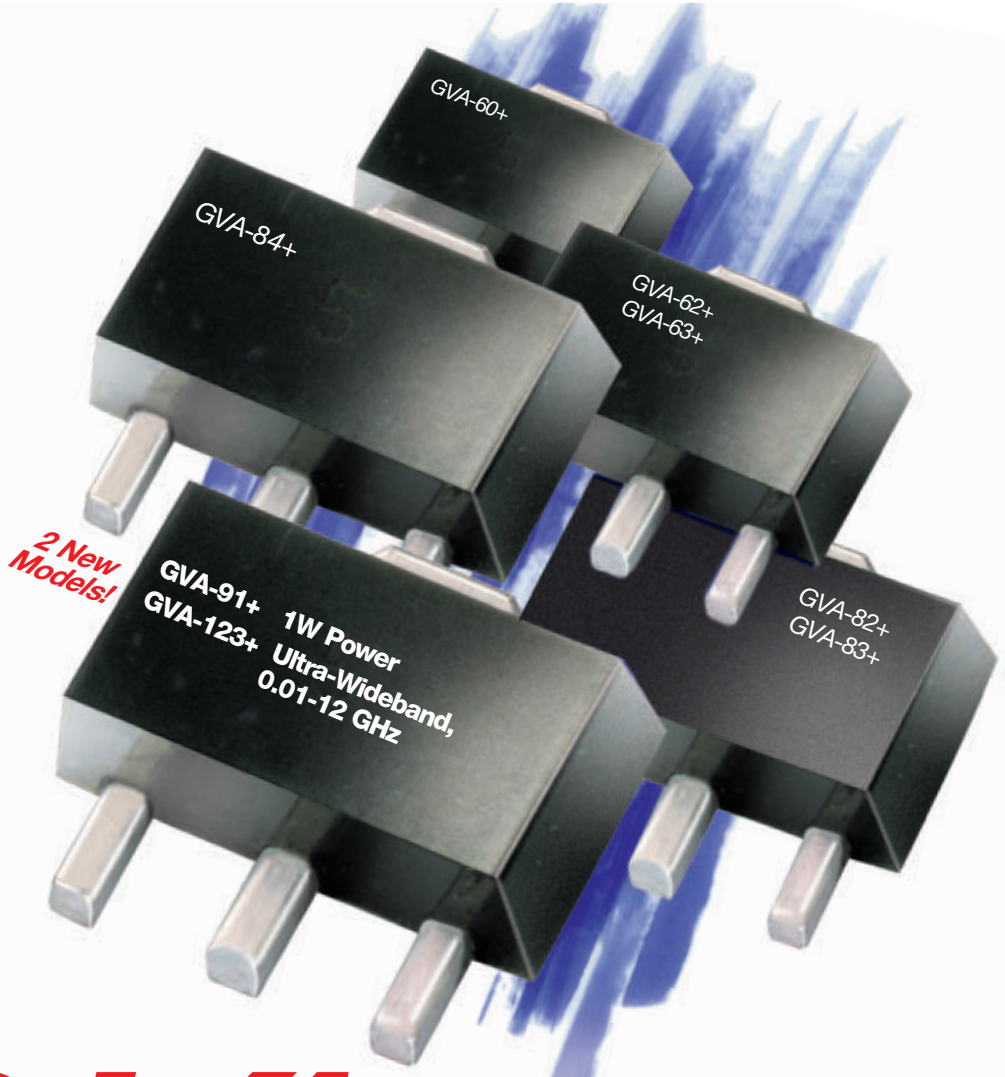

GVA AMPLIFIERS

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DC* to 12 GHz up to 1W Output Power

from 94¢ ea. (qty. 1000)

GVA amplifiers now offer more options and more capabilities to support your needs. The new **GVA-123+** provides ultra-wideband performance with flat gain from 0.01 to 12 GHz, and new model **GVA-91+** delivers output power up to 1W with power added efficiency up to 47%! These new MMIC amplifiers are perfect solutions for many applications from cellular to satellite and more! The GVA series now covers bands from DC to 12 GHz with various combinations of gain, P1dB, IP3, and noise figure to fit your application. Based on high-performance InGaP HBT technology, these amplifiers are unconditionally stable and designed for a single 5V supply in tiny SOT-89 packages. All models are in stock for immediate delivery! Visit minicircuits.com for detailed specs, performance data, export info, **free X-parameters**, and everything you need to choose your GVA today! *US patent 6,943,629*

**Low frequency cut-off determined by coupling cap.*
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Nikola Tesla was a Serbian American inventor, electrical engineer, mechanical engineer, physicist and futurist best known for his contributions to the design of the modern alternating current (AC) electricity supply system. Tesla gained experience in telephony and electrical engineering before immigrating to the United States in 1884 to work for Thomas Edison in New York City. His patented AC induction motor and transformer were licensed by George Westinghouse, who also hired Tesla for a short time as a consultant. His work in the formative years of electric power development was involved in a corporate alternating current/direct current "War of Currents" as well as various patent battles. Tesla went on to pursue his ideas of wireless lighting and electricity distribution in his high-voltage, high-frequency power experiments in New York and Colorado Springs and made early (1893) pronouncements on the possibility of wireless communication with his devices. In his lab he also conducted a range of experiments with mechanical oscillators/generators, electrical discharge tubes and early X-ray imaging.

Nikola Tesla. (2015, May 10). In Wikipedia, The Free Encyclopedia. Retrieved 17:29, May 11, 2015, from http://en.wikipedia.org/w/index.php?title=Nikola_Tesla&oldid=661752110

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Heterogeneous Integration for Revolutionary Microwave Circuits at DARPA

Daniel S. Green
U.S. Defense Advanced Research Projects Agency (DARPA), Arlington, Va.
Carl L. Dohrman, Jeffrey Demmin, Yan Zheng
Booz Allen Hamilton Inc., Arlington, Va.
Tsu-Hsi Chang
HetInTec Corp., Rockville, Md.

The DARPA Microsystems Technology Office is developing revolutionary materials, devices and integration techniques for meeting the performance requirements for advanced microwave and RF systems. The DARPA Compound Semiconductor Materials on Silicon (COSMOS) program focused on the development of new methods to tightly integrate compound semiconductor (CS) technologies within state-of-the-art silicon CMOS circuits in order to achieve unprecedented circuit performance levels. The DARPA Diverse Accessible Heterogeneous Integration (DAHI) program is continuing that work by developing heterogeneous integration processes to intimately combine advanced CS devices, as well as other emerging materials and devices, with high-density silicon CMOS technology. Taken together, these programs are addressing many of the critical challenges for next-generation microwave and RF modules and seek to revolutionize DoD capabilities in this area.

Modern microwave and RF systems are under constant pressure to make use of the spectrum in sophisticated ways, while working within limited power budgets on platforms with reduced size and weight. The compound semiconductor electronics industry is well-positioned to address these challenges, due to the superior properties and diversity of CS materials. For example, high electron mobility and peak velocity of InP-based material systems have resulted in transistors with f_{max} above 1 THz[1] as well as ultra-high-speed mixed-signal circuits.[2] The wide energy bandgap of GaN has enabled large voltage swings as well as high breakdown voltage RF power devices.[3] Excellent thermal conductivity of SiC also makes tens-of-kilowatt power switches possible.[4] Additionally, on-chip high Q microelectromechanical resonators and switches in various materials, such as AlN, have been demonstrated that potentially can be used for clock references and frequency selective filters.[5]

As indicated by ***Table 1***, compound semiconductors exhibit many superior properties relative to silicon technology. On the other hand, silicon CMOS-based digital technologies

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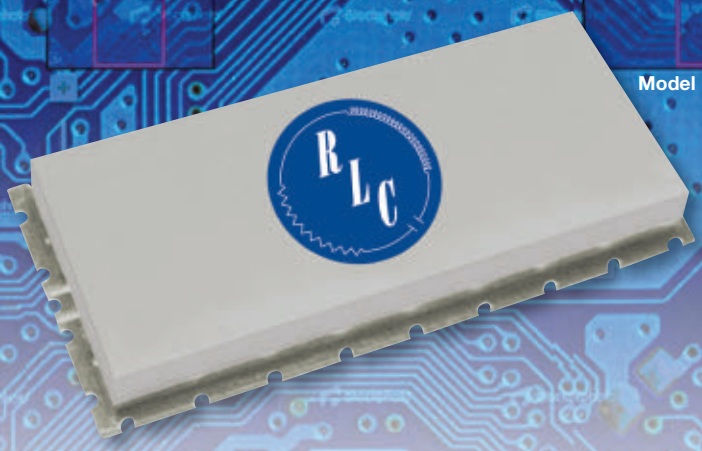

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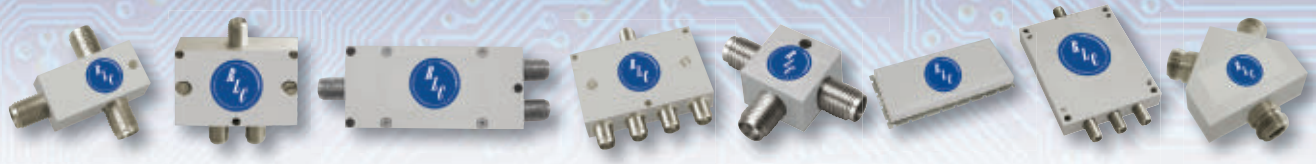

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TABLE 1

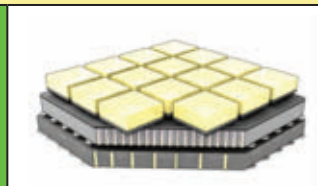
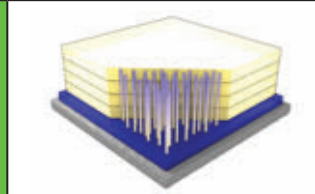
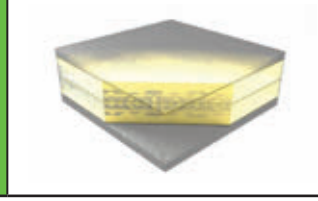
MATERIAL PROPERTIES AND CIRCUIT MATURITY OF SEMICONDUCTOR TECHNOLOGIES

Parameter	Why?	Unit	Si	GaAs	ABCS[1]	InP[2]	GaN[3]
Electron Mobility	Carrier Velocity	10^3 cm^2/V-s	1.4	8.5	40	12	<1
V_{peak}	Transit Time	10^7 cm/s	1	2	8	2.5	2.5
E_{BK}	Voltage Swing	10^5 V/cm	5.7	6.4	0.4	4	40
E_g	Charge Density	eV	1.12	1.42	0.35	0.74	3.4
κ	Heat Removal	W/cm·K	1.3	0.5	0.27	0.05	2.9
Maturity	Circuit Complexity		Excellent	Good	Limited	Ok	Limited

Notes: 1) ABCS–antimonide-based CS, InAs channel, 2) InGaAs channel, 3) SiC substrate

TABLE 2

ADVANCED Si CMOS INTEGRATION TECHNOLOGIES

Chip to Wafer: ***Passive Si interposer with TSVs and interconnect (2.5D)***		Status: LVM FPGAs, Si-Partitioning Manufacturers: Amkor, ASE, TSMC, etc. Source: TSMC[10]
Wafer Level: ***TSVs through active stacked devices***		Status: HVM DRAM, NAND, sensors LVM Logic+Memory Manufacturers: Micron, Samsung, Hynix, etc. Source: Micron[11]
Wafer Level: ***Face to face wafer bonding of active devices***		Status: Development/prototyping Manufacturers: Tezzaron, Ziptronix, Novati Source: Qualcomm[12]

have achieved tremendous levels of complexity and integration, while also demonstrating high levels of yield and manufacturability. At the same time, RF CMOS[6] and SiGe HBT[7] device speeds have continued to increase into the multi-100 GHz regime, albeit at the expense of breakdown voltage. These facts can be attributed to the aggressive device scaling and the advanced levels of back-end-of-line integration driven by Moore's Law over the past 50 years. In addition, Si-based digital correction and linearization techniques[8] have become critical to achieve excellent RF and mixed-signal circuit performance despite drawbacks of the material system.

Given these trends, it is our view that the future of CS electronics depends not on displacing Si, but rather on heterogeneous integration of compound semiconductors with silicon technology in a way that will allow the advantages of the two technology types to be optimally combined. In particular, heterogeneous integration enables size reduction that is critical for miniaturized arrays that are required for 5G proliferation.[9]

The semiconductor industry has approached the challenges of heterogeneous integration primarily at the macro-scale with assembly-based approaches, such as package and IC stacking with wire bond or flip-chip interconnects. This facilitates pre-integration testing of components, as well as flexibility in selection of device technology and suppliers. More advanced technologies based on interposers and wafer-level assembly are currently gaining traction (see ***Table 2***), but these are primarily for homogeneous integration of Si devices (e.g., logic and memory, FPGAs) and reflect a range of maturity levels.

Figure 1 illustrates the potential impact of heterogeneous integration in RF/mixed signal systems, using a representative transceiver as an example. Essentially all major components in a typical transceiver can benefit from the reduced parasitics of heterogeneous integration, utilizing the benefits of high-performance CS materials with the control and calibration capabilities of Si CMOS.

In order to realize the value of heterogeneous integration for DoD microwave systems, DARPA has invested in heterogeneous integration of microwave technology through several programs. A timeline overview of these programs is shown in ***Figure 2***.

DARPA COSMOS PROGRAM

The DARPA Compound Semiconductor Materials on Silicon (COSMOS) program, initiated in 2007, focused on the development of new methods to tightly integrate CS technologies within state-of-the-art silicon CMOS circuits, in order to achieve unprecedented circuit performance levels. COSMOS explored three different approaches (see ***Figure 3***) to achieving InP BiCMOS integrated circuit technology, featuring InP HBTs and deep submicron Si CMOS[13, 14, 15] for RF and mixed-signal applications. These approaches included micrometer-scale assembly of InP chiplets with Si CMOS after completion of back-end-of-line (BEOL) processing,[13] an epitaxial layer printing approach[14] in which unprocessed InP-based heterostructures are transferred to a fully processed Si CMOS substrate and a monolithic "middle-end-of-line" approach[15] in which InP HBTs are heteroepitaxially grown coplanar with Si CMOS using a multi-layered Si-based substrate platform.[16]

These three approaches all achieved success demonstrating heterogeneously integrated differential amplifier circuits using InP HBTs as the differential pair and Si CMOS for the load and current source transistors, resulting in world-record DC gain-unity gain-bandwidth prod-

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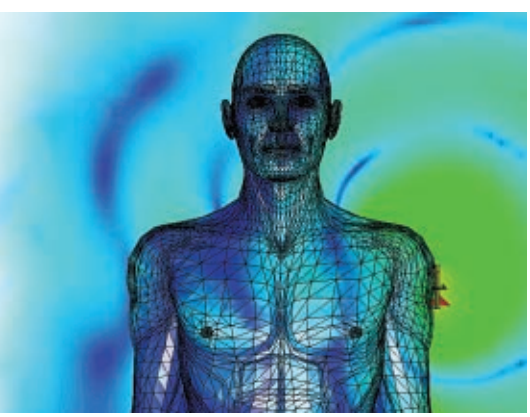

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ucts. In later stages of the COSMOS program, performers demonstrated more complex heterogeneously integrated mixed-signal circuit designs, including digital-to-analog converters (DAC) and analog-to-digital converters (ADC). These circuits are utilizing a number of advanced calibration and self-healing techniques that are enabled by the heterogeneous integration of deep submicron Si CMOS with high speed InP HBTs. Due to the required circuit complexity, these calibration and self-healing techniques would not be possible in circuits implemented in a purely InP-based technology. However, the InP HBTs provide higher speed, higher breakdown voltage and intrinsically better transistor matching than could be accomplished with a purely CMOS-based mixed signal circuit.

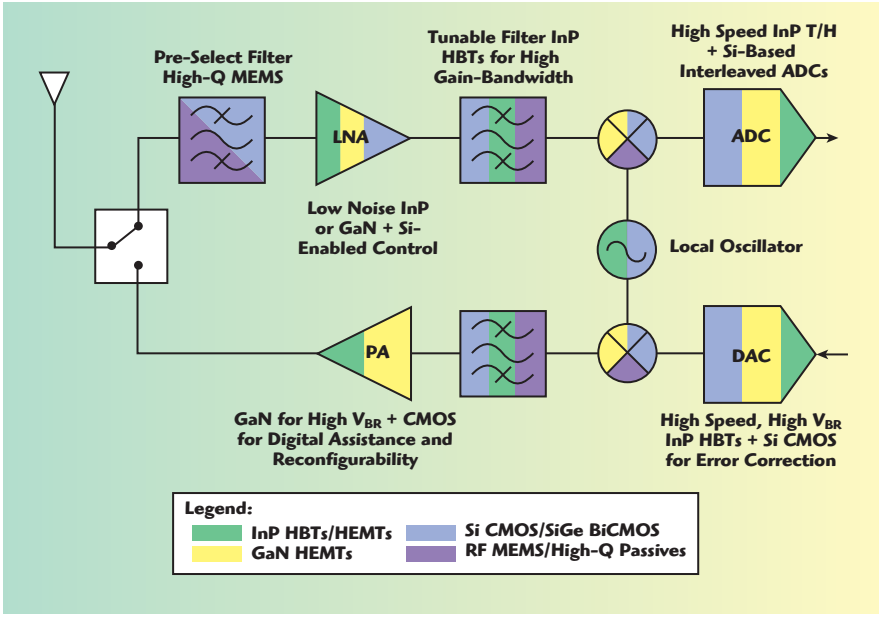

Fig. 1 A representative transceiver system is a typical application that can leverage heterogeneous integration.

One of the advanced circuits demonstrated in the COSMOS program is an ADC with revolutionary mixed-signal performance in InP BiCMOS technology.[17] The ADC design employs a time-interleaved architecture utilizing InP HBTs for track-and-hold circuitry and 130 nm Si CMOS to provide the sub-ADCs and the circuitry required for complex time-interleaving. This ADC represents the most complex heterogeneously integrated circuit to date, with ~1000 InP HBTs, ~16,000 Si HBTs and 2500 Si MOSFETs, with more than 1800 heterogeneous interconnects between the InP HBT chiplet and the Si base chip (see ***Figure 4***). This approach has resulted in an ultra-wideband ADC with state-of-the-art signal-to-noise-and-distortion (SINAD) ratio of over 30 dB across frequency ranges of 2.75 to 8.75 GHz and 14.25 to 20.25 GHz (see ***Figure 5***). The COSMOS ADC performs on par with 32 nm ADCs[18] despite using 130 nm CMOS, demonstrating the power of heterogeneous integration to improve the performance of older Si CMOS or augment advanced Si CMOS as the integration process is compatible across nodes.

In another COSMOS project, a team of performers at Raytheon/MIT has demonstrated a process for the

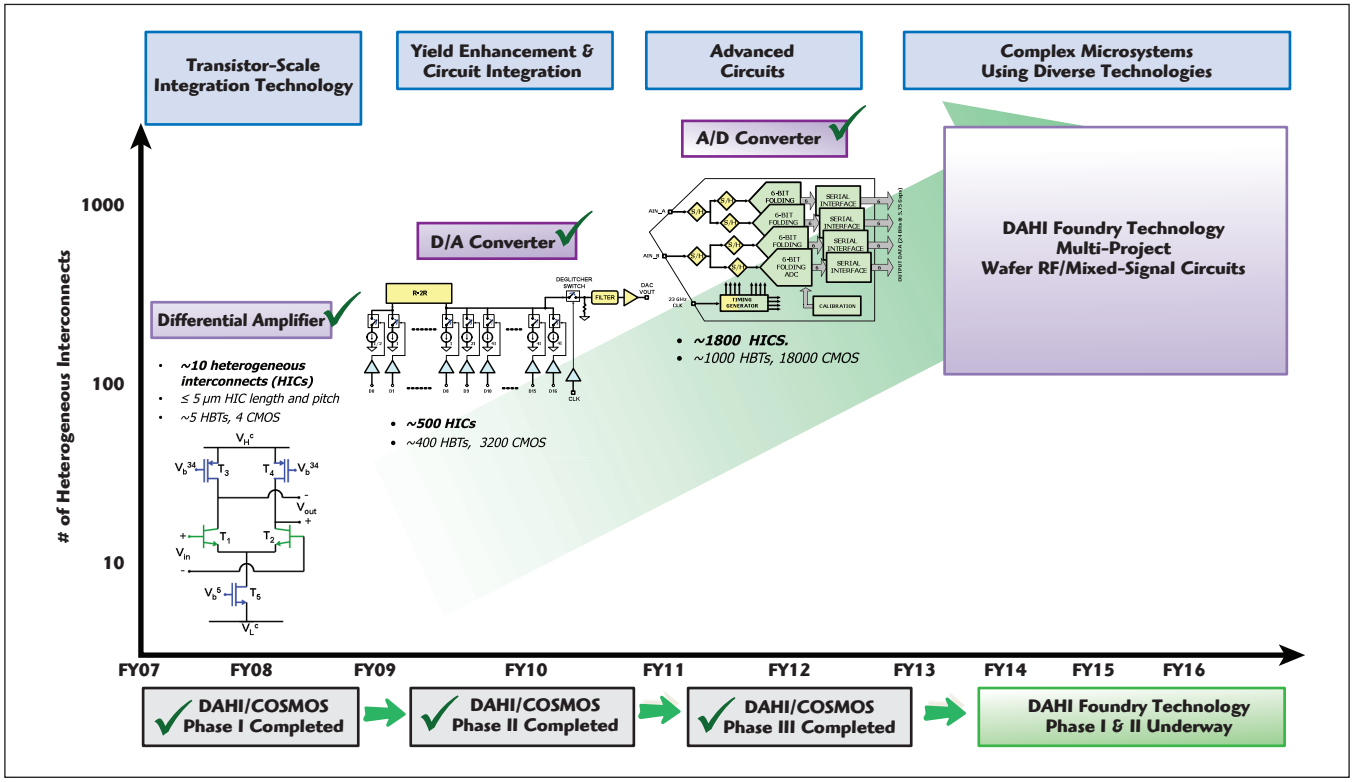

Fig. 2 Timeline of DARPA investment in heterogeneous integration for microwave applications.

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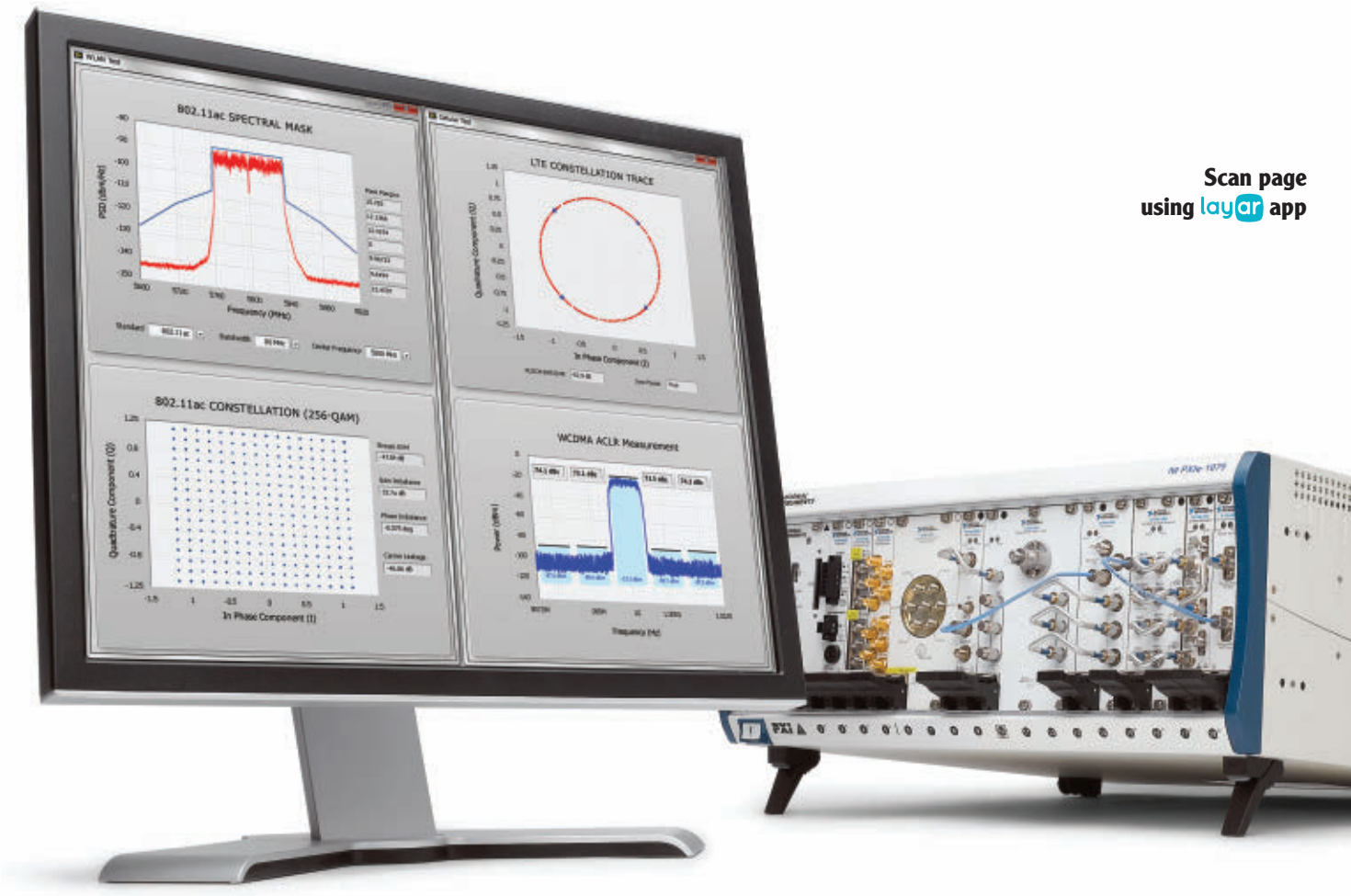

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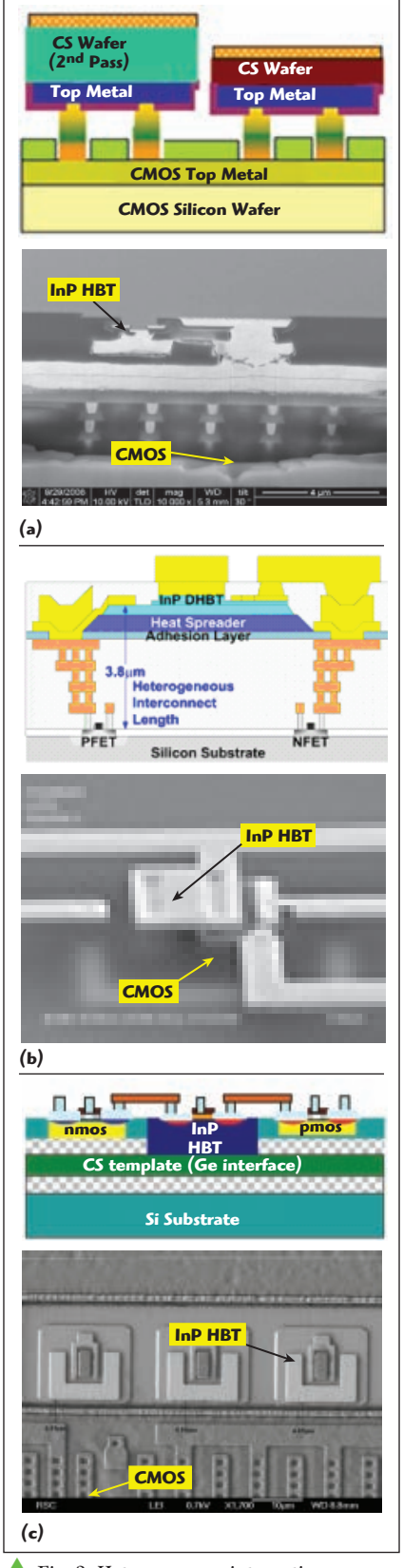

Fig. 3 Heterogeneous integration processes being pursued in the DAHI/COSMOS thrust: micrometer scale assembly (a) epitaxial layer printing (b) and monolithic epitaxial growth using a multi-layered lattice-engineered substrate (c).

monolithic integration of GaN HEMTs and Si CMOS on a modified silicon-on-insulator (SOI) wafer. The SOI wafer consists of a Si (111) handle substrate and Si (100) device layer. By opening windows through the Si device layer and buried oxide layers, GaN HEMT structures can be epitaxially grown in the windows on the Si (111) surface, as shown in ***Figure 6a***. Using this approach, the Raytheon/MIT performers demonstrated the world's first monolithically integrated GaN and CMOS RF amplifier circuit (see ***Figures 6b*** and ***7***) using heterogeneously interconnected GaN HEMTs and pMOS gate bias control.[19]

COSMOS MULTI-PROJECT WAFER

During the course of COSMOS, an InP BiCMOS multi-project wafer (MPW) activity was also initiated based on the HRL Laboratories DAHI/COSMOS technology using 90 nm CMOS and 0.25 μm InP HBTs. In this effort, InP BiCMOS technology was utilized by nine external circuit design teams.

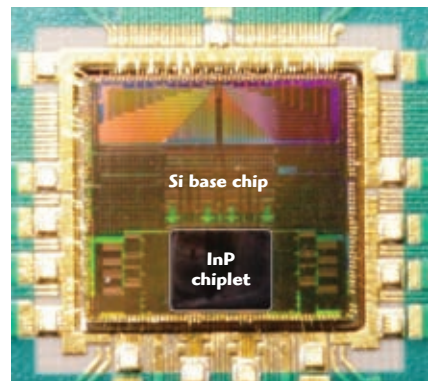

Fig. 4 Micrograph of COSMOS ADC showing InP chiplet and Si CMOS base chip.

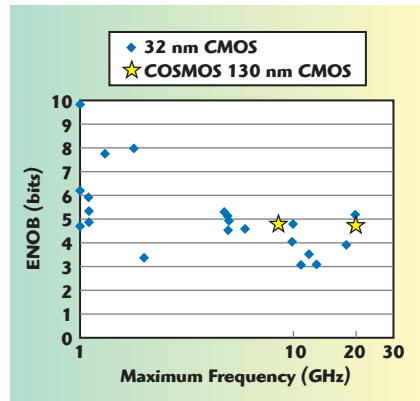

Fig. 5 Effective number of bits (ENOB) vs. maximum frequency for state-of-the-art ADCs compared to the COSMOS ADC. COSMOS performs on par with 32 nm ADCs despite using 130 nm CMOS.

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A team at the University of California, San Diego recently demonstrated a 30 GSPS track-and-hold amplifier on the InP BiCMOS platform.[20] Differential output spectra with 1 and 31 GHz inputs are shown in ***Figure 8***. This InP track-and-hold (T/H) amplifier on an InP BiCMOS platform represents a key building block for interleaved ADCs, enabling complex interleaving using advanced Si CMOS for high bandwidth, high resolution performance.

An additional circuit design fabricated through the DAHI/COSMOS MPW effort is a four-stage W-Band low-noise amplifier (LNA), designed by a team from the Air Force Research Laboratory.[21] Measured results indicate a noise figure (NF) as low as 5.7 dB at 92 GHz (NF < 7.2 dB from 75 to 100 GHz), peak gain of 27.7 dB (gain > 20 dB from 75 to 100 GHz) and power dissipation of 19.2 mW from 75 to 100 GHz. Plots of gain and noise figure versus frequency are shown in ***Figure 9***. This device dem-

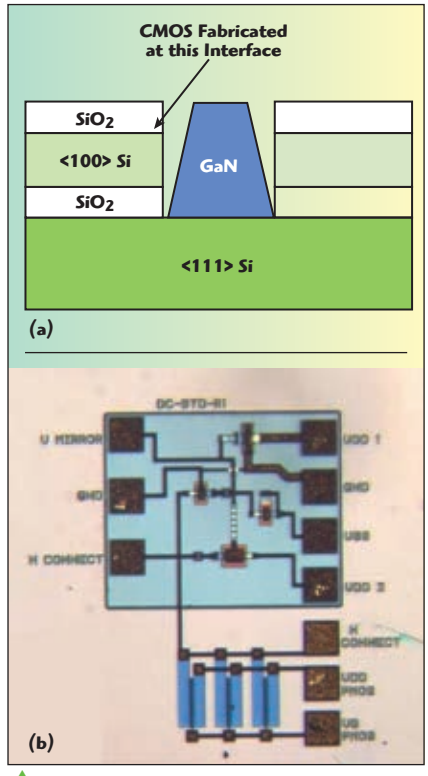

Fig. 6 Cross-sectional schematic of GaN growth on multi-layered Si-based substrate (a). Optical micrograph of Raytheon/MIT's monolithic heterogeneously integrated GaN HEMT + CMOS RF power amplifier circuit (b).

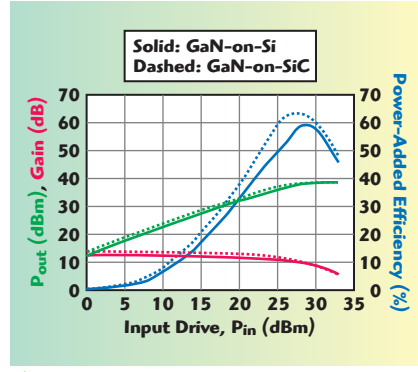

Fig. 7 Representative microwave measurements at 10 GHz for the GaN HEMTs shown in Fig. 6 (solid lines) compared to control samples fabricated on SiC substrates (dashed lines).

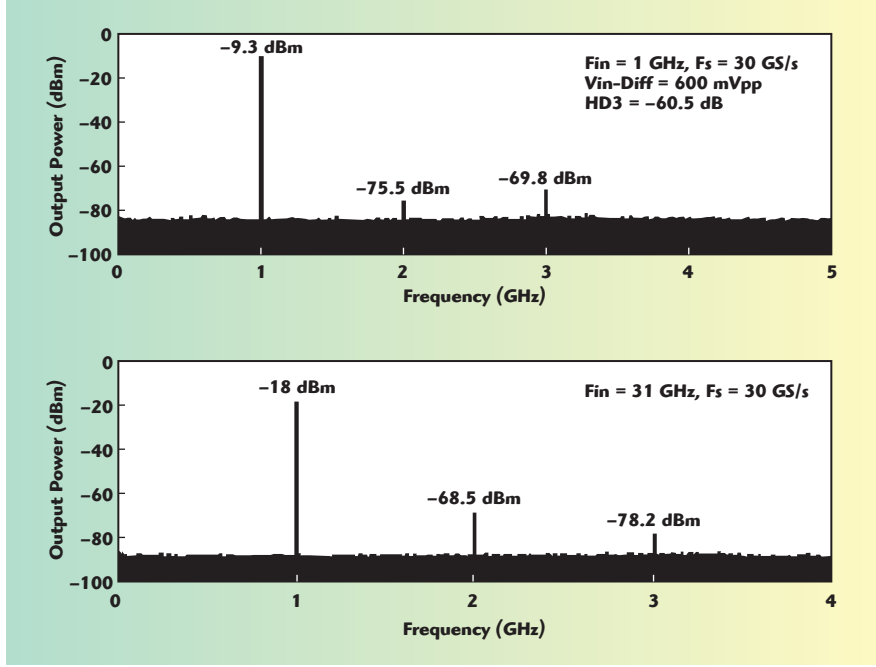

Fig. 8 Differential output spectra for InP BiCMOS T/H amplifier[20](used with permission).

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onstrated superior noise figure, gain-bandwidth product and power dissipation compared to SiGe BiCMOS W-Band LNAs.

DIVERSE ACCESSIBLE HETEROGENEOUS INTEGRATION (DAHI)

The COSMOS program significantly expanded the state of the art in heterogeneous integration technology and demonstrated the potential of this technology for producing revolutionary microsystem capabilities. In order to build upon this success, a new DAHI Foundry Technology thrust was initiated[22] in 2013 to advance the diversity of heterogeneous device and materials available in a silicon-based platform and make this technology available to the greater DoD and commercial microsystems design community through an accessible, manufacturable foundry for device-level heterogeneous integration. This foundry includes a wider array of materials and devices (including, for example, multiple electronics and MEMS technologies) with complex silicon-enabled (e.g., CMOS) architectures on a common silicon substrate platform. The goal of the DAHI Foundry Technology thrust is to develop a mature, reliable heterogeneous integration technology and to establish cost-effective access to sustainable DAHI foundry capabilities that will enable microsystem designers to choose a range of available semiconductor technologies for transistors or circuit building blocks, to optimize performance of novel advanced microsystems. This capability will not only have significant impact on the performance of both military and commercial microsystems, but it also represents a new paradigm for the CS electronics community.

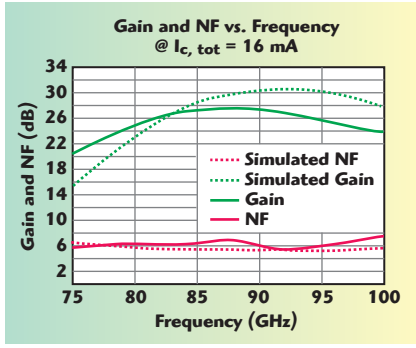

Fig. 9 Gain and noise figure versus frequency for InP BiCMOS W-Band LNA[21] (used with permission).

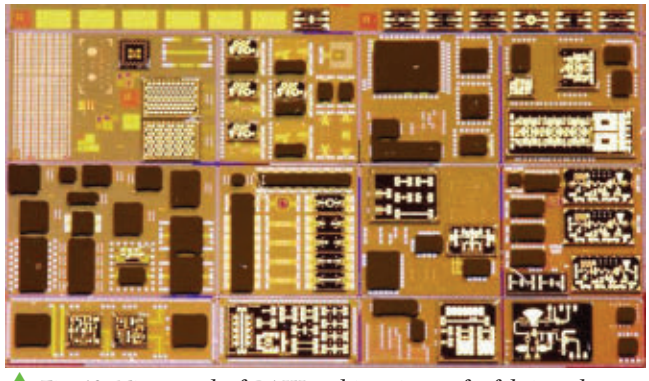

Fig. 10 Micrograph of DAHI multi-project wafer fabricated reticle [23] (used with permission).

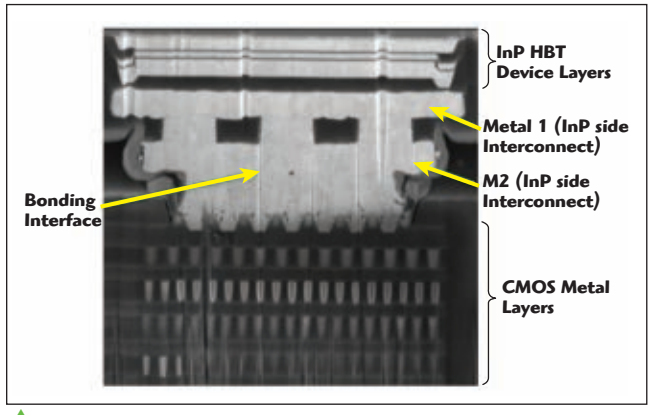

Fig. 11 SEM FIB cross section of DAHI Foundry Technology heterogeneous interconnect (HIC)[23] (used with permission).

In order to realize this goal of highly flexible, diverse heterogeneous integration, an assembly-based multi-technology integration process was developed. This approach confers a number of important advantages for the establishment of a diverse, accessible foundry technology. By conducting the heterogeneous integration after standard BEOL processing, no process changes are required for the Si base or CS technologies being integrated. This allows rapid introduction of new process technologies within the foundry. Other approaches, in which heterogeneous integration occurs prior to or during BEOL processing, require

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significant levels of process change with often extensive process development timescales and budgets. Only a post-BEOL heterogeneous integration approach can allow rapid integration of third-party technologies into a foundry. This allows the foundry to easily incorporate advances in Si and CS technology nodes into their technology offerings.

Recently, a DAHI multi-project wafer run was demonstrated[23] utilizing 0.25 µm InP HBTs and 0.2 µm GaN HEMTs heterogeneously integrated with 65 nm Si CMOS (see ***Figures 10*** and ***11***). This is the first known instance of heterogeneous integration of three device technologies at the transistor level. This heterogeneous integration process utilizes a chiplet assembly-based approach occurring after the completion of BEOL processing. This allows maximum flexibility for the inclusion of novel technologies and requires no changes to the technologies to be integrated. Initial characterization of process control monitors indicates high yield of heterogeneous interconnects among all technologies; characterization is still underway. This multi-project wafer included numerous designs which yielded, including a heterogeneous integrated Q-Band VCO-amplifier chain.[24] The InP VCO demonstrated 2 GHz of tuning range at 35 GHz while the GaN amplifier provided 15 dB gain. Output power versus frequency for the VCO-amplifier chain is shown in ***Figure 12***. Other circuits from the multi-project wafer run are currently being tested.

IP REUSE IN HETEROGENEOUS INTEGRATION

Advances in heterogeneous integration have enabled groundbreaking system performance, but proliferation of the technology will depend on the development of robust and efficient design methodologies. Looking ahead, this challenge is further complicated by the dramatic increase in the complexity and performance requirements of electronic systems. For instance, while early mobile phones could only handle one low bandwidth RF signal, today's mobile devices are packed with technology that enables Wi-Fi, Bluetooth, near field communications (NFC), AM/FM, Qi and GPS in addition to multiple cellular bands. In the digital domain, field programmable gate arrays (FPGAs) have enabled designers to greatly reduce design time and increase system longevity by providing in-field programmability. However, microwave and mixed signal technologies lack a well-developed field-programmable integrated circuit capability. Consequently, increasingly

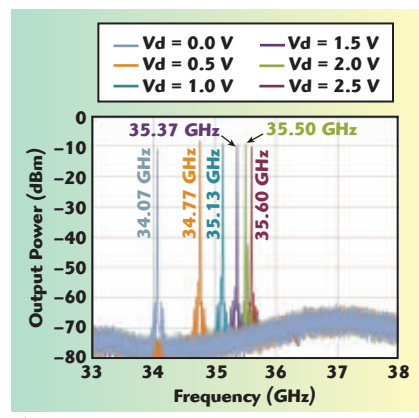

Fig. 12 Heterogeneously integrated VCO-amplifier chain output for various input tuning voltages[24] (used with permission).

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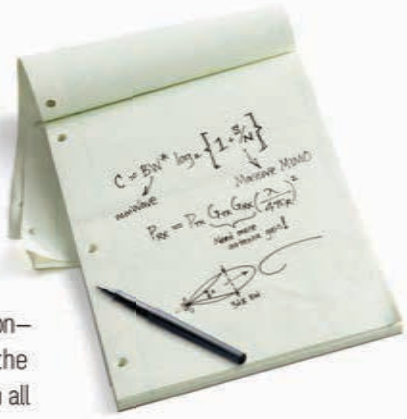

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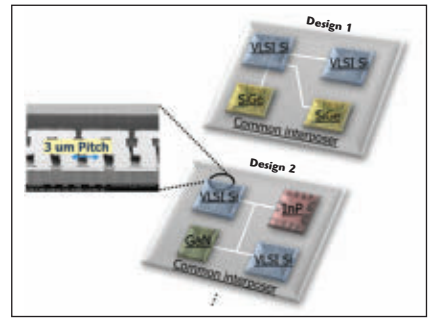
complex custom application-specific integrated circuits (ASICs) need to be developed to meet the needs of modern microwave systems. Since design costs have become the largest fraction of chip development for low-volume producers like the DoD, constantly designing customized solutions is becoming prohibitively expensive and forcing many designers to compromise performance and capability for cost and design time.

The superior performance of advanced CS device technology offers a path towards meeting future microwave system requirements, but the lack of accessible and cost-effective integration strategies limits their use. By expanding upon recent demonstrations of device-level heterogeneous integration with a circuit design block intellectual property (IP) reuse strategy, designers could leverage IP blocks developed across the DoD and commercial markets to choose technologies that best accomplish a mission,



▲ *Fig. 13 Vision for IP reuse using assembly-based heterogeneous integration.*

rather than being constrained to a single technology or process node. Such design blocks can be implemented as standardized chiplets, which can be assembled on a standardized interposer substrate to create high-performance microwave systems for a wide variety of defense system needs. Implemented correctly, this new design flow will drastically reduce design cost and development time, while enhancing system flexibility. This vision is depicted in ***Figure 13***.

There are many challenges faced in successfully implementing this vision, such as the creation of an IP reuse ecosystem that can manage IP blocks from various process modules (e.g., Si, GaAs, GaN, InP and SiGe) across the design and fabrication cycle. Additionally, developing a design flow that properly handles device modeling, documentation and easy integration with commercial design tools will need to be addressed. Finally, expansion of the heterogeneous integration strategy demonstrated in DAHI to the wider design community to enable any current or future process module to be combined interchangeably using standard interfaces is needed to unlock the full potential.

The benefit of an ecosystem that enables rapid deployment of heterogeneous IP would be immense. Future designs could be optimized to fully leverage the advantages of the wide range of available technologies. More importantly, reusing IP blocks would reduce design cycle times and greatly lower design costs. DARPA sees development of IP reuse methodologies as a priority for further progress in heterogeneous integration. ■

ACKNOWLEDGMENTS

The authors would like to thank the program participants in the

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Df @ 10 GHz	0.0028 - 0.0036	0.0028, 0.0031 & 0.0034	0.0031*	0.0030*	0.0017
CTE Z-axis (50 to 260°C)	2.90%	2.80%	2.80%	2.90%	2.90%
T-260 & T-288	>60	>60	>60	>60	>60
Halogen free	No	No	No	Yes	No
VLP-2 (2 micron Rz copper)	Available	Available	Available	Standard	Standard
Stable Dk & Df over the temperature range	-55°C to +125°C	-55°C to +125°C	-55°C to +125°C	-55°C to +125°C	-40°C to +140°C
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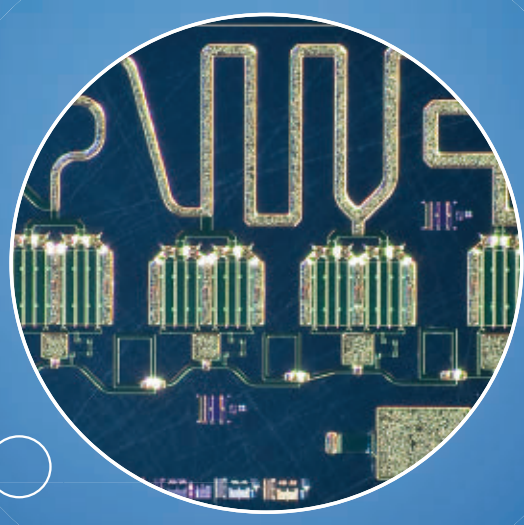

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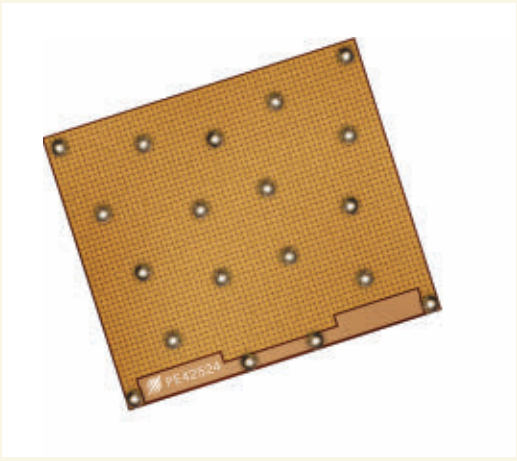

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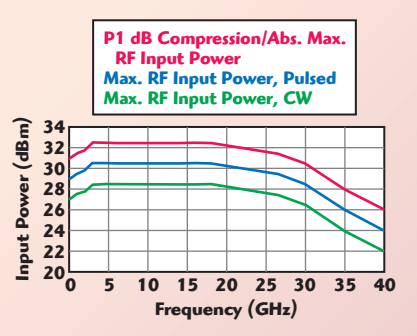

Fig. 1 PE42524 switch power handling capability at 25°C and 85°C ambient.

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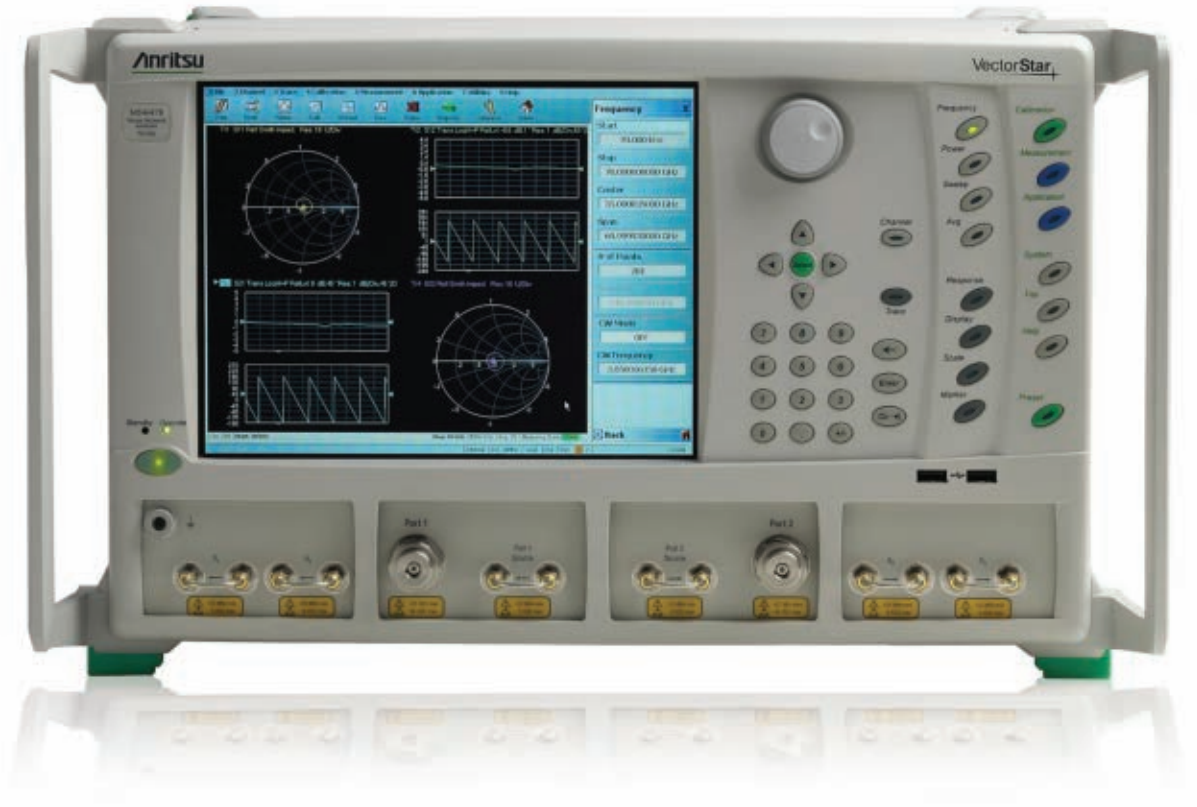

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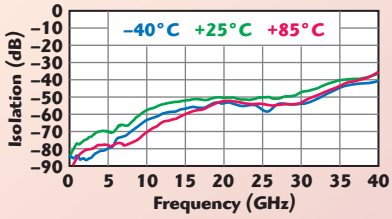


Fig. 2 Port-to-port isolation performance over temperature and frequency.

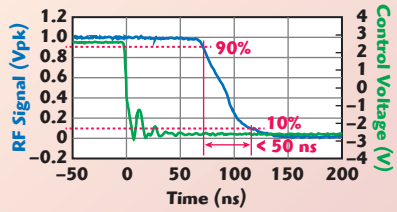


Fig. 3 The PE42524 has a switching time of less than 200 ns and an RF fall and rise time of less than 50 ns (fall time shown).

flip-chip die with 500 microns bump pitch, which eliminates high-frequency performance variations due to bond wire length variances.

Because the PE42524 is based on UltraCMOS technology, it features several attributes that GaAs technology cannot match:

- Broad bandwidth that maintains performance across the frequency range and over manufacturing lots
- Low frequency power handling that maintains signal fidelity as the power passes through
- Fast settling time that avoids the gate-lag phenomenon
- High linearity that ensures minimal signal compression
- High ESD rating that offers four times more protection
- Low power consumption that uses less than 50 nA of DC current

These attributes make the PE42524 ideal for test-and-measurement, microwave backhaul, radar and military communications applications.

TARGET APPLICATIONS

Test and measurement equipment benefits most from the PE42524's very constant – nearly flat – insertion loss across a wide frequency range. This performance helps equipment designers minimize any variations within the test system to ensure accurate readings for the device being tested. As with insertion loss, the power handling maintains a very steady performance across the frequency range, offering additional equipment stability. In addition, the switch delivers very broadband measurement capabilities within the test equipment, allowing it to test a wider range of devices.

Peregrine's PE42524 is also well suited to narrowband applications, including military communications and microwave backhaul. In the case of military communications, the switch offers insertion loss that is competitive to GaAs and other offerings while delivering the best-in-class isolation performance. The frequency range covers L- through X- to Ka-Band, and the switch provides consistent power handling for 0.5 to 1.0 W applications. Peregrine's switch also addresses the need for greater linearity with signal integrity, which facilitates getting more bits per hertz of bandwidth.

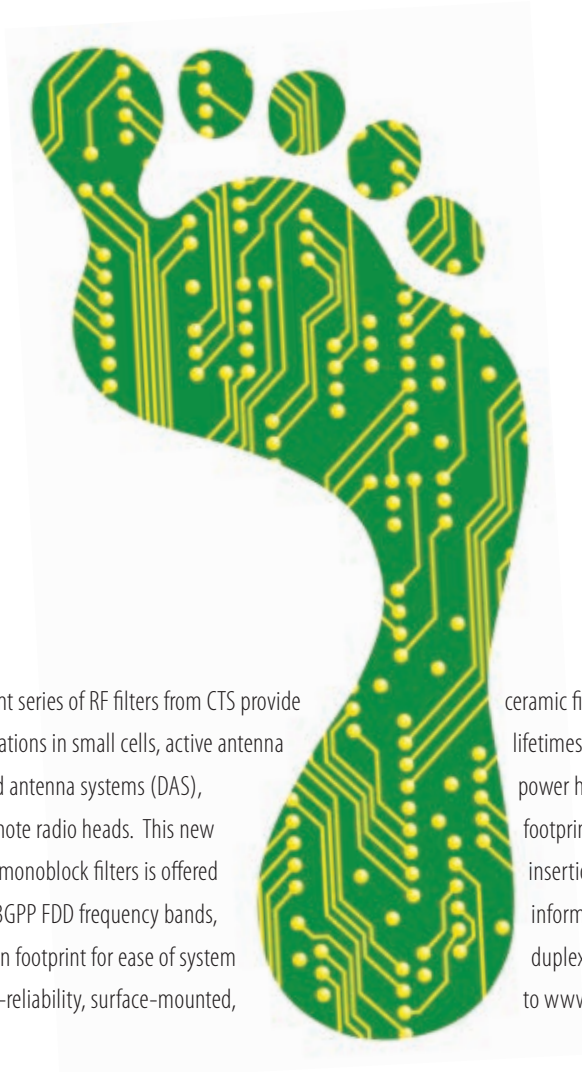
Microwave backhaul equipment is another narrowband application where the PE42524 excels. Rather than creating a different reference design for each region, due to FCC and other regulatory agency restrictions, microwave backhaul engineers now have the flexibility of using a single switch in a number of unique microwave backhaul plans in multiple geographies.

Finally, the PE42524 marks Peregrine Semiconductor's first step in proving a high-performance RF SOI switch in the radar market. Future enhancements are planned to make this technology available to a broader range of radar applications that require an even faster switching speed. ***Figure 3*** shows that the 90 percent to 10 percent RF fall time of the PE42524 is less than 50 ns, and the corresponding RF rise time is virtually identical.

The UltraCMOS PE42524, the first RF SOI switch to operate up to 40 GHz, offers RF engineers a high-performance, high reliability RF SOI alternative to GaAs switches in K- and Ka-Band. With high port-to-port isolation, low insertion loss, excellent linearity and high power handling capability, the PE42524 is ideal for test and measurement, microwave-backhaul, radar and military communications applications.

Peregrine Semiconductor
San Diego, Calif.
www.psemi.com

Universal Footprint RF Duplexers



Universal-footprint series of RF filters from CTS provide better communications in small cells, active antenna arrays, distributed antenna systems (DAS), repeaters and remote radio heads. This new breed of ceramic monoblock filters is offered for all the major 3GPP FDD frequency bands, sharing a common footprint for ease of system design. Our high-reliability, surface-mounted, ceramic filters support 20-year operating lifetimes and as much as 200 W peak input power handling capability. Universal footprint filters provide industry-leading insertion loss and rejection. For more information on our ceramic universal duplexers and bandpass filters go to www.ctscorp.com.

Filters with Industry-leading insertion loss and rejection.

	UMB/UMD Pair of Bandpass Filters For Metro Cell	USD DUPLEXER For Small Cell	UPD DUPLEXER For Pico Cell
Input Power Rating	20W Avg 200W Pk	6W Avg 60W Pk	1.5W Avg 15W Pk
Insertion Loss (5MHz AVG)	2.2dB	2.6dB	3.0dB
Rx Band Isolation*	80dB	72dB	63dB
Tx Band Isolation	74dB	66dB	57dB
Universal Footprint Size (mm)	62 x 44	63 x 18	44 x 18
Operating Temp Range	-40 to +85°C	-40 to +85°C	-40 to +85°C

* Note: "Difficult" bands may have 2dB lower worst case Rx band isolation.

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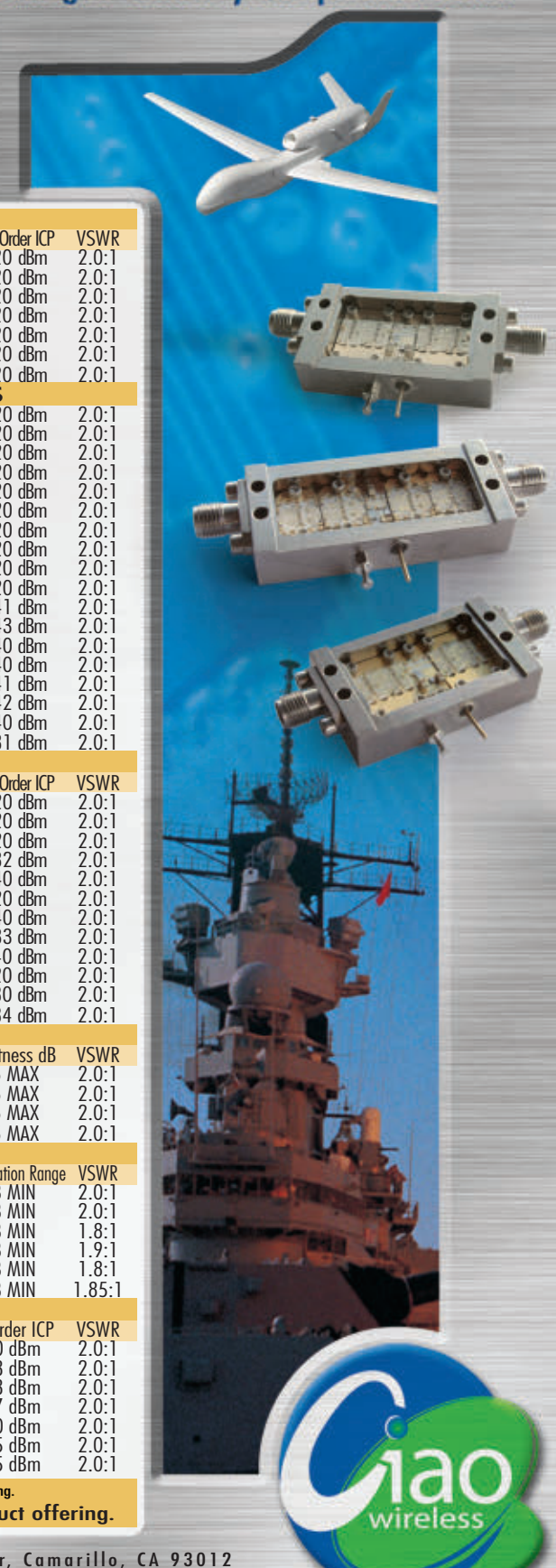

OCTAVE BAND LOW NOISE AMPLIFIERS

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

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

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

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

LIMITING AMPLIFIERS

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

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

LOW FREQUENCY AMPLIFIERS

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

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JCREW Counter IED Program Approved for Operational Testing

Naval Sea Systems Command recently announced that the Joint Counter Radio-Controlled Improvised Explosive Device (IED) Electronic Warfare (JCREW) program is approved for operational testing, The Commander Operational Test and Evaluation Force will conduct the testing to verify the program's effectiveness and suitability. It is expected to enter low rate initial production later this fiscal year. The Navy designed the JCREW system using an innovative modular, open architecture platform that allows rapid improvements in system performance in order to counter the constantly evolving IED threat.

JCREW IED (Source: U.S. Navy)

"The Navy is developing the JCREW system to protect the warfighter on patrol, in vehicles or in forward operating bases from advanced radio-controlled improvised explosive devices (RCIED)," said Capt. Aaron Peters, expeditionary missions program manager.

The program includes three variants that provide critical support to warfighters. The dismounted variant is carried via backpack; the mounted variant is attached to tactical vehicles, such as the Humvee and Mine Resistant Ambush Protected; and the fixed variant provides protection at static locations, such as buildings, entry control points or forward operating bases. These systems provide a "protective bubble" around warfighters, preventing the initiation of an improvised explosive device within a lethal range.

The JCREW program is managed by the Expeditionary Missions Program Office as part of the Naval Sea Systems Command's Directorate for Acquisition and Commonality. The directorate brings together personnel dedicated to bridging communication gaps between government and industry, in order to enable cost and variance reductions throughout the acquisition lifecycle. The directorate also provides leadership support to expeditionary missions, and the Explosive Ordnance Disposal and special warfare communities.

> "The Navy is developing the JCREW system to protect the warfighter on patrol, in vehicles or in forward operating bases..."

Unmanned K-MAX Helicopter Conducts First Collaborative Casualty Evacuation

Dangerous frontline operations call for a safe and efficient method to locate and evacuate wounded personnel. To address this critical need and help save lives, Lockheed Martin, Kaman Aerospace and Neya Systems recently demonstrated the first ever collaborative unmanned air and ground casualty evacuation using the unmanned aerial system (UAS) control segment architecture and K-MAX® cargo helicopter.

During the demonstration, a distress call led ground operators to send an unmanned ground vehicle to assess the area and injured party. The ground operators used control stations that communicated with one another using the UAS control segment architecture. Upon successful identification, the ground operators requested airlift by unmanned K-MAX of one individual who was injured. From the ground, the K-MAX operators used a tablet to determine the precise location and a safe landing area to provide assistance to the team. The injured team member was strapped into a seat on the side of the unmanned K-MAX, which then flew that individual to safety.

"This application of the unmanned K-MAX enables day or night transport of wounded personnel to safety without endangering additional lives," said Jay McConville, director of business development for Unmanned Integrated Solutions at Lockheed Martin Mission Systems and Training. "Since the K-MAX returned from a nearly three-year deployment with the U.S. Marine Corps, we've seen benefits of and extended our open system design incorporating the UAS control segment architecture, which allows rapid integration of new applications across industry to increase the safety of operations, such as casualty evacuation, where lives are at stake."

K-MAX Cargo Helicopter (Source: Lockheed Martin Corp.)

While deployed with the U.S. Marine Corps from 2011 to 2014, unmanned K-MAX successfully conducted resupply operations, delivering more than 4.5 million pounds of cargo during more than 1,900 missions. Manufactured by Kaman and outfitted with an advanced mission suite by Lockheed Martin, unmanned K-MAX is engineered with a twin-rotor design that maximizes lift capability in the most challenging environments, from the mountainous Alps to the Persian Gulf. Its advanced autonomy allows unmanned K-MAX to work day and night, in all-weather, even when manned assets are unable to fly. Lockheed Martin continues to extend and mature the K-MAX helicopter's onboard technology and autonomy for defense operations, as well as demonstrate its use for civil and commercial applications.

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

EW Market Worth $24.2B by 2020

According to a new market research report from Aerospace and Defense News, the global electronic warfare market is estimated to be $17.7 billion in 2014 and is expected to register a CAGR of 5.37 percent, to reach $24.2 billion in 2020. The major growth regions expected will be Latin America, the Middle East and Asia-Pacific.

Electronic warfare is an indispensible component of any military force. The capability and efficiency of the electronic warfare system can change the outcome of a war. Electronic warfare systems in the past consisted of analog systems with capabilities limited by the hardware and software. The advancements in the field of electronics enables today's electronic warfare systems to incorporate more digital capability and faster signal processors to enable better performance.

Though airborne and naval platforms have dominated electronic warfare in the past decade, the land-based electronic warfare systems are now gaining importance. There is also an increasing popularity of smaller electronic warfare systems that can be integrated with smaller platforms such as unmanned aerial vehicles (UAV) and patrol vessels. The market will see considerable growth due to stealth aircraft and naval vessels. These platforms are hard to detect and track due to which the electronic warfare system will play a crucial role with respect to maintaining stealth, and at the same time, counter stealth.

> The market will see considerable growth due to stealth aircraft and naval vessels.

Brazil will be the leader in the Latin American region due to their commitment to electronic war systems' research, development and implementation. Border disputes and the counter response to these disputes will propel the growth of EW in APAC and the Middle East regions.

The key market players include Raytheon, Alliant Techsystems Inc., Rockwell Collins, L-3 communications and General Dynamics Corp.(U.S.); BAE Systems and Teledyne Defense Ltd. (U.K.); Thales (France) IAI Elta (Israel); and SAAB (Sweden).

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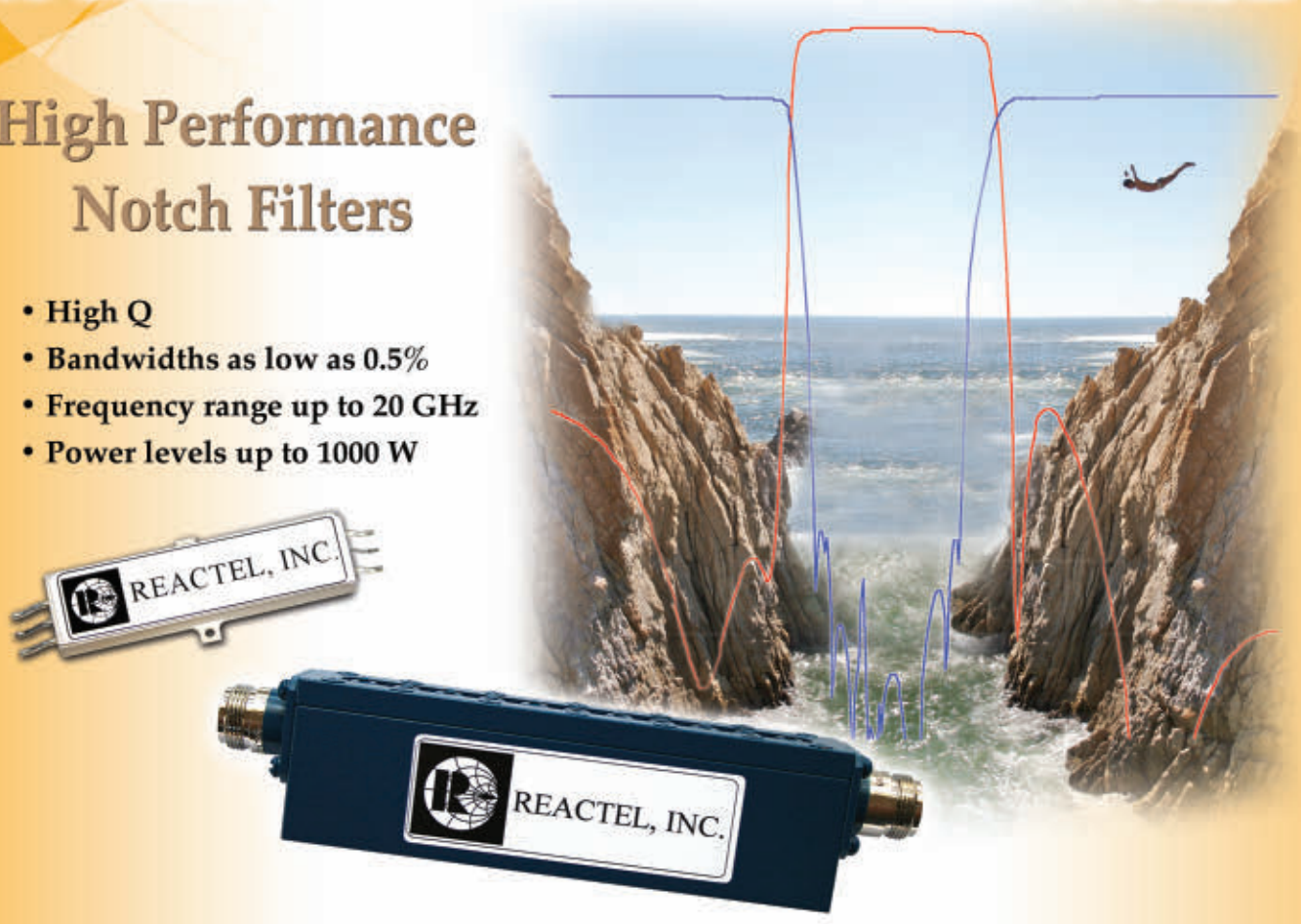

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The 2015 Defence, Security and Space Forum

At European Microwave Week

EuMA

Microwave Journal
Frequency Matters.

Wednesday 9 September – Palais Des Congrès, Paris – 10:50-18:45

A focused Forum addressing the application of RF integrated systems for UAVs.

The emphasis of the 2015 EuMW Defence, Security and Space Forum will be on RF systems and technology for UAVs, covering specifics such as: Synthetic Aperture Radar (SAR) for UAVs, ESM and EW for UAVs, operational use of integrated RF systems for UAVs, along with Airborne SARs. It will feature executives from industry, academia, the military and from space agencies, be held in combination with the opening of EuRAD and will conclude with a round-table discussion.

Programme:

10:50-12:30 EuRAD Opening Session

12:40-13:40 Strategy Analytics Lunch & Learn Session
This session will add a further dimension by offering a market analysis perspective, illustrating the status, development and potential of market.

13:50-15:30 *Microwave Journal* Industry Panel Session
The session offers an industrial perspective on the key issues facing the defence, security and space sector. In accordance with the theme for 2015, the Panel will address: RF and microwave development for UAVs.

16:10-17:50 EuMW Defence & Security Executive Forum
Speakers from leading European defence industries have confirmed their participation. These high-level speakers will present their view on RF microwave technology trends for the next generation UAV platforms and systems. The industrial speakers are complemented by speakers from government, agencies and research organizations who will offer their perspective of military/security needs, programmes, budgets and scientific research for next generation systems.

18:00-18:45 Cocktail Reception
The opportunity to network and discuss the issues raised throughout the Forum in an informal setting.

Registration and Programme Updates

Registration fees are €10 for those who have registered for a conference and €50 for those not registered for a conference.

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

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Huawei Launches Institute To Gear Up European Digitization Progress

Huawei has launched its European Research Institute (ERI), located in Leuven, Belgium. As a key tool for helping Europe achieve the targets of its Digital Agenda. The Institute will further strengthen the ongoing partnership between Huawei and European industry.

The ERI will manage the company's growing array of European R&D facilities, overseeing the work of the 18 R&D sites that Huawei has established in eight European countries. The research activities of the network focus on next-generation network technology.

Huawei rotating CEO Guo Ping stated, "Europe enjoys a favourable industrial environment, and is the global competence centre for Huawei. The ERI will manage Huawei's European research and innovation activities, and strengthen our cooperation with European industry and academia. As digitization transforms every business into a digital business, Huawei is working with its partners to achieve a smooth transition towards 'Europe 4.0' – the digitized European Union of the future in which everyone and everything will be connected. Our aim is to help Europe achieve smart growth and build a better connected Europe."

> "...a smooth transition towards 'Europe 4.0' – the digitized European Union of the future..."

The Institute will support the company's various 5G projects underway in Europe. As a member of several 5G research projects, including the EU's METIS and 5G-PPP, Huawei is working with partners to achieve breakthroughs in technology research. It is conducting joint research into future mobile networks and implementing a 5G testbed at the University of Surrey's 5G Innovation Centre in the UK. It has also launched a 5G Vertical Industry Accelerator (5G VIA) and built a 5G testbed with European partners in Munich, Germany to simulate real-world scenarios in vertical industries, enabling a more rapid application of 5G technology.

ITU To Study Network Standardization Requirements of 5G

The International Telecommunication Union (ITU) has established a new focus group to identify the network standardization requirements for the 5G development of International Mobile Telecommunications (IMT) for 2020 and beyond. The network studies will be hosted by ITU's Standardization Sector (ITU-T), benefiting from the strength of ITU-T standardization in wireline communications.

These IMT-2020 systems will enable wireless communication to match the speed and reliability achieved by fibre-optic infrastructure. The potential application fields of these systems, in addition to voice and video, span from healthcare to industrial automation, virtual reality, automated driving, and robotic systems controlled with an imperceptible time lag. One-millisecond end-to-end latency is necessary for technical systems to replicate natural human interaction with our environment; a goal that experts say should be within reach of future networks.

The new focus group, which is open to participation by any interested party, will provide the launching point for ITU-T's contribution to IMT-2020 standardization. The group will follow an intensive work plan to complete its study prior to the December 2015 meeting of ITU's standardization expert group responsible for future networks, cloud computing and network aspects of mobile communications, ITU-T Study Group 13.

IMT-2020 research and development is underway in a wide range of industry and public sector bodies. The focus group's scope of activity will be concentrated in identifying the standardization needs of the wireline elements of 5G networks, building on an analysis of IMT-2020 studies being undertaken by other entities.

ITU-T standardization activity based on the findings of the focus group will prioritize the alignment of its IMT-2020 deliverables with those of the ITU's Radiocommunication Sector (ITU-R), ensuring that standardization work on the network aspects of IMT-2020 supports the further evolution of IMT.

CHOICE Delivers Outcomes on EU-China ICT Research Cooperation

There is great potential for cooperation between China and Europe on ICT research, however finding partners, information and support in an unfamiliar market can be a daunting task. Over the past 16 months, the CHOICE project team has been developing tools and services and organising events that can facilitate organisations in this process. The team is already reporting positive results, including the creation of EU-China partnerships and cooperation agreements.

For instance, the CHOICE website has developed as a hub for information, offering helpdesk support, news on activities as well as extended services to European organisations interested in joint R&D projects. And the service works both ways – a mirror website in Chinese serves Chinese organisations in the same way.

Among the host of tools now available on the CHOICE website is the online database which features 60 ongoing and concluded China-EU and associated countries projects. The 'Ask an Expert' tool offers European researchers who need support or guidance in the development of joint research projects the opportunity to receive feedback from CHOICE experts. They can also consult the CHOICE

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> "...boosting new initiatives and improving future policies..."

info pack on Chinese ICT R&D research funding programmes and other initiatives/projects or study the handbook which presents the mechanisms and structures in China to support the development of Chinese regulations and standards for emerging ICT technologies.

Apart from working with EU and Chinese organisations, the CHOICE team also aims to reach decision-makers in order to contribute to boosting new initiatives and improving future policies. Looking forward to the final eight months of the project, the team will be focused on completing its roadmap and subsequent action plan towards a strengthened EU-China ICT R&D cooperation strategy for EU-China research cooperation beyond FP7.

Terma and Aselsan Sign Memorandum of Understanding

Aselsan and Terma have signed a Memorandum of Understanding (MoU), which defines potential areas of collaboration. The MoU also includes transferring of ownership and intellectual property rights of Terma's F-16 Modular Reconnaissance Pod from Terma to Aselsan.

> "We see strong synergies between our companies."

Terma has substantial expertise and experience in developing, designing, and manufacturing advanced structures for fighter aircraft including reconnaissance pods, electronic components and software to industries and customers within the international defence market. Aselsan has substantial expertise and experience in design, development, and integration of radar and electronic warfare systems.

Senior vice president Steen M. Lynenskjold said, "We see strong synergies between our companies. Terma's aerospace experience within electronic warfare equipment including 3D-Audio high-end technology provides promising opportunities for collaboration. We look forward to combining Aselsan's and our core capabilities to provide air forces with proven and reliable solutions."

Aselsan vice president and head of Aselsan Radar and EW Systems Business Sector Mr. Oğuz Şener added, "Collaboration with Terma brings more benefit to our customers who will use the indigenous radar and EW systems designed and developed by Aselsan for fighters."

10 New Models Added!

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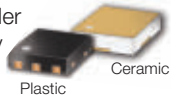
The ceramic hermetic ***RCAT*** family is built to deliver reliable, repeatable performance from DC-20GHz under the harshest conditions. With prices starting at only $4.95 ea. (qty. 20), these units are qualified to meet MIL requirements including vibration, PIND, thermal shock, gross and fine leak and more, at up to 125°C!



The molded plastic ***YAT*** family uses an industry proven, high thermal conductivity case and has excellent electrical performance over the frequency range of DC to 18 GHz, for prices starting at $2.99 ea. (qty. 20).

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Smart Home Automation System Revenues to Hit $34B in 2020

Global revenues from smart home automation systems will grow at a 21 percent CAGR between 2015 and 2020, according to ABI Research. North America will account for the lion's share of the smart home automation system revenues in 2020, contributing close to 46 percent globally, followed by Europe and Asia-Pacific.

"Smart home automation system revenue was primarily driven by mass consumer adoption of smart home security systems but the market is also witnessing strong revenue growth from the adoption of smart plugs and smoke and air quality monitors," says senior analyst Adarsh Krishnan.

Regional differences are also reflected in device adoption. In 2014, North America and Western Europe witnessed increased adoption of security cameras, especially those with embedded motion sensors which were used not only for home security but also indoor activity tracking. In China, due to increasing concern about air quality, environmental sensors are gaining popularity. To augment growing domestic demand, in 2014, Alibaba, Xiaomi, Tencent, and Baidu announced their entry into the smart home market with air quality monitors.

With regard to wireless protocol adoption, proprietary wireless technologies from United Technologies, Honeywell and Bosch Security—operating in 433 and 900 MHz spectrum bands—continue to dominate in low-cost, battery-operated devices including contact sensors and motion sensors. "Higher quality of service assurance and longer battery life are primary drivers for the continued adoption of proprietary technologies in smart home security," says principal analyst Jonathan Collins.

> "Smart home automation system revenue was primarily driven by mass consumer adoption of smart home security systems..."

Low power mesh networking wireless technologies Z-Wave and ZigBee also continued increased adoption in the smart home market. Sigma Designs' Z-Wave is embedded in over 1,000 interoperable devices while ZigBee's latest 3.0 protocol will help drive its growth as it addresses many of the earlier interoperability issues.

802.11ac Wi-Fi CPE Shipments to Accelerate in 2015

The worldwide consumer Wi-Fi equipment market increased 5 percent in 2014, surpassing 166.1 million unit shipments. "Shipments of devices which support the 802.11ac standard grew significantly in 2014, representing more than 11 percent of total access point shipments," says Jake Saunders, VP and practice director, ABI Research.

Since 802.11ac device shipments started to accelerate, the market share of devices with older generation Wi-Fi standards has started to decline. "In 2014, total shipments of consumer Wi-Fi devices with the 802.11n standard declined 3 percent from 2013. New generation 802.11ac products are expected to gain market share in the years to come. ABI Research expects that nearly 71 million 802.11ac access points will be shipped in 2015," adds Khin Sandi Lynn, industry analyst.

> "Shipments of devices which support the 802.11ac standard grew significantly in 2014..."

The next Wi-Fi standard likely to enter the market is 802.11ad which can provide up to 7 Gbps. Leading Wi-Fi chipset manufacturer, Qualcomm, has recently demonstrated its newer Wi-Fi solutions which support tri-band, 802.11ad (60 GHz), and 802.11ac (5 GHz and 2.4 GHz). According to Qualcomm, the tri-band access point is likely to be shipped in the second half of 2015.

In the enterprise Wi-Fi market, 10.5 million access points were shipped in 2014, an 11 percent increase from 2013. The enterprise class Wi-Fi access point market is expected to surpass 19.4 million unit shipments in 2020. Consumer Wi-Fi devices shipments are expected to reach 219 million in 2020 with a faster growth in residential gateway shipments compared to access points and Wi-Fi routers. Total consumer Wi-Fi equipment is expected to generate $13.5 billion in 2020.

Data Captured by IoT Connections to Top 1.6 Zettabytes in 2020

A new report from ABI Research estimates that the volume of data captured by IoT-connected devices exceeded 200 exabytes in 2014. The annual total is forecast to grow seven-fold by the decade's end, surpassing 1,600 exabytes—or 1.6 zettabytes—in 2020.

Principal analyst Aapo Markkanen says, "The data originating from connected products and processes follows a certain journey of magnitudes. The yearly volumes that are generated within endpoints are counted in yottabytes, but only a tiny fraction of this vast data mass is actually being captured for storage or further analysis. And of the captured volume, on average over 90 percent is stored or processed locally without a cloud element, even though this ratio can vary greatly by application segment. So far, the locally dealt data has typically been largely inaccessible for analytics, but that is now starting to change."

In terms of deployment architectures, the IoT is currently

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> "Edge computing is a huge challenge for the entire IoT value chain, as...analytics vendors and gateway suppliers are scrambling to collaborate with each other "

undergoing a major paradigm shift from cloud computing toward edge computing. On one hand, this shift is opening up edge-based data to meaningful analysis, by distributing the analytic workloads across the network. On the other hand, it is also shoring up the cloud-level capabilities by making the transmitted data more actionable, by enriching and contextualizing the payloads.

Practice director Dan Shey adds, "Edge computing is a huge challenge for the entire IoT value chain, as we can see from the way that cloud platforms, analytics vendors and gateway suppliers are scrambling to collaborate with each other. It is also a great opportunity for various software and hardware players that have been working towards this goal even far before the IoT as a concept became fashionable. Names like AGT International, Eurotech, Kepware Technologies, OSIsoft and Panduit are all examples of firms whose background in distributed intelligence now allows them to expand their target market significantly."

Small Cell Backhaul Market on Track for $4B in 2020

Millimeter wave technology, thanks to its large bandwidth, is the fastest growing technology in the forecast, outpacing the overall market with a very high growth through 2020. Sub 6 GHz technology will capture the largest share of small cell backhaul "last mile" links, also outperforming the total market by 2020. Traditional microwave equipment remains a top technology for small cell backhaul applications with a leading share of revenue and one-fourth share of links in 2020.

"We believe that 4G/LTE small cell solutions will again drive most of the microwave, millimeter wave, and sub 6 GHz backhaul growth in metropolitan, urban, and suburban areas with backhaul for 4G/LTE small cells growing at double-digit rates and surpassing 3G in this year," says Nick Marshall, research director at ABI Research.

"The North American, European and Asia-Pacific regions will all outperform the total market with double-digit growth between 2015 and 2020," continues Marshall. Leading vendors such as Alcatel-Lucent, NEC, Ericsson, DragonWave, Ceragon, Aviat, CCS, Siklu and Fastback/Sub10 are among the vendors that stand to benefit from this growth.

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Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

API Technologies Corp. announced that it has entered into a definitive agreement with a wholly owned subsidiary of ***Cobham plc***, to acquire ***Aeroflex/Inmet Inc.*** and ***Aeroflex/Weinschel Inc.*** Inmet and Weinschel have each been in business for more than 50 years, and each manufactures and sells RF and microwave products for defense, space, avionics, wireless, and test and measurement applications. Pursuant to the terms of the definitive agreement, API will acquire 100% of the shares of the acquired companies for a total purchase price of $80 million. This transaction is subject to customary closing conditions, including Hart Scott Rodino.

Zentech Manufacturing Inc. announced the acquisition of ***Colonial Assembly & Design***. Located in Fredericksburg, Va., Colonial Assembly & Design has a 30-year legacy of outstanding performance as a prime contractor for electronics systems design and manufacturing for the Department of Defense and in the commercial aviation sectors. The acquisition provides tremendous synergy with Zentech's established customer set in the DoD and military C4ISR (Command, Control, Computers, Communications, Intelligence, Surveillance, Reconnaissance) sectors while also providing enhanced engineering, product design, circuit design, machining, over-molded cable assembly and wire harnessing capabilities to the Zentech portfolio.

NATEL Engineering Co. Inc. and ***OnCore Manufacturing LLC*** announced that an agreement has been signed to merge the two firms. The merger will create a new EMS company with an expansive array of capabilities and an expanded manufacturing and technology portfolio to service critical customer needs. The combined company will be one of North America's largest electronic manufacturing service companies building high-reliability low-to-medium volume and high-mix electronic subassemblies and systems with strategic market focus on the medical, industrial and aerospace and defense sectors. The new organization will have13 manufacturing locations, approximately 3,750 employees and annual revenue of approximately $770 million.

COLLABORATIONS

Empower RF Systems and ***Advanced Test Equipment Rentals*** (ATEC) announced an agreement to become a preferred rental distributor of Empower RF's high power amplifiers for EMC compliance and product testing applications, bringing greater product availability to customers with immediate test equipment needs. ATEC will now carry the Empower Next Generation Platform of RF amplifiers, including the 1 to 3.1 GHz, 1 kW HPA, model 2170, which is ideal for automotive and DO-160 pulsed and CW immunity requirements.

NXP Semiconductors N.V. announced a partnership with ***Xiaomi***, a global leader in wireless connectivity and security solutions. The agreement will see NXP provide its latest innovative low power wireless connectivity solution for the new Xiaomi Smart Home Suite. Xiaomi has adopted NXP's JN516x ZigBee low-power wireless solution to power the connectivity of the Smart Home Suite. The suite consists of four wireless products: a motion sensor; door and window sensors; a wireless switching device for controlling appliances; and a multifunctional gateway that wirelessly links all the components together using ZigBee Wi-Fi interconnectivity.

ACHIEVEMENTS

Based on its recent analysis of the oscilloscopes market, ***Frost & Sullivan*** recognizes ***Rohde & Schwarz*** with the 2015 Global Frost & Sullivan Award for Competitive Strategy Innovation and Leadership. Within just five years of entering the oscilloscope market, Rohde & Schwarz developed an impressive product portfolio that helped it expand its footprint globally. Recognizing early on that penetrating this market would be a challenge, Rohde & Schwarz focused on making value additions to its solutions by offering new capabilities and/or enhancing existing solutions.

CONTRACTS

Communications and IT company ***Harris Corp.*** announced that it has received a 25 million order from a NATO nation for Falcon III manpack and handheld tactical radios. According to the company these radios will provide that country's armed forces with a secure, field-proven wideband tactical communications solution. Under this order, the nation is acquiring Falcon III AN/PRC-117G manpack and AN/PRC-152A handheld radios. Both radios are equipped with the Harris Adaptive Networking Wideband Waveform, which enables military forces to leverage advanced battle management applications such as collaborative chat, streaming video and intelligence collection.

The Malibu Division of ***Communications & Power Industries LLC*** has been awarded a production contract totaling more than $3.5 million to supply advanced antenna products, including dual-axis Ku-Band ground and airborne data links, for a mid-altitude long endurance (MALE) unmanned aerial vehicle (UAV) platform. CPI Malibu Division's vital advanced antenna products will support long-range intelligence, surveillance and reconnaissance (ISR) missions for a NATO country. Advanced data link antennas and ground data terminals are an essential part of a UAV's ISR systems. Data link systems transmit data and images from the UAV to the ground-based mission control and transmit command and control data from ground-based warfighters to the UAV.

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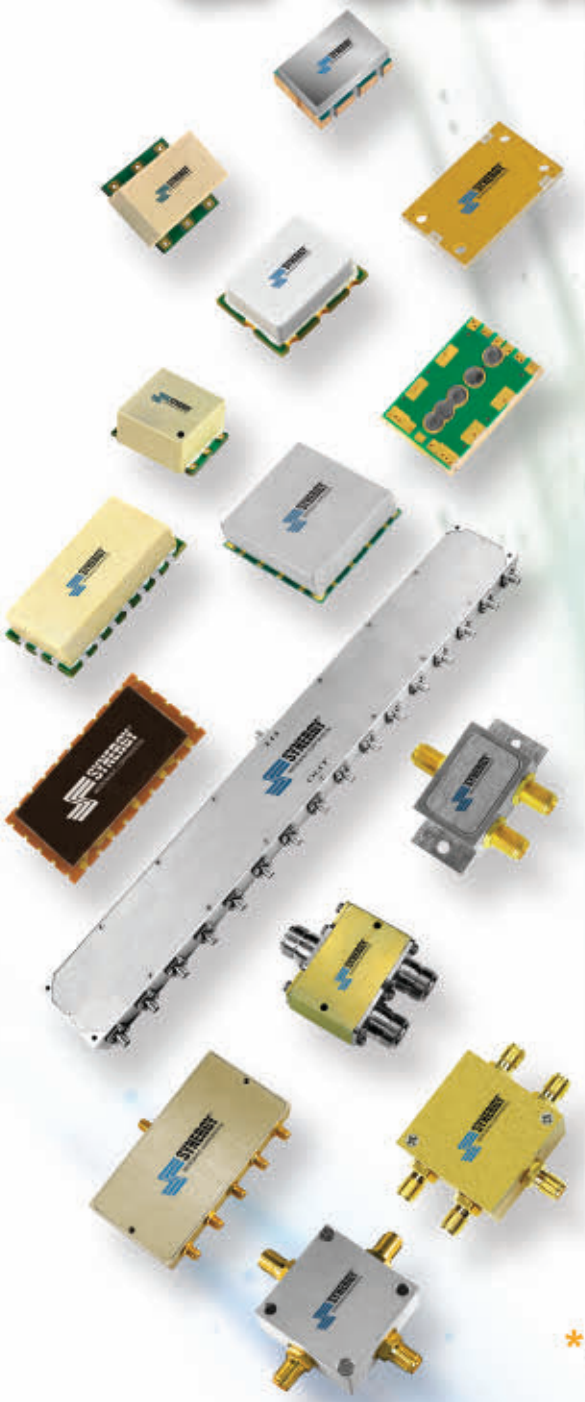

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4-way: 1 to 6 GHz
5-way: 0.5 to 18 GHz
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Around the **Circuit**

PEOPLE


▲ John Hassett

Analog Devices Inc. announced the promotion of **John Hassett** to senior vice president of worldwide manufacturing. Hassett holds a Bachelor of Science degree in manufacturing engineering and a master of business administration degree from the University of Limerick. Hassett has assumed his new role effective May 3, 2015, taking over for retiring senior vice president of worldwide manufacturing, Rob Marshall, who will continue with ADI as senior advisor to the CEO until his retirement during the first half of ADI's 2016 fiscal year.


▲ Mike Clark

Crane Aerospace & Electronics, a segment of Crane Co., has announced the appointment of **Mike Clark** to vice president of microwave components and integrated systems of Crane Aerospace & Electronics. In this role, Clark will be responsible for driving customer satisfaction, continued growth and strategic direction of the microwave business along with overseeing the operations at the Beverly, Mass. design center and Chandler, Ariz., and West Caldwell, N.J. manufacturing facilities. He will be located in Chandler, Ariz.


▲ Josh Levine

RFMW Ltd. announced that **Josh Levine** has been promoted to the position of director of operations - sales and product management. Levine has served in sales and product management roles for the last nine years. Levine supports RFMW's premier suppliers with a high degree of competence and professionalism. In recognition of Levine's perseverance and skills, he will be overseeing the coordination of RFMW's worldwide sales operations and worldwide product management activities. Levine's accumulated background knowledge and insight into day-to-day operations will enhance RFMW's competitiveness in the market and promote further growth of the company.


▲ Mark Blackwood

Pasternack Enterprises Inc. announced the appointment of **Mark Blackwood** as the company's product manager for Passive RF Components. Blackwood joins Pasternack with more than 20 years of engineering, program management, product marketing and product line management expertise in the RF and microwave industry. Blackwood brings with him a successful track record of developing new technologies and product platforms, growing revenues while improving the bottom line as well as creating and implementing impactful marketing programs.


▲ Meta M. Rohde

Dr. Meta M. Rohde, president of **Synergy Microwave Corp.** in Patterson, N.J., is the recipient of the 2014 IEEE Region 1 Award for outstanding management in the design and production of state-of-the-art RF and microwave components. Dr. Rohde's dedication and leadership have made a profound effect on the microwave industry notably in pioneering new ways of making RF and microwave products efficiently. She introduced for the first time the concept of surface mounted device (SMD) in electronic industries in 1985. This technology is now being used by almost all electronic industries worldwide.

REP APPOINTMENTS

East Coast Microwave and **Maury Microwave** announced an authorized distribution agreement to stock and supply Maury's line of ColorConnect™ color-coded precision adapters, Test Essentials™ lab adapters, and the high-performance ruggedized Stability™ RF/microwave cable assemblies, designed specifically for phase-stable and amplitude-stable applications.

Custom MMIC, a developer of performance driven monolithic microwave integrated circuits (MMIC), announced the appointment of **ACETEC Inc.**, as a new technical representative covering the Southern California territory. ACETEC was founded in 1995 and has an established team of high-tech professionals offering state-of-the-art components and related technologies of the RF/microwave and wireless markets.

Digitaltest Inc., global provider of advanced in-circuit test, flying probe and process software solutions announced that it has appointed **Torenko Associates** as its exclusive manufacturers' representative for the Texas and Mexico regions. Torenko Associates will represent Digitaltest's complete product line in Texas, Mexico, Oklahoma, Arkansas and Louisiana. Headquartered in Sunnyvale, Texas, Torenko Associates has a team across the U.S. and Mexico dedicated to helping its customers make the right decision.

Versatile Power Inc. announced the addition of **Saelig Co. Inc.**, Fairport, N.Y., to its list of authorized distributors of Versatile Power's new family of BENCH programmable power supplies. The Versatile Power BENCH series are compact, programmable, DC power supplies and are nearly half the cost compared to the industry's leading producer of power supplies.

PLACES

NI announced the opening of the new Wireless Innovation Lab at its Austin, Texas headquarters. In the lab, NI supports ongoing collaborations with top academic and industry research groups participating in its RF/Communications Lead User program. Researchers at Intel, Lund University, Nokia Networks, NYU Wireless, Samsung, The University of Texas at Austin and TU Dresden are driving significant advances in the development of next-generation wireless systems and furthering research in 5G. Current demos and projects on display in the lab include mmWave cellular systems, the 5G Massive MIMO Testbed and the LabVIEW Communications System Design Suite.

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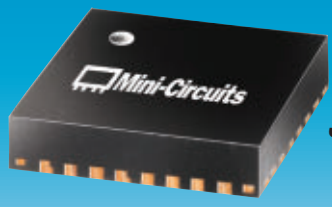

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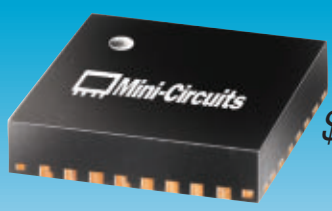

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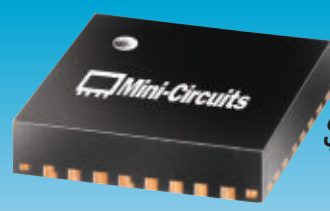

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INVITED PAPER

On the Road to 5G, GaN Targets 3.5 GHz

Jeff Gengler and James Nelson
Qorvo Inc., Richardson, Texas

The demands on the wireless network infrastructure are expected to continue to grow at a substantial, if not alarming, pace. The infrastructure for wireless communication is constantly adapting to address these demands. Network operators are perpetually striving for continuous improvements in cost, capacity, coverage, quality of experience, reliability, functionality, interoperability, spectral efficiency, mobility and more acronyms and words ending in 'ibility' than one cares to mention.

This is not to imply that the demands are trivial and unfounded. Cisco has reported mobile traffic grew 69 percent in 2014 and reached 2.5 exabytes per month. To state this data transfer rate differently, the mobile traffic volume in 2014 was nearly 30 times the entire globe's internet traffic in 2000. By 2019, monthly data rates are forecast to grow 10 times the current rate to 24 exabytes per month. The increase in data traffic will be driven both by traditional mobile users and the anticipated growth of various data connections, the so-named Internet of Things (IoT). The demand for additional network capacity appears endless, and even as LTE continues to rollout in areas of the world for the first time, network operators are already planning to address the next major evolution of the mobile network – 5G.

5G is the fifth generation of the mobile infrastructure network; it will encompass many network advancements and promises. As previous generations provided, 5G is expected to continue to increase spectral efficiency, support more users, provide higher data rates and improve the user's experience. Exactly how network operators will provide a 5G experience is yet to be known; however, it is clear that all network operators share a common need to satisfy the growing network demand with more bandwidth. The use of additional frequency spectrum is a major requirement and focus of next generation network systems. Multiple research and development programs are active in all areas of the spectrum: low frequency TV white space, unlicensed bands at 2.4 and 5 GHz, existing point-to-point and point-to-multipoint bands at 15, 28 to 30, 50, 60 and 71 to 86 GHz (E-Band) and 3.5 GHz. Each band has advantages and disadvantages, and it is likely that next-generation networks will include solutions in all of these bands as the heterogeneous network continually widens.

ATTRACTIVENESS OF 3.5 GHz

3.5 GHz is a band that offers an immediate solution to the growing spectral needs, and it does not require network operators to wait for a 5G solution. Providing solutions at 3.5 GHz offers hardware manufacturers a design platform that is very similar to existing traditional cellular bands, compared to higher frequency alternatives.

3.5 GHz provides 200 MHz of spectrum, from 3.4 to 3.6 GHz, that is available in most of the world and has been recognized as a potential global harmonized band for TDD. Japan is at the forefront of using 3.5 GHz for mobile infrastructure, and recent announcements reporting field trials in China are expanding the footprint. Europe has long allocated the band

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for fixed broadband; mobile infrastructure is expected to dominate future use. The U.S. has a more difficult challenge to harmonize the band with the rest of the world since portions are used for radar. However, the FCC recently opened 100 MHz for commercial use, the newly dubbed "innovation band." Given these spectrum allocations, 3.5 GHz will play a key role in future network expansion, with the potential for both carrier aggregation and stand-alone operation.

These new installments are expected to continue with a common theme, i.e., networks will become denser. Increasing network density utilizes a layered approach for coverage, meaning installing multiple layers of access to improve capacity in high traffic areas. Depending on whether the coverage is indoor or outdoor, base stations are developed to provide various power levels, which often differ by manufacturer:

- Femtocell, less than 0.25 W,
- Picocell, 0.25 to 0.5 W,
- Microcell, 1 to 5 W,
- Metrocells, 5 to 10 W, and
- Traditional macrocells, greater than 10 W.

Varying power levels allows maximum flexibility for the operators to create smaller, denser, higher capacity coverage areas within the network. Initially thought to be an ideal candidate for only small cells, 3.5 GHz is expected to see deployment at all power levels to offer a fully layered solution for network operators.

DESIGN CONSIDERATIONS

In response to the growing demand for outdoor solutions at 3.5 GHz, Qorvo is developing new GaN amplifier products and Doherty power amplifier reference designs targeting 1, 2 and 20 W average output power at the antenna reference plane. Future developments will target 10 W metrocell and 40 W macrocell solutions. GaN is ideally suited for the band due to excellent gain, high power density and high efficiency, providing significant performance improvements over competing technologies. These designs utilize Qorvo's 0.25 µm gate length GaN on SiC process on 100 mm wafers. Process options allow for 28 to 32 V operation for small cells and 48 V for macrocell applications. 100 mm GaN costs have dropped significantly in the last few years, and a planned transition to 150 mm wafers will further reduce cost.

0.25 µm GaN provides higher gain and higher frequency operation than GaN processes with longer gate lengths (e.g., 0.5 µm). To maintain high efficiency of the power amplifier line-up, including driver and pre-driver stages, the gain of the final Doherty amplifier – a premium at 3.5 GHz – needs to be as high as possible. GaN's high power density results in lower drain-source capacitance, compared to GaAs or silicon, which enables higher bandwidths. The low Cds and high inherent impedance of the device allow for internal package matching networks that are suitable for high video bandwidth applications. The video bandwidth for the 3.4 to 3.6 GHz band needs to be high, since 100 MHz signal bandwidth is planned and 200 MHz is being discussed.

At 3.5 GHz, the insertion loss between the power amplifier (PA) and antenna – which includes the circulator, board losses and filtering – is estimated to be 2 dB. Thus, 20 W average radiated power at the antenna will require 32 W at the Doherty PA reference plane. The required peak power of the Doherty PA is a function of the modulated carrier peak-to-average ratio. For the downlink LTE signals of macrocell base stations, these are typically on the order of 7 dB with crest factor reduction. Further headroom of 1 dB for digital predistortion (DPD) is added to the PA specification to compensate for performance over temperature and device-to-device variability. Thus, 20 W average power at the antenna will require 200 W of peak power, or 8 dB above 32 W.

DOHERTY PA REFERENCE DESIGNS

To show the performance available from GaN, a symmetric Doherty PA reference design for Band 42 (3.4 to 3.6 GHz) was developed. It delivers 2 W at the antenna, using TQP0103 GaN transistors for both the carrier and peaking amplifiers (see ***Figure 1***). The PA delivers more than 20 W

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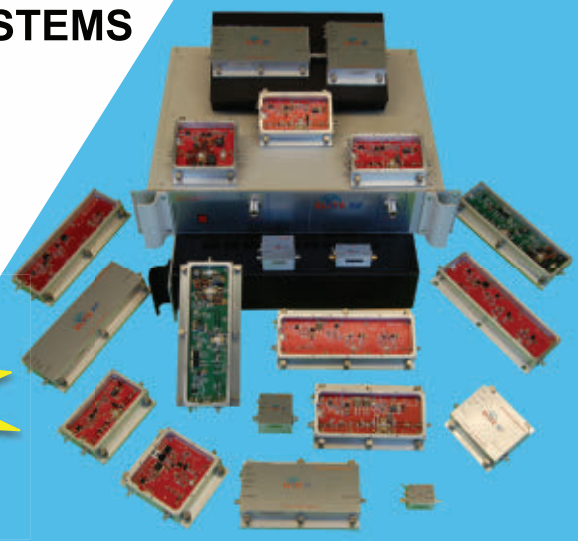

Amplifier Product Line

1 MHz to 10 GHz / 1 Watt to 10K Watts

Short Form List

P - Pallet Amplifier M - Module Amplifier A - Amplifier System R - 19" Rack Amplifier System

Model	CLASS	Freq - min	Freq - max	Power	Gain	Supply
	(Bias)	(MHz)	(MHz)	(Watts)	(dB)	
P10006A	A	20	1000	10	12	28 vdc
A10017A3	A	200	2200	25	50	48 vdc
A10024A3	A	100	1000	50	50	28 vdc
M10025A3	A	1000	2600	10	40	48 vdc
M10031A3	A	2000	6000	2	40	28 vdc
A10017B3	AB	200	2200	60	50	48 vdc
A10020P3	AB	470	860	600 PEP	40	48 vdc
A10021B2	AB	30	512	100	30	48 vdc
A10022P3	AB	300	500	1000 PEP	40	48 vdc
A10023B3	AB	470	860	100	40	48 vdc
A10024B3	AB	100	1000	80	50	28 vdc
A10026B3	AB	1.5	30	300	40	48 vdc
R10017B3Q	AB	200	2200	100	50	120/240 ac
R10025B3Q	AB	1000	2600	50	40	120/240 ac
R10024B3Q	AB	100	1000	150	40	120/240 ac

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peak power with greater than 44 percent efficiency at 8 dB back-off. The gain and efficiency as a function of the output power are shown in ***Figure 2***.

An asymmetric Doherty PA reference design for 1 W average output at the antenna uses a TQP0102 GaN transistor for the carrier amplifier and the TQP0103 for the peaking amplifier. The power ratio of the peaking amplifier to the carrier amplifier is 2:1. The asymmetric Doherty will have higher efficiency than the symmetric Doherty at 8 dB back-off. This reference amplifier design will achieve greater than 50 percent efficiency at the amplifier reference plane. At the same back-off power, this boosts efficiency more than 6 points above a symmetric Doherty.

Designing an asymmetric Doherty requires extra caution to ensure the AM-AM and AM-PM responses of the Doherty are smooth and monotonic, necessary to work with DPD. The gain and phase responses must be monotonic through the transition when the peaking amplifier switches from off to on and load modulates the carrier amplifier to peak power. Achieving the appropriate gain and phase responses is challenging, since two different devices are used, each with different gain and phase responses. Further, the modes of operation are also different, with the carrier amplifier operated in Class AB and the peaking amplifier biased to Class C. Better than -60 dBc ACPR has been demonstrated with asymmetric GaN Doherty designs with 10 MHz signal bandwidth using third party DPD systems (see ***Figure 3a***). With a 20 MHz LTE signal, the DPD corrects to better than -57 dBc ACPR over a wide range of back-off power levels (see ***Figure 3b***). The range extends from deep back-off, where only the carrier amplifier is active, through the transition of the peaking amplifier turning on and load modulating the carrier amplifier. The DPD will improve the linearity as long as the average power plus the peak-to-average ratio of the modulated carrier is less than the Doherty amplifier saturated power. The DPD system

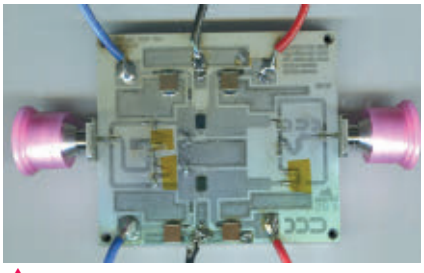

Fig. 1 Symmetric Doherty PA delivering 2 W average in Band 42. The design uses two TQP0103 GaN transistors, each in a 3 × 4 mm plastic QFN package.

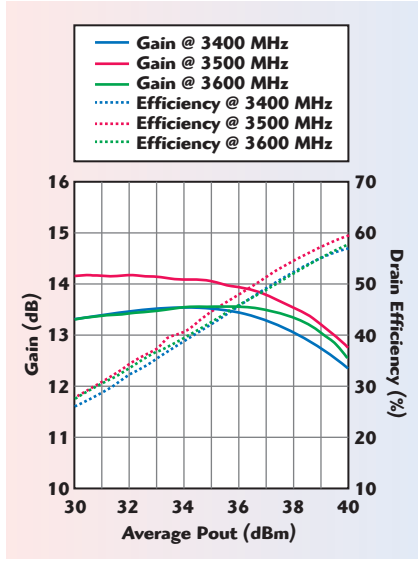

Fig. 2 Symmetric Doherty PA gain and efficiency as a function of output power, using a single carrier, 64 DPCH, 10 dB PAR WCDMA test signal at 3.5 GHz.

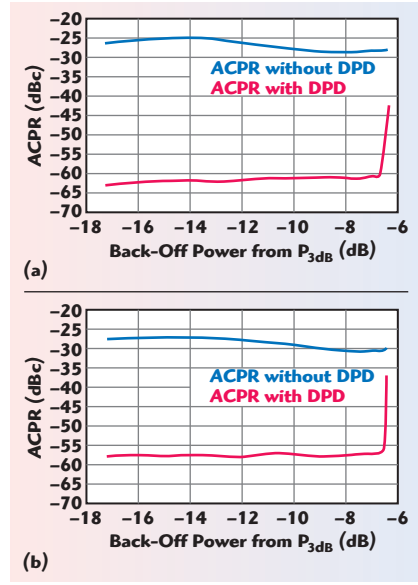

Fig. 3 ACPR vs. output power below P_{3dB} for an asymmetric Doherty PA and 10 MHz, 6.5 dB PAR WCDMA signal (a) and 20 MHz, 6.5 dB PAR LTE signal (b).

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	Model	Frequency (MHz)	Gain (dB)	Pout @ Comp. 1 dB (W)	Pout @ Comp. 3 dB (W)	$ Price (Qty. 1-9)
	ZVE-3W-83+	2000-8000	35	2	3	1295
	ZVE-3W-183+	5900-18000	35	2	3	1295
NEW	ZHL-4W-422+	500-4200	25	3	4	1570
NEW	ZHL-5W-422+	500-4200	25	3	5	1670
	ZHL-5W-2G+	800-2000	45	5	6	995
	ZHL-10W-2G	800-2000	43	10	13	1295
•	ZHL-16W-43+	1800-4000	45	13	16	1595
•	ZHL-20W-13+	20-1000	50	13	20	1395
•	ZHL-20W-13SW+	20-1000	50	13	20	1445
	LZY-22+	0.1-200	43	16	32	1495
	ZHL-30W-262+	2300-2550	50	20	32	1995
	ZHL-30W-252+	700-2500	50	25	40	2995
	LZY-2+	500-1000	47	32	38	2195
	LZY-1+	20-512	42	40	50	1995
•	ZHL-50W-52+	50-500	50	40	63	1395
•	ZHL-100W-52+	50-500	50	63	79	1995
•	ZHL-100W-GAN+	20-500	42	79	100	2395
	ZHL-100W-13+	800-1000	50	79	100	2195
	ZHL-100W-352+	3000-3500	50	100	100	3595
	ZHL-100W-43+	3500-4000	50	100	100	3595
	LZY-5+	0.4-5	52.5	100	100	1995

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

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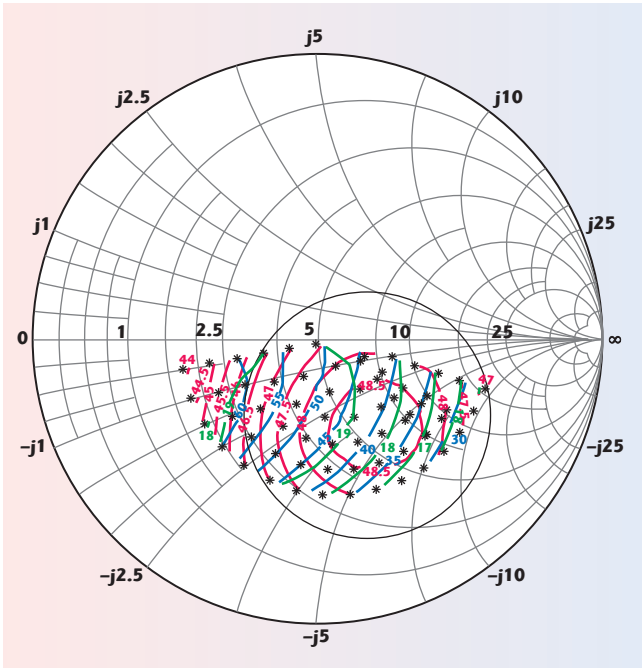

▲ *Fig. 4 Load-pull output power, efficiency and gain contours for a QDP3600 carrier amplifier transistor used in an asymmetric, 20 W Doherty amplifier.*

cannot compensate for nonlinearities at powers exceeding the saturated power capability of the Doherty amplifier. ACPR degrades rapidly when this is attempted, to a near vertical slope. Figure 3 shows the case when the power of a 6.5 dB PAR is driven to less than 6.5 dB back-off.

The asymmetric Doherty architecture is also being used for a 20 W average power (at the antenna) reference design. This amplifier uses the QDP3600 as the carrier amplifier and a T1G4012036-FS as the peaking amplifier, both operating at 48 V. The loads are designed to achieve carrier and peaking amplifier powers of 70 W and 140 W at peak power, netting a combined P_{3dB} of 200 W at the Doherty PA output. The design is based on load-pull measurements of the transistors. The carrier amplifier load-pull contours at 3.5 GHz are shown in ***Figure 4***. The red contours show the peak power (P_{3dB}) capability of the device. The black circle is a 3:1 VSWR contour around the maximum power and shows carrier amplifier efficiency match conditions that the device can achieve in a Doherty configuration. The green contours show the gain, and the blue contours show the drain efficiency at the 45 dBm targeted average power of the Doherty amplifier. Following the 3:1 VSWR circle around to the left side shows that 60 percent drain efficiency and 19.6 dB of gain can be achieved at the carrier amplifier efficiency match. When the peaking amplifier turns on, it will load modulate the carrier amplifier to the center of the 3:1 VSWR circle and be at a load condition with 48.9 dBm P_{3dB}. With the peaking amplifier matched to a 2:1 power ratio, the expected design performance is 14 dB gain and 55 percent efficiency at 45 dBm average output power.

This efficiency is substantially higher than what can be achieved with silicon LDMOS, which is the incumbent PA technology for the cellular infrastructure market. The gap between GaN and LDMOS increases with increasing frequency. Based on data sheet specifications, the latest LDMOS devices in development at 3.5 GHz show expected Doherty efficiencies of 37.5 percent.

CONCLUSION

There is much discussion and excitement around the future 5G network. While the 3.5 GHz band has yet to reach the potential of a globally harmonized band, there are many opportunities for 3.5 GHz to fulfill the immediate need for mobile infrastructure bandwidth, well in advance of a 5G deployment. Plans for developing the new spectrum are growing rapidly for both small cell and macrocell deployments, with GaN well suited to address the needs for high power, high efficiency and wide video bandwidth. ■

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Bandwidth	50 MHz/70 MHz/100 MHz	70 MHz/100 MHz/150 MHz/ 200 MHz	300 MHz/400 MHz/500 MHz

Model	R&S®HMO1002	R&S®HMO Compact	R&S®HMO3000
Number of channels	2	2/4	2/4
Customers	training, hobby	training, hobby, service/maintenance, general development	training, hobby, service/maintenance, general development
Measurement types	elementary (QuickView key with 9 parameters)	basic, incl. statistics (QuickView key with 9 parameters)	basic, incl. statistics (QuickView key with 9 parameters)
Trigger types	elementary	basic	basic
Operating system	embedded: very short startup time	embedded: very short startup time	embedded: very short startup time
Display	VGA with VirtualScreen	VGA with VirtualScreen	VGA with VirtualScreen
User interface languages	multilingual	multilingual	multilingual
Mixed signal option	retrofittable	retrofittable	retrofittable
Applications	general debugging, serial protocol analysis, pattern generator (rectangle, bus signal source, counter, programmable 4-bit pattern), function generator, component tester	general debugging, serial protocol analysis, signal source (rectangle, bus signal source, counter, random 4-bit pattern), component tester	general debugging, serial protocol analysis, signal source (rectangle, bus signal source, counter, random 4-bit pattern)
Compliance tests			
Probes	standard BNC	standard BNC with probe factor identification	standard BNC with probe factor identification

R&S®RTM2000

200 MHz/350 MHz/500 MHz/
1 GHz

R&S®RTE1000

200 MHz/350 MHz/500 MHz/
1 GHz/1.5 GHz/ 2 GHz

R&S®RTO1000

600 MHz/1 GHz/2 GHz/4 GHz

Bandwidth

R&S®RTM2000	R&S®RTE1000	R&S®RTO1000	Model
2/4	2/4	2/4 R&S®RTO1044: 4	**Number of channels**
training, production, service/maintenance, general development	training, production, service, general development	R&D, production, complex development (signal integrity and RF)	**Customers**
basic, incl. statistics (QuickView key with 9 parameters)	advanced, incl. statistics (QuickMeas function with 8 parameters)	advanced, incl. statistics (QuickMeas function with 8 parameters)	**Measurement types**
basic	advanced	advanced	**Trigger types**
Embedded: very short startup time, secure data erasure	Windows 7 Embedded: full network support, USB printer, mouse and keyboard, exchangeable hard disk	Windows 7 Embedded: full network support, USB printer, mouse and keyboard, exchangeable hard disk	**User interface**
XGA with VirtualScreen	XGA with touchscreen	XGA with touchscreen	**Display**
multilingual	multilingual	multilingual	**Operating system languages**
retrofittable	retrofittable	retrofittable	**Mixed signal option**
general debugging, analysis of serial protocols, power, frequency	general debugging, analysis of serial protocols, power, frequency	general debugging, analysis of serial protocols, power, frequency, I/Q data, jitter, broadband RF signals	**Applications**
		optional	**Compliance tests**
Rohde&Schwarz active probe interface; passive, active single-ended and differential probes, current probes and high-voltage probes, extensive accessories	Rohde&Schwarz active probe interface; passive, active single-ended and differential probes, current probes and high-voltage probes, extensive accessories	Rohde&Schwarz active probe interface; passive, active single-ended and differential probes, current probes and high-voltage probes, extensive accessories	**Probes**

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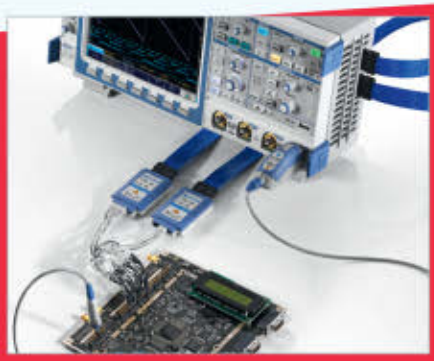
Power measurements

Many special measurements are necessary when developing and integrating switched-mode power supplies and power electronics. Such measurements include analyzing the input and output parameters, the safe operating area for the power semiconductor, the modulation of the control loop and the switching frequency of the current and its harmonics. The R&S®RTx-K31 option for the R&S®RTM, R&S®RTE and R&S®RTO oscilloscopes makes it easy to implement these specific measurements and document the results. A wide range of passive high-voltage probes, active differential probes, current probes and a deskew fixture are available for use with the oscilloscopes.

Protocol analysis

Serial bus systems are integrated into a variety of electronic circuits. In order to verify the overall functioning of the circuit, both the physical layer and the protocol layer must be tested. All Rohde&Schwarz oscilloscopes offer trigger and decode options for the most frequently used protocols, including I^2C, SPI and UART/RS-232. The R&S®RTO offers 13 different protocols. All of the options provide hardware-based triggering for rapidly isolating specific data messages or protocol errors and clearly display the decoded messages in table format.



Frequency analysis and EMI debugging

Ever higher clock and data rates and the use of switched-mode power supplies increase the occurrence of EMI in and around a circuit. A reliable, fast and easy method for analyzing the frequency range is therefore essential. Decades of frequency domain experience have gone into the FFT analysis function featured in the R&S®RTM, R&S®RTE and R&S®RTO oscilloscopes. The user interface corresponds to that of a spectrum analyzer. The hardware-based FFT implementation combined with the low-noise frontends ensures unrivaled sensitivity and processing speed.

Probe portfolio

Probe	Type	Bandwidth	Dynamic range
R&S®RT-ZP10, R&S®RTM-ZP10	passive, single-ended	500 MHz	400 V (RMS)
R&S®RT-ZH10, R&S®RT-ZH11	passive, single-ended	400 MHz	1 kV (RMS)
R&S®RT-ZZ80	passive, broadband	8 GHz	20 V (RMS)
HZO30	active, single-ended	1 GHz	±8 V
R&S®RT-ZS10E	active, single-ended	1 GHz	±8 V
R&S®RT-ZS10*	active, single-ended	1 GHz	±8 V
R&S®RT-ZS20*	active, single-ended	1.5 GHz	±8 V
R&S®RT-ZS30*	active, single-ended	3 GHz	±8 V
R&S®RT-ZS60*	active, single-ended	6 GHz	±8 V
R&S®RT-ZD01	active, differential	100 MHz	±140 V (100:1) / ±1400 V (1000:1)
HZO40	active, differential	200 MHz	±20 V
HZO41	active, differential	800 MHz	±15 V
R&S®RT-ZD10*	active, differential	1 GHz	±5 V, with R&S®RT-ZA15: ±70 V DC / ±46 V AC (peak)
R&S®RT-ZD20*	active, differential	1.5 GHz	±5 V, with R&S®RT-ZA15: ±70 V DC / ±46 V AC (peak)
R&S®RT-ZD30*	active, differential	3 GHz	±5 V, with R&S®RT-ZA15: ±70 V DC / ±46 V AC (peak)
R&S®RT-ZD40*	active, differential	4.5 GHz	±5 V
HZO50	AC/DC, current probe	100 kHz	20 A (RMS) / ±30 A (peak)
HZO51	AC/DC, current probe	20 kHz	100 A (RMS) / 1000 A (RMS)
R&S®RT-ZC10	AC/DC, current probe	10 MHz	150 A (RMS) / ±300 A (peak)
R&S®RT-ZC20 R&S®RT-ZC20B	AC/DC, current probe	100 MHz	30 A (RMS) / ±50 A (peak)
R&S®HZ-15	passive, E and H near-field probes	30 MHz to 3 GHz	

* R&S®ProbeMeter and micro button for instrument control

Oscilloscope portfolio

Series	R&S®HMO1002	R&S®HMO Compact	R&S®HMO3000
Vertical			
Bandwidth	50 MHz, 70 MHz, 100 MHz (upgradeable)	70 MHz, 100 MHz, 150 MHz, 200 MHz	300 MHz, 400 MHz, 500 MHz (upgradeable)
Number of channels	2	2/4	2/4
V/div 1 MΩ	1 mV to 10 V	1 mV to 10 V	1 mV to 5 V
V/div 50 Ω		1 mV to 10 V (150 MHz and 200 MHz)	1 mV to 5 V
Horizontal			
Sampling rate	500 Msample/s per channel 1 Gsample/s (2 channels interleaved)	1 Gsample/s per channel 2 Gsample/s (2 channels interleaved)	2 Gsample/s per channel 4 Gsample/s (2 channels interleaved)
Max. memory (per channel/1 channel active)	500 ksample/1 Msample	1 Msample/2 Msample	4 Msample/8 Msample
Segmented memory			option
Acquisition rate	10000 waveforms/s	2000 waveforms/s	5000 waveforms/s (200000 waveforms/s in segmented memory mode*)
Trigger			
Types	elementary (five trigger types)	basic (six trigger types)	basic (nine trigger types)
Mixed signal			
Number of digital channels*	8	8	16
Sampling rate, digital channels	500 Msample/s	1 Gsample/s	1 Gsample/s
Max. memory, digital channels	500 ksample	1 Msample	2 Msample
Analysis			
Cursor measurement types	11	13	12
Standard measurement functions	22	22	25
Mask test	elementary (tolerance mask around the signal)	elementary (tolerance mask around the signal)	elementary (tolerance mask around the signal)
Mathematics	elementary	basic (math on math)	basic (math on math)
Serial protocol triggering and decoding*	I²C, SPI, UART/RS-232, CAN/LIN	I²C, SPI, UART/RS-232, CAN/LIN	I²C, SPI, UART/RS-232, CAN/LIN
Display functions			
Applications*			
Compliance tests*			
Display and operation			
Size and resolution	6.5", color, 640 × 480 pixel	6.5", color, 640 × 480 pixel	6.5", color, 640 × 480 pixel
Operation	optimized for fast button operation	optimized for fast button operation	optimized for fast button operation
Dimensions			
Size (W × H × D)	285 mm × 175 mm × 140 mm	285 mm × 175 mm × 140 mm	285 mm × 175 mm × 220 mm
Weight	2.5 kg (5.5 lb)	2.5 kg (5.5 lb)	3.6 kg (7.9 lb)

* Requires an option.

R&S®RTM2000	R&S®RTE1000	R&S®RTO1000
200 MHz, 350 MHz, 500 MHz, 1GHz (upgradeable)	200 MHz, 350 MHz, 500 MHz, 1 GHz, 1.5 GHz, 2 GHz (upgradeable)	600 MHz, 1 GHz, 2 GHz, 4 GHz (upgradeable)
2/4	2/4	2/4 (only 4 channels in 4 GHz model)
1 mV to 10 V	500 µV to 10 V	1 mV bis 10 V (500 µV to 10 V in HD mode*)
1 mV to 2 V	500 µV to 5 V	1 mV to 5 V (500 µV to 5 V in HD mode*)
2.5 Gsample/s per channel 5 Gsample/s (2 channels interleaved)	5 Gsample/s per channel	10 Gsample/s per channel 20 Gsample/s (2 channels interleaved in 4 GHz model)
10 Msample/20 Msample (460 Msample in segmented memory mode*)	standard: 10 Msample/40 Msample max. upgrade: 50 Msample/200 Msample	standard: 20 Msample/80 Msample max. upgrade: 400 Msample/800 Msample
option	standard	standard
12500 waveforms/s (200000 waveforms/s in segmented memory mode*)	1000000 waveforms/s (2000000 waveforms/s in ultra-segmented memory mode)	1000000 waveforms/s (3000000 waveforms/s in ultra-segmented memory mode)
basic (seven trigger types)	advanced, digital trigger (13 trigger types)	advanced, digital trigger (14 trigger types)
16	16	16
2.5 Gsample/s	5 Gsample/s	5 Gsample/s
10 Msample/20 Msample	100 Msample	200 Msample
14	3	3
31	47	47
elementary (tolerance mask around the signal)	advanced (freely configurable, hardware-based)	advanced (freely configurable, hardware-based)
basic (math on math)	advanced (formula editor)	advanced (formula editor)
I²C, SPI, UART/RS-232, CAN/LIN, I²S, MIL-STD-1553, ARINC 429	I²C, SPI, UART/RS-232, CAN/LIN, I²S, MIL-STD-1553, ARINC 429, FlexRay™, CAN FD, USB2.0/HSIC, Ethernet, Manchester, NRZ	I²C, SPI, UART/RS-232, CAN/LIN, I²S, MIL-STD-1553, ARINC 429, FlexRay™, CAN FD, MIPI RFFE, USB2.0/HSIC, MDIO, 8b10b, Ethernet, Manchester, NRZ
track*	histogram, trend, track*	histogram, trend, track*
power, digital voltmeter (DVM), spectrum analysis and spectrogram	power, 16-bit high definition	power, 16-bit high definition, jitter, clock data recovery, I/Q data, RF analysis
		USB 2.0, 10/100/1000MBase-T Ethernet, 10GBase-T Ethernet, Broad-R Reach Ethernet, MIPI D-Phy
8.4", color, 1024 × 768 pixel	10.4", color, 1024 × 768 pixel	10.4", color, 1024 × 768 pixel
optimized for fast button operation	optimized for touchscreen operation, parallel button operation	optimized for touchscreen operation, parallel button operation
403 mm × 189 mm × 142 mm	427 mm × 249 mm × 204 mm	427 mm × 249 mm × 204 mm
4.9 kg (10.8 lb)	8.6 kg (18.96 lb)	9.6 kg (21.2 lb)

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Cross-Coupled Tri-Band SIW Bandpass Filter Using Frequency Transformation

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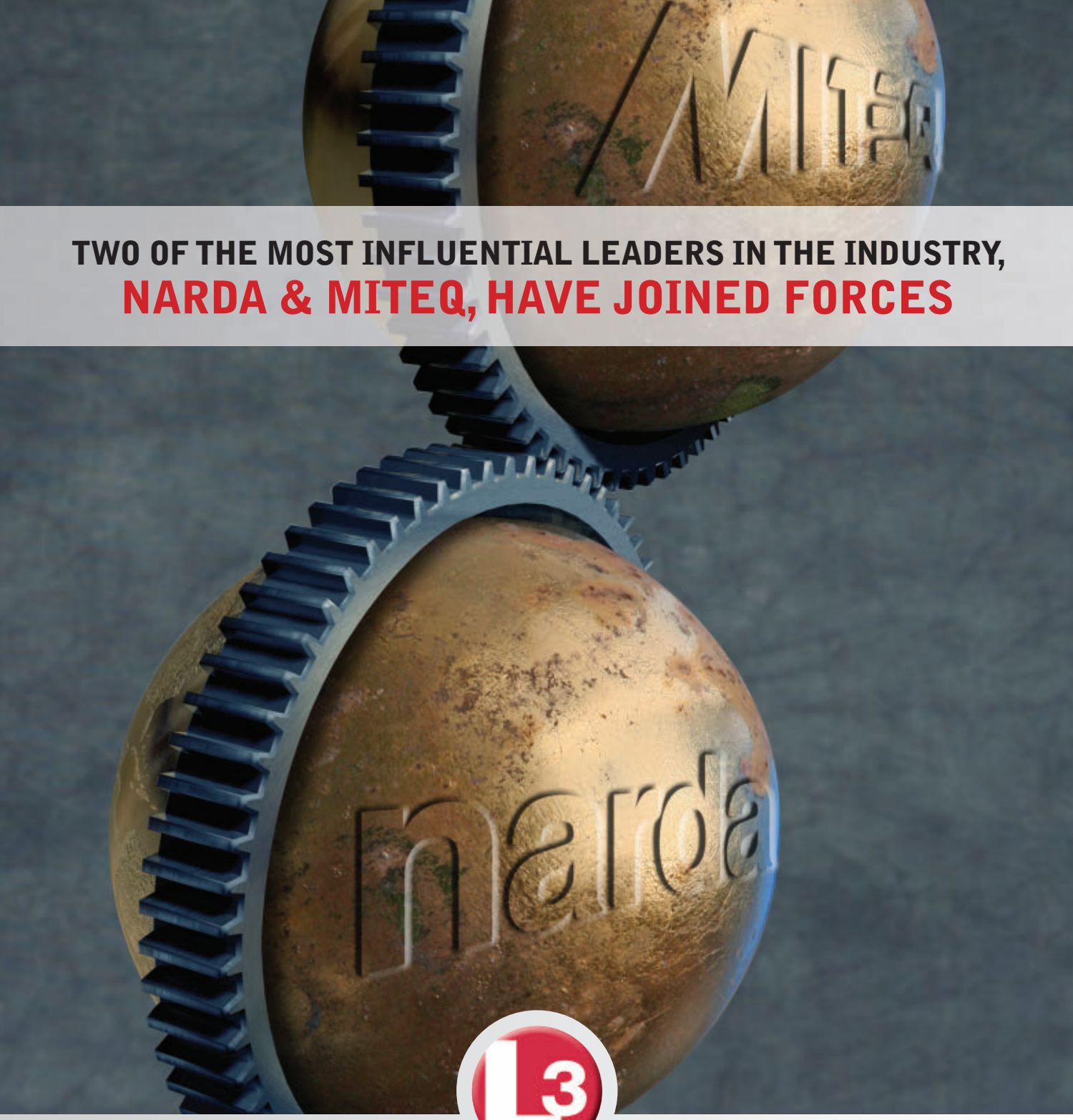
Xidian University, Xi'an, Shaanxi, China

A tri-band substrate integrated waveguide (SIW) bandpass filter is based on a suitably defined frequency transformation and well-established prototype synthesis techniques, where coupling coefficients and external quality factors can be calculated analytically. In this realization, an inverter coupled resonator section replaces each capacitance as the basic building block in the lowpass prototype circuit. A practical cross-coupled tri-band SIW filter is designed and fabricated with passbands at 5.85 to 5.9 GHz, 6.05 to 6.15 GHz and 6.25 to 6.35 GHz, respectively. Measured results show good agreement with analysis.

Multi-band bandpass filters (BPF) are key components in modern wireless communication systems. They simplify the system architecture while reducing circuit mass and volume. Tri-band BPFs have been extensively investigated and various design approaches have been reported. Among these techniques, the use of multi-mode resonators to build up tri-band BPFs are the most popular.[1-4] A tri-band BPF is designed by Hsu et al.,[1] using cascaded stepped impedance resonators (SIR) with controllable second and third harmonics. Composite resonators consisting of split-ring resonators are used as well.[2] To further reduce size, the combination of one set of half-wavelength resonators and one set of stub-loaded resonators is used.[3,4] The dependence on the resonant frequencies and coupling coefficients of multi-mode resonators, however, complicates tri-band BPF design. Alternatively, synthesis methods for dual-band filters using frequency transformations are used where the analytical and systematic design procedure is attractive.[5,6] In addition, SIW has been widely applied to microwave and millimeter wave circuit design due to its high-Q factor and high power handling capability, as well as its low cost and ease of integration.[7-8]

In this article, a cross-coupled tri-band SIW BPF based on frequency transformation is described. First, the frequency transformation from the actual frequency domain to the normalized frequency domain is derived. Then, the coupling coefficients and the external quality factors of the tri-band BPF topology are calculated. Lastly, a practical cross-coupled tri-band SIW BPF operating at 5.85 to 5.9 GHz, 6.05 to 6.15 GHz and 6.25 to 6.35 GHz with two normalized transmission zeroes at ± j1.8, is designed and fabricated. Measured results



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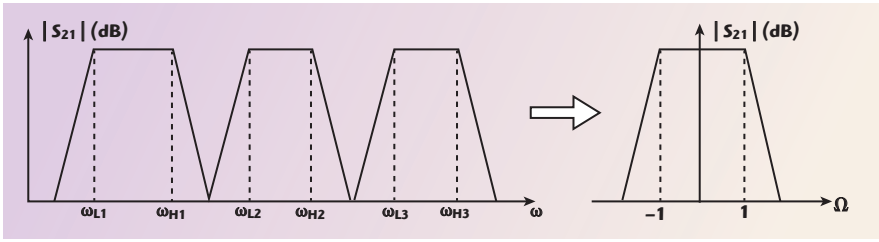

Fig. 1 Frequency transformation from ω-domain to Ω-domain.

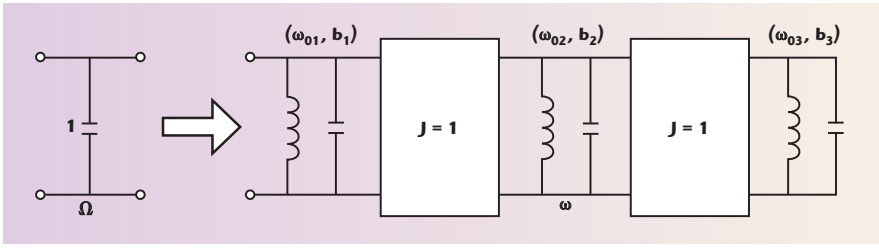

Fig. 2 Element transformation from Ω-domain to ω-domain.

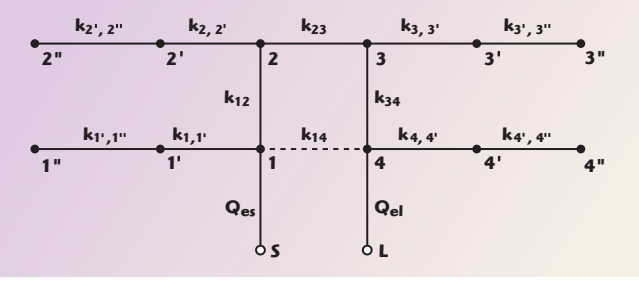

Fig. 3 Fourth order cross-coupled tri-band BPF topology. Each black node represents a resonator; the lines represent the couplings.

show good agreement with simulation.

SYNTHESIS BY FREQUENCY TRANSFORMATION TECHNIQUE

The ω-domain response of the tri-band BPF that operates at passbands $(\omega_{L1}, \omega_{H1})$, $(\omega_{L2}, \omega_{H2})$ and $(\omega_{L3}, \omega_{H3})$ is shown in ***Figure 1***. The lowpass prototype operates at the normalized Ω frequency domain and the frequency transformation function from the actual ω-domain to the normalized Ω-domain is:

$$\Omega = T(\omega) = b_1\left(\frac{\omega}{\omega_{01}} - \frac{\omega_{01}}{\omega}\right) - \frac{1}{b_2\left(\frac{\omega}{\omega_{02}} - \frac{\omega_{02}}{\omega}\right) - \frac{1}{b_3\left(\frac{\omega}{\omega_{03}} - \frac{\omega_{03}}{\omega}\right)}} \quad (1)$$

The six unknown coefficients b_1, b_2, b_3, ω_{01}, ω_{02} and ω_{03} that define the transformation can be analytically determined by imposing suitable requirements. To determine these parameters, it can be assumed that the lower limits $(\omega_{L1}, \omega_{L2}, \omega_{L3})$ of the three passbands map to -1 in the normalized Ω domain, while the upper limits $(\omega_{H1}, \omega_{H2}, \omega_{H3})$ map to 1. Taking into account that the transformation T(ω) in (1) is an odd function, these mapping relationships can be expressed as follows:

$$T(\omega_{H1}) = T(\omega_{H2}) = T(\omega_{H3}) = 1 \quad (2a)$$

$$T(-\omega_{L1}) = T(-\omega_{L2}) = T(-\omega_{L3}) = -(-1) = 1 \quad (2b)$$

Expressing the transformation Equation 1 as the ratio of two polynomials and substituting it into U(ω) = T(ω)-1, yields the following rational function:

$$U(\omega) = \frac{N(\omega)}{D(\omega)} = \frac{\omega^6 + n_5\omega^5 + n_4\omega^4 + n_3\omega^3 + n_2\omega^2 + n_1\omega + n_0}{-n_5\omega^5 - n_3\omega^3 - n_1\omega} \quad (3)$$

where,

$$n_0 = -\omega_{01}^2\omega_{02}^2\omega_{03}^2, n_1 = -\omega_{01}\omega_{02}^2\omega_{03}^2 / b_1 \quad (4a)$$

$$n_2 = \omega_{01}^2\omega_{02}^2 + \omega_{01}^2\omega_{03}^2 + \omega_{02}^2\omega_{03}^2 + \omega_{01}^2\frac{\omega_{02}\omega_{03}}{b_2b_3} + \omega_{03}^2\frac{\omega_{01}\omega_{02}}{b_1b_2} \quad (4b)$$

$$n_3 = \frac{\omega_{01}}{b_1}\left(\omega_{02}^2 + \omega_{03}^2\right) + \frac{\omega_{01}\omega_{02}\omega_{03}}{b_1b_2b_3} \quad (4c)$$

$$n_4 = -\left(\omega_{01}^2 + \omega_{02}^2 + \omega_{03}^2\right) - \frac{\omega_{02}\omega_{03}}{b_2b_3} - \frac{\omega_{01}\omega_{02}}{b_1b_2} \quad (4d)$$

$$n_5 = -\omega_{01} / b_1 \quad (4e)$$

The frequencies $-\omega_{L1}$, ω_{H1}, $-\omega_{L2}$, ω_{H2}, $-\omega_{L3}$, ω_{H3} are the zeroes of U(ω), i.e., they are the roots of the numerator N(ω); so, the unknown parameters $n_0 \sim n_5$ can be easily determined by solving a set of linear equations.

Using Equations 4a through 4e, the six parameters that define the transformation T(ω) can be expressed as follows:

$$\omega_{01} = \sqrt{-\frac{n_0n_5}{n_1}} \quad (5a)$$

$$\omega_{02} = \sqrt{\frac{n_1^2n_4n_5 - n_0n_1n_5^2 - n_1^2n_3}{n_0n_3n_5^2 + n_1^2n_5 - n_1n_2n_5^2}} \quad (5b)$$

$$\omega_{03} = \sqrt{\frac{n_1}{n_5\omega_{02}^2}} \quad (5c)$$

$$b_1 = \sqrt{-\frac{n_0}{n_1n_5}} \quad (5d)$$

$$b_2 = \sqrt{\frac{n_1n_5^2}{\left(\frac{n_0n_3}{n_1} + \frac{n_1}{n_5} - n_2\right)\left(n_4n_5 - \frac{n_0}{n_1}n_5^2 - n_3\right)}} \quad (5e)$$

$$b_3 = \frac{\omega_{01}\omega_{02}\omega_{03}}{b_1b_2\left(n_3 + n_5\left(\omega_{02}^2 + \omega_{03}^2\right)\right)} \quad (5f)$$

Applying the above frequency transformation, a normalized unit capacitance in the lowpass prototype can be transformed to an inverter coupled resonator section (see ***Figure 2***).

With the previous analysis and cross-coupled lowpass prototype, a fourth order cross-coupled tri-band BPF is constructed with the topology depicted in ***Figure 3***. Note that the first resonators of the inverter-coupled resonator sections are cross-coupled and the coupling coefficients between these resonators can be expressed in the form of matrix **K**:

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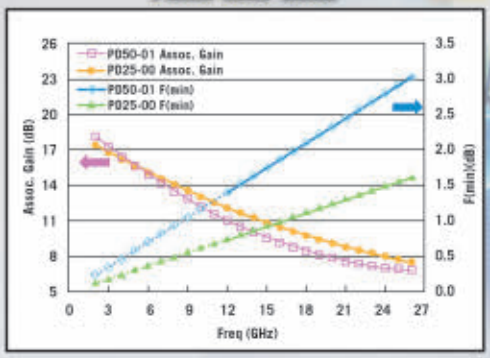
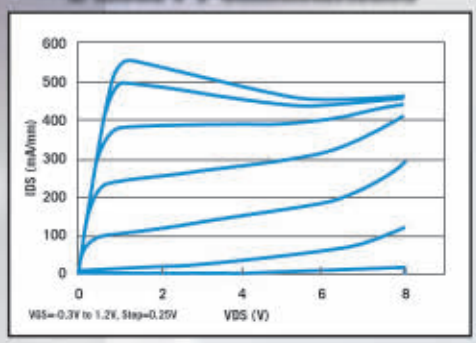
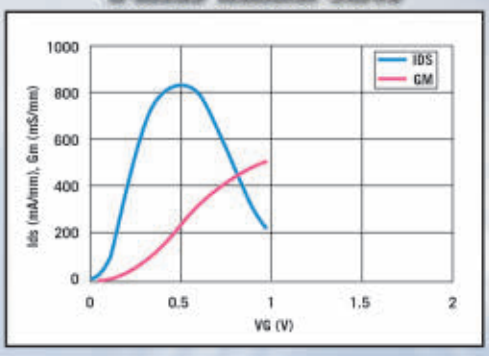


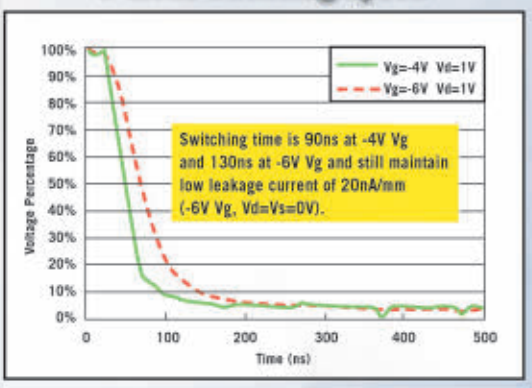
E-mode I-V Characteristics



E-mode Transfer Curve



D-mode Switching Speed



D-mode Device Performance

	PD50-01		PD25-00	
	Single	Triple	Single	Triple
Ron (ohm.mm)	1.9	3.7	1.3	2.2
Coff (fF/mm)	168	83	163	92
RonxCoff(ohm.fF)	316	310	209	198

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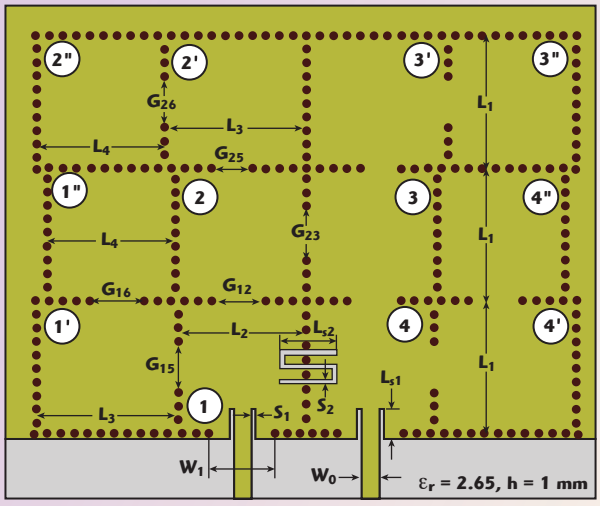

Fig. 4 Tri-band SIW BPF layout.

$$\mathbf{K}=\mathbf{M}/b_1 \quad (6)$$

where M is the coupling matrix of the cross-coupled lowpass prototype. The coupling coefficients of the resonators inside the inverter coupled resonator section are expressed as:

$$K_{i,i'}=1/\sqrt{b_1 b_2}, K_{i',i''}=1/\sqrt{b_2 b_3}, i=1\sim 4 \quad (7)$$

and the external quality factors at the source and load terminals can be calculated using the following expressions:

$$Q_{es}=b_1/R_1, Q_{el}=b_1/R_N \quad (8)$$

where R_1 and R_N are the source and load impedance of the lowpass prototype, respectively.

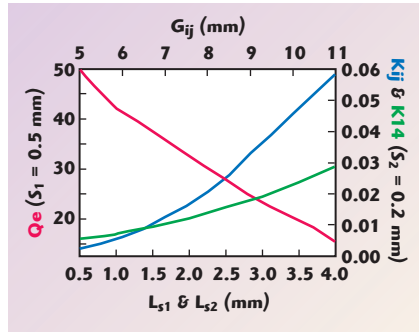

Fig. 5 Extracted external quality factor and coupling vs. physical parameters.

CROSS-COUPLED TRI-BAND SIW BPF DESIGN

Based on the above synthesis procedure, a new fourth order cross coupled tri-band SIW BPF is designed. The three operating bands are 5.85 to 5.95 GHz, 6.05 to 6.15 GHz and 6.25 to 6.35 GHz, and each band features a 20 dB maximum return loss. A generalized Chebyshev lowpass prototype with two finite transmission zeros at ± j1.8 and 20 dB return loss are first synthesized. Then, the coupling coefficients and the external quality factors are calculated employing Equations 6 through 8 as follows:

$$K_{12}=K_{34}=0.0429,\ K_{23}=0.0378, K_{14}=0.01 \quad (9a)$$

$$K_{ii'}=0.0464, K_{i'i''}=0.0367,\ i=1\sim 4 \quad (9b)$$

$$Q_{es}=Q_{el}=19.385 \quad (9c)$$

Finally, the circuit is realized with SIW structures. The relative dielectric constant, thickness and loss tangent of the substrate are 2.65, 1 mm and 0.001, respectively. The diameter of each metal hole is 1.5 mm and the distance between holes is 2.25 mm. The layout is shown in ***Figure 4***. HFSS is used to extract the relationships between the coupling coefficients and corresponding physical dimensions that are shown in ***Figure 5***. By using Figure 5 along with some optimization, the final physical parameters are obtained (see ***Table 1***).

MEASURED RESULTS

Figure 6 is a photograph of the fabricated filter. ***Figure 7*** compares the simulated frequency response using HFSS with the measured response using Keysight's 8719ES network analyzer. The fabricated BPF operates from 5.85 to 5.95 GHz, 6.05

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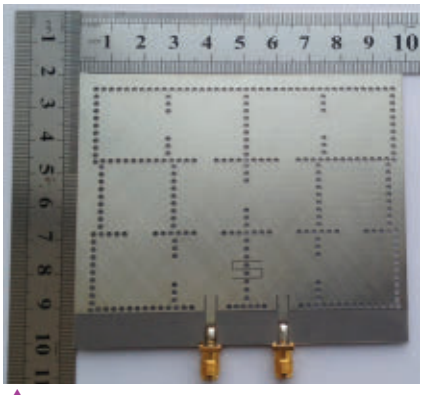
TABLE 1
FILTER PHYSICAL DIMENSIONS (MM)

W_0	W_1	L_1	L_2	L_3	L_4	L_{S1}	L_{S2}
2.7	0.5	21.30	20.94	21.41	23.20	3.5	2
S_1	S_2	G_{12}	G_{15}	G_{16}	G_{23}	G_{25}	G_{26}
0.5	0.2	10.2	10.4	9.4	9.3	10.3	9.4

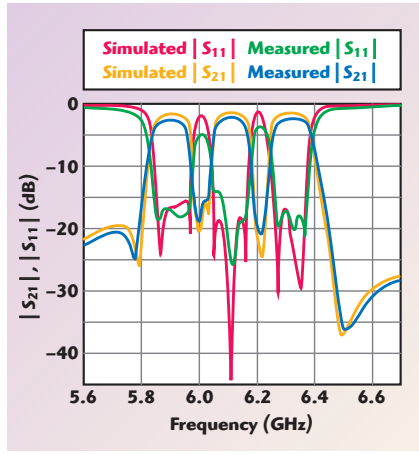


▲ *Fig. 6 Photograph of the fabricated tri-band SIW BPF.*

to 6.15 GHz and 6.25 to 6.35 GHz centered at 5.89, 6.09 and 6.3 GHz, respectively. Measured results show good agreement with simulation. The simulated insertion loss is about 1.5 dB at the three center frequencies, while measured losses are 2.27, 2.11 and 2.31 dB. Differences are attributed to dielectric losses and process tolerances.

CONCLUSION

A new cross-coupled triple-band SIW BPF is analyzed based on the frequency transformation technique. The relationship between parameters defining the transformation and the passband limit frequencies of the three passbands is derived and expressions for coupling coefficients and external quality factors are given. The theoretical frequency response of the filter meets its prescribed specifications and is verified through measurement. ■



▲ *Fig. 7 Comparison of simulated and measured results.*

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INVITED PAPER

A High Efficiency Class J RF Power Amplifier

Mouqun Dong
California Eastern Laboratories, Santa Clara, Calif.

A 460 MHz Class J power amplifier achieves a drain efficiency greater than 80 percent at 4 W output power with a 7.5 V supply. Detailed analysis is provided, noting assumptions used and their implications on circuit realization. Performance measurements are in good agreement with the analytical predictions.

Today, short-range wireless communication systems are increasingly employed for various applications. These systems usually operate in sub-GHz frequency bands for better radio wave propagation and include portable wireless devices powered by relatively low battery supply voltages. Consequently, one of the critical development challenges for these wireless systems is the design of a high efficiency power amplifier at the chosen frequency and required supply voltage.

High efficiency power amplifier design has long been an interest of RF engineers and is a topic widely covered in the literature. While classical high efficiency amplifiers, Class AB/B/C, are still discussed in most textbooks on RF amplifier designs,[1,2] recent research activities are focused on various switch-mode amplifiers such as Class E and Class F.[3,4] Lately, another type of high efficiency power amplifier, Class J, first introduced in 2006,[5] has gained the attention of design engineers as well as researchers for the simplicity of its matching networks and relevance in real circuit designs.[6,7,8] In this article, a review of the Class J power amplifier is presented along with an outlined design approach using the Class J concept for a 460 MHz power amplifier. The amplifier achieves a drain efficiency of more than 80 percent at 4 W output power with a 7.5 V supply. The device used in the design is Renesas' Silicon Power LDMOS FET, NE5550779A. It has rated output power of 7 W and is suitable for VHF to UHF applications with relatively low supply voltages (< 10 V).

CLASS J POWER AMPLIFIER BACKGROUND

The Class J amplifier was first proposed by Cripps[5] in 2006, followed by a more systematic analysis in 2009.[6] Since then there has been a significant number of publications on this mode of operation, mostly found in academic journals or white company papers, where a detailed treatment is usually omitted. Here, the principle of a Class J amplifier is provided in detailed steps, with particular attention paid to the assumptions used in circuit analyses and their implications on circuit realization.

Like classical high-efficiency linear amplifiers such as Class B, Class J is also considered a linear amplifier in that the drain current is assumed to be controlled only by the input level (gate voltage in the case of LDMOS) and is independent of the drain voltage. The difference between them is in the output load condition. For Class B, it is assumed that all harmonics are shorted at the output and therefore only the fundamental and DC components exist in the drain voltage. The actual circuit implementation of such a condition (all harmonics being shorted) is not always realistic, however, even at moderately high frequencies due to the presence of the internal output capacitance, C_{out}.[5] In the Class J mode, the second harmonic reactive component associated with C_{out} is actually utilized in combination with an appropriate fundamental load impedance to generate the so-called flattening effect on the drain-voltage waveform. This effect allows a further increase

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in the fundamental amplitude of the drain voltage such that the same efficiency and output power of a Class B amplifier can be achieved.

TRANSISTOR MODEL AND EQUIVALENT CIRCUIT

The transistor used in the Class J analysis is characterized, in the same manner as that for classical linear amplifiers, by a set of highly idealized I-V curves as shown in ***Figure 1a***. In this idealization, the drain current, i_d is assumed to be flat (independent of the drain voltage, v_d). Therefore, the transistor can be modeled as a controlled current source. The knee voltage denoted by V_k in Figure 1a marks the transition voltage below which the linear assumption is no longer valid. The requirement that $v_d \geq V_k$ is a crucial condition in the analysis of linear amplifiers. For simplicity, $V_k = 0$ is assumed and, as a result, the constraint that $v_d \geq 0$ is used throughout this article. When compared with experimental data, an effective DC voltage, V_{dc}-V_k should be used in the place of V_{dc} in the formulas obtained in this article. Furthermore, actual I-V curves change gradually and V_k can only be estimated. ***Figure 1b*** shows measured data in the knee voltage area for the NE5550779A transistor.

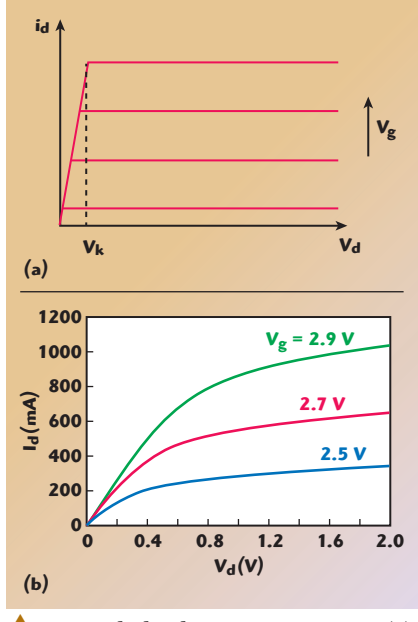


Fig. 1 Idealized transistor I-V curves (a) and I-V curves for NE5550779A FET (b).

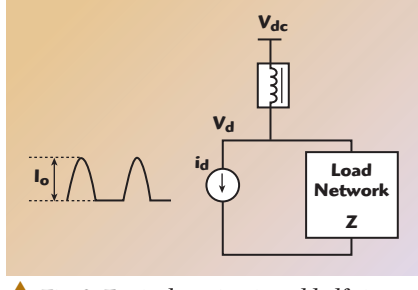


Fig. 2 Equivalent circuit and half-sine waveform of i_d.

With the transistor modeled as a current source, the complete equivalent circuit is shown in ***Figure 2***. In principle, the equation for the drain voltage can be solved in the frequency domain when the Fourier components of the drain current, i_d and the load impedance, Z are known:

$$v_{dn} = i_{dn} Z_n \tag{1}$$

where n is the index for nth harmonic. For the Class J PA, it is assumed that the second harmonic, v_{d2} is present and all higher harmonic components are shorted, i.e., $v_{dn} = 0$ for $n > 2$. Consequently, only the first three Fourier components of i_d must be considered. In addition, as in the Class B analysis, i_d is assumed to be a half-sine wave (the conduction angle is π). Then the drain current can be written as:[2]

$$i_d = I_{dc} + i_{d1} + i_{d2} = I_{dc} + I_1 \cos\theta + I_2 \cos 2\theta \tag{2}$$

here $\theta = \omega t$, and the amplitudes are explicitly given by:

$$\text{DC}: I_{dc} = \frac{I_0}{\pi}$$

$$\text{Fundamental}: I_1 = \frac{I_0}{2}$$

$$\text{Second Harmonic}: I_2 = \frac{2I_0}{3\pi}$$

where I_0 is the amplitude of the half-sine wave (see Figure 2). Correspondingly, the drain voltage has the form:

$$v_d = V_{dc} + v_{d1} + v_{d2} \tag{3}$$

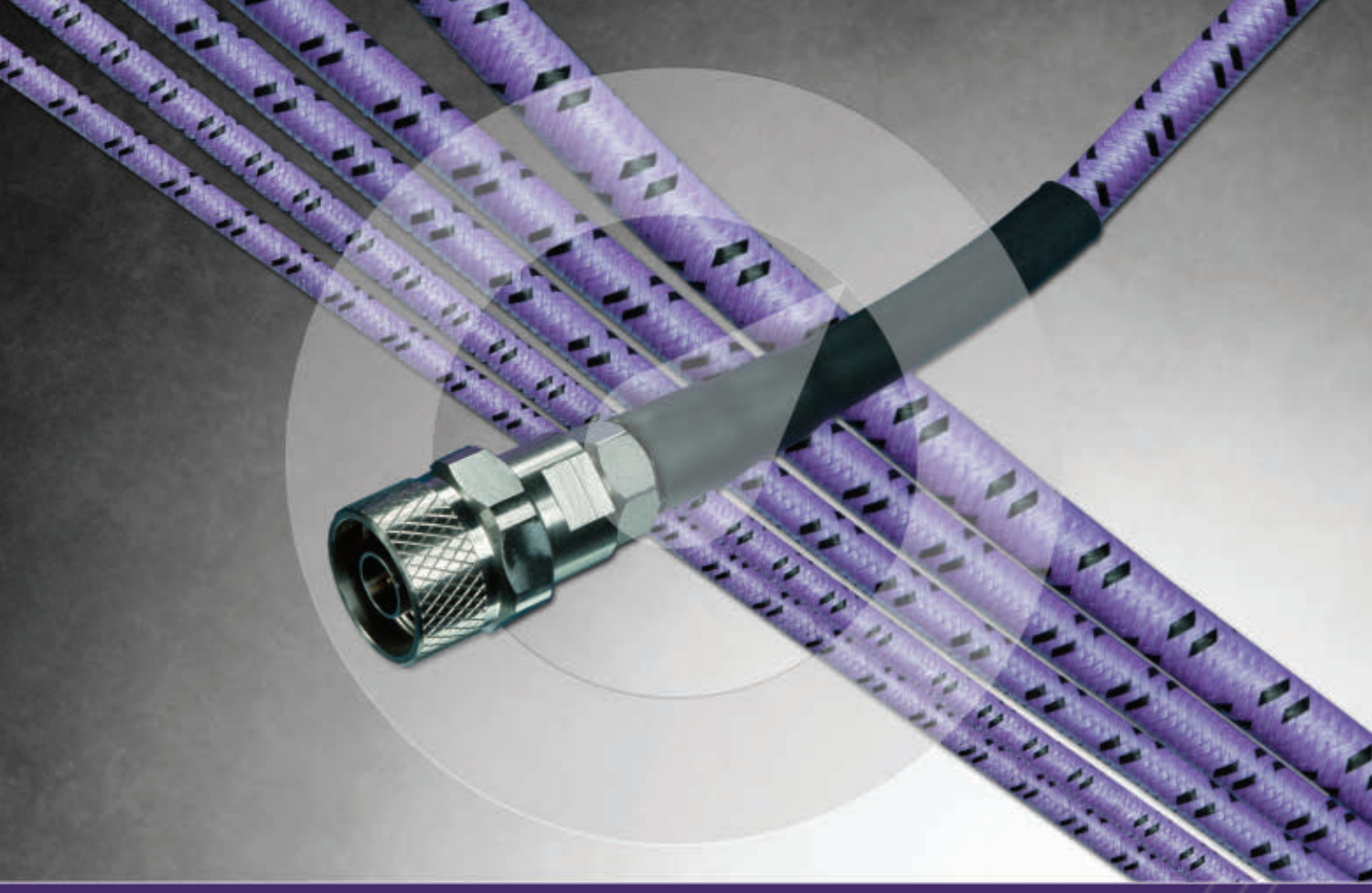
In Equation 3, V_{dc} is the same as the supply voltage, and v_{d1} and v_{d2} can be expressed as:

$$v_{d1} = -i_{d1} Z_1 ; v_{d2} = -i_{d2} Z_2 \tag{4}$$

The negative sign is the result of the convention used for the current source indicated in Figure 2.

V_d WAVEFORM AND THE FLATTENING EFFECT

When the drain voltage contains only the DC and fundamental components, the maximum fundamental amplitude is the same as the DC value due to the constraint of $v_d \geq 0$, as il-



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lustrated by the plot of y = 1 + cos(x) in ***Figure 3***. The figure also shows that when a second harmonic component, 0.4cos(2x), is added, the bottom part of the new waveform is flattened. This implies that the addition of a second harmonic component with an appropriate phase allows the fundamental component to further increase without changing the DC level. Evidently the increase in drain voltage at the fundamental frequency can potentially boost the output power, and therefore the efficiency. This flattening effect associated with the second harmonic component is the basic idea behind Class J operation. The task for Class J PA analysis is to determine the appropriate phase and amplitude relationships between the fundamental and second harmonic components such that the fundamental amplitude is maximized while the overall waveform satisfies the constraint that $v_d \geq 0$.

Consider a general form for waveforms that have the first three Fourier components:

$$v_d(\theta) = 1 + A_1 \cos(\theta + \theta_1) + A_2 \cos(2\theta + \theta_2) \quad (5)$$

here all amplitudes are normalized to the DC value. To maximize the voltage swing while still in compliance with the constraint $v_d \geq 0$, the waveform in Equation 5 should reach 0 at its lowest points. Let θ_0 be the location of the lowest point of $v_d(\theta)$, then we require

$$v_d(\theta_0) = 0 \quad (6)$$

$$v_d'(\theta_0) = 0 \quad (7)$$

Equation 7 is due simply to the fact that a function's derivative is zero at its minimum point. It turns out that the mathematical solution for θ_0 is quite tedious for the general expression in Equation 5. The analysis can be done with a simplified expression as described in the next section.

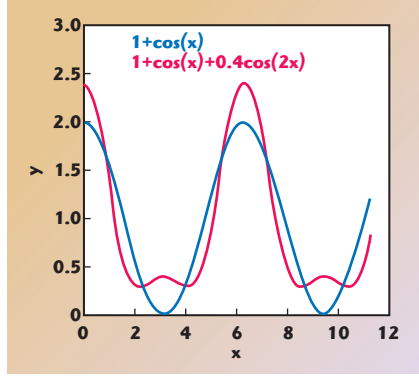
CLASS J MODE OF OPERATION

A special case of Equation 5 that is in factored form is used to analyze the Class J PA:[6]

$$v_d(\theta) = (1 - \cos\theta)(1 + \alpha \sin\theta) \quad (8)$$

Equation 8 has an obvious solution, $\theta_0 = 0$ that simultaneously satisfies Equations 6 and 7. It can be proved that for $|\alpha| < 1$, $\theta_0 = 0$ is the only solution. For $|\alpha| = 1$, there is a second solution in addition to $\theta_0 = 0$. When $|\alpha| > 1$, $\theta_0 = 0$ is only a local minimum and the requirement of $v_d \geq 0$ is no longer true in certain regions of θ. Therefore, $|\alpha| \leq 1$ is the range of α that corresponds to physically meaningful solutions.

It will be proven that the waveform described by Equation 8 represents a class of amplifiers that have the same



▲ *Fig. 3 Flattening effect of the second harmonic component.*

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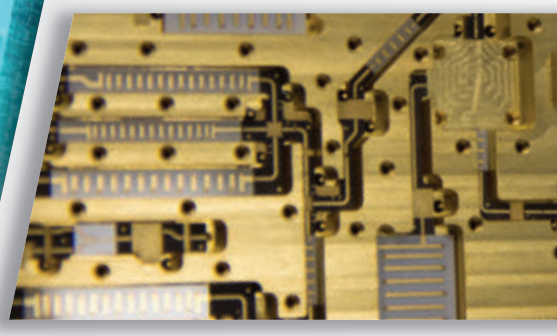

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output power and efficiency. The parameter, α in the equation is a distinguishing attribute for this class of amplifiers with a range of $|\alpha| \leq 1$. At α = 0, v_d is reduced to the classical Class B mode (only DC and fundamental components exist). While Class J is sometimes defined in the literature as a special case for α = 1, in this article "Class J" is used loosely for the entire class of waveforms described by Equation 8. In the following, the load impedances that will generate the required Class J waveforms are derived.

Equation 8 can be rewritten as:

$$v_d(\theta) = 1 - \cos\theta + \alpha\sin\theta - \alpha\cos\theta\sin\theta \quad (9)$$

With trigonometric identities, $v_d(\theta)$ can be further explicitly expressed as a sum of three Fourier components:

$$v_d(\theta) = 1 - \sqrt{1+\alpha^2}\cos\left(\theta + \arctan(\alpha)\right) - \frac{\alpha}{2}\sin 2\theta \quad (10)$$

Now if the fundamental load impedance, Z_1 is chosen to be in the form of:

$$Z_1 = R + j\alpha R \quad (11)$$

then, the amplitude and phase of Z_1 in the phasor form,

$$Z_1 = |Z_1|e^{j\Theta_0}, \text{are } |Z_1| = R\sqrt{1+\alpha^2}$$

and Θ_0=arctan (α) repectively. Using Equations 2 and 4, the fundamental drain voltage is

$$V_{d1} = -i_{d1}Z_1 = -\frac{I_0}{2}R\sqrt{1+\alpha^2}\cos\left(\theta + \arctan(\alpha)\right) \quad (12)$$

The second harmonic load impedance is chosen as a pure reactance:

$$Z_2 = -j\frac{3\pi}{8}\alpha R \quad (13)$$

It is confirmed in the next section that such a form of Z_2 is realistic for real circuit designs. This is because the external matching network is usually a type of lowpass filter and the dominant contribution to the second harmonic impedance is the internal output capacitance.

The drain voltage at the second harmonic becomes:

$$v_{d2} = -i_{d2}Z_2 = -\frac{2I_0}{3\pi}\frac{3\pi}{8}\alpha R\cos\left(2\theta - \frac{\pi}{2}\right) = -\frac{I_0}{4}\alpha R\sin 2\theta \quad (14)$$

Including the DC term, the complete expression for v_d is

$$v_d = V_{dc} - \frac{I_0}{2}R\sqrt{1+\alpha^2}\cos\left(\theta + \arctan(\alpha)\right) - \frac{I_0}{4}\alpha R\sin 2\theta \quad (15)$$

When R is chosen to be:

$$R = \frac{2V_{dc}}{I_0} \quad (16)$$

Equation 15 becomes exactly the same as Equation 10. So the impedances defined in Equation 11 and 13 lead to the drain voltage waveform of the Class J mode defined in Equation 8 (note in Equation 8 V_{dc} is normalized to unity).

The power delivered to the load at the fundamental frequency is

$$P_1 = \frac{1}{2}V_{1R}I_1 \quad (17)$$

where V_{1R} is the amplitude of the in-phase (with current, i_{d1}) component of the fundamental drain voltage and is given by

$$V_{1R} = |v_{d1}|\cos\Theta_0 = \frac{I_0R}{2} = V_{dc} \quad (18)$$

Here, Equations 12 and 16 are used. Thus

$$P_1 = \frac{I_0V_{dc}}{4} \quad (19)$$

On the other hand, using the expression for I_{dc} in Equation 2 the DC power is obtained as

$$P_{dc} = I_{dc}V_{dc} = \frac{I_0V_{dc}}{\pi} \quad (20)$$

Therefore, the drain efficiency is

$$\eta = \frac{P_1}{P_{dc}} = \frac{\pi}{4} = 78.5 \text{ percent} \quad (21)$$

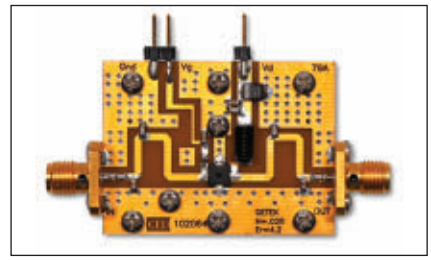

Fig. 4 460 MHz circuit board.

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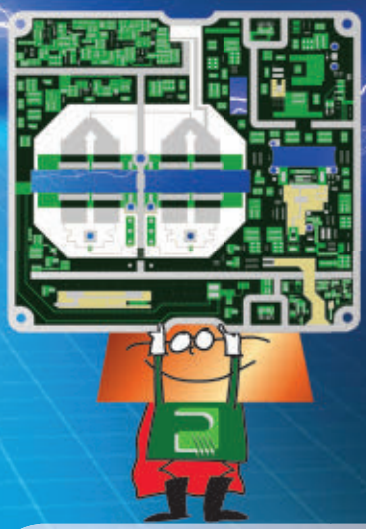

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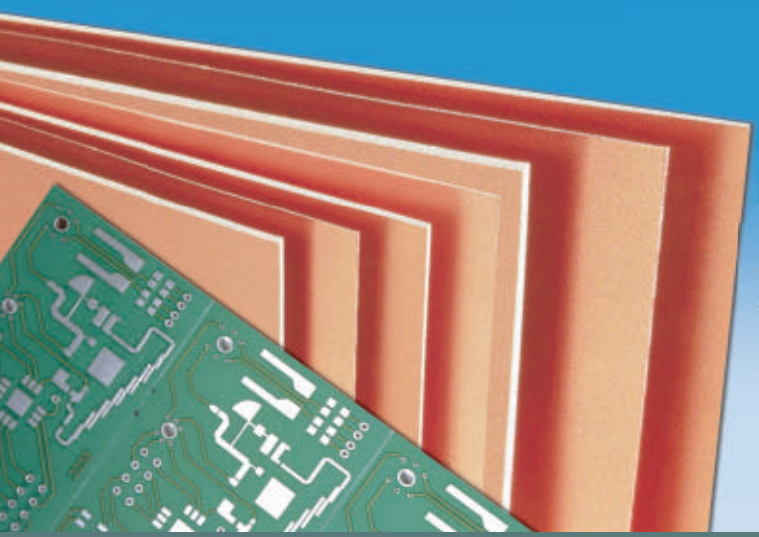

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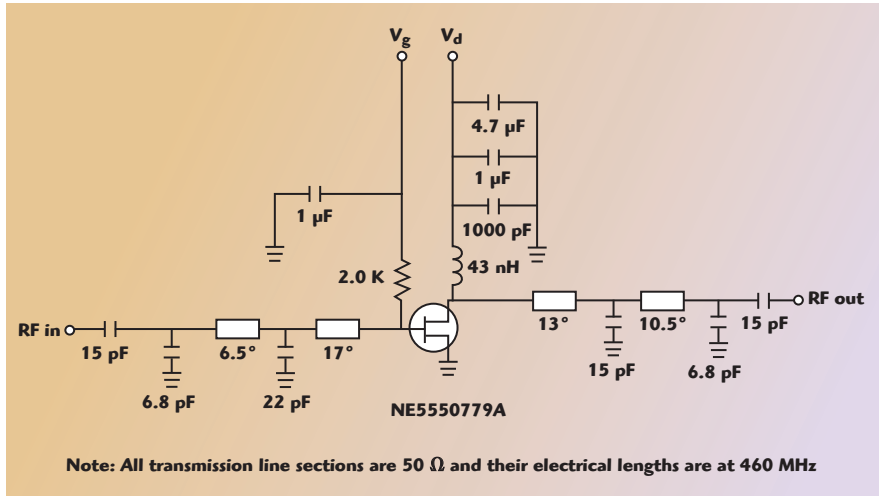

Fig. 5 460 MHz circuit board schematic.

This confirms the output power and drain efficiency for this class of linear power amplifiers are independent of the parameter α.

So far, it has been shown that Class J is a class of linear high efficiency power amplifiers whose drain voltage waveform and load impedance can be uniformly described by Equations 8, 11 and 13. The members of this class of amplifiers are characterized by a parameter, α which has a valid range of $|\alpha| \leq 1$. Mathematically, the classical Class B mode is just a special case of the Class J PA for $\alpha = 0$. However it can be proved (the details are not presented here) that when α approaches 0, the circuit realization for the required load impedance described in Equations 11 and 13 becomes unrealistic. So, to achieve true Class B mode operation in practice, a classical approach of a parallel resonant circuit is still required. In the next section, a circuit realization of the Class J PA with $\alpha \sim 0.5$ is presented.

CIRCUIT REALIZATION FOR MAXIMUM OUTPUT POWER

The device used for this design is Renesas' medium power LDMOS transistor, NE5550779A. It performs well with relatively low supply voltages ranging from 3.5 to 9 V, and therefore is suitable for battery operation. It has up to a 7 W output power capability, which is in a typical range for portable wireless devices. The chosen operating frequency is 460 MHz, a popular band for short range wireless communications.

Several standard evaluation circuit boards for the NE5550779A,

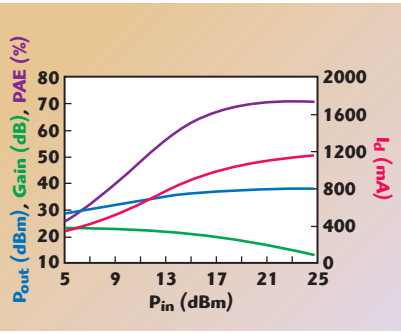

Fig. 6 460 MHz evaluation board - typical performance.

tuned for different frequency bands, are available from California Eastern Laboratories. ***Figure 4*** is a photo of the circuit board and ***Figure 5*** shows the 460 MHz circuit schematic. The matching networks consist of multiple sections of shunt capacitors and serial transmission lines, a circuit topology commonly used in practice. The low-pass nature of the network is what is required by the Class J analysis. The input matching network is designed for good return loss while the output matching is tuned for maximum saturated output power. Typical performance plots with a 7.5 V supply are shown in ***Figure 6***. As the data indicates, 38 dBm of output power and greater than 70 percent PAE are achieved with an input power of 20 dBm.

The impedance of the output matching network seen from the transistor's internal current source is analyzed using Keysight's design software, ADS. The simulation setup is shown in ***Figure 7***. In addition to the external matching components, a shunt capacitor (C4) and serial inductor (L1)

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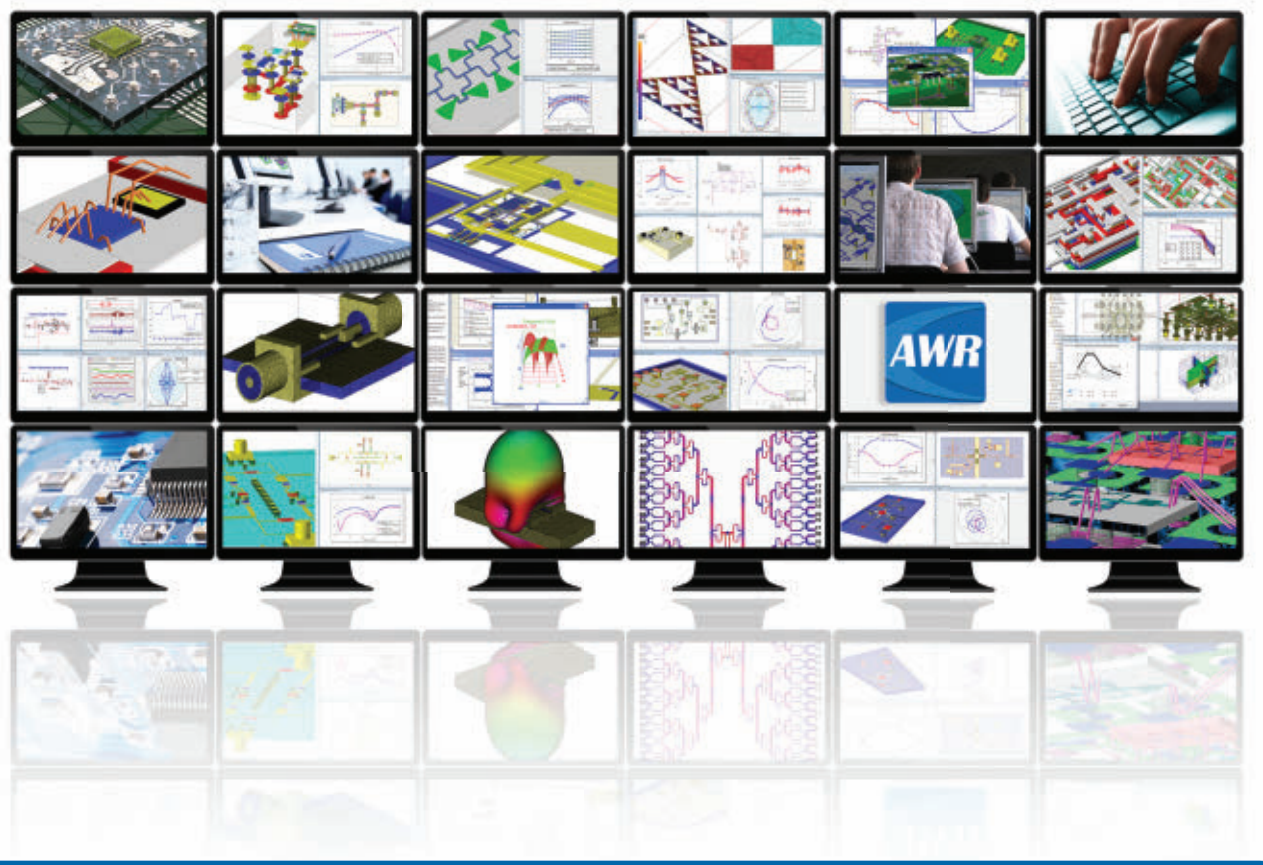

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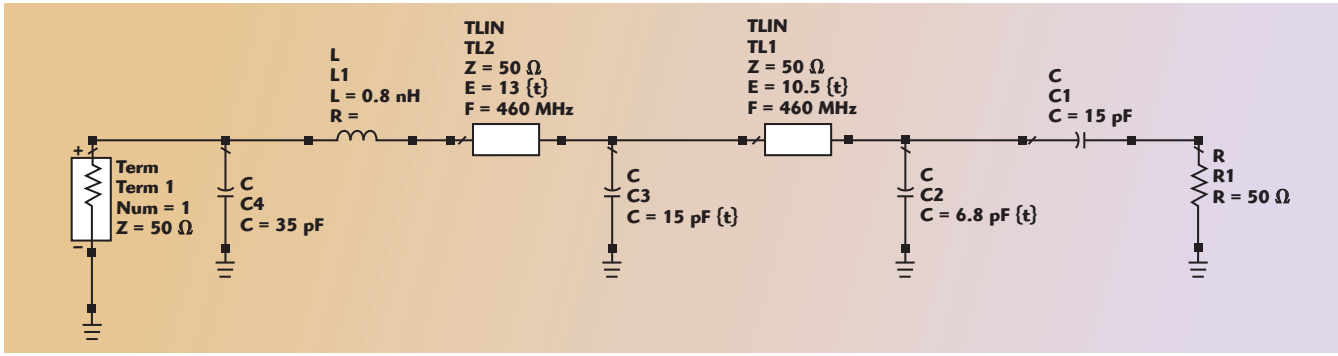

Fig. 7 Setup for output load impedance simulation.

are included in the matching network to account for the effects of transistor internal output capacitance and package inductance. ***Figure 8*** shows the calculated impedance in a Smith chart format. As the marker, m1, in the plot indicates, the fundamental-frequency impedance is essentially purely resistive at about 5.7 Ω. For a linear power amplifier, the relationship between the output power, P_{out}, and optimal load resistance R_{opt} is described by a classical formula:[3]

$$P_{out} = \frac{V_{dc}^2}{2R_{opt}} \quad (22)$$

When using Equation 22 for estimating actual circuit performance, the knee voltage V_k should be subtracted from the supply voltage for V_{dc}. In this case, if V_k is taken as 1 V (see the actual I-V curve in Figure 1b) then P_{out} = 3.7 W (35.6 dBm) for R_{opt} = 5.7 Ω. In reference to the plots in Figure 6, this output power level indeed corresponds to an input power

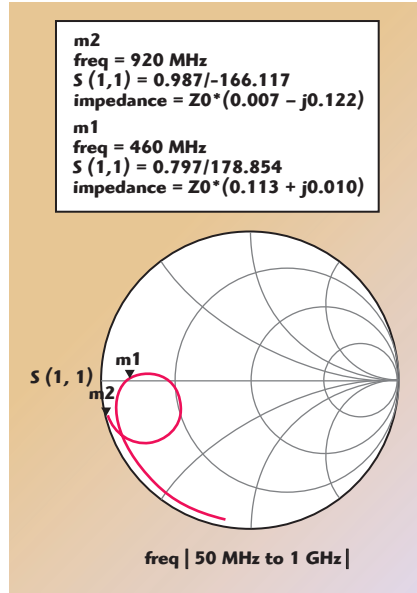

Fig. 8 Load impedance simulation of the standard evaluation circuit.

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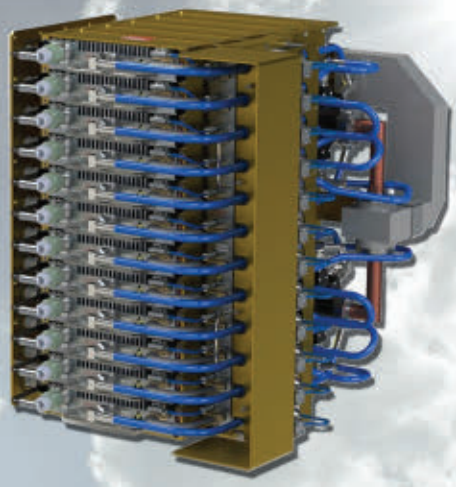

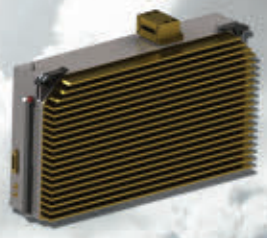

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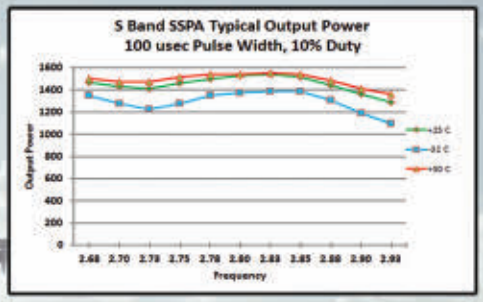

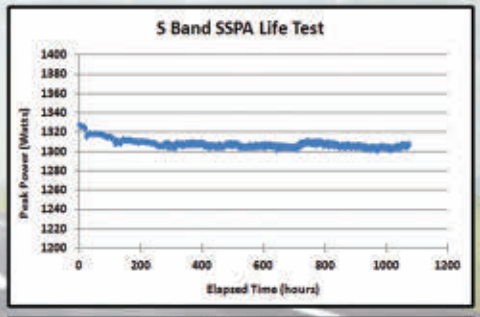

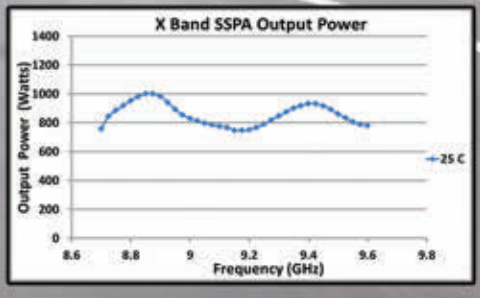

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level (around 13 dBm) where the amplifier starts to significantly deviate from the linear region. Beyond the linear region, the plot shows that efficiency further increases along with input power, which is a well known fact. From an analytical perspective, in the nonlinear region the drain current is no longer independent of the drain voltage and the simple current source model breaks down. The exact circuit behavior in the region $v_d < V_k$ depends on the details of the i_d vs. v_d characteristics and the load-termination condition. Some quantitative results that are based on much simplified circuit models have been reported on circuit performance in this region.[2,9] While accurate predictions of the circuit behavior in the nonlinear region can perhaps be determined from a simulation with an appropriate nonlinear device model, analytical works based on simple models do demonstrate that the output power and efficiency can be further increased along with the input power in this region.

CIRCUIT USING CLASS J CONCEPT

It was found that by tuning the circuit components with the ADS tuning tool (see Figure 7) the relationship between the fundamental and second harmonic load impedances described in Equations 11 and 13 can be achieved, as illustrated in ***Figure 9***. Specifically, after changing C3 from 15 to 20 pF and TL2 from 13° to 14.64°, the load impedance becomes:

$$Z_1 = 10.1 + j5.3\Omega;$$
$$Z_2 = 0.2 - j5.95\Omega \quad (23)$$

This confirms that Z_2 is indeed nearly purely reactive. It can also be seen that the numerical values of Z_1 and Z_2 are within 5 percent of the values for the Class J mode if R = 10.1 Ω and α = 0.52 are used in Equations 11 and 13. This observation suggests that Class J mode operation can be

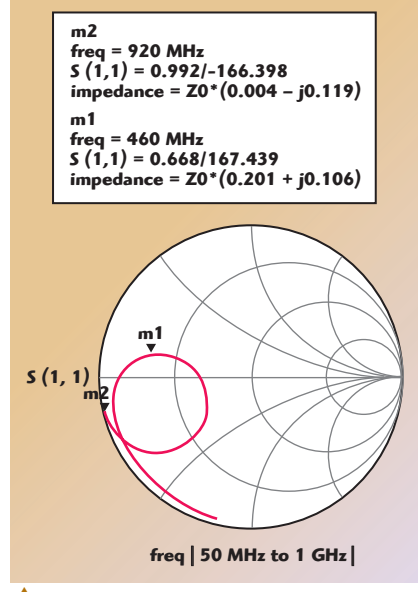

Fig. 9 Load impedance simulation after tuning for the Class J mode.

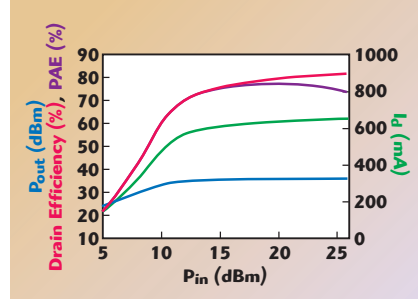

Fig. 10 Actual performance with the Class J matching network.

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realized on the existing circuit board with some simple changes to component values.

Figure 10 shows the performance of the actual circuit with the Class J matching network of Figure 9 implemented. A distinctive difference in Figure 10 versus Figure 6, is that efficiency at an input power level of around 13 dBm, the region where linear-to-nonlinear transition occurs, is significantly higher (PAE changes from 55 to 72 percent), while the output power is similar to that in Figure 6. This confirms that the Class J concept can be utilized in real circuit designs to achieve high efficiency, particularly in the linear region. Beyond the linear region the efficiency continues to increase with input power while the output power increases at a much lower rate. Eventually the drain efficiency exceeds 80 percent and the PAE peaks at 78 percent.

The output power saturates at a level of around 4 W, considerably lower than what was achieved on the standard circuit. The reduced saturation level for output power is due to a modified output load line condition that imposes a more severe restriction on the drain current in the nonlinear region, $v_d < V_k$. The effect of load-line matching on output power is discussed in many textbooks.[3] In practical design, this trade-off between efficiency and saturated output power is a consideration designers should keep in mind when seeking high efficiency performance.

Another noticeable feature of the plot in Figure 10 is that efficiency remains high (PAE > 70 percent) over a wide range (more than a decade) of input power. This feature makes high efficiency performance relatively insensitive to the input power, which is desirable in certain situations.

Finally, in many applications the saturation point of the PA output power is required to be limited at a certain level. It is found that the same tuning process (i.e., changing C3 and TL1/2 in Figure 7) used for Class J operation can be carried out on the bench to adjust the saturated power level while maintaining high efficiency (see ***Table 1***). The data points in the table are taken at an output power level roughly 0.25 dB below full saturation. As the data shows, the output power saturation point can be adjusted from roughly 1 to 5 W, a power range commonly used in short range communication systems, while PAE remains at a relatively high level (greater than 74 percent). This technique allows designers to use the same device to achieve high efficiency at different saturated output power levels. In principle, some power capability is wasted when a power transistor is used at power levels significantly lower than its capability. Nevertheless, using one device for multiple designs with different output power specifications may be advantageous, considering that for the power and frequency ranges discussed in this article the pricing difference among different devices is often manageable.

CONCLUSION

Utilizing the flattening effect associated with the second harmonic component in the drain voltage waveform to increase the fundamental ampli-

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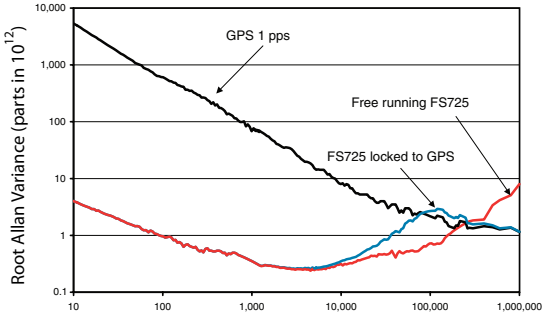

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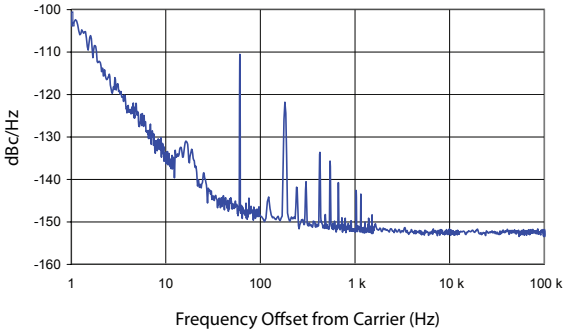

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tude, and thus to increase efficiency, is the key concept of the Class J power amplifier. In this article, a PA design employing Renesas' NE5550779A using the Class J concept is demonstrated for 460 MHz applications. It is shown that the load impedances required for Class J operation can be realized with a commonly used circuit topology. A relatively simple simulation with an EAD tool on the load network can facilitate the process to determine appropriate component values. Sophisticated nonlinear models are helpful but not necessary. In fact, the same results can be achieved with bench tuning without performing any simulations. Performance measurements on an actual circuit with a Class J load network are in good agreement with the analytical predictions. The circuit yields a drain efficiency of 80 percent with a PAE of 78 percent. The boosted efficiency, along with a much wider range of allowable input power to yield high efficiency, makes the Class J PA a suitable circuit choice in many real-world applications. ■

TABLE 1

SATURATED OUTPUT POWER, EFFICIENCY AND GAIN FOR DIFFERENT OUTPUT MATCHING CONDITIONS

P_{out} (W)	Gain (dB)	Drain Efficiency (percent)	PAE (percent)
5.3	14.5	77.2	74.5
4.4	15.7	78.8	76.7
3.8	16.0	80.2	78.2
2.4	15.9	78.5	76.5
1.7	14.4	77.5	74.0

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Mouqun Dong *is an RF engineer with California Eastern Laboratories. He received his Ph.D. degree in physics from Syracuse University in 1996, and M.Sc. and B.S. degrees in physics, from Chinese Academy of Sciences and Beijing Jiaotong University respectively.*

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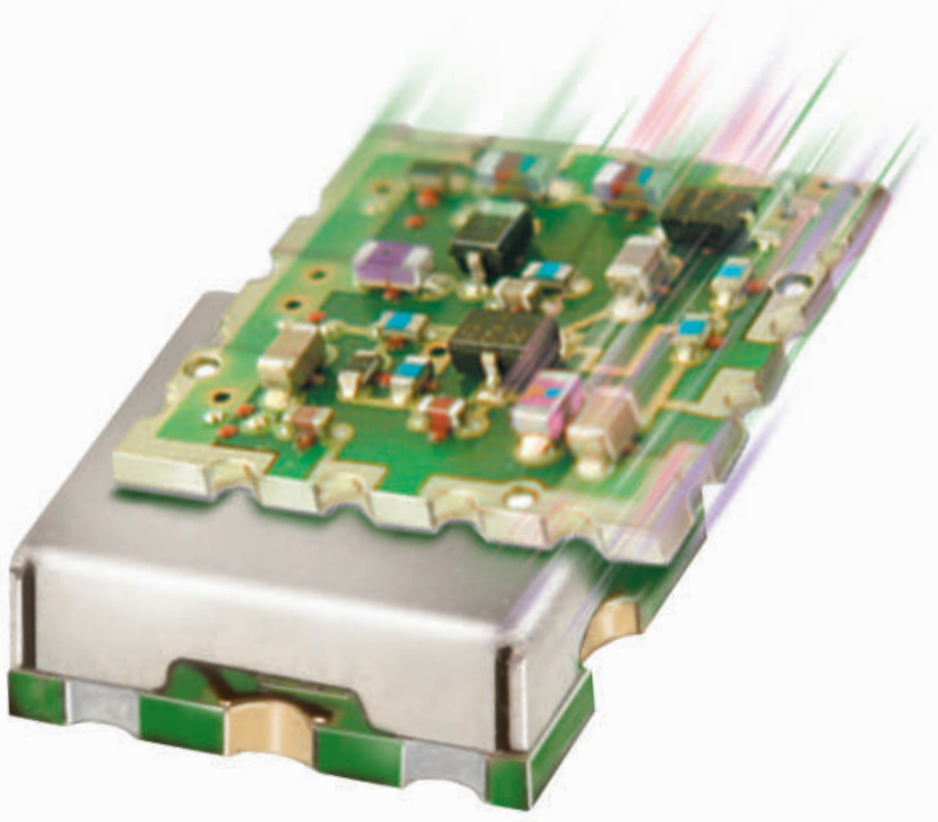

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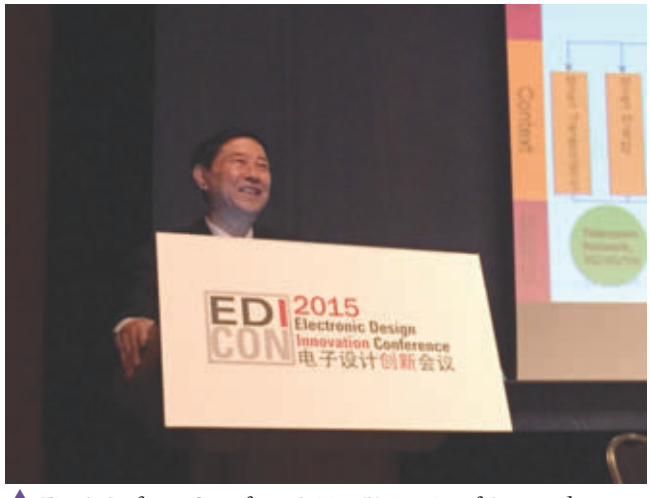
EDI CON China 2015 Reaches Olympic Heights

Patrick Hindle
Microwave Journal ***Editor***

EDI CON China 2015 took place in the heart of the Beijing Olympic Village on April 14–16 at the China National Convention Center (CNCC). Over the three-day event, a record setting 2625 attendees visited the exhibition and conference with a delegate count of 1214. The conference featured five parallel tracks on topics such as amplifier and component design, radar simulation and analysis, design for the Internet of Things (IoT), RF/microwave measurement and modeling, high speed design and measurement, subsystem and system design, PCB and connector design, and EMC/EMI modeling and measurement. New this year was a full day 5G forum featuring keynotes by China Mobile and Ericsson, an expert panel session, eight technical sessions and two workshops. The 5G panel keynote session had 124 attendees, the panel session more than 150. The average session size for all of the EDI CON sessions and workshops was close to 50 attendees.



▲ *Fig. 1 Professor Song from Beijing University of Posts and Telecommunications opened the plenary with a keynote presentation about smart cities.*

The plenary kicked off with EDI CON Chairman Professor Song from the Beijing University of Posts and Telecommunications discussing Smart Cities (see ***Figure 1***). He stated that more than 500 smart cities are under development in China with a forecast of $5 trillion in investment through 2017. Keynotes from China Mobile, China Unicom and ZTE followed, discussing their visions of 5G and the latest results for 5G prototypes. China Mobile highlighted their smart tile transceiver approach to massive MIMO for 5G deployments. The three main sponsors – Keysight Technologies, Rohde & Schwarz and National Instruments – also presented on the latest trends in test and measurement and their contributions to 5G research. This was followed by the Keysight sponsored reception dinner, where about 350 attendees enjoyed traditional Chinese cuisine and music.

The exhibition had close to 100 companies displaying products and services. The wide

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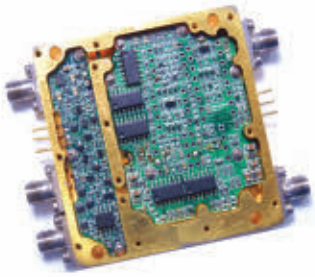

- Frequency Range: 100 MHz to 18.0 GHz
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- Flatness: ±2.0 dB typ., ±2.5 dB max.
- TSS: -65 dBm max.
- Pulse Range: +10 dBm ±2.5 dB typ.
- Rise Time: 20 ns max. (10% to 90%)
- Recovery Time: 200 ns max.
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Millimeter Wave

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- Log Linearity: ±2.0 dB @ 25°C, ±3.0 dB Over Temp
- Log Slope: 25 mV/dB nominal
- Flatness: ±2.5 dB max. @ 25°C
- TSS: -65 dBm @ 25°C
- Pulse Range: 30 ns to CW
- Rise Time: 11 ns max., 8 ns typ.
- Recovery Time: 60 ns max., 40 ns typ.
- Size: 2.37" x 1.80" x 0.42"

Ultra-Highspeed

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- Log Linearity: ±1.8 dB
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- Flatness: ±3 dB max.
- TSS: -64 dBm max.
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- Log Linearity: +1.5 dB max.
- Log Slope: 50.5 ±5% mV/dB
- Flatness: <4.0 dB @ -60 to -50 dBm Input, <6.0 dB @ -50 to 0 dBm Input
- TSS: -70 dBm min.
- Pulse Range: 100 ns to CW
- Rise Time: 20 ns (10% to 90%)
- Fall Time: 50 ns (90% to 10%)
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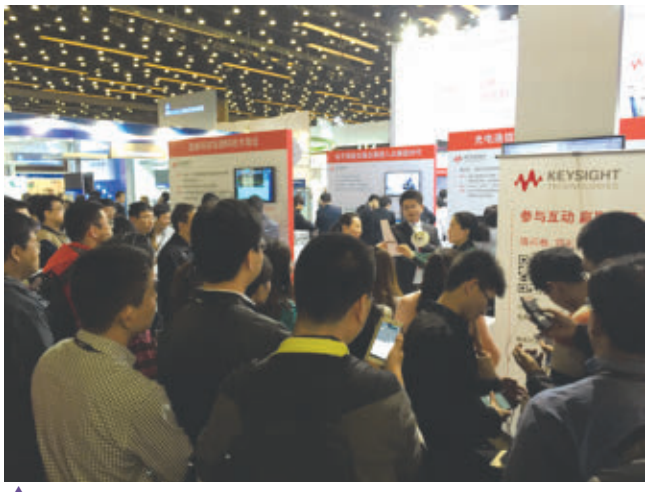
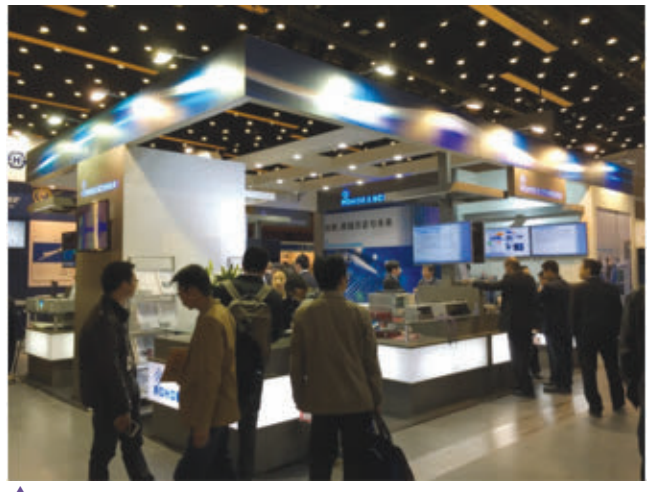


▲ *Fig. 2 Delegates watch one of many demos at the Keysight booth.*



▲ *Fig. 3 Rohde & Schwarz demonstrated 5G channel modeling using their vector signal generator system.*

range of products included test and measurement, software/modeling, devices/components, EMC/EMI, PCB materials and cable/connector companies. Our three main sponsors' displayed the following products at the exhibition.

Keysight, the host sponsor of EDI CON, had many demos in their booth showcasing their cutting edge test and measurement systems (see ***Figure 2***). They had a 5G demo to verify wide bandwidth Tx/Rx prototypes in real environments, helping to implement new 5G candidate waveforms that generate up to 4 GHz of bandwidth for both sub-6 GHz and mmWave frequencies and reach up to 10 Gbps data throughput.

For high speed digital applications, Keysight offers complete PAM-4 solutions for simulation plus input and output design characterization for 32 Gbaud and beyond. The company provided an overview of PAM-4 and PAM-N designs, an explanation of the latest measurement techniques, and an illustration of design and debug approaches and test solutions. Keysight's solutions for DDR memory applications are driven and supported by Keysight experts that are active in the Joint Electronic Devices Engineering Council (JEDEC). Their involvement in standards groups enables Keysight to bring the right solutions to the market when customers need them. Keysight offers a complete solution set from electrical to protocol. The Keysight E5080A is the next-generation ENA Series Network Analyzer, providing best-in-class performance, flexible functionality and advanced usability. With its intuitive, touch-based interface, the E5080A streamlines measurement flow and achieves better results in less time. This new instrument implements a converged platform that leverages the best attributes of the ENA and PNA families.

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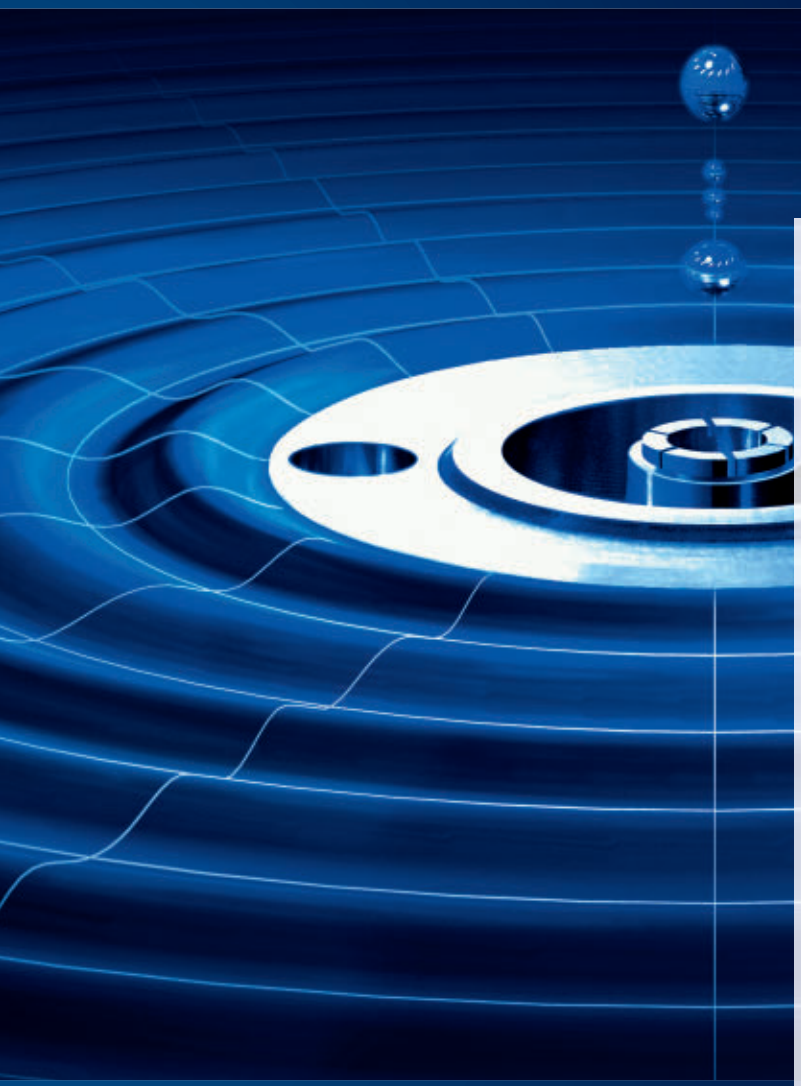

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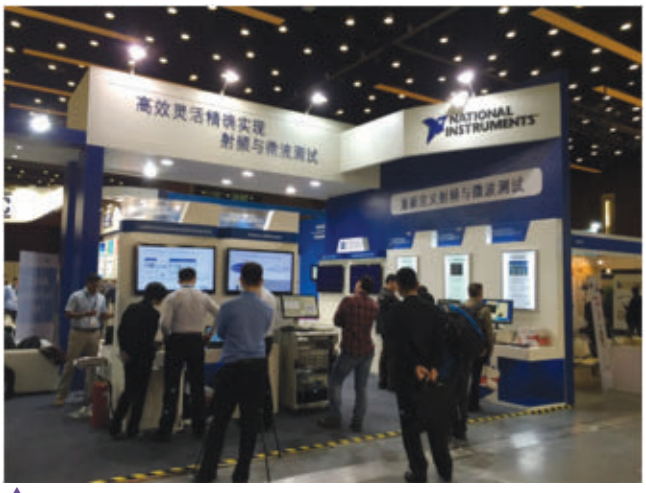

Fig. 4 National Instruments featured their new signal analyzer that operates to 26.5 GHz with 765 MHz bandwidth.

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Rohde & Schwarz showed their vector signal generator system with optional integrated real-time MIMO fading that supports two RF ports (up to 20 GHz each) and two digital/analog I/Q outputs (to connect additional R&S®SGS100A/SGT100A RF units). They demonstrated this setup for 5G channel modeling at EDI CON China (see ***Figure 3***). The I/Q modulator has up to 2 GHz RF modulation bandwidth (bandwidth of up to 160 MHz with internal baseband), with a phase coherence option, e.g., for beam forming applications. They also offer signal and spectrum analyzer and multi-port to support 5G development. The analyzer's frequency range extends from 2 Hz to 8, 13.6, 26.5, 43.5, 50 or 67 GHz (with external harmonic mixers from Rohde & Schwarz extending coverage to 110 GHz) and with up to 500 MHz analysis bandwidth. The vector network analyzer product family offers a wide range of test capabilities, ranging from 9 kHz to 4.5, 8, 20 or 40 GHz and supports massive MIMO test applications using network analyzers with up to 24 test ports or switch matrix solutions up to 48 ports.

Rohde & Schwarz demonstrated an automotive sensor analysis and test system with a touch screen and Ethernet control operating at 77 GHz. It can simulate and measure the signal characteristics for a full sensor test suite. Another demo featured a multi-test system that can measure wide band communications, audio quality and environmental testing in one set-up. Full performance and functional testing can be performed to international standards, with user equipment testing of data and audio quality from the user's perspective.

Rohde & Schwarz has a wide range of oscilloscopes, from value class for service, maintenance and education to top instruments for R&D or EMI debugging in the 600 MHz to 4 GHz range. Their oscilloscopes provide high definition, real-time analysis. The integrated digital down-conversion provides fast feedback from EMI probing. Illustrating Rohde & Schwarz collaboration, they featured a load-pull demonstration with Focus Microwaves.

National Instruments featured their new signal analyzer, which operates up to 26.5 GHz with 765 MHz of bandwidth (see ***Figure 4***). Coupled with an FPGA module, many different types of signal analysis can be performed. Their demo included real-time spectral analysis with a POI of 1.5 microseconds. NI also demonstrated their 5G rapid prototyping system with a massive MIMO setup (16 antennas in the booth). The demo utilized USRP Rio radios and a PXI chassis to aggregate all of the data. This demo was a replica of the system being evaluated at Lund University.

A second 5G demo included the Rio radio evaluating alternative modulation schemes. It uses LABVIEW Communication Design Suite with reference designs (LTE, 802.11xx) that allows users to evaluate new waveforms, such as FBMC, UFMC, BFDM and GFDM. The design suite can load the reference design and allows researchers to modify portions of the standard signals to test different scenarios.

Join us next year for EDI CON China 2016 at the CNCC in Beijing, April 19–21, 2016. ■

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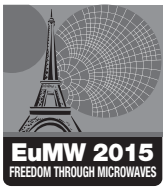

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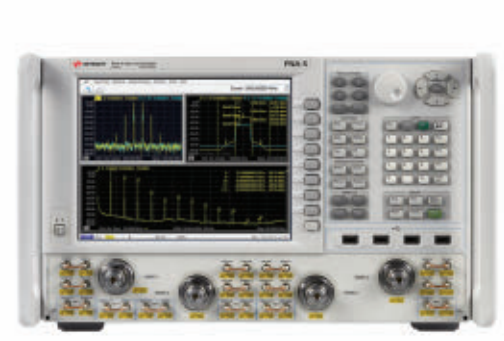
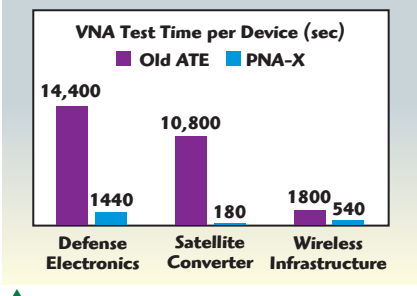


Faster Testing with High-Performance Spectrum Analysis in a VNA

Keysight Technologies Inc.
Santa Rosa, Calif.

Whether engineers are designing, developing or testing a new component, they will often use a network analyzer and a spectrum analyzer to fully understand the device under test (DUT). A vector network analyzer (VNA) measures or calculates informative responses such as S-parameters, gain compression and noise figure. A spectrum analyzer (SA) provides additional insights about the presence of harmonically related signals, non-harmonic spurious signals and more. During a typical troubleshooting session, the need to frequently connect, disconnect and reconnect the DUT to the VNA or SA will soon become inconvenient and time-consuming. One answer is to incorporate both capabilities in a single instrument.



▲ *Fig. 1 Modern VNAs are reducing test times significantly across a variety of applications.*

Of course, the notion of performing basic spectrum analysis with a VNA is not new. This capability exists, to some extent, in a few previous-generation analyzers. Today, faster digitizers, digital signal processors (DSP) and central processing units (CPU) are making it possible to implement an SA capability that is fast enough to accelerate crucial and often tedious measurements, such as spur searches.

ACCELERATING MEASUREMENT SPEED

In the past several years, VNAs have become significantly faster in all essential measurements: match, gain/loss, noise figure, two-tone IMD, leakage, conversion gain, compression, delay and more. Today's most advanced models cut test time per device by 10× in defense electronics, 6× in satellite converters and more than 3× in wireless infrastructure devices (see ***Figure 1***).

The technologies underlying these perfor-

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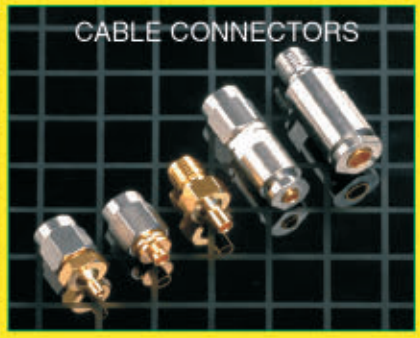

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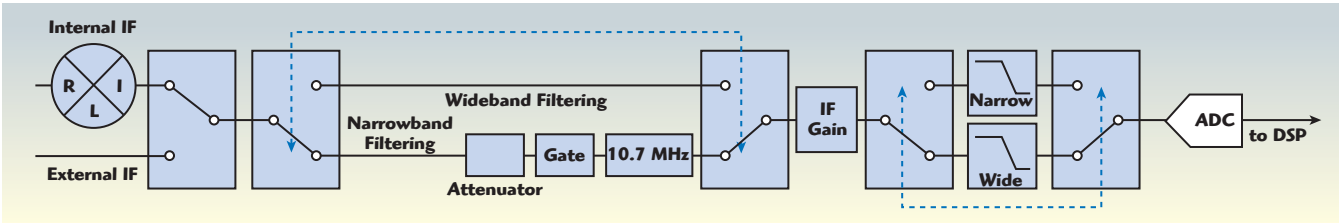
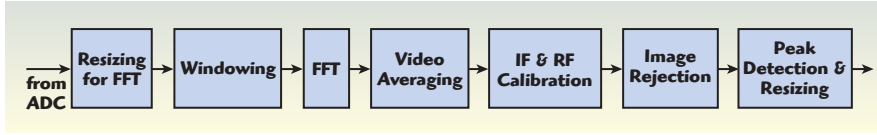


▲ *Fig. 2 To retain the expected level of VNA performance, the fundamental block diagram of the receiver was left intact.*

mance improvements were the necessary foundation for a high performance spectrum analyzer capability. Keysight's goal was to find a new and better way to provide an SA capability in a VNA without altering the core architecture of the instrument. This led to Option 090 for the Keysight PNA Series VNAs. This capability addresses the spur search problem in four ways. First, it provides fast searches over broad frequency ranges, up to 67 GHz, and test times are 10 to 500 times faster than a stand-alone SA when looking for medium-level spurs. Next, multi-channel spectrum analysis is synchronized with internal swept signal generators, providing additional insight into cause and effect. Third, it provides in-fixture spectrum measurements that benefit from the added accuracy of VNA calibration and de-embedding techniques. It is also compatible with the single-connection, multiple-measurement (SCMM) capability of the PNA-X microwave network analyzers. With these solutions, engineers have new ways to reach deeper insights into device performance.

LEVERAGING THE EXISTING ARCHITECTURE

The proven block diagram of a microwave VNA is one of the reasons it delivers excellent measurement results. This is why Keysight's design team wanted to leave the receiver block diagram untouched while adding meaningful SA capability (see ***Figure 2***). As implemented in the PNA Series, the receiver has a bandwidth of 38 MHz and uses a wideband anti-aliasing filter. The 100 MSa/s analog-to-digital converter (ADC) has a theoretical maximum bandwidth of 50 MHz. The key to the successful addition of SA capability was the addition of a new data-processing flow that pulls digitized data from the output of the receiver ADC. Similar to any advanced signal analyzer, the process creates a finite-sized time record of data, applies a windowing function and then computes a fast Fourier transform (FFT) to produce the frequency spectrum of the incoming signal (see ***Figure 3***). As shown, a few additional steps ensure an accurate and useful spectrum display: video averaging to reduce trace noise, calibration to ensure amplitude accuracy, image rejection to remove unwanted artifacts and peak detection to enhance frequency accuracy.



▲ *Fig. 3 SA-style processing and enhancement of digitized data provides fast and accurate spectrum measurements.*

Retaining the expected level of VNA performance precluded the addition of the hardware preselection filter or "preselector" that is used in stand alone spectrum analyzers to block unwanted harmonics or mixing products (i.e., images). Within the data flow, the solution was the development of a powerful software-based preselector that is part of the SA capability. On the test bench, engaging this capability virtually eliminates images. In addition, the analyzer can be configured to make harmonic measurements on one or more channels using the receiver attenuator and a narrow resolution bandwidth (RBW) to reduce the displayed noise floor.

SOLVING THE SPUR-SEARCH PROBLEM

Spurs are unwanted, non-harmonic signals that cause interference or false signals, reducing dynamic range in the DUT. The process of searching for spurs presents two challenges: time and complexity. Checking spurious performance is time-consuming, especially when searching for low-level signals over a broad frequency range. Characterizing spurs over the operating range of typical mixers and frequency-conversion devices tends to be tedious and complicated.

As an example, suppose a spike appears in a conversion-gain measurement made with a VNA. When using a typical SA, simply viewing the output spectrum is not much help. Getting to the necessary detail requires a signal analyzer and one or more tracking generators, which can be built in or may be external units the SA can control. Making the spectrum measurement requires several steps. First, disconnect the DUT from the VNA. Next, connect a signal generator to the DUT input and the SA to its output. Finally, configure the SA and signal generator to measure over the frequency range where the spur appeared in the conversion-gain trace. This may require measurements over one or more wide spans followed by several measurements made over narrower spans, one at a time.

This process is simpler and faster with the SA capability in the PNA. The VNA and DUT have three connections (LO, RF and IF) that enable the full complement of VNA measurements. In addition, the SA capability adds spectrum analysis across all ports of the DUT (RF input, RF output, LO input and IF output). Each spectrum analyzer channel provides additional insights into device behavior. For example, crossing spurs that affect fixed-output measurements are easily observed by sweeping the RF and LO sources over their respective frequency bands. Using the existing connections to the DUT, a PNA or PNA-X can make multiple simultaneous network and spectrum

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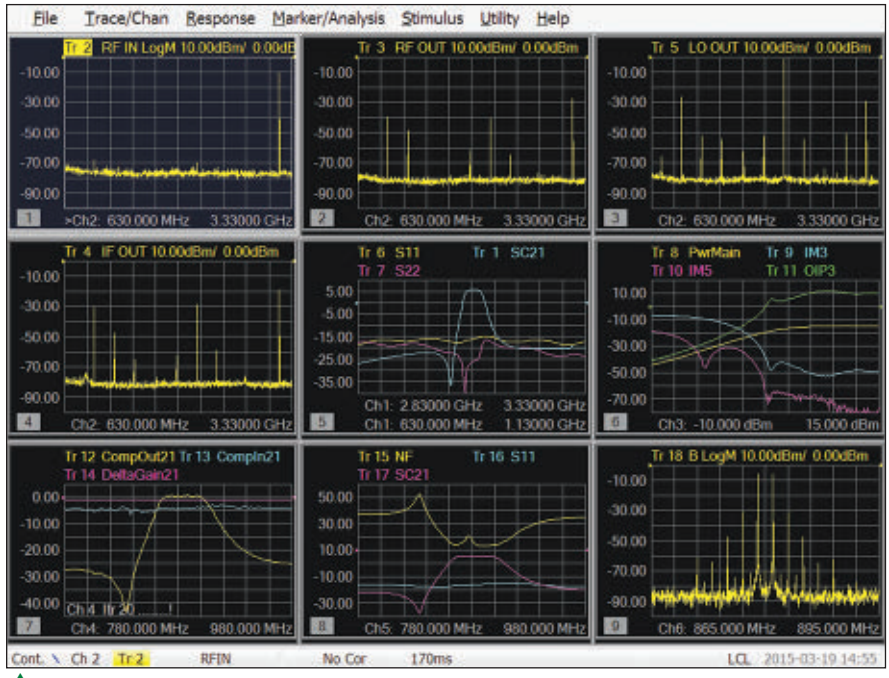

▲ *Fig. 4 Using the SCMM capability, this nine-window display shows five spectrum measurements along with four VNA measurements, including conversion gain (center), gain compression (bottom left) and noise figure (bottom center).*

measurements. With the SCMM capability in the PNA-X, a single set of connections is all that is needed to measure input spectra, output spectra, gain compression, conversion gain, noise figure, two-tone IMD and more (see ***Figure 4***). If an anomaly appears on a VNA trace, the user can place a marker at that point and use the "marker to SA" function to initiate a spectrum measurement that appears in a new window on the analyzer screen. As an added convenience, markers can also be used to perform band power and noise power measurements.

In-fixture and on-wafer measurements gain the benefits of VNA calibration and de-embedding, which correct receiver-response errors and also remove cable and fixture effects. The resulting improvement in test accuracy makes it possible to achieve narrower test margins and tighter device specifications. On the production line, this capability makes it possible to remove a switch matrix and standalone spectrum analyzer from the test system. This addresses the increasingly important need to reduce the size and complexity of component characterization test systems. It also helps system developers make better tradeoffs between test time and test coverage.

ACHIEVING UNRIVALLED EXCELLENCE

Providing spectrum analyzer measurements inside a VNA is not a new idea. However, the technology available today — ADC, DSP, CPU — makes it possible to implement those measurements at a speed that makes them truly useful to engineers who are designing and testing advanced components. When characterizing active devices, the right mix of speed and performance provides a competitive edge. In R&D, this provides a level of measurement integrity that helps developers transform deeper understanding into better designs. On the production line, it ensures the throughput and repeatability needed to transform great designs into competitive products. With the SA capability in the Keysight PNA series, the ability to make multiple simultaneous network and spectrum measurements lets engineers gain deeper insights into their DUT and, ultimately, achieve unrivalled excellence in measurements and designs.

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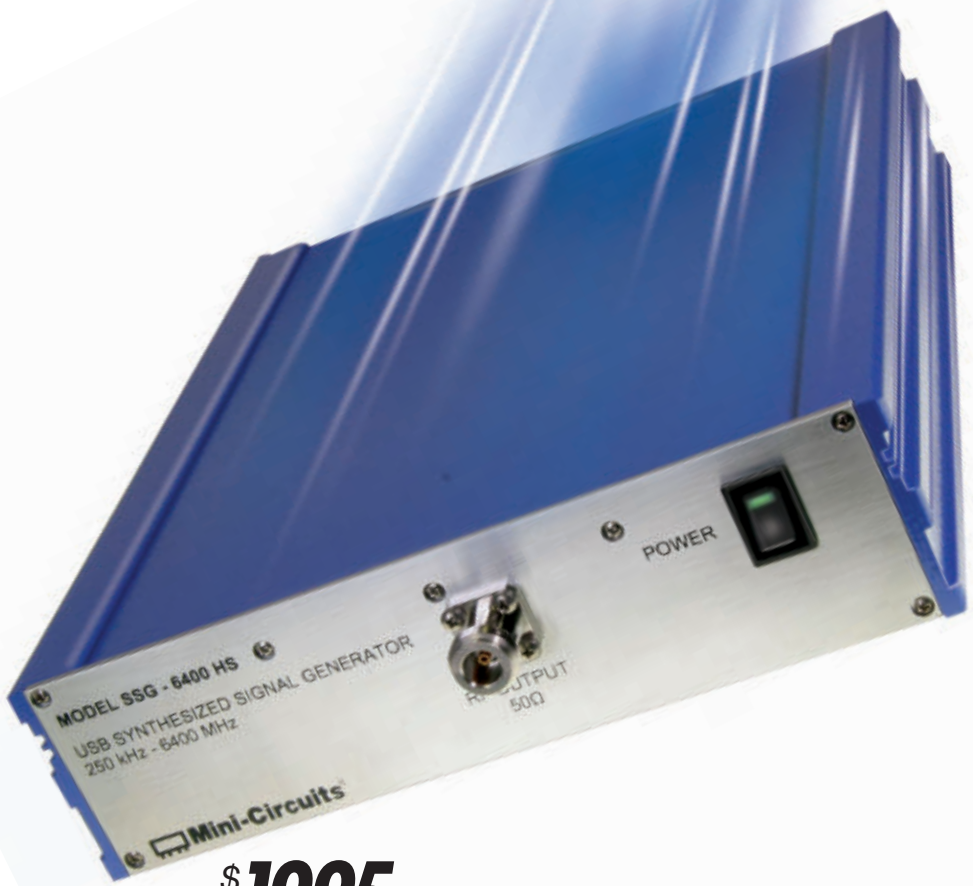

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1250 W CW RF Transistor in Plastic

Freescale Semiconductor
Tempe, Ariz.

Long after most semiconductor devices had transitioned to plastic packages, RF power transistors remained in ceramic packages, due to a combination of performance and established manufacturing practices. In the past decade, the shift towards plastic packages accelerated in the high volume wireless infrastructure segment, with devices for cellular base stations now preferred in plastic. In February, Freescale Semiconductor introduced two new LDMOS devices for industrial applications. With power levels of 600 and 1250 W, these are the industry's highest CW power transistors in plastic packages.

SUPERIOR RELIABILITY

The biggest advantage of using plastic packaged power transistors is their improved thermal performance. Plastic packages use a copper heat spreader, on which the die is mounted, while ceramic packages use a copper-based laminate heat spreader. The benefit is 15 to 30 percent better thermal resistance, depending on the transistor. The new Freescale 1.25 kW power transistor (MRFE6VP61K25N) in plastic features an Rjc of 0.06°C/W (soldered), compared to 0.15°C/W for the ceramic version (MRFE6VP61K25H) (bolted down with thermal grease). It is indeed important to solder high power RF transistors rather than bolting or clamping them down. Solder mounting provides good, consistent thermal and electrical contacts between the package source and heat sinks. This improves the thermal and electrical performance of the device. The thermal resistance of Freescale's high power plastic packaging is lower than traditional industry plastic packages; Freescale's process provides a superior die attach to the flange.

This thermal advantage either relaxes the design requirements for cooling, reducing system cost, or provides better design margin and MTTF. For example, at 100 MHz where the device operates with 80 percent efficiency, the junction temperature of the ceramic package will be 112°C with the transistor flange at 65°C.

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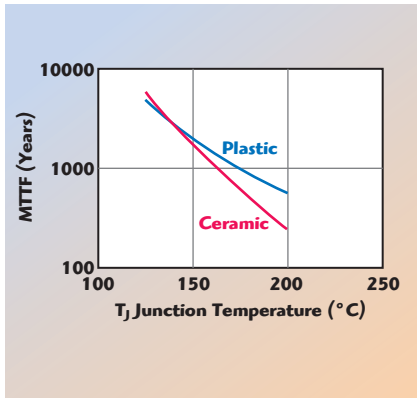
TABLE 1

MRFE6VP61K25N LDMOS TRANSISTOR PERFORMANCE

Parameter	*Performance*
Frequency Range	1 to 600 MHz
Output Power	1250 W
Gain (FM Band)	24 dB
Efficiency (FM Band)	80%
Maximum Load Mismatch	65:1 VSWR
Drain Voltage	50 V
Thermal Resistance	0.06°C/W
Package	OM-1230 over-molded plastic



▲ *Fig. 1 MTTF comparison of plastic over-molded and ceramic air cavity packaged transistors.*

The plastic version reduces the Tj to 84°C. Plastic packaged devices have tighter dimensional tolerances than ceramic. The key dimensional specifications on a plastic part (e.g., seating plane height) have tolerances on the order of ±3 mils (±76 micron) or better. Ceramic packages have tolerances typically in the range of ±5 mils (±127 micron) or higher. This makes plastic devices more suitable to automated manufacturing processes such as pick-and-place and surface-mount reflow. Additionally, making the leads and flange of the plastic package with tin-plated copper reduces the thermal expansion mismatch between the leads and the printed circuit board. This improves the reliability of the solder joint and, ultimately, the power amplifier.

Over the years, Freescale's reliability tests and qualification efforts for various devices in over-molded plastic packages have accumulated 3.5 million device hours at various temperatures and test conditions. Similar measurements were done with Freescale's ceramic devices. Based on the accumulated test hours, failure in time (FIT) rate and mean time to failure (MTTF) have been calculated for both package platforms at various maximum junction temperatures under field use conditions. ***Figure 1*** compares the MTTF for products in over molded plastic and ceramic packages.

NO RF PERFORMANCE COMPROMISE

Over the 87.5 to 108 MHz FM band, the performance of the plastic packaged transistor is similar to its ceramic predecessor (see ***Table 1***). It is an extremely rugged device, surviving a 65:1 VSWR – the same high-mismatch environments as a ceramic transistor. These include such applications as CO_2 laser or plasma generation, particle accelerators, MRIs, industrial heating/welding systems and FM and VHF broadcast transmitters.

The 1250 W (MRFE6VP61K25N) and 600 W (MRFE6VP6600N) devices complement Freescale's family of extremely rugged transistors. The portfolio now comprises five power transistors in ceramic and five in plastic, addressing all output power needs from 25 to 1250 W. Freescale's new plastic-packaged transistors deliver the RF performance that is traditionally associated with devices in ceramic, with even better thermal and mechanical characteristics for higher reliability.

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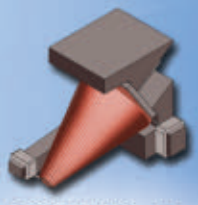

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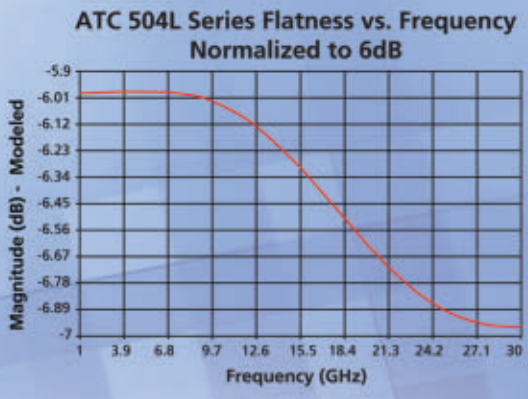

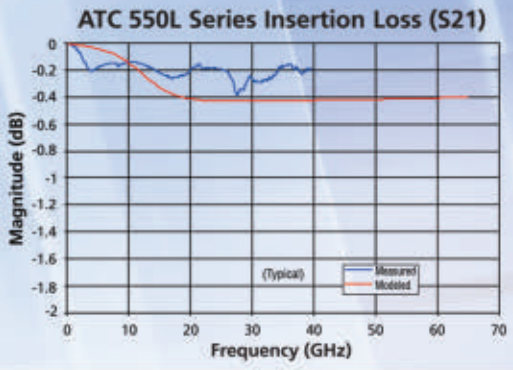

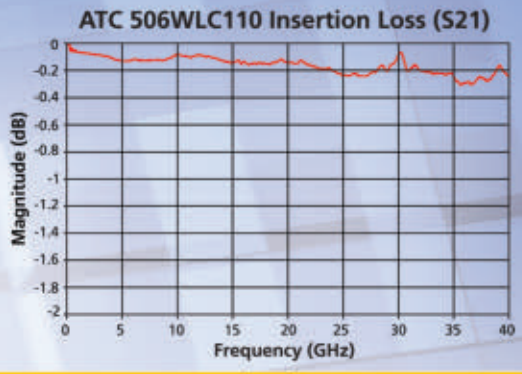

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Over the past three decades there has been vast research and academic development in millimeter wave (mmWave) technology, which has corresponded to the steady growth in customer demand for mmWave components and systems that has, in turn, created a need for cost effective test and measurement solutions for high frequency applications. A large number of test instruments are already available in the field as well as new developments coming on-stream for engineers to choose from, ranging from signal generators and spectrum analyzers to network and noise figure analyzers.

Farran Technology supplies frequency extension modules for vector network analyzer (VNA) applications in a range of 40 to 325 GHz that are external to the VNA instruments. With the increased interest in 60 GHz communication links, the company has developed a new range of frequency extension products designed specifically to meet the needs of customers involved in this growing mmWave test area.

mmWave APPLICATIONS

mmWave applications correlate closely with how such signals propagate in the atmosphere. The frequencies for which atmospheric attenuation is low (44, 86, 94, 140 GHz) are particularly useful in communication systems operating at long ranges, such as satellite communications, backhaul mmWave radios and point to multi-point radio links. For short range communications, the 60 GHz band provides enough range where only a local area, short distance transmission is required.

During the last decade, substantial knowledge about the 60 GHz mmWave channel has been accumulated and different architectures have been analyzed to develop new mmWave communication systems for commercial applications. Due to the large propagation and penetration losses, 60 GHz wireless local area networks (WLAN) are primarily intended for use in short-range and single room environments. Moreover, demands for high speed multimedia data communications, such as huge data

file transmission and real-time video streaming, are markedly increasing.

Hence, one of the most promising solutions to achieve a gigabit class wireless link is to use mmWaves for the carrier frequency. Many system proposals under the IEEE 802.15.3c task group for wireless local personal networks (WPAN) have been studied. The assignment of a large unlicensed bandwidth (~8 GHz) around 60 GHz created new opportunities for 60 GHz front-end technology. High frequency and even mmWave analog communication circuits, which were traditionally built on more expensive technologies such as bipolar or gallium arsenide (GaAs), are gradually being implemented on CMOS.

Also, recent progress in electronic devices has opened the way to operate at data rates up to several Gbps. Quadrature amplitude modulation (QAM) is widely used for the high-speed data transmission. Compared with other digital modulation techniques like phase shift keying (PSK) or pulse-amplitude modulation (PAM), QAM modulation has better anti-noise performance and could make full use of the bandwidth.

COMMUNICATION LINK FREQUENCY EXTENDERS

The S-parameter characterization at RF and microwave frequencies is readily available in most VNAs available on the market today. To extend the range of microwave test systems, frequency extension modules that utilize both multiplier as well as harmonic mixer technologies must be used. mmWave S-parameter measurements are necessary where material characterization, on-wafer measurement and research in communication, imaging and security are of interest.

To this end, Farran Technology offers frequency extension modules for VNA applications that are external to the VNAs. The operation of these modules is based on phase and amplitude up- and down-conversion, which can be applied to all major VNAs. The setup relies on the internal firmware configuration of the VNA which defines RF, LO and IF signal frequencies to and from the extension heads.

The modules effectively multiply the existing RF range capabilities of the network analyzers, enabling measurements to be taken at mmWave frequencies and down-converting the results to the intermediate frequency (IF) that are then supplied back to analyzer for its own RF conditioning and post processing. The front panel of the VNA working at mmWave band reflects the frequency of operation of the device under test (DUT) with no need for further user frequency scaling. That way the

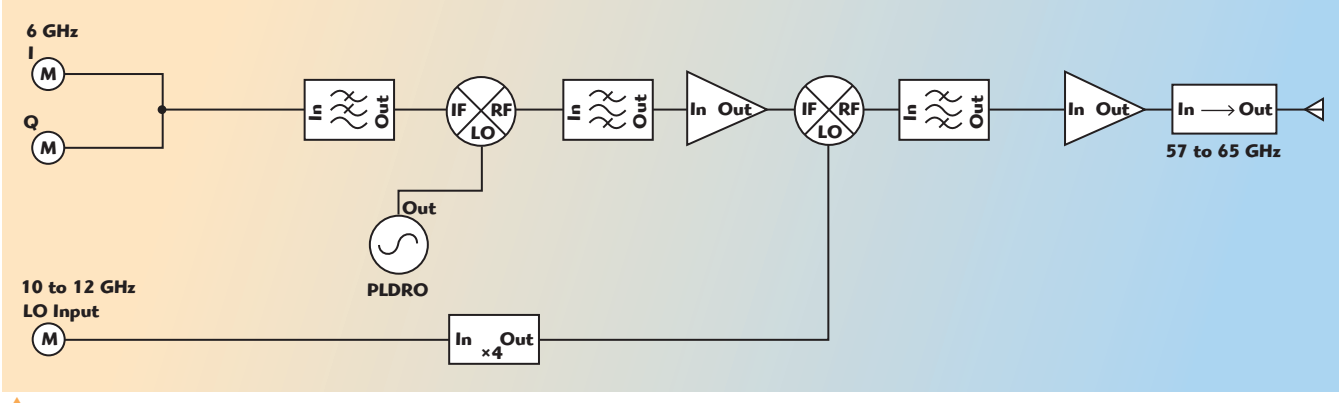

Fig. 1 FEC-15 up-converter.

analyzer microwave functionality is available at the mmWave range, which includes the setup, calibration and measurements.

With the increased interest in 60 GHz communication links, Farran Technology has developed a new range of frequency extension products designed specifically to meet the needs of customers involved in this growing mmWave test area. This product is an extension of the successful Frequency Extension VNA (FEV) range and the new product family is known as the Frequency Communication Extender (FCE) range.

SYSTEM ARCHITECTURE

The FCE-15 system is designed to work with an arbitrary waveform generator in the up-conversion chain and a suitable oscilloscope at the receiver side. The general system architectures are given in ***Figure 1*** and ***Figure 2***. The current up-converter takes an input of an I/Q signal on a 6 GHz carrier but there is also a release that will have an extra stage of up-conversion allowing for direct I/Q signals without the need for the carrier.

The current system demo (see ***Figure 3***) is an example of the system operating in conjunction with the Keysight M8190A arbitrary waveform generator (AWG) and the Keysight DSA series oscilloscope with vector signal analyzer (VSA) software to analyze the signal, which can also be viewed on video: www.microwavejournal.com/60ghzlink. The system takes external LO to allow for the RF signal to be swept across the full 57 to 65 GHz band of interest for 60 GHz communication systems.

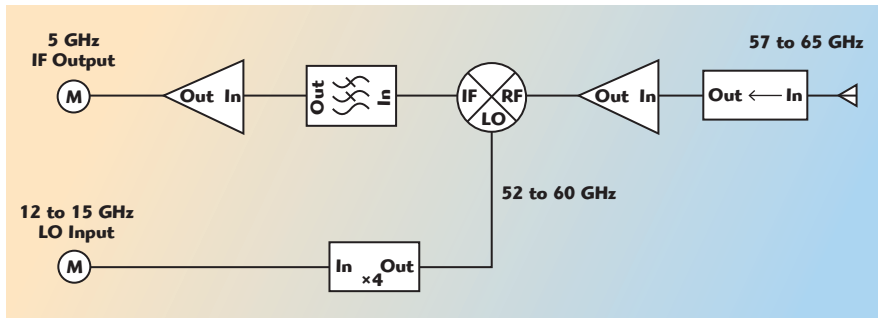

Fig. 2 FEC-15 down-converter.

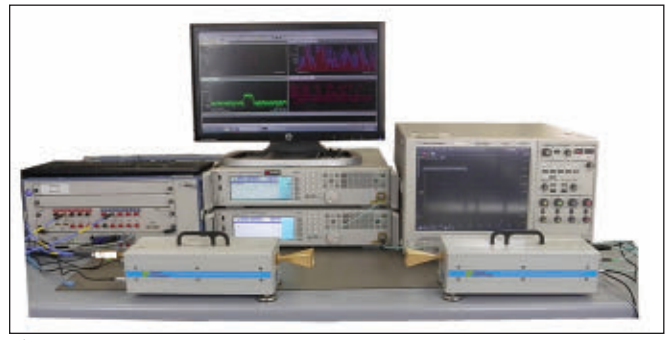

Fig. 3 FEC-15 connected to the Keysight M8190A AWG and the Keysight DSA series oscilloscope with VSA software to analyze the signal.

The system is designed to produce output power at 1 dB compression (P1dB) of +20 dBm from the transmitter and a receiver noise figure of less than 10 dB (~ 7 dB typical), thus giving excellent dynamic range within the system. The up- and down-conversion gains can be adjusted to suit system architecture (optimal IF input and output levels, etc.). The system also incorporates dual conversion in the up-converter chain to allow for unwanted sideband filtering. Individual converters can be used as references (or "golden radios") for transmitter or receiver testing, or the combination can be used for antenna or component testing.

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www.farran.com

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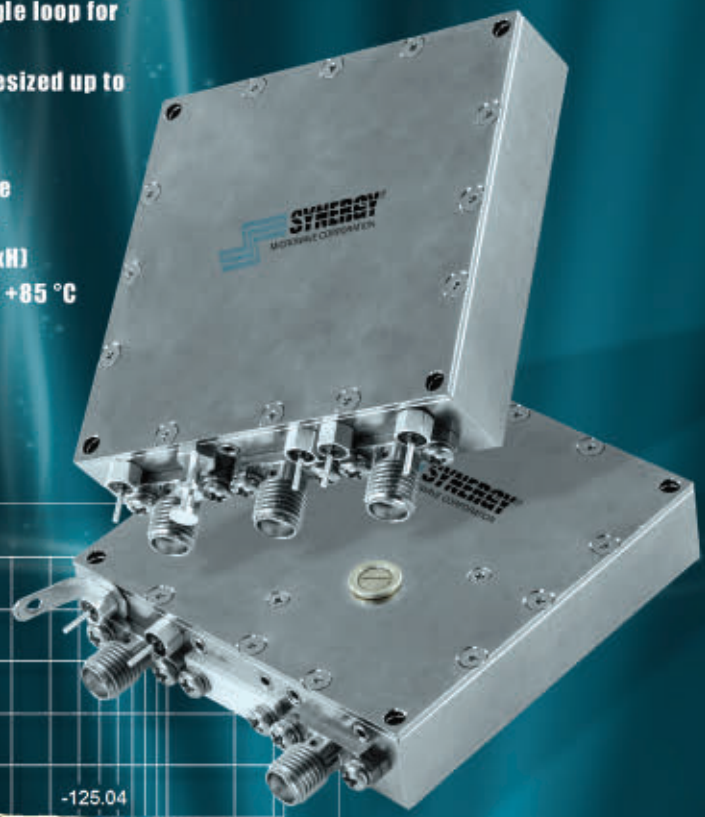
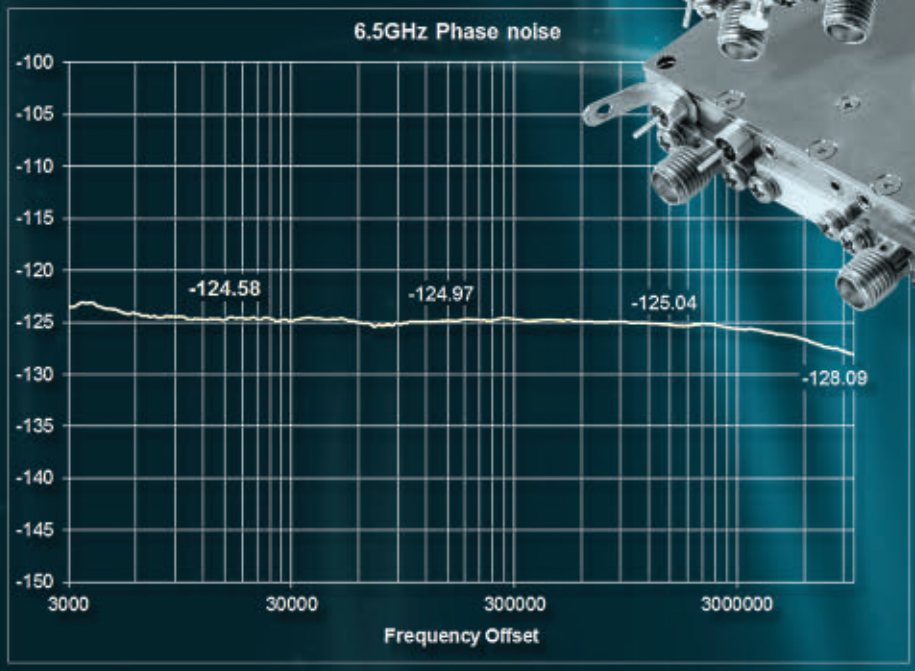


Applications:

- SATCOM, RADAR, MICROWAVE RADIO



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USB-Controlled Amplifiers, Attenuators and Switches

Pasternack recently released brand new lines of USB-controlled RF/microwave and millimeter wave components, including amplifiers, attenuators and PIN diode switches. These new components are controlled and powered by a convenient USB 2.0 port with driverless installation, meaning no external power supply is required. The attenuators and PIN diode switches require an easy-to-use, downloadable software program which interfaces with any Windows-based computer.

Pasternack has released two models each of the amplifiers, switches and attenuators that cover extremely wide frequency bands up to 40 GHz. The modules are 50 ohm hybrid MIC designs that do not require any external matching components. All models operate over a broad temperature range of -40° to +85°C and, depending on the frequency, are available with either female SMA or 2.92 mm connectors.

The new USB-controlled amplifiers provide 12 dB gain, 10 dBm P1dB and 4.5 dB noise figure (typical) and operate from either 50 MHz to 18 GHz or 50 MHz to 40 GHz. The attenuators provide 30 dB attenuation with 1 dB step size and 5 to 8 dB insertion loss (typical) and are available in two programmable models that cover 100 MHz to 18 GHz or 100 MHz to 40 GHz. The SPDT switches have 3 to 5 dB insertion loss, 65 to 70 dB isolation and 6 µs switching speed (typical) and are available in two models that cover 500 MHz to 18 GHz or 500 MHz to 40 GHz.

Pasternack's new USB-controlled components and downloadable software are in-stock and ready to ship. Each component is classified as EAR99.

VENDORVIEW

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Irvine, Calif.
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www.pasternack.com

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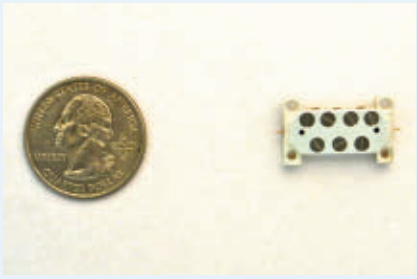

Surface-Mount Cavity Filters to 30 GHz

RLC Electronics has developed a new line of high frequency surface-mount cavity filters for small scale, low profile system integration. Cavity filters are desirable for their low insertion loss, tight frequency selectivity and broad spectrum rejection. On the other hand, cavity filters can be difficult to integrate with planar topologies such as microstrip and coplanar waveguide. Critical space is often consumed with coaxial connectors and cables, leading to higher losses and mismatches. The surface-mount cavity filter design from RLC eliminates coaxial connectors and utilizes RF pins or PC boards, saves space, cost and weight and improves electrical performance.

Various mounting methods can be used, determined by the available space and configuration of the subassembly. Where the filters need to be integrated onto multi-level circuit boards, the part must be attached directly onto the top layer ("drop-on"). Metallized pads or RF pins on the filter can be directly attached by solder reflow or by applying epoxy to the launch traces on the circuit board. Wire or ribbon bonding may also be used. The filter body itself is also attached using the same processes, which provides grounding and isolation. Optionally, the complete filter may be installed by pick-and-place. In cases where a pocket can be made in the circuit board and housing of the subassembly, the filter is mounted into the pocket ("drop-in"), and the body is attached with mounting screws.

Using full 3D electromagnetic modeling software, the challenging task of transitioning from common planar topologies into cavity structures is optimized. Designs are created and constructed using proprietary techniques that result in rugged, stable performance over a full range of environmental stresses.

High Q cavity filter performance is available through X-, Ku- and Ka-Bands with profile height as low as 200 mils. Typically, designs achieve up to 60 dBc rejection out to 3× the center frequency while maintaining good passband matching (e.g., 14 dB return loss).

RLC Electronics Inc.
Mt. Kisco, N.Y.
www.rlcelectronics.com

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International Conference on Microwaves, Communications, Antennas and Electronic Systems

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The very successful IEEE COMCAS 2013, attracted over 1400 attendees with approx. 180 professional lectures, 40 sessions in a 3 days conference, participants from 37 countries, and exhibitors from more than 90 industrial companies. This conference has been co-sponsored by four IEEE Societies and two European associations.

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Simplified Search

Amphenol RF launched its new corporate website, www.amphenolrf.com. The new site is home to thousands of standard products and boasts an advanced feature set allowing buyers and engineers to quickly find the ideal RF connector, coaxial adapter or cable assembly for their application. Dramatically improved search functionality includes a full parametric search allowing users to narrow their search by product attribute and an ultra-fast, full-text search engine that provides search suggestions as keywords and part numbers are entered. Downloadable product data, product compliance center, competitor cross reference search and video library also available.

Amphenol RF
www.amphenolrf.com

Web Remote Tools

VENDORVIEW

Anritsu introduced Web Remote Tools™ capability for its MS2720T handheld spectrum analyzer that allows the instrument to be controlled from any web-enabled device, including laptops, tablets and smartphones over an Ethernet link. Field technicians now have greater flexibility by conducting essential spectral measurements remotely. Testing remote radio heads (RRUs) and other inaccessible radio units at 3G and 4G base stations has never been easier. The result is reduced site visits and improved time and cost efficiency. For more information, visit www.anritsu.com.

Anritsu Co.
www.anritsu.com

Modernized Websites

VENDORVIEW

AR has modernized their corporate and RF/Microwave Instrumentation websites by providing easier navigation and more comprehensive information. The menu system is easier to read and the sites are search engine friendly. Flash spotlights work with various touch screen tablets and mobile devices. The 'Find It Fast' charts are one of the most popular features. Use these comprehensive charts to quickly access the AR amplifier, TWTA, hybrid power module or antenna you are looking for. Visit www.arworld.us or www.arww-rfmicro.com/html/00000.asp.

AR RF/Microwave Instrumentation
www.arworld.us

Ku-Band Iso-Divider Family

VENDORVIEW

Crane Aerospace & Electronics Microwave Solutions has added a new Ku-Band Iso-Divider product family web page. The Ku-Band Iso-Divider family combines the functions of high performance power dividers (or combiners) with ferrite isolators. They have exceptional insertion loss and band flatness performance in a small, lightweight package while providing the high reliability that is crucial for space applications. It is designed for satellite receiver redundancy applications, without introducing complex switch-based solutions. Product details, specifications and data sheets are now available online.

Crane Aerospace & Electronics
www.craneae.com/isodivider

One Source Solutions

VENDORVIEW

Keysight Technologies continues to expand its multi-vendor calibration services, adding thousands of non-Keysight products including electrical, physical, dimensional and optical instruments. A new section of the company's website, Keysight One Source Solutions, provides engineering managers with one point of accountability for all of their test equipment, regardless of manufacturer, enabling them to improve operational performance, reduce complexity and reduce costs. This web page also details how to consolidate laboratory calibration services with a single trusted partner committed to metrology, technical expertise and globally shared engineering processes.

Keysight Technologies Inc.
www.keysight.com/find/AmericasOneSource

Information That Matters

Mercury Systems launched its newest mrcy.com website to reflect the company's focus on its core capabilities, innovation and next generation business model. With clean, inviting graphics and content and information that matters, the new website makes it easier for customers, influencers and industry leaders to find essential information on advanced, interoperable, next generation defense electronics. Mercury Systems is the better alternative for affordable, secure and sensor processing subsystems designed and made in the USA. For more information visit www.mrcy.com.

Mercury Systems
www.mrcy.com

Specialty Mixer Components

Polyphase Microwave manufactures high-performance specialty mixer components, assemblies and instrumentation for demanding RF/microwave transmitters and receivers. Their website features a complete line of specialty mixer components including image-reject mixers, quadrature (I/Q) modulators, quadrature (I/Q) demodulators and single-sideband modulators. Their products are critical elements in wireless communications systems, radar/EW systems, test instrumentation and scientific R&D. Visit the company's website for product selection guide, software and drivers, and application notes available for download. Users may also buy products online or complete an online RFQ for their next project.

Polyphase Microwave Inc.
www.polyphasemicrowave.com

Robust Redesign

VENDORVIEW

Signal Hound's recent website redesign adds an 'Applications' section, spotlighting device features critical to specific industry applications. The redesign also includes improved navigation for both desktop and mobile viewing, as well as new product pages with updated product photos and lists of related information such as data sheets, user manuals and forums. In addition to the visual changes, Signal Hound's website now resides on a robust new sever configuration, enhancing security and performance on a variety of levels.

Signal Hound
www.signalhound.com

Modular By Design

X-Microwave offers an innovative system for RF and microwave design from simulation to prototype to production hardware. Visit xmicrowave.com to experience the FREE online, X-parameter based, nonlinear system simulator and hundreds of modeled drop-in components (X-MWblocks), all designed around a modular building block system called X-MWsystem. After simulation, physically compatible drop-ins are first used to prototype systems on an innovative prototype station. The same drop-ins are then used in production hardware. X-Microwave combines X-MWblocks as a service making the realization of production IMAs fast and inexpensive.

X-Microwave LLC
www.xmicrowave.com

New Products

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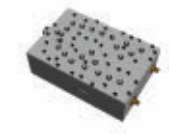
Components

Band 21 Duplexer

VENDORVIEW



3H Communication Systems, new LTE, band 21, high power duplexer covers the 1500 MHz band, 3GPP. The duplexer offers channel spacing of 1447.9 to 1462.9 MHz and 1495.9 to 1510.9 MHz with >60 dB co-channel isolation with insertion loss of < 0.80 dB in-band. The duplexer is rated for 50 W CW. Additional frequency bands and power options available.

3H Communications
www.3hcomm.com

Micro-ITLA

Avago Technologies announced the availability of its new micro-integrated tunable laser assembly (Micro-ITLA) device, the AFCU-UITLAXX. The device is a high-performance, narrow-linewidth Micro-ITLA component designed for both the transmission and local oscillator laser in coherent dense wave division multiplexing (DWDM) systems. The new Micro-ITLA device delivers a very narrow linewidth, low phase noise and superior frequency accuracy improving system performance by reducing signal to noise penalties.

Avago Technologies
www.avagotech.com

Space Qualified Isolator

VENDORVIEW

DiTom Microwave has released a new Ku-Band (13.75 to 14.80 GHz) space qualified isolator. The DS1011 is manufactured to meet or exceed environmental space-level reliability including thermal shock, sine and random vibration, temperature cycling, and thermal vacuum survivability over a specified qualification and acceptance test plan. DiTom's current space level manufacturing process allows for delivery in as quickly as 4 weeks depending on the test requirements. Contact DiTom at (559) 225-7042 or space@ditom.com for additional information.

DiTom Microwave
www.ditom.com

Ultra-High K Dielectric

UX material has the highest dielectric constant of any of DLI's wide variety of materials and allows for higher capacitance values in existing case sizes, or smaller sized components – all achieved without sacrificing performance. The material is space qualified to MIL-PRF-38534 Class K. This new 50 V rated dielectric complements the existing 25 V rated material and is available to be specified across DLI's broad range of standard Thin Film architectures - including Di-Caps®, Border Caps®, Bar Caps® and Gap Caps®.

Knowles Capacitors
www.knowlescapacitors.com

Compact Directional Coupler

VENDORVIEW

KRYTAR Inc. announced the continued expansion of its growing line of directional couplers. Model 120406 offers 6 dB of coupling over 4 to 12.4 GHz, in a single, compact and lightweight package. KRYTAR's new directional coupler adds to the family of superior performance narrow-band products covering the frequency range of 0.3 to 50 GHz. KRYTAR's latest addition enhances the selection of multipurpose, stripline designs that exhibit excellent coupling.

Krytar Inc.
www.krytar.com

Air Coil Inductor Engineering Kits

Piconics announced its new Air Coil Inductor Engineering Kits. Piconics air coil inductors are the highest performing inductors on the market. Precision stripping, consistent winds on any diameter. Coils are used for narrower band applications up to 20 GHz. Now you can have a variety of air coils at your fingertips to optimize your designs. Piconics' coils can be manufactured with copper wire, copper wire with gold plate or gold wire.

Piconics Inc.
www.piconics.com

Digital Set-Top Box Tuner

Silicon Labs introduced a new family of high-performance digital set-top box (STB) tuner ICs designed to reduce the cost, complexity and power consumption of cable, terrestrial, hybrid terrestrial/satellite and IP-based STB products. Silicon Labs' new Si2144 and Si2124 digital tuner ICs help STB designers reduce board space and bill of materials (BOM) cost through a combination of exceptional single-chip integration and the industry's smallest package size. The Si2144/24 tuner family's integrated loop-through technology also helps reduce system-level cost and power consumption.

Silicon Labs
www.silabs.com

Adjustable Low PIM Attenuator

VENDORVIEW

The low PIM attenuator can be adjusted between 15 and 30 dB and performs with -160 dBc/-165 dBc in mobile carrier frequencies. It claims it can reduce costs by ensuring greater flexibility during installation. In many projects, radiated power can be set only on site and adjustment has to be performed with attenuators. Instead of installing and replacing various splitter/load combinations to test the targeted power level, the new low PIM attenuator is installed once and adjustment can be performed easily during operation.

Spinner GmbH
www.spinner-group.com

E-Band Diplexer

VENDORVIEW

Universal Microwave Technology Inc. announced its line of E-Band diplexers for 80 GHz millimeter-wave radio application. This E-Band diplexer features 0.5 dB insertion loss, 18 dB return loss and 75 dB isolation at frequency band 71 to 76 GHz and 81 to 86 GHz. The diplexer length is less than 60 mm with waveguide interface of WR12.

Universal Microwave Technology
www.umt-tw.com

2-Way Combiner/Divider

The D10005 is a 2-Way combiner/divider, covering the full 1 to 3 GHz band, and is rated at 600 W CW. This robust design operates with full port-to-port isolation of 15 dB minimum, and less than 0.5 dB insertion loss. The D1005 is designed to handle an input failure, at rated power, while operating at a +70°C baseplate temperature. Ideal for coherent or non-coherent combining, the D10005 is suitable for multiple military applications.

Werlatone
www.werlatone.com

Cables & Connectors

Cable Assemblies

Stability™ cable assemblies are now offered with 1.85 mm connectors and operate mode-free to 67 GHz. Maury's new SC-185 1.85 mm 67 GHz cable assembly continues the Stability legacy with superior amplitude and phase stability with flexure, reliable and repeatable measurements, durable, ruggedized and

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600 to 3600 MHz

Heat sink available

from $189.95 ea. (qty.1-9)

Up to 100W 2 Way-0°

- ✓ Low insertion loss, 0.5 dB
- ✓ Amplitude unbalance, 0.15 dB
- ✓ Good isolation, 22 dB
- ✓ Excellent VSWR, 1.2:1

ZB4PD-332HP+

500 to 3300 MHz

Heat sink available

from $266.95 ea. (qty.1-9)

Up to 100W 4 Way-0°

- ✓ Low insertion loss, 0.8 dB
- ✓ Amplitude unbalance, 0.2 dB
- ✓ Excellent VSWR, 1.15:1
- ✓ Good isolation, 22 dB

ZN8PD-362HP+

600 to 3600 MHz

Heat sink available

from $369.95 ea. (qty.1-9)

Up to 100W 8 Way-0°

- ✓ Low insertion loss, 1.0 dB
- ✓ Amplitude unbalance, 0.4 dB
- ✓ Good isolation, 23 dB
- ✓ Good VSWR, 1.2:1

ZA2CS-251-20W+

10 to 250 MHz

from $94.95 ea. (qty.1-9)

Up to 25W 2 Way-0°

- ✓ Up to 20W as combiner
- ✓ Low insertion loss, 0.17 dB
- ✓ Low amplitude unbalance, 0.05 dB
- ✓ High isolation, 30 dB
- ✓ Excellent VSWR, 1.1:1

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crush-resistant, offering longer flex life. Stability cable assemblies can be ordered from stock in standard lengths from Maury's website, or ordered in custom lengths through Maury sales.
Maury Microwave
www.maurymw.com

26.5 GHz SMA Panel Cable Connectors

The SMA female/jack 2 and 4 hole offers configurations for .085 semi-rigid cable (direct solder). They feature DC to 26.5 GHz, low VSWR and insertion loss and gold plated 303 stainless steel bodies for solder ability and durability. Quality, performance and reliability you can count on!
SGMC Microwave
www.sgmcmicrowave.com

E-Band Adapter

Spacek Labs model T79-W is one of the E-Band models in its series of waveguide to coaxial transitions or adapters. The T79-W covers the available commercial E-Band spectrum from 71 to 86 GHz with a typical insertion loss of 0.6 dB (typ). The maximum VSWR is 1.30:1. This transition can be used to adapt a component or system from WR-12 (UG387/U) waveguide to the 1 mm coaxial connector. This transition is also available covering the entire 60 to 90 GHz waveguide band.
Spacek Labs Inc.
www.spaceklabs.com

Amplifiers

High Power Broadband RF Amplifier Module

Exodus Advanced Communications introduced a new high power SSPA module covering the 2 to 6 GHz frequency spectrum featuring state-of-the-art GaN devices and good efficiency. This compact, lightweight module features an impressive 250 W min CW output power at 28 V DC with 5 uSec switching speed.
Exodus Advanced Communications
www.exoduscomm.com

Amplifier

Herotek offers a multi-octave wideband low noise high gain amplifier. Model AF01-6371810B operates from 0.1 to 6 GHz. It has noise figure of 1.8 dBm, gain of 37 dB with max gain variation of ±0.8 dB, P1dB output of +10 dBm, and current draw of 120 mA at +12 V bias. This amplifier comes in a hermetically sealed package with removable connectors for drop-in assembly and is designed for both military and commercial applications.
Herotek Inc.
www.herotek.com

Upper Millimeter Wave Power Modules

Leveraging its industry-leading Microwave Power Module (MPM) product line, L-3 Electron Devices announced two new upper millimeter wave products that are complete amplifier subsystems. These fully integrated, airborne-capable amplifier subsystems feature an integral power supply and a control electronics module within an ultra-compact, ruggedized package. The package enables users to physically mount the hardware extremely close to radiating apertures, thus minimizing RF losses while maximizing size, weight and power (SWaP) advantages.
L-3 Electron Devices
www.L-3com.com

250 W Bipolar Transistor

The versatile and reliable TAN250A bipolar transistor remains a best-value design choice for a civilian or military, ground-based or airborne, TACAN, DME, or Mode-S transponder system power amplifiers. The rugged emitter ballasted 50 V silicon bipolar junction power transistor delivers greater than 250 W across the 960 to 1215 MHz band under many pulsing formats, making it an ideal choice for pulsed power transmitters. The TAN250A transistor is available from stock. For product sales or technical information contact RFMWD@microsemi.com.
Microsemi
www.microsemi.com

Monolithic Amplifier

VENDORVIEW

Mini-Circuits' GVA-91+ (RoHS compliant) is an advanced wideband amplifier fabricated using GaAs HBT technology, offering high gain and excellent power output with excellent power added efficiency in application bands. Lead finish is tin-silver over nickel. It has repeatable performance from lot to lot and is housed in an SOT-89 package for very good thermal performance.
Mini-Circuits
www.minicircuits.com

Log Video Amplifiers

VENDORVIEW

Pasternack introduced an all new line of broadband log video amplifiers covering multi-octave bandwidths from 0.5 to 18 GHz. The 5 models being released include 4 successive detection log video amplifiers (SDLVA), and 1 detector log video amplifier (DLVA), which offer a wide input dynamic range, high signal sensitivity, fast recovery times, and excellent temperature stability. Pasternack's log amplifiers are used to measure widely varying signals at high frequencies in applications where rapid and precise tracking is required across the entire frequency band.
Pasternack
www.pasternack.com

Low Noise Amplifier

VENDORVIEW

PMI model no. POB-16-48-22-LCA is a 4 to 8 GHz low noise amplifier that provides 16 dB of gain while maintaining a gain flatness of ±1 dB typically over the operating frequency. The noise figure is 3 dB typical and offers a typical OP1dB of +22 dBm. The amplifier requires +12 to +15 VDC and the current draw is 225 mA typical. The unit is supplied with SMA(F) connectors in PMI's standard PE2 housing.
Planar Monolothics Industries Inc.
www.pmi-rf.com

Systems

Radar Development Kit

The Radar Development Kit (RDK) is an easy-to-use platform for those needing to measure distance or speed of an object. It is designed to quickly be up and running out-of-the-box, enabling the customer to start elaborating and optimizing the right parameters of the targeted object within a detection zone. Once parameters are set and an application is tailored to the customer needs, Sivers IMA will be capable of manufacturing the final customer solution in volume to support roll-out of the end-user application. Applications include level measurement in silos and tanks, anti-collision in industrial automation and safety in railroad applications.
Sivers IMA
www.siversima.com

Sources

2.45 GHz Generators

The PlasMaster claims to be the first in a series of generators available between 10 to 200 W. The generators include a control circuit to accomplish hot S-parameter measurements and to identify the best S11-value in the IMS-band.
Heuermann HF-Technik GmbH
www.hhft.de

Active Multiplier

VENDORVIEW

Model SFA-713863410-12KF-S1 is a 71 to 86 GHz ×4 active multiplier designed for E-Band communications and automotive radar applications. The active multiplier converts 17.75 to 21.5 GHz/+5 dBm input signal to deliver 71 to

86 GHz frequency band with a typical +10 dBm output power. The spurious and harmonic suppressions of the multiplier are 60

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Innovations in EDA
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Presented by: Keysight Technologies
Live webcast: 6/4/15

Technical Education Training
Internet of Things (IoT) and Over-the-Top (OTT) Applications – How to Quantify Signaling Impact and Power Consumption
Presented by: Rohde & Schwarz
Live webcast: 6/9/15

RF/Microwave Training
MMIC Design Overview
Sponsored by: National Instruments (formerly AWR Corp.)
Live webcast: 6/10/15

Technical Education Webinar
GaN Going Mainstream
Sponsored by: Freescale, MACOM, Qorvo
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Technical Education Training
Qorvo GaN on SiC: 15 Years of Reliability and Producibility
Presented by: RFMW/Qorvo
Live webcast: 6/17/15

Technical Education Training
Simulating MRI Heating of Medical Implants
Presented by: COMSOL
Live webcast: 6/18/15

Keysight in Aerospace/Defense
Closed Loop Adaptive EW Simulation
Live webcast: 6/23/15

Technical Education Training
Narrowband Planar Filter Design with NI AWR Design Environment Software
Presented by: National Instruments (formerly AWR Corp.)
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Past Webinars On Demand

RF/Microwave Training Series
Presented by: Besser Associates
- Mixers & Frequency Conversion
- RF and Microwave Filters

Technical Education Training Series
- Linearity: The Key to Successful Data Transmission in Cable and Beyond
- Narrowband Combline Filter Design with ANSYS HFSS
- Advanced Multi-Emitter Radar Simulation with Off-the-Shelf T&M Equipment
- Multipactor Basics and How Numerical Analysis Can Safely Increase Margins
- Understanding Filter Technology and the Selection Process Including Qorvo's Specialized LowDrift™ and NoDrift™ Filters
- EMIT 4.0 – The Next Generation in RF Cosite Interference Modeling and Simulation
- Effect of Laminate Properties on PIM Distortion in Microstrip Transmission Lines
- Modern Trends in Broadband Diode Mixers
- Practical Antenna Design for Advanced Wireless Products
- RF and Microwave Heating with COMSOL Multiphysics

CST Webinar Series
- CST STUDIO SUITE 2015 Update Webinar on MW&RF Simulation
- CST STUDIO SUITE 2015 Update Webinar on EDA/EMC Analysis

Innovations in EDA
Presented by: Keysight Technologies
- How to Design an RF/Microwave Power Amplifier: The Basics
- Understanding 5G and How to Navigate Multiple Physical Layer Proposals

Keysight in LTE/Wireless Communications Series
- A Flexible Testbed for 5G Waveform Generation and Analysis

Keysight Technologies Webcast
- Addressing Multi-Channel Synchronization for MIMO and Beamforming Test
- Bridging the Gap from Benchtop to PXI: A Common Software Strategy
- MVG-Orbit/FR μ-Lab – A Compact Integrated Test Facility for mm-Wave Antenna Testing
- One Size Does Not Fit All – Choose the Right Instrument Form Factor

FieldFox Handheld Analyzers Series
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- Transmission Line Theory and Advanced Measurements in the Field

RF and Microwave Education Series
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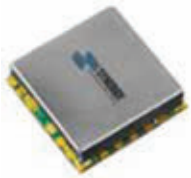
dBc, 20 dBc or better, respectively. The multiplier draws 250 mA current from a +8 VDC DC power supplier

SAGE Millimeter Inc.
www.sagemillimeter.com

Surface-Mount Intelligent Synthesizer

The MFSH50100-50 is a tiny surface-mount intelligent synthesizer which allows frequencies between 500 to 1000 MHz to be generated when locked to an external 10 MHz reference. This design features an on-board micro-controller that allows for self-programmable fixed frequencies or wideband signal generation. Phase noise performance is -96 dBc/Hz at 10 kHz offset and -118 dBc/Hz at 100 kHz offset. Output power of +5 dBm minimum is through a buffered output stage and operating temperature is -40° to +85°C.



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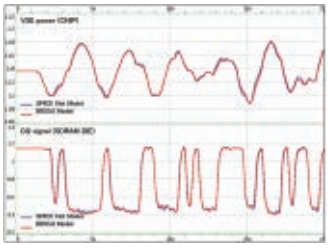
Hyperlynx Tool



Mentor Graphics Corp. announced its newest version of the HyperLynx® Signal Integrity/Power Integrity (SI/PI) product for high-speed printed circuit board (PCB) designs. The HyperLynx product addresses high-speed systems design problems throughout the design flow—starting at the earliest architectural stages through post-layout verification. With the increased complexity and high-speed performance of today's integrated circuits (IC), a growing number of PCBs suffer from signal degradation and timing problems which are exacerbated by power delivery issues; this impacts board performance and possibly total failed logic, requiring costly redesign.

Mentor Graphics
www.mentor.com

Multi-Touch Operating System

MPI automated probe systems are controlled by the unique and revolutionary, multi-touch operation software suite named SENTIO™. simple and intuitive operation saves significant training time, the scroll, zoom, move commands mimic mobile devices and allows everyone to become an expert in just minutes. For RF applications there is no need to switch to another software platform – the MPI RF calibration software program QAlibria™ is fully integrated – for ease of use by following a single operational concept methodology.

MPI
www.mpi-corporation.com

Packaging

Leadless Ceramic SMT Packages

Remtec Inc. introduced a new line of standard SMT leadless packages for electro optical circuits matching standard TO-type window lids. These new packages address the long-standing demands of the photonics industry for an SMT packaging solution as a viable alternative to standard TO-type packages. Now standard economical surface mounted packages can be produced for a wide range of circuits and I/O configurations fully compatible with most of JEDEC TO-style window caps such as TO-8, TO-46 and beyond at operating frequencies up to 10 GHz and higher.

Remtec Inc.
www.remtec.com

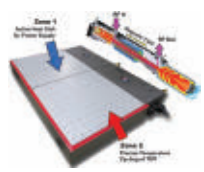
Test Equipment

3-in-1 Device

DS Instruments extends its product line with a miniature 2.75" wide 3-in-1 device providing frequency counting, RF power meter, and signal generator. Power metering and counting both operate to 7 GHz with signal generation to 4.8 GHz. A USB port provides power and data connection. The TT7000 can also be used with no host computer as a stand-alone instrument with the front OLED display.

DS Instruments
www.dsinstruments.com

Two-Zone Temperature Plate

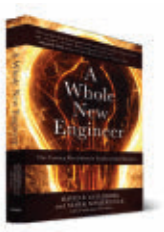


inTEST Thermal Solutions (iTS) has designed a multi-zone thermal plate for hot/cold temperature cycling of microwave signal amplifiers used in satellite data communications. The heart of the amplifier is a travelling wave tube (TWT) and power supply. In their space-borne environment, TWTs are exposed to extreme temperatures that influence the strength and stability of their magnetic field and can adversely affect their RF signal output. Rigorous thermal stressing of TWTs is required to characterize RF signal outputs and ensure trouble-free operation after deployment.

inTEST Thermal Solutions
www. intestthermal.com

MICRO-ADS

BookEnd



A Whole New Engineer: The Coming Revolution in Engineering Education

David E. Goldberg and Mark Somerville

The effectiveness of our educational systems has become a controversial topic. Even though the desired outcomes haven't really changed in decades, we seem to have lost the recipe for success. While the common core and early childhood programs get the headlines, engineering education isn't immune from critique and experimentation to find a better way. "A Whole New Engineer" recounts a collaboration that shows promising and surprising results. It begins with an engineering school start-up, Franklin W. Olin College of Engineering, and the counterintuitive lessons that have emerged about how students best "learn" engineering. Mark Somerville, a professor of EE and physics at Olin College since 2001 and one of the authors, helped create that success.

However, you can draw an infinite number of lines from a single data point, and one might argue that success is inevitable at a school with a $500 million endowment and a tiny student body with 1500+ SAT scores. 1000 miles away at the University of Illinois, in 2007, David Goldberg co-founded iFoundry, an initiative to make some "minor changes" to improve the university's engineering program. iFoundry was inspired by Olin College, however it had neither significant funding nor power. The experiment began with a single course and one extracurricular program. Surprisingly, the outcome from iFoundry was similar to Olin's experience, despite the disparity in resources. After pondering the seeming paradox, authors Goldberg and Somerville said, "We came to recognize that our initial thinking about the keys to educational reform was wrong. The key variables weren't pedagogical. They weren't financial. They weren't curricular. They weren't research. They weren't any of the usual things we've always talked about as the engines of change. The variables were deeply emotional and cultural."

Their conclusions and recommendations for reform reflect a new vision for engineering education that, fortunately, isn't expensive to implement. The "pillars" of transformation they propose are joy, trust, courage, openness and connectedness/collaboration/community. Joy refers to the fulfillment that comes from mastering complexity, solving a difficult problem, or whatever fuels someone's passion. Trust arises when the student feels valued by the school and is given the freedom to explore and tackle complex problems without fearing failure. Feeling trusted naturally leads to developing the courage to explore ideas and embrace challenging problems, since failure is not failure, rather one step on the path to a solution. Openness reflects the ability to consider ideas without initially judging them, to be comfortable with uncertainty and the need to iterate. The last pillar is fairly obvious, as any technical project requires the ideas, skills and collaboration of many specialists.

"A Whole New Engineer" is an intriguing story about reforming engineering education. Can it really be this simple?

To order this book, contact:
http://wholenewengineer.org
Publisher: ThreeJoy Associates Inc.

288 pages
$22.62 for the hardcover edition;
$9.95 for the Kindle edition at
www.amazon.com
ISBN-13: 978-0986080005

Microwave Journal

Frequency Matters.

NEW VIDEO LIBRARY

Microwave Journal has launched a powerful new video library that allows customers to upload unlimited videos that are indexed by application, market, event and company. The library also includes educational videos that the editors curate into the library plus webinars and demos that the MWJ staff produce and record. The Microwave Journal RF and microwave bi-weekly video update series, Frequency Matters, is also part of the library.

A new bi-weekly video newsletter has been created to feature customer videos and drive traffic to the video library for maximizing views. Selected videos are also highlighted on the home page and video landing pages. The new platform supplies analytics so that the customer sees the performance of each video. Below are the programs available:

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- Periodic highlight of videos on library landing pages
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	RUDAT-6000-60	0-60 dB	±0.3 dB	0.25 dB	✓	-	✓	$625
	RCDAT-6000-60	0-60 dB	±0.3 dB	0.25 dB	✓	✓	-	$725
	RUDAT-6000-90	0-90 dB	±0.4 dB	0.25 dB	✓	-	✓	$695
	RCDAT-6000-90	0-90 dB	±0.4 dB	0.25 dB	✓	✓	-	$795
NEW	RUDAT-6000-110	0-110 dB	±0.45 dB	0.25 dB	✓	-	✓	$895
NEW	RCDAT-6000-110	0-110 dB	±0.45 dB	0.25 dB	✓	✓	-	$995
NEW	RUDAT-4000-120	0-120 dB	±0.5 dB	0.25 dB	✓	-	✓	$895
NEW	RCDAT-4000-120	0-120 dB	±0.5 dB	0.25 dB	✓	✓	-	$995

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FABS and LABS

An Out of Body Experience at Cambridge Consultants

Cambridge Consultants delivers cutting edge product development engineering and technology consulting to its clients. They are one of the largest independent wireless development teams, with more than 120 experts working in areas such as ultra-low-power short-range wireless connectivity and global satellite communication, with locations in Boston, Mass. and Cambridge, UK.

The company has a track record of creating world-firsts for their clients. During its 55-year history, the company has helped develop technology ranging from the world's first wireless implanted pacing system, to the ground-to-air radio system that controls the majority of air traffic across the globe. A recent example is the completion of initial trials of the first fully digital radio transmitter that can be an enabler for the Internet of Things (IoT) and 5G technology. Their first trial of the technology created 14 simultaneous cellular base station signals. They also developed the first single-chip Bluetooth radio that led to the spinout of the global short-range wireless and audiovisual company CSR.

MWJ recently visited Cambridge Consultant's new downtown Boston facility. The facility has impressive labs and testing capabilities that mainly focus on medical device development, including an anechoic chamber, fully equipped operating room and various phantom bodies and test vehicles to mimic the body. Dr. Arun Venkatasubramanian designs antennas for medical applications and took us on a lab tour. He explained how many previous medical devices have been difficult to work with at the standard 401 to 406 MHz medical band, due to highly regulated power levels and other restrictions. The cost to customize a wireless connection can also be extremely high. However, with the commercialization of low energy Bluetooth, the cost of 2.4 GHz connections has become very inexpensive and convenient to use with smartphones and tablets. Allowing doctors to control implanted medical devices with smartphones or tablets is becoming a common request with application development and wide availability of devices.

Implantable devices found in wireless body area networks for healthcare applications such as disease prevention, diagnosis and therapy rely on antennas to transmit reliable information from inside the human body to an external receiver. In many applications, traditional antenna designs would not allow the low energy Bluetooth signal to make it out of the body. Due to the EM interaction between the implanted antenna and human tissue, wireless devices experience high energy consumption during transmission (as much as 99 percent of the radiated energy can be lost inside the body), irregularly distributed signals and possible failure to meet the minimum range requirements. Recently, Dr. Venkatasubramanian designed a dual band (MICS and ISM) antenna that was optimized in a small planar structure that is 40 x 45 mm in size with no passive components. The low Q nature of the compound field antenna desensitizes the antenna from the impact of being implanted within the body, eliminating the need for retuning the antenna to account for different body dimensions.

The designs are tested and evaluated in their anechoic chamber and other labs using phantoms to represent various parts of the body. They use standard phantoms and their own custom setups to evaluate their designs. The operating room also helps them work with doctors to step through the entire operation of implanting and communicating with the device so that the methods can be exactly replicated step-by-step. This ensures proper simulation, modeling and testing to make sure the device operates under real life conditions.

Cambridge Consultants is tackling some of the most challenging wireless projects in our industry within the walls of their state-of-the-art testing facilities. Their ongoing work on getting device signals out of the body to create a reliable wireless link is enabling significant advances in the medical field.

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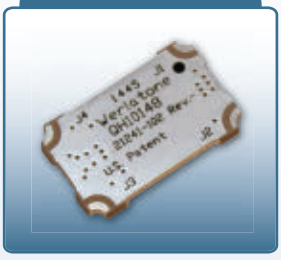
Model QH10148



90° Hybrid Coupler

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The QH10148, one of our newest 90° Hybrid Couplers, delivers best-in-class amplitude balance, specified at ± 0.5 dB Max. An amplitude balance **measuring half that of competing products**, insures that your transistors run more evenly and thus more efficiently. The Model QH10148 provides an insertion loss of less than 0.3 dB, is robust, and highly repeatable.

Model D10149

2-Way 0° Combiner

Tolerates a Full Input Failure

The D10149 is a connectorized solution, designed for system level and lab use of both military and commercial applications. Rated at 200 W CW, the D10149 is fully isolated, and **able to withstand a full input failure**, at rated power. Measuring just 2.9 x 2.7 x 1.06", the D10149 is designed to tolerate MIL-STD-810 environmental conditions.

Model H10126

180° Hybrid Combiner

Excellent Phase Tracking

The Model H10126 is a surface mount 180° Hybrid covering a full 2 to 6 GHz at 100 W CW. Measuring just 1.15 x 0.6 x 0.31", this unit is ideal for combining applications encountering 2nd Order Harmonic conditions and for combining two lower power 90° Hybrid Couplers. The H10126 provides excellent phase tracking and 20 dB port-to-port isolation.

Model D10296

4-Way 0° Combiner

Fully Isolated

Delivering a minimum of 15 dB port-to-port isolation, the D10296 is a connectorized, 4-Way Combiner / Divider, conservatively rated at 200 W CW. Able to withstand a full input failure, at rated power, the D10296 operates with less than 1.0 dB of insertion loss and measures just 3.9 x 3.6 x 1.06".

Model D9922

2-Way 0° Combiner

Surface Mount Design

The D9922, rated at 200 W CW, is a surface mount 0° Combiner / Divider which **provides very low loss** across the entire 2 to 6 GHz bandwidth. Ideal for amplifier houses concentrating on modules only, the Model D9922 is robust and measures only 1.4 x 1.1 x 0.14". Buy the engine without having to buy the entire car!

Model C10117

Dual Directional Coupler

Mismatch Tolerant 700 to 6000 Mhz

Werlatone's Model C10117 is a 40 dB Dual Directional Coupler conservatively rated at 250 W CW and offers excellent electrical performance. Measuring just 2 x 2 x 1.06", this ***Mismatch Tolerant*** **design** operates with less than 0.2 dB of insertion loss and is designed to tolerate a full load mismatch, at rated power.

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