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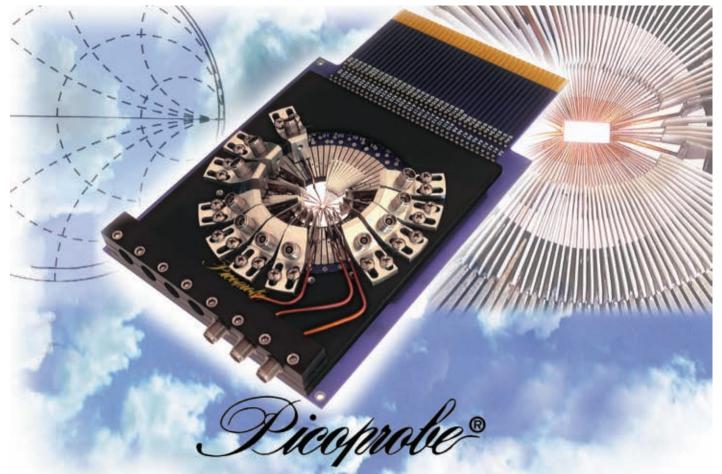
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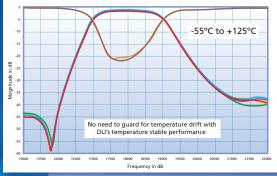


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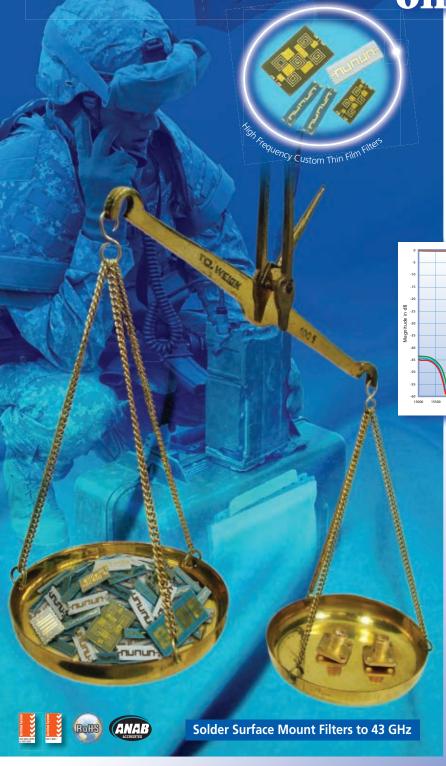
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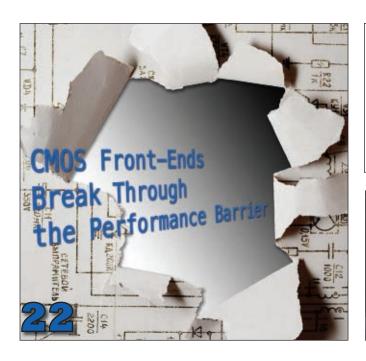




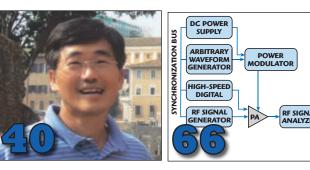
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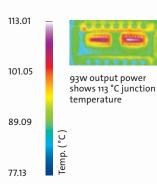
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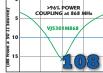
3 x 6 mm dual flat no-leads (DFN) package





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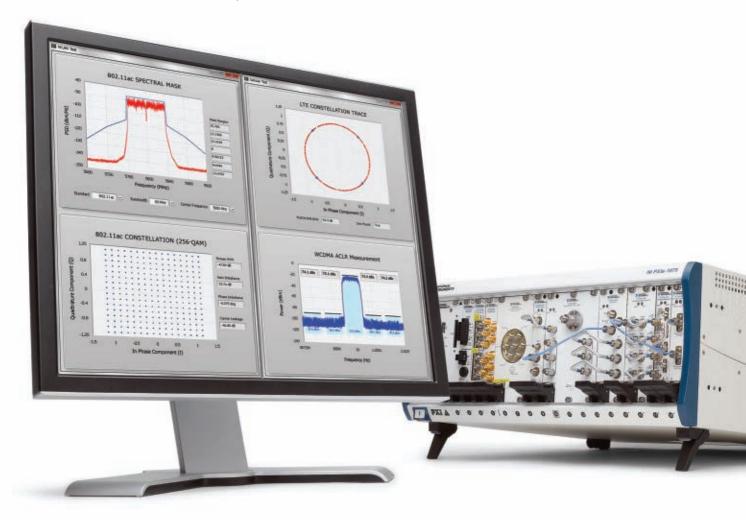
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Executive Interviews



Professor Joel L. Dawson, CTO and founder of Eta **Devices**, talks about how this new startup was formed, its potentially revolutionary power amplifier technology (Asymmetric Multilevel Outphasing) and the benefits to the marketplace.

6/13



Michael Noonen, executive vice president, global sales and marketing at Global Foundries, discusses the company's acquisitions, fast growth and RF CMOS processes plus new developments in the area of FinFETs.

White Papers

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RF/Microwave EDA Software Design Flow Considerations for PA MMIC Design **AWR**

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Overview of Tests on Radar Systems and Components Rohde & Schwarz

Introduction to Radar System and Component Tests Rohde & Schwarz

T&M Solutions for Software Defined Radios (SDR) Rohde & Schwarz



April Survey What medium do you design for?

Waveguide [46 votes] (39%)

PCB (Cu clad laminates) [27 votes] (23%)

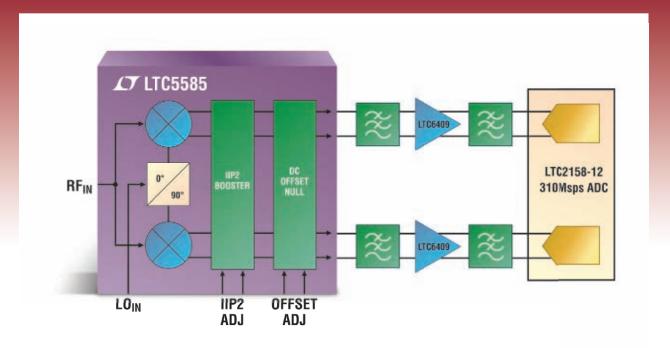
Ceramics (Alumina, LTCC, etc.) [4 votes] (3%)

MMIC & RFIC [20 votes] (17%)

Mixed Mediums [20 votes] (17%)

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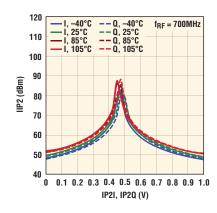
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IIP3	31dBm@450MHz	25.7dBm@1.9GHz		
Adjustable IIP2	>80dBm	>80dBm		
DC Offset Cancellation	Yes	Yes		

IIP2 Optimization vs Trim Voltage





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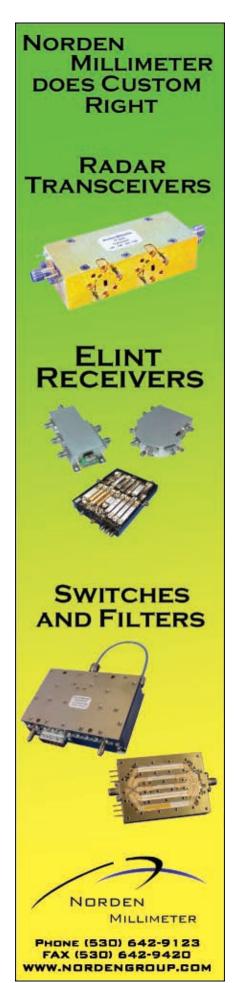
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SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
30	1	2	3	4	5	6
7	8	Antenno USNC-U	10 IE International Symposium on s and Propagation and MSI National Radio Science Mare EEE (1/8)		12	13
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July 7–12, 2013 • Lake Buena Vista, FL www.2013apsursi.org

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August 5–8, 2013 • Austin, TX www.ni.com/niweek

EMC 2013

IEEE INTERNATIONAL SYMPOSIUM ON ELECTROMAGNETIC COMPATIBILITY

August 5–9, 2013 • Denver, CO www.emc2013.org

AUVSI's UNMANNED SYSTEMS 2013

August 12–15, 2013 • Washington, D.C. www.auvsishow.org

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September 1–6, 2013 • Mainz, Germany www.theconference2013.com

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13TH MEDITERRANEAN MICROWAVE SYMPOSIUM

September 2–5, 2013 • Saida, Lebanon www.iutsaida.ul.edu.lb/mms2013

ICUWB 2013

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September 15–18, 2013 • Sydney, Australia www.icuwb2013.org

ION GNSS+ 2013

September 16–20, 2013 • Nashville, TN www.ion.org

OCTOBER

AMTA 2013

35th Annual Symposium of the Antenna Measurement Techniques Association

October 6–11, 2013 • Columbus, OH www.amta2013.org

EuMW 2013

EUROPEAN MICROWAVE WEEK

October 6–11, 2013 • Nuremberg, Germany www.eumweek.com

COMSOL CONFERENCE 2013

October 9–11, 2013 • Boston, MA www.comsol.com/conference2013/usa

PHASED ARRAY 2013

IEEE International Symposium on Phased Array Systems & Technology

October 15–18, 2013 • Boston, MA www.array2013.org

MICROWAVE UPDATE 2013

October 18–19, 2013 • Morehead, KY www.microwaveupdate.org

IEEE COMCAS 2013

International Conference on Microwaves, Communications, Antennas and Electronic Systems

October 21–23, 2013 • Tel Aviv, Israel www.comcas.org

IME/CHINA 2013

8TH INTERNATIONAL CONFERENCE AND EXHIBITION ON MICROWAVE AND ANTENNA

October 23–25, 2013 • Shanghai, China www.imwexpo.com

4G WORLD 2013

October 28–30, 2013 • Dallas, TX www.4gworld.com

NOVEMBER



APMC 2013

ASIA-PACIFIC MICROWAVE CONFERENCE

November 5–8, 2013 • Seoul, Korea www.apmc2013.org

2013 LOUGHBOROUGH ANTENNAS & PROPAGATION CONFERENCE

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MILCOM 2013

MILITARY COMMUNICATIONS CONFERENCE

November 17–20, 2013 • San Diego, CA www.milcom.org

DECEMBER

IMARC 2013

IEEE INTERNATIONAL MICROWAVE AND RF CONFERENCE

December 14–16, 2013 New Delhi, India www.imarc-ieee.org

AEMC

4TH **APPLIED ELECTROMAGNETICS CONFERENCE**

December 18–20, 2013 • Bhubaneswar, India http://ieee-aemc.org

JANUARY 2014

IEEE RWW 2014 RADIO WIRELESS WEEK

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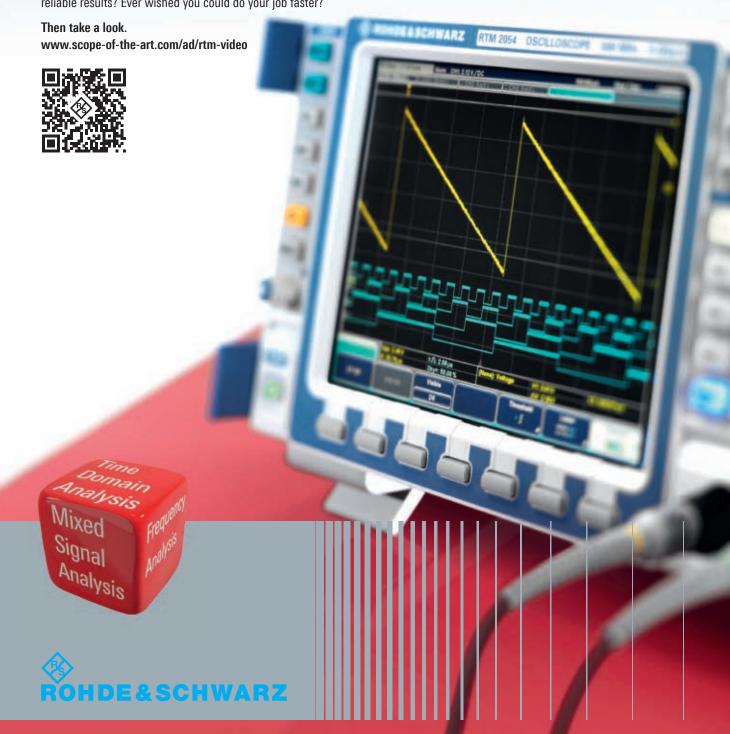
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COVER FEATURE INVITED PAPER

CMOS Makes Waves in the Mobile Front-End

he GaAs device industry has posted eight consecutive years of growth and it closed 2012 with revenues of slightly more than \$5.3 billion. This expansion began in 2004, and GaAs device revenue has more than doubled since then. That this expansion occurred with the commercial wireless communications era is no coincidence. The GaAs device industry has benefitted enormously from rapid growth in mobile handset adoption as power amplifiers and switches have formed the RF backbone in increasingly sophisticated mobile phone designs. As wireless standards evolve to HSPA+ and LTE and countries designate new frequency bands to satisfy the insatiable desire for data consumption, the RF content in the front-end of handsets increases. Strategy Analytics estimates that the combination of increasing mobile device shipments, coupled with a trend of higher GaAs dollar content per device drove this segment to more than $5\bar{5}$ percent of total GaAs device revenue in 2012. With handset shipment increases forecast in 2013 and smartphones continuing to capture market share, it would seem GaAs device revenue is poised for continued long-term growth, but recent announcements signal a threat.

Just prior to Mobile World Congress in late February, Qualcomm officially launched its RF360 family of CMOS-based front-end products, consisting of multimode, multiband PAs, envelope tracking (ET) power management ICs, antenna tuners and modular packaging for PAs, switches and filters. Qualcomm's preconference announcement shook investors on Wall Street as most GaAs PA manufacturers saw their stocks drop significantly after the announcement. In addition to the investors, the announcement also prompted power amplifier suppliers and envelope tracking (ET) specialists to release a flurry of competitive counter-

announcements, with no fewer than 10 companies releasing new details at MWC about how they will support LTE devices with multimode, multiband PAs (MM-PA) and ET.

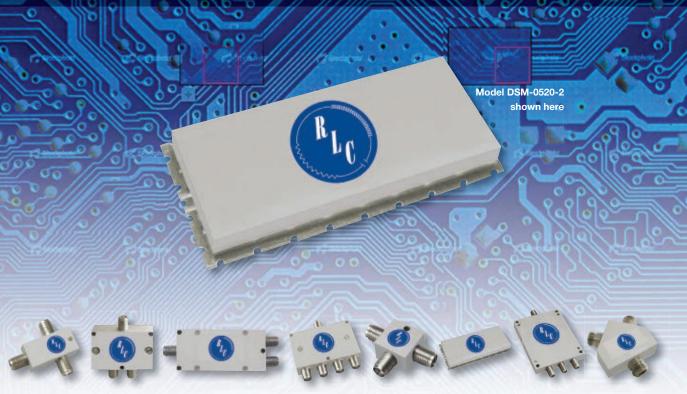
Qualcomm announced that it developed this family of handset RF front-end component solutions to address the problem of band fragmentation, a barrier to the success of its LTE chipsets. With the company occupying a dominant position as an LTE chipset supplier, they have a large stake in enabling the anticipated fast growth of the LTE mobile device market. The solution introduces several innovations to the PA market. While lower tier GGE handsets have increasingly used CMOS PAs over the past two years, this is the first commercial multimode, multiband PA fabricated in CMOS. It is also the first PA to include monolithic onchip distribution and antenna switches, as well as the first production CMOS PA designed to work with ET and support LTE.

As expected, the GaAs community has offered counterpoints to Qualcomm's RF360 family of front-end products. The main criticism centers on the belief that the traditional approach of mixing and matching GaAs-based PAs, PMICs, duplexers, filters and switches will always provide the best possible solution in terms of efficiency, performance and flexibility. Ultimately, the market will decide the best solutions, and many more developments in both technologies will probably occur before the best path emerges. However, with more than half of existing GaAs device revenue potentially at risk, the Qualcomm CMOS announcement has definitely captured the attention of GaAs device manufacturers.

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Less is More: The New Mobile RF Front-End

PETER CARSON AND STEVE BROWN Qualcomm, San Diego, CA

₹he printed circuit board area inside of a smartphone has become the second most precious—and contested—real estate in the mobile landscape, right behind radio spectrum. Ironically, the proliferation of newly-added radio spectrum bands—aimed at alleviating bandwidth scarcity—is what has intensified the pressure on PCB space in smartphones. More bands demand more discrete RF front-end components such as power amplifiers, multiband switches, duplexers and filters, along with matching components. Add the demands for bigger screens, quad-core application processors, connectivity, batteries and add-ons, all wrapped up in thin sleek form factors, and it is clear there is no room to expand the space devoted to RF frontends, even to accommodate the doubling or tripling of bands needed for global LTE roaming in a single-SKU design (see $Figure\ 1$).

The Qualcomm® RF360 RF frontend solution from Qualcomm Technologies Inc. (QTI) has been designed to address this issue, and others, with a highly integrated RF front-end combining essentially all the components between the modem and the antenna: an RF power amplifier integrated with the antenna switch, the transceiver, an antenna matching tuner and an envelope power tracker. This is a "360-degree" approach to simplifying and addressing multiple complex challenges to the cellular RF front-end, starting with band proliferation and extending across multiple performance and size enhancements so product appeal as well as the significant production scale advantages of reducing unique SKU designs—can be maximized. Announced in February for OEM products anticipated to ship later in 2013, the front-end has been designed from the ground up as a full system solution that also works interactively with the device's modem, transceivers and sensors to deliver unique new performance gains.

DESIGN APPROACH

At the broadest technological level, the design primarily addresses the RF band fragmentation that comes with the expansion of 4G LTE (FDD and TDD) on top of continuing 2G and 3G coverage worldwide, and the need to support all the associated bands in a single device, or at

least fewer SKUs and to do that without increasing the demand for space or compromising performance.

At an economic level, it is also designed to enable production scale—and its dramatic cost benefits—for cellular device manufacturers. Instead of needing up to ten different designs to competitively support the required LTE band combinations around the world, an OEM may only need three, or even fewer, and the differences across those can be addressed without a change in board layout, or an increase in board space.

RF BAND PROLIFERATION WITH NO INCREASE IN PCB SPACE

The central RF challenge today is the proliferation of cellular bands worldwide—already 40 and counting—required to address exploding service demands and network capacity. This is compounded by the need to simultaneously launch multiple handsets to meet OEMs' desire to maximize their returns on product investments. This has pushed mobile device makers to develop multiple versions of each device model, each with smaller produc-

Antennas Connectivity Wi-Fi/BT/FM AP, Modem, Filters, Duplexers, Memory, PMIC, Power Amps and Multi-port Switch Transceiver, Sensors, etc. Packed into pproximately 15% of Total Area Battery Consumes **PCB** Only has Nearly 60% of Total Area (one example of typical

tion unit potential, using legacy RF solutions that handle only a subset of bands or require multiple chipsets in a single device for greater regional coverage.

The Qualcomm solution addresses this RF band proliferation challenge with a single board-level SKU designed to work across any combination of modes and bands (all major cellular modes from GSM onwards and bands currently fully specified in 3GPP) that enables global roaming, particularly for 4G LTE. How is this possible, when no single RF solution can yet address all bands worldwide, without resorting to a brute force approach using a large number of discrete parts? It actually requires a combination of key technologies, all of which are integrated into the Qualcomm solution and optimized as an end-to-end system.

POWER ENVELOPE TRACKING

The first key technology is power envelope tracking (ET) that tailors the





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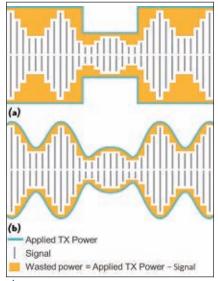


Fig. 2 Power wasted with average power tracking (a) compared to power saved with power envelope tracking (b).

PA power supply to the instantaneous needs of the signal content being transmitted. It is an advancement over conventional average power tracking (APT), that adjusts the PA power supply on power level groupings instead of on the instantaneous signal need. The unused energy with APT not only wastes battery power, but also generates waste heat, creating added demands for space for dissipation of the heat (see **Figure 2a**). With envelope tracking, the transmission power supplied is tailored to the instantaneous needs of the signal content being transmitted (see Figure 2b).

Working interactively with the device's modem, the envelope power tracker adjusts transmission power to match instantaneous requirements of the content being transmitted, rather than adjusting after long intervals of constant power. This modem-assisted envelope tracking, the for 3G/4G LTE, re-

duces power consumption by up to 20 percent, and heat generation by almost 30 percent (based on QTI testing and analysis). This extends battery life and reduces the thermal footprint inside the thin cavity of a smartphone.

Envelope tracking works with the modem to sense instantaneous power needs, and manages the PA. With CMOS-based PAs, the level of integration can be substantially increased, and points toward the idea of a fully integrated RF front-end system-on-chip. A system-on-chip means advanced 3D packaging

techniques

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first in the industry \triangle Fig. 3 RF POP 3D design CMOS front-end.

have now become possible for the RF front-end.

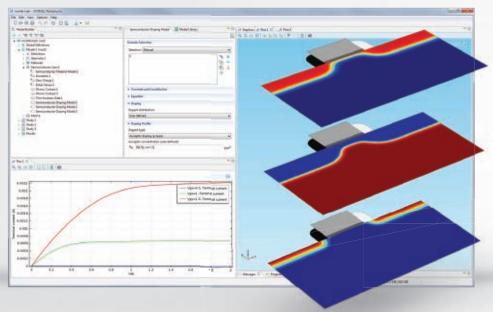
RF POP

The second technology the Qualcomm front-end lution is the industry's first stacked. 3D RF packaging, or RF POPTM solution. using advanced 3D packaging that





SEMICONDUCTOR DESIGN: Model of the DC characteristic of a MOSFET device.



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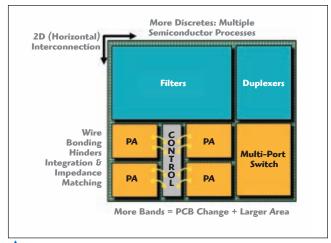
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▲ Fig. 4 Side-by-side conventional RF front-end discrete design.

integrates the single-chip multimode power amplifier and antenna switch (AS) into a base package, integrates the filters and duplexers onto a single substrate and then stacks the substrate on top of the base package into a single "3D" chipset combination, reducing overall complexity and eliminating the need for the wire bonding commonly used in

today's RF front-end modules. The package containing the integrated PA and AS form the base substrate layer, and have a common footprint for all devices. The package containing the filters and duplexers is configurable for global and/or multi-regional band combinations and goes on top of the PA/AS base, much like a customizable "roof" over a universal foundation. The combination is one millimeter thick and uses half the board area of previous Qualcomm RF front-end solutions. Importantly, customizing devices for different regions does not require changes to the board layout since the base PA/AS layer can remain constant (see *Figure 3*).

This design is based on an architecture capable of supporting 700 MHz to 2.7 GHz LTE bands worldwide, along with legacy 2G/3G bands, and reduces local RF band customization to simplified variations in the "roof." With the RF POP approach, two to three PCB designs can now replace what would take a dozen or more designs otherwise to cover an OEM's worldwide needs, since multiple frequency configurations can use the same board layout. This creates the potential to drive LTE economies of production scale in much the same way that quad-band did for GSM and penta-band did for 3G.

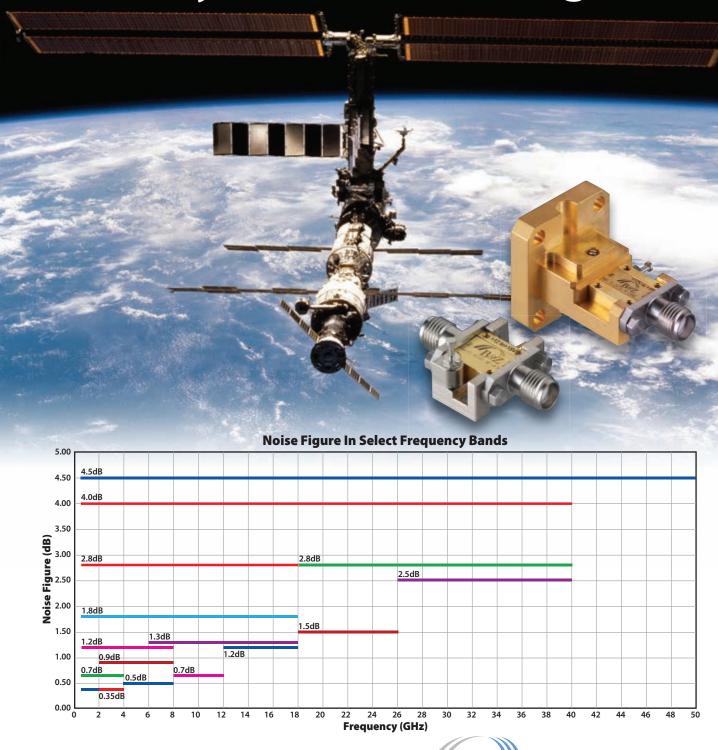
In contrast, conventional PCB module-based solutions mix and match different technologies such as GaAs- and CMOS-based components device-by-device for an optimum solution within a single device's operating environment. Accommodating a broader array of environments is more complex, resulting in some cases in multiple solutions residing side-by-side within a single device. These side-by-side solutions require multiple PAs, depending on the band combinations being designed for, with more discrete chips and the associated wire bonding, which hinders integration due to introducing radiated interference and added impedance matching requirements. If more bands are needed, a board change is required, including the possibility of a size increase, and reducing the volume potential of each unique design (see *Figure 4*).

ADAPTIVE ANTENNA TUNING

The third key technology is adaptive antenna tuning. One RF problem that has been exacerbated by thinner, sleeker device designs is that the much closer physical proximity of users' hands and head to the antenna causes the antenna to de-tune from the targeted frequency, losing signal with the base station beyond the signal attenuation caused by the physical impediment of the hand and/or head. The base station responds by instructing the device to increase transmission power to compensate for the lost signal. If more device transmission power is available, battery drain is increased. If the device is already at maximum transmis-



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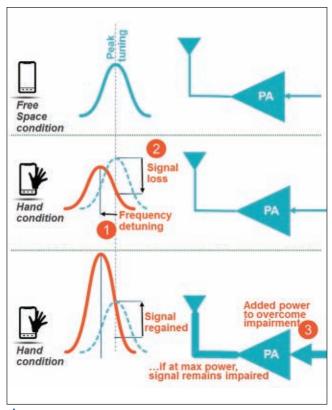




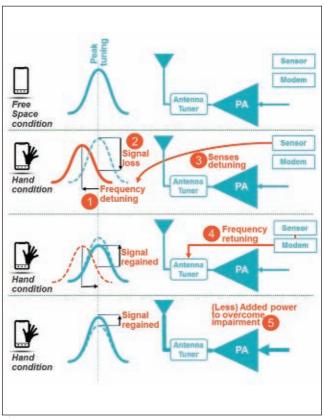


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▲ Fig. 5 Conventional RF front-end de-tuning causes power increase or call drop.



▲ Fig. 6 Qualcomm RF 360 de-tuning provokes re-tuning.

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sion power, the call is compromised or dropped (see *Figure 5*).

In contrast, the Qualcomm system works with the device's sensors, which detect the antenna de-tuning and gain loss, and the modem directs the antenna matching tuner to re-tune to the correct frequency. This eliminates the need to increase power to compensate for off-frequency transmission, reducing the power increase to only that needed to compensate for the attenuation caused by the physical impediment (see *Figure 6*).

POWER AMPLIFIER PERFORMANCE

The Qualcomm RF360 solution utilizes a comprehensive system design to enable an all-CMOS RF front-end, which historically has been judged inadequate to meet cellular power performance requirements, when compared to the module-based, GaAs/CMOS mixed technology approach. However, testing by QTI has demonstrated that—utilizing only the current generation power envelope tracking enabled by the CMOS integration—transmission power performance (power consumption for TX power produced) of the Qualcomm





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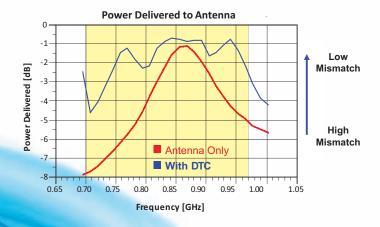
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solution closely matches the profile of conventional power amplifiers using today's average power tracking across the broad range of transmission power levels (see *Figure 7*).

The Qualcomm solution with envelope tracking and the conventional average power tracking solution have small differences at different power levels. The system has been optimized for performance efficiency to deliver best in class talk time and data transmission

across power ranges most used in real world experience (see Figure 8), based on QTI field data collected across commercial networks in rural California from 8 AM to 8 PM over seven days in 2013 and urban Los Angeles from 6 AM to 7 PM over one day in 2011, and closely matches the profile of conventional power amplifiers even outside of these most used ranges of transmission power.

When power performance is weighted based on real-world usage

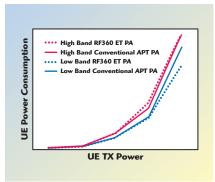


Fig. 7 PA performance comparisons.

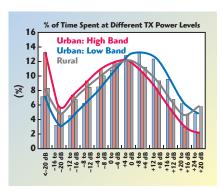


Fig. 8 TX power usage patterns.

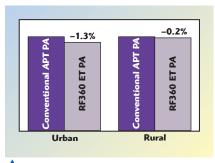


Fig. 9 Usage-based total power consumption comparisons.

distribution patterns across high and low bands, the total power consumption using the Qualcomm RF360 solution is virtually identical to conventional PAs for rural settings and slightly better for urban settings (see Figure 9).

It is worth noting that these performance comparisons do not factor in improvements from the use of precision analog circuitry to optimize PA and ET operation, for example, through the addition of multiple programmable gain states. Antenna tuning gains have also not been factored into the comparison. QTI Testing has shown a 2 dB gain contribution from antenna tuning, which would shift the frequency of TX power usage curves "left" by -2 dB in the usage patterns (see **Figure 10**).

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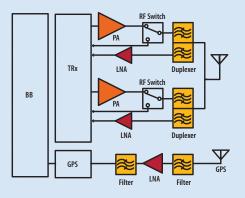
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Applying these shifted TX power usage frequency distribution patterns to the performance analysis would indicate additional improvements in total power consumption. So even without PA optimizations and antenna tuning gains, overall system performance meets today's requirements and is comparable in efficiency to existing front-end solutions, accomplished with a much smaller PCB space requirement and much greater RF band scalability.

CONCLUSION

The Qualcomm front-end is a collection of innovations:

- The first fully integrated monolithic die multimode, multiband CMOS power amplifier with an integrated antenna switch
- The first stacked RF POP solution (3D packaging) that reduces the RF front-end footprint while enabling common board layout and simplified RF band customization or expansion

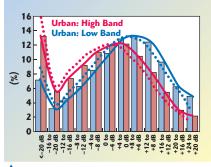


Fig. 10 Shift in TX power usage patterns with antenna tuning.

- The first CMOS power amplifier for LTE
- The first CMOS power amplifier with envelope tracking
- The first dynamic reconfigurable LTE multimode antenna tuner
- In total, the first fully integrated CMOS-based RF front-end, including everything between the modem and the antenna

The solution is focused on addressing the fact that worldwide LTE band proliferation has created a direct challenge to producing mobile devices at economic scale, and doing it within an extremely limited PCB space. The RF POP approach enables a common global board-level design, with sim-

110

plified RF band expansion or customization,

to help regain device design and production scale. Smaller RF front-end footprint, heat dissipation and size, along with longer battery life, help enable sleek, thin, powerful and efficient device designs. Plus, the solution is sampling now in order to meet the immediate challenges of establishing LTE economies of scale and global roaming.







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ZHL-30W-262+	2300-2550	50	20	32	1995	1920
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Listed performance data typical, see minicircuits.com for more details.

- * To order without heat sink, add X suffix to model number (example: LZY-22X+).
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oonton (a Wireless Telecom Group company) has introduced its new 55 Series line of wideband USB power sensors that brings ultra-fast pulse and modulation power measurement capabilities typically associated with top-end benchtop peak power analyzers to the popular USB sensor form factor. The new line includes 6, 18 and 40 GHz models, and is designed for measurement of wideband modulated signals and the fast RF pulse and burst waveforms. Video bandwidth for the fastest models exceeds 70 MHz, with less than 5 ns risetime, making the 55 Series well suited for high-speed signal analysis.

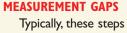
Continuous sample rate is 100 MSa/ sec, with a 10 GSa/sec effective sample rate and 100 picosecond time resolution for repetitive signals. This is more than one hundred times faster than most existing USB power sensors, and enables exceptional trigger stability and waveform fidelity when characterizing complex modulation and pulsed signals. Combining the wide dynamic range, fast bandwidth and risetime, and excellent time resolution that Boonton has long been known for with its Real-Time Power ProcessingTM (Patent pending)

technology, the 55 Series offers capabilities beyond those of many other USB power sensors and even competing scope-based peak power analyzers. This architecture permits sustained acquisition speeds exceeding 40,000 triggered sweeps per second, ensuring no signal information is missed due to the "snapshot" approach employed by traditional power meters and USB sensors. Gapfree gated and continuous statistical analysis can be performed concurrently at a sustained 100 Mpoints/sec.

CONVENTIONAL PEAK POWER METER ARCHITECTURE

Conventional peak power meters digitize the detected RF signal at a high sample rate and store the digitized samples into a FIFO or memory buffer. A typical triggered sweep measurement cycle is shown in Figure 1. Once a trigger occurs, sampling continues until the buffer contains enough samples to complete the sweep, then acquisition halts so a microprocessor or DSP can process the raw samples into a trigger-synchronous trace buffer. Following that, the computed power versus time trace may be further analyzed to yield time-gated or event-gated measurements such as

average or peak pulse power and statistical measurements. CONVENTIONAL In USB sensors, the sweep and/ processed measurement data is periodically scaled to dBm or watts, then transmitted to the host PC for display and additional analysis.



RE-ARM LATENCY AND

Typically, these steps must take place sequentially, and sample acquisition for a new sweep cannot restart until the microprocessor has completed most or all steps in the sweep processing sequence. This results in acquisition gaps during which time no data is gathered and the trigger cannot be armed. Processing and re-arm latency can range from 10 to 300 milliseconds for typical triggered pulse measurements. Re-arm times are further extended when pre-trigger measurements are required - common when measuring pulses, transients and signal edge transitions, since the leading edge usually serves as the trigger signal.

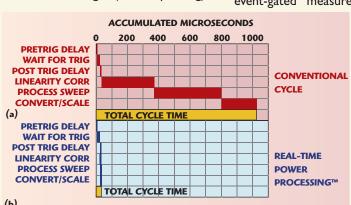
If the pulse repetition interval (PRI) of a periodic signal is shorter than the sweep's measurement cycle time, then one or more pulses will occur before the trigger re-arms, and events of interest will be missed. When trace averaging and multi-sweep envelope accumulation are enabled, it will take far longer than expected to acquire enough sweeps to fulfill the averaging criteria.

A conventional power meter capable of acquiring 3 to 30 triggered sweeps per second has difficultly providing fast and meaningful test results with some of today's high-speed, agile wireless and microwave signals. Although some models offer buffered measurement speeds up to several thousand measurements per second, these untriggered, "streamed" readings offer little useful information for synchronous signals.

THE REAL-TIME SOLUTION: **CLOSE THE GAP**

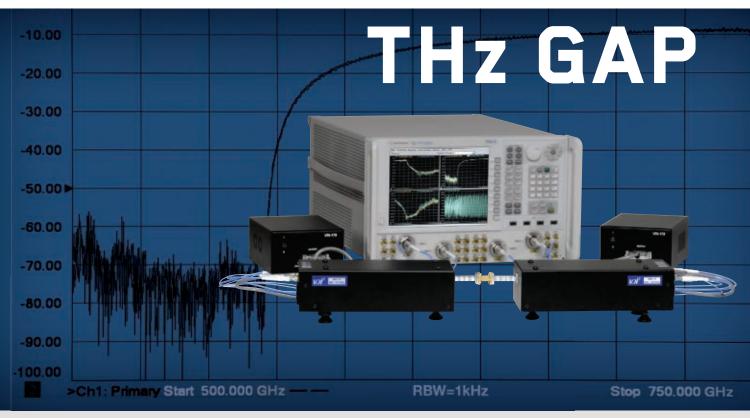
Boonton's Real-Time Power Processing technology addresses

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▲ Fig. 1 Sequential processing overhead of conventional triggered measurement cycle (a) and Real-Time Power Processing with no delays (b).

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provide high performance frequency extension of vector network analyzers into the THz range. Models are currently available that cover 50GHz to 1.1THz and combine high test-port power with superb dynamic range to offer unparalleled performance. VDI's VNA Extension Modules are compatible with all modern network analyzers. Contact VDI to discuss VNA and Extender configurations that will yield the best performance for your application.

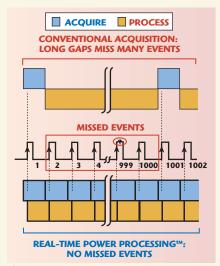
Waveguide Band (GHz)	WR15 50-75	WR12 60-90	WR10 75-110	WR8.0 90-140	WR6.5 110-170	WR5.1 140-220	WR4.3 170-260	WR3.4 220-325	WR2.8 260-400	WR2.8 325-500	WR1.5 500-750	WR1.0 750-1,100
Dynamic Range (BW=10Hz,dB,typ)	120	120	120	120	120	120	115	115	100	100	100	60
Dynamic Range (BW=10Hz,dB,min)	100	100	100	100	100	100	100	100	80	80	80	40
Magnitude Stability (±dB)	0.15	0.15	0.15	0.15	0.25	0.25	0.3	0.3	0.5	0.5	0.8	1
Phase Stability (±deg)	2	2	2	2	4	4	6	6	8	8	10	15
Test Port Power (dBm)	6/13	6/10	6/10	6/10	0	-4	-6	-9	-16	-17	-25	-35



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▲ Fig. 2 Gap-less triggered acquisition of Real-Time Power Processing USB power sensor captures all signal events including an intermittent glitch (circled).

shortcomings of conventional power measurement techniques in several ways. By combining a dedicated acquisition engine, hardware trigger, deep sample memory, and a real-time optimized parallel processing architecture, it is possible to perform most of the sweep processing steps simultaneously, and beginning immediately after the trigger instead of waiting for the end of the acquisition cycle.

The advantages of the Real-Time Power Processing technique are shown in Figure 2. Key processing steps take place in parallel, and keep pace with the signal acquisition. With no added computational overhead to needlessly prolong the sweep cycle, the sample buffer can't overflow, so there is no need to halt acquisition for trace processing. This means gap-free signal acquisition, and guarantees that intermittent signal phenomena such as transients, dropouts, or interference will be reliably captured and analyzed. These sorts of events are most often missed by conventional power meters due to their acquisition gaps while processing takes place.

AVOIDS LATENCY AND DECIMATION

Since acquisition is continuous, and the trigger system is implemented in dedicated hardware, it is possible to further shorten the cycle by eliminating the pre-trigger interval for all but the initial trigger event. In most cases, the trigger can be re-armed within microseconds of the end of the acquisition interval rather than the tens or hundreds of milliseconds later, as is the

case with conventional power meters.

Along with the benefits of ultrafast triggered acquisition, Real-Time Power Processing is able to perform full sample rate pre-averaging, envelope detection and statistical analysis, so there is no need to discard samples when measuring long-duration signals at slower timebases. Conventional power meters, and especially memoryconstrained USB power sensors, often reduce their acquisition rates considerably at slower timebases to avoid sample buffer overflow. This "decimation" process causes added measurement noise, signal aliasing, reduced confidence for statistical measurements, and missed peaks or glitches when transients fall between samples.

WHY SNAPSHOTS ARE NOT ENOUGH

So what does Real-Time Power Processing offer to the typical user? The result can be likened to viewing a live video versus a slideshow – there is never an instant during which the signal is not being acquired, analyzed and presented to the user. The Boonton 55 Series USB power sensors are capable of capturing more than 40,000 triggered sweeps per second and analyzing each for gated or overall peak, average and minimum power, as well as performing real-time statistical analysis (CCDF) on the signal.

As an example, a typical short-range radar transceiver might use a 15 microsecond chirped pulse repeating at 2 kHz (a 500 microsecond PRI). For this signal, the power meter would typically be set for a time-base of 2 µs/div (total sweep duration of 20 microseconds), with a few microseconds of pre-trigger delay so both the leading and trailing edges of the pulse could be analyzed. If captured at a 100 MSa/sec acquisition rate, this sweep would contain 2000 power samples. Using a fast microprocessor or DSP, the steps needed to process the sample buffer into a usable sweep might take an additional 20 milliseconds once the sample buffer fills and acquisition has been halted. During this processing time, another 40 signal pulses will have passed by - untriggered and unmeasured. So the conventional power meter has captured only one of every 41 pulses, and discarded over 97 percent of the usable signal. Increase the PRI to 20 kHz, and 99.8 percent of the signal information is missed.

USB 2.0 high-speed communication with a PC host permits simultaneously acquired, overlaid average and envelope (peak-minimum) traces to be displayed at full video rates. In this way, a quiet, trace-averaged waveform can be viewed, while still spotting fleeting transients. Flexible peak/min hold capabilities allow even a single transient occurring over hours of monitoring to be reliably captured and displayed.

REAL-TIME MEANS REAL RESULTS

In a power meter equipped with Real-Time Power Processing technology, the sweep processing takes place as the power samples are acquired, so there is minimal latency to re-arm the trigger system. Even the fastest signals can be acquired and analyzed without missing any triggerable events. With no acquisition gaps or sample decimation, users are ensured of maximum accuracy and minimum test times.

Key benefits of this technology include:

- Every pulse is captured, none discarded
- Trace averaging and envelope time drastically reduced
- · Lower noise, no missed glitches
- Continuous or gated CCDF statistical analysis computed from ALL signal events
- "Live Video" presentation versus "slide-show" speeds
- Far superior waveform fidelity and trigger stability
- Simultaneous display of trace average and envelope (peak/min)

The 55 Series sensors are made in the USA, and include a flexible, multipurpose I/O connector that can serve as an analog input, status output, external trigger input or trigger output. Connecting two or more sensors with a simple "tee" connection permits master/slave triggering for synchronized, multi-channel measurements – no external trigger modules are required. The bus-powered sensors connect directly to a standard USB 2.0 port with a locking, removable cable. A full-color, programmable LED indicates acquisition status, faults or alarm conditions.

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- •SMA Adaptor (50 Ω only)
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* Measurement speed as fast as 10 ms with PWR 8 FS. All other models as fast as 30 ms.

† See datasheets for an extensive list of compatible software.
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Model	Frequency	Price \$ ea.
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PWR-2.5GHS-75	100 kHz-2.5 GHz	795.00
PWR-6GHS	1MHz-6 GHz	695.00
PWR-8GHS	1MHz-8 GHz	869.00
PWR-8FS	1MHz-8 GHz	969.00
₩! PWR-4RMS	50 MHz-4 GHz	1169.00

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SAMUEL CHO, CTO, RFHIC CORP.

cross the world, mobile phones are the one united technology in all countries, nationalities and groups. Some estimates indicate that there are more cell devices than people, with countries like Hong Kong and Saudi Arabia at over 170 percent participation. Now that 96.5 percent of Americans have one, the competition for higher data speeds and increased customer retention has put carriers in a bind: How do you maximize cash flow and reduce expenses to fuel expansion?

Top executives of wireless carriers have a common goal: effectively covering more subscribers with less Operating Expenses (Opex). With over 285,000 cell sites in the United States, electrical usage could reach up to 712 million kWh per year. Gene Beall of Mobilite, a former senior leader at AT&T, recently stated that wireless carriers in North America will need to spend an estimated \$25 billion during the next four years to improve and expand their existing wireless infrastructure, regardless of whether they use CDMA- or GSM- and HSPA-based protocols. According to Beall, an additional \$3.5 billion is required to rollout 4G networks by the top four U.S. wireless carriers.

As in any other business, there are basically two methods to fund the expansion and rollout: 1) through external investments such as stock/bond offerings or 2) through internal cash flow. The first option, with volatile stock prices, remains more difficult in the economic downturn. AT&T, for example, has lost and regained one third

of its stock price in the past three making years, them a harder sell to investors. One of the efficient most ways to promote a healthy cash flow is to reduce company Opex. In 2011, the top four U.S. wireless carriers spent more than \$130 billion in overall operating costs. Shaving off even a small bit of this enormous expense can go very far for the carriers.

Leasing and renting third-party owned properties (both towers and rooftops) and managing their own properties is the single biggest portion of the on-going operating cost for a wireless carrier. AT&T, for example, has more than 10,000 towers of its own, yet according to its annual report, it spent \$3.6 billion on rental

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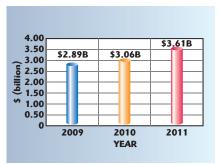
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Perspective



▲ Fig. 1 AT&T's annual rental expenses.

fees alone in 2011 (see *Figure 1*). Reducing this section of the Opex has a direct impact to shareholder value as this affects the carriers' bottom line and future success. Experts say that U.S. wireless carriers spend more than \$20 billion a year just on leasing and rental to house their wireless equipment.

Ironically, for an industry dedicated to innovation and creativity with handsets, cell sites are still heavily reliant

on less efficient, older technology. LDMOS power amplifiers have been in use for decades, with little improvement in power efficiency, power density, performance and thermal characteristics. In essence, LDMOS is too large, too hot and too inefficient to run lean, fast, powerful wireless networks for the biggest four carriers; they are burning money that could be used for expanding their networks.

The better suited alternative is GaN transistors that have much higher efficiency for Remote Radio Head (RRH), while producing much smaller amounts of heat and leading to cost savings across the board.

For carriers, weight and size directly translate into the leasing and rental expenses in the same way that every pound of luggage on a commercial airline deprives profit. It is not just major airlines that are charging for additional weight; tower and building landlords are charging carriers for the weight and size of the wireless equipment on their properties. Naturally, carriers are making every effort to reduce the size and weight of their equipment to reduce the cost and, moreover, reduce expensive installations of heavy equipment.

GaN's intrinsic wideband and high efficiency characteristics enable designers of wireless base stations, remote radio heads, and small cells to make systems smaller by reducing the heat sink size and power supply requirements. This directly translates to lower installation and equipment space rental expenses for carriers. Additionally, overall reliability also affects the carriers' bottom lines by producing more reliable LTE services to end users, and also by reducing expected maintenance expenses. Furthermore, carriers can save on future upgrades as GaN-based RRHs can support multiband, multi-mode and multi-carrier technology. RFHIC estimates that carriers would save billions just on the leasing and rental expenses alone. They also estimate that carriers can save \$2 billion per year on electricity by adopting a GaN-based power amplifier for RF transmit needs, promoting carriers' sustainability and corporate responsibilities. GaN can provide many benefits in all sorts of RF applications but for now, wireless infrastructure is the clear winner to take this great cost saving benefit of GaN technology.



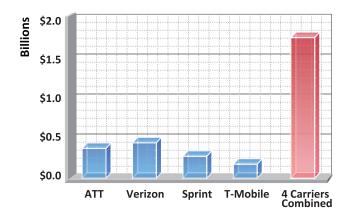






Wireless carriers can save BILLIONS of dollars spent on energy expenses per year by simply switching to RFHIC's GaN.

Energy Savings per Year





More data coverage Less energy cost

- Less maintenance cost
- Lower installation cost
- Lower space rental cost
- Multi-Band, Multi-Mode, Multi-Carrier Technology

For these applications customers have one thing in common;

Goodbye! GaAs & LDMOS Hello! RFHIC GaN

Are you still using inefficient LDMOS or GaAs technology for your telecom RF Transmitting needs?

No brainer for <u>Point to Point Radio</u> (Under Development)

- More efficient than GaAs
- More reliable than GaAs.
- SMT Type Package Available
- Input/Output Matching
- 6W~200W Peak Power
- Small Size

No brainer for **Small Cell**

- More efficient than LDMOS
- More reliable than LDMOS
- Cost comparable to LDMOS
- SMT Type Package Available
- Input/Output Matching
- 2W~10W Average Power (Peak Power 10W~60W)
- Small Size





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OCTAVE BA					0 10 1 150	VCVVD
Model No. CA01-2110	Freq (GHz) 0.5-1.0	Gain (dB) MIN 28	Noise Figure (dB) 1.0 MAX, 0.7 TYP	Power-out@P1-dB +10 MIN	3rd Order ICP +20 dBm	VSWR 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 CA812-3111	4.0-8.0 8.0-12.0	29 27	1.3 MAX, 1.0 TYP 1.6 MAX, 1.4 TYP	+10 MIN +10 MIN	+20 dBm +20 dBm	2.0:1 2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.4 TH	+10 MIN +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 B	0.4 - 0.5	NOISE ANI	D MEDIÚM POV	VER AMPLIF +10 MIN	+20 dBm	2.0:1
CA01-2111 CA01-2113	0.4 - 0.5	28	0.6 MAX, 0.4 TYP 0.6 MAX, 0.4 TYP	+10 MIN +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 CA34-2110	2.7 - 2.9 3.7 - 4.2	29 28	0.7 MAX, 0.5 TYP 1.0 MAX, 0.5 TYP	+10 MIN +10 MIN	+20 dBm +20 dBm	2.0:1 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 CA1315-3110	9.0 - 10.6 13.75 - 15.4	25 25	1.4 MAX, 1.2 TYP 1.6 MAX, 1.4 TYP	+10 MIN +10 MIN	+20 dBm +20 dBm	2.0:1 2.0:1
CA13-33110	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 CA812-6115	5.9 - 6.4 8.0 - 12.0	30 30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm +40 dBm	2.0:1
CA612-6115	8.0 - 12.0	30	4.5 MAX, 3.5 TYP 5.0 MAX, 4.0 TYP	+30 MIN +33 MIN	+40 dBm	2.0:1 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 MIIITI-00	3.5 MAX, 2.8 TYP CTAVE BAND AN	+21 MIN	+31 dBm	2.0:1
Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power -out @ P1-dB		VSWR
CA0102-3111	0.1-2.0	28	1.6 Max, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA0106-3111 CA0108-3110	0.1-6.0 0.1-8.0	28 26	1.9 Max, 1.5 TYP 2.2 Max, 1.8 TYP	+10 MIN +10 MIN	+20 dBm +20 dBm	2.0:1 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 CA26-4114	2.0-6.0 2.0-6.0	26 22	2.0 MAX, 1.5 TYP 5.0 MAX, 3.5 TYP	+10 MIN +30 MIN	+20 dBm +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 CA218-4110	2.0-18.0 2.0-18.0	30 30	3.5 MAX, 2.8 TYP 5.0 MAX, 3.5 TYP	+10 MIN +20 MIN	+20 dBm +30 dBm	2.0:1 2.0:1
CA218-4112	2.0-18.0	29	5.0 MAX, 3.5 TYP	+24 MIN	+34 dBm	2.0:1
LIMITING A	MPLIFIERS					
Model No. CLA24-4001	Freq (GHz) 2.0 - 4.0	nput Dynamic R -28 to +10 de	<mark>lange Output Power F</mark> 3m +7 to +11		er Flatness dB /- 1.5 MAX	VSWR 2.0:1
CLA26-8001	2.0 - 6.0	-50 to +20 dB		8 dBm +	/- 1.5 MAX /- 1.5 MAX	2.0:1
CLA712-5001	7.0 - 12.4	-21 to +10 dl		9 dBm +	/- 1.5 MAX	2.0:1
CLA618-1201 AMPLIFIERS V	6.0 - 18.0	-50 to +20 de		9 dBm +	/- 1.5 MAX	2.0:1
Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB) Pow	er-out@P1-dB Gain	Attenuation Ranae	VSWR
CA001-2511A	0.025-0.150	21 5	5.0 MAX. 3.5 TYP -	+12 MIN	30 dB MIN	2.0:1
CAO5-3110A CA56-3110A	0.5-5.5 5.85-6.425	23 2 28 2		+18 MIN +16 MIN	20 dB MIN 22 dB MIN	2.0:1 1.8:1
CA612-4110A	6.0-12.0	24 2	2.5 MAX, 1.5 TYP -		15 dB MIN	1.0.1
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	3.0 MAX, 2.0 TYP -	+18 MIN	20 dB MIN	1.85:1
Model No.		Gain (dB) MIN	Noise Figure dB F	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 CA001-3113	0.04-0.15 0.01-1.0	23 28	4.0 MAX, 2.2 TYP 4.0 MAX, 2.8 TYP	+23 MIN +17 MIN	+33 dBm +27 dBm	2.0:1 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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Defense News

Dan Massé, Associate Technical Editor



Astrium Adds Yahsat's Military Ka-Band to Its Multi-Band Offering to the U.S. Government

strium Americas announced that its subsidiary, Astrium Services Government Inc., will offer UAE-owned Yahsat Military Ka-Band service to the U.S. government. This service allows any U.S. government or Department of Defense (DoD) end user to utilize Yahsat Military Ka-Band capacity that is compatible with the Wideband Global Satellite (WGS) constellation for greater global coverage and reliability.

Astrium was the prime contractor for the construction of the Yahsat satellite fleet. Astrium Services will provide end-to-end services using Yahsat Military Ka-Band capacity in order to meet DoD requirements on contract vehicles such as the Defense Information System Agency's Future Commercial Satellite Communications (COMSATCOM) Services Acquisition (FCSA) program. This deal deepens

"Yahsat selected Astrium due to our extensive experience in building satellites and selling SATCOM services to many armed forces worldwide as well as our strong history and relationships with the U.S. government market." Astrium Services' commitment to be the leading provider of COM-SATCOM and MIL-SATCOM services to the U.S. government.

"Yahsat selected Astrium due to our extensive experience in building satellites and selling SATCOM services to many armed forces worldwide as well as our strong history and relationships with the U.S. market," government said Bob Baker, heading Astrium Services Government Inc. "We build end-to-end solutions

that meet the government's need for interoperable, secure, satellite services, and Yahsat's military Ka-Band will be another tool for us to utilize in designing the right solution for our customers mission requirements."

Harris Receives \$29 M Order from an Asian Nation for Tactical Radios

arris Corp. has received a \$29 million order to provide a nation in Asia with Falcon III® wideband tactical radios. The radios will provide the country's armed forces with critical country-wide data communications and improved mission capabilities as part of an overall modernization effort.

The nation is acquiring the company's new RF-7800H high-frequency wideband manpack and RF-7800W High-

Capacity Line-of-Sight radios. The new RF-7800H is the world's first HF radio with high-speed wideband data capabilities. These advanced capabilities allow users to efficiently transmit large data files such as video images over very long range beyond-line-of-sight links. The radio is 20 percent smaller and lighter and offers data rates that are 10 times greater than other HF radios.

"Our RF-7800H and RF-7800W radios will enable these armed forces to operate with more detailed situational awareness than previous generations of radios," said Brendan O'Connell president, international business unit, Harris RF Communications.



Boeing Brings B-52 into Digital Age with Significant Communications Upgrade

oeing is providing an upgraded communications system for U.S. Air Force B-52 bombers so aircrews can send and receive information via satellite links, allowing crews to change mission plans and retarget weapons in flight and better interact with aircraft and ground forces.

To date, mission information has been uploaded to

a B-52 only before a flight, not during. The upgrade, one of the largest improvements to the venerable bomber fleet, will therefore significantly improve B-52 effectiveness and flexibility.

"We are bringing this amazing workhorse of a bomber into the digital age and giving our customer the infrastructure necessary for continued future improvements," said Scot Oathout, Boeing B-52 program director.

"We are bringing this amazing workhorse of a bomber into the digital age and giving our customer the infrastructure necessary for continued future improvements."

The upgrade will be done through a new \$76 million Combat Network Communications Technology (CONECT) contract that covers low rate initial production of the first CONECT kits, along with spare parts and main-

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Defense News

tenance and service at Tinker Air Force Base, OK. System installation will begin during the latter part of 2014.

Other improvements will include a state-of-the-art computing network with workstations at each crew position and an integrated digital interphone with increased capacity; it will enable crew members to talk to one another on headsets with noise-cancelling technology.

Raytheon Completes Second Launch Exercise for Next Generation GPS Satellites

aytheon Co. successfully completed the second launch readiness exercise for the Ū.S. Air Force's next generation Global Positioning System (GPS) operational control system (OCX). Successful completion of Exercise 2 is a key milestone demonstrating that Raytheon's OCX software meets mission requirements and is on track to support the first GPS III satellite launch.

Completed over a three-day period in late February, the joint industry and government exercise demonstrated OCX mission software capability. The exercise, building on the functionality tested in Exercise 1, simulated a liquid apogee engine burn to insert the GPS III vehicle into transfer orbit and evaluated vehicle telemetry, maneuver planning and execution.

The Lockheed Martin-built GPS III satellites and Raytheon's OCX are critical elements of the Air Force's plan to affordably replace aging GPS satellites while improving capabilities to meet the evolving demands of military, commercial and civilian users worldwide.

The Lockheed Martin-built GPS III satellites and Raytheon's OCX are critical elements of the Air Force's plan to affordably replace aging GPS satellites...

"Successful completion of Exercise 2 is a clear indicator that the solid design and strong command and control and mission planning capability meet the requirements to support the GPS III launch," stated Ray Kolibaba, a vice president of Raytheon's Intelligence, Information and Services business and GPS OCX program manager. "The entire government-industry team is working hand-in-hand to successfully deliver the OCX ground system and GPS III space vehicles for a successful first launch."

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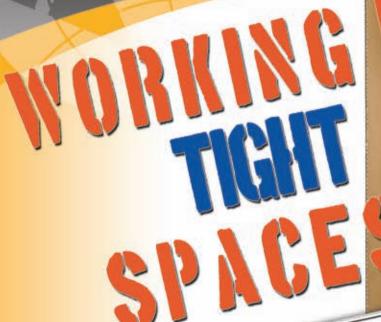


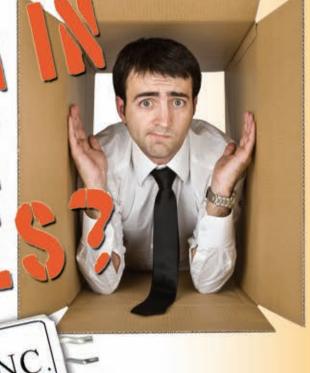


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International Report

Richard Mumford, International Editor



Research Project Strengthens Europe's Role in Semiconductor Production

he Enhanced Power Pilot Line (EPPL) research project, which is aimed at further strengthening Europe as a high-technology industrial semiconductor production site, was launched at a two-day meeting hosted by Infineon Technologies AG at its Villach, Austria, site.

A total of 32 European partners from industry and research are collaborating to advance production technology for power semiconductors, an industry segment where Europe already has the leading position. Europe is home to the first power semiconductor production sites manufacturing devices using 300 mm thin-wafer technology. With EPPL, Europe intends to further expand this production advantage.

The EPPL research aims to develop an advanced generation of power semiconductors manufactured in the 300 mm thin-wafer production technology, such as CoolMOS, IGBT and SFET, as well as to further refine the production

With EPPL, Europe intends to further expand this production advantage. technology itself. The results of the project shall include the setup of a pilot-line as well as application demonstrators.

The partner organizations cover the entire industry and research value chain of 300 mm power semiconductor

production, comprising material research with a focus on silicon, semiconductor development that includes 3D integration and packaging, and related developments in logistics and automation technologies. The project will run until mid 2016, with Infineon as the project lead.

"A project volume of €74 million and the commitment of 32 partner organizations strongly underline the importance of EPPL for the semiconductor industry in Europe," said Sabine Herlitschka, chief technology and innovation officer of Infineon Technologies Austria. "Infineon currently is the only company worldwide to produce power semiconductors on 300 mm thin-wafers. We are proud and honoured to contribute our experience in this area to the EPPL project and thus to Europe's technology advancement."

3GPP Makes Statement on LTE Standards

public statement has been issued by the 3rd Generation Partnership Project's (3GPP) Project Coordination Group (PCG) regarding LTE Standards. It states: "3GPP defines the standards for LTE, with the latest work focusing on LTE-Advanced, which includes all work from 3GPP Release 10 onwards.

"3GPP recognises that in the marketplace a number of differing terms related to LTE are appearing. 3GPP reaf-

firms that the naming for the technology family and its evolution continues to be covered by the term LTE-Advanced, which remains the correct description for specifications currently being defined – from Release 10 onwards, including 3GPP Release 12.

"The Partnership Project is working with its members and in coordination with the ITU Working Party 5D to be able to provide future guidance on "3GPP reaffirms that the naming for the technology family and its evolution continues to be covered by the term LTE-Advanced, which remains the correct description for specifications currently being defined..."

how 3GPP LTE will progress in future Releases."

Senior MoD Figures Debate UK Army's Future Capabilities

hirty senior UK Ministry of Defence (MoD) figures attended a Land Forces Event, hosted by Roke and Chemring EOD to debate the Army's future capabilities. Under the new MoD Capability Action Plan, UK Defence Forces' front line command is now responsible for the specification and purchase of equipment.

The event focused on new military capability technology developments, including a debate led by Brigadier Simon Deakin, director army force development for the British Army, discussing the UK Army's future acquisition of research and development services. More than 30 demonstrations of innovative technologies, currently in use and under development, were showcased. These included counter-IED technologies, a virtual simulator to evaluate future technology concepts, Electronic

Warfare systems, fullmotion video to track ground movement, and under-vehicle scanning.

Major General Paul Jaques, director general logistics, support & equipment for the The event focused on new military capability technology...

British Army, said: "The event was an excellent way for those in Army HQ to get a clear industry perspective on how technology can be applied in the Land Environment and a good insight into Roke's capabilities."

Guests included senior figures from the UK Government's Defence Science and Technology Laboratory (Dstl), Defence Equipment & Support for the British Army, MoD Joint Forces Command and Front Line Command from Army Headquarters.

1

International Report

NGMN Alliance Announces Converged Operations Showcase

he Next Generation Mobile Networks (NGMN) Alliance's Next Generation Converged Operations Requirements (NGCOR) project demonstrated the 'Catalyst' network operations showcase at TM Forum World held in Nice in May. The showcase with the title Converged Network Operations Improving Customer Experience represents the first implementation of a common 3GPP and TM Forum information model based on NGCOR requirements, aiming to enhance the integrated management of wireline and wireless networks.

One of today's main operator challenges is the management of a variety of network and service production infrastructures, from mobile and fixed network environments up to converged networks and services across regions. The NGCOR project aims to reduce complexity and cost, and seeks to obtain more flexibility in the area of network management by achieving standardised interfaces between the Telco infrastructure and the Operations Support Systems (OSS). The integrated management of wireless and wireline networks is thereby supported by an Umbrella Infor-

mation Model (3GPP TS 28.620) which is jointly elaborated and approved by 3GPP and TM Forum, and is based on the requirements defined by the NGCOR project.

The showcase has been developed by NGMN Partners and leading industry players including: Comarch, Deutsche Telekom, "Efficient converged operations are key for future networks in order to flexibly introduce services and to improve customer experience."

France Telecom/Orange, HP, Juniper, Orchestral Networks, Telecom Italia, Telefonica and ZTE, supported by specifications from 3GPP and the TM Forum.

"Efficient converged operations are key for future networks in order to flexibly introduce services and to improve customer experience," said Rachid el Hattachi, SVP, Deutsche Telekom AG. "We are happy to see the successful proof of concept of the related NGMN requirements and encourage all industry stakeholders to support the further development and deployment of these requirements."



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Commercial Market

Dan Massé, Associate Technical Editor



More Than 30 B Devices will Connect to the Internet of Everything in 2020

BI Research's latest data on the Internet of Everything (IoE) shows that there are more than 10 billion wirelessly connected devices in the market today, with over 30 billion devices expected by 2020.

"The emergence of standardized ultra-low power wireless technologies is one of the main enablers of the IoE, with semiconductor vendors and standards bodies at the forefront of the market push, helping to bring the IoE into reality," said Peter Cooney, practice director. "The year 2013 is seen by many as the year of the Internet of Everything, but it will still be many years until it reaches its full potential. The next 5 years will be pivotal in its growth

"The year 2013 is seen by many as the year of the Internet of Everything, but it will still be many years until it reaches its full potential."

and establishment as a tangible concept to the consumer."

Bluetooth, Wi-Fi, Zig-Bee, Cellular, RFID, and many other wireless technologies are all important to drive Internet of Everything growth. The long term expansion of the market will be dependent on wireless technology

becoming invisible so that the consumer will be oblivious to which technology is used and only know that it works.

"Today, Hub devices such as smartphones, tablets, and laptops are pivotal in enabling the IoE ecosystem and will continue to be an essential building block," added Cooney. "Future growth, however, is driven by node or sensor type devices and by 2020 these will account for 60% of the total installed base of devices."

Market for GaN and SiC Semiconductors Set to Rise 18× by 2022

he emerging market for Silicon Carbide (SiC) and Gallium Nitride (GaN) power semiconductors is forecast to grow a remarkable factor of 18 during the next 10 years, energized by demand from power supplies, photovoltaic (PV) inverters and industrial motor drives.

Worldwide revenue from sales of SiC and GaN power semiconductors is projected to rise to \$2.8 billion in 2022, up from just \$143 million in 2012, according to a new report entitled "The World Market for SiC & GaN Power Semiconductors - 2013 Edition" from IMS Research, now part of IHS. Market revenue is expected to rise by the double digits annually for the next decade.

SiC Schottky diodes have been around for more than 10 years, with SiC metal-oxide semiconductor field-effect transistors (MOSFET), junction-gate field-effect transistors (JFET) and bipolar junction transistors (BJT) appearing in recent years. In contrast, GaN power semiconductors are only just appearing in the market.

GaN is a wide bandgap material that offers similar performance benefits to SiC but has greater cost-reduction potential. This price/performance advantage is possible because GaN power devices can be grown on silicon substrates that are larger and lower in cost compared to SiC.

"The key factor determining market growth will be how quickly GaN-on-silicon (Si) devices can achieve price parity and equivalent performance as silicon MOSFETs, insulated-gate bipolar transistors (IGBT) or rectifiers," said Richard Eden, senior market analyst for power semiconductor discretes and modules at IHS. "IHS expects this will be achieved in 2019, driving the GaN power market to pass the \$1 billion mark in 2022."

SiC Schottky diode revenue exceeded \$100 million in 2012, making it the best-selling SiC or GaN device currently. But even though SiC Schottky diode revenue is forecast to grow until 2015, it will decline when lower-priced 600 V GaN diodes become available. Still revenue will recover to approach \$200 million by 2022, with sales concentrated at voltage ratings of 1200 V and above.

By then, SiC MOSFETs are forecast to generate revenue approaching \$400 million, overtaking Schottky diodes to become the best-selling SiC discrete power device type. Meanwhile, SiC JFETs and SiC BJTs are each forecast to generate less than half of SiC MOSFET revenues at that time, despite their likelihood of achieving good reliability, price and performance. End users now strongly prefer SiC MOSFETs, so vendors of SiC JFETs and BJTs have a major task ahead in educating their potential customers on the benefits of these technologies.

Q1 Handset Market Grows Despite Samsung and Apple Heading in Different Directions

n estimated 405 million handsets, including 197 million smartphones, were shipped in the first quarter of 2013, according to market intelligence firm ABI Research. Smartphone shipments grew 38 percent year-over-year (YoY) while feature phone shipments declined 5.2 percent YoY. Shipments of all handsets grew 12 percent YoY in the first quarter thanks to the continued strength of the smartphone market, which achieved an all-time high of 49 percent shipment penetration.

"Worldwide handset and smartphone shipments exhibited classic Q1 softness," says senior analyst Michael Morgan. "Samsung accomplished strong smartphone growth while Apple dismissed a troubling mix of slowed growth and declining margins as a sign that the older iPhone 4S was in high demand."

Nokia handset shipments plummeted to 62 million in Q1 with smartphone shipments at a 5-year low of 6.1 million. Considering market and OEM specific conditions, Black-Berry delivered a respectable 6 million shipments, with 1 million coming from the launch of BlackBerry 10-based devices. Despite HTC's well-designed ONE devices, ship-

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Commercial Market

ments continued to decline 37 percent YoY to 4.8 million. LG continued its revival with 10.3 million smartphone shipments and 16.2 million handset shipments.

"The last time a major smartphone OEM showed a trend of decreasing margins combined with falling ASPs and slowing growth, BlackBerry was still on the favorable side of a large market share and revenue drop," adds senior practice director Jeff Orr. "With major product announcements teased for Q3, Apple risks falling behind the innovation curve unless the next iPhone is more revolutionary than evolutionary."

Top 10 Mobile Carriers Generate \$202 B in Profit, Up 4.2%

orldwide service revenue, year-on-year (YoY) for 4Q-2012 grew 2.8 percent to US\$240.5 billion. From ABI Research's investigations, the regional dynamic is varied. Western Europe and Africa's mobile operator actually demonstrated a contraction in service revenue YoY of 8.2 percent and 6.9 percent respectively. Middle East, Latin America, and Asia-Pacific are still showing reasonably robust rates of growth of 7 to 11 percent. Eastern Europe and North America, however, are only barely keeping their service revenue growth in positive territory.

"As the underlying lift from accumulating subscribers has matured, carriers are starting to cast around for ad-

ditional revenue streams that don't just boost revenues but also profitability," said Jake Saunders, VP for core forecasting at ABI Research. "There is still tremendous income to be generated from mobile services; the top 10 mobile carriers alone generated US\$202 billion in gross profit, up 4.2 percent year-on-year in 2012."

For some of those in the top 10, subscriber growth is still a major contribution (e.g., China Mobile is 1st; MTN is 6th; and China Telecom, 8th). These carriers may rely on expanding subscriber bases to drive overall profit for another 3 to 5 years, but after that, they will need to tap other sources.

For the other carriers in the top 10, securing a significant market share in their domestic/regional markets, combined with pooling infrastructure resources such as data centers, as well as group-level handset and equipment purchasing, has led to economies of scale. Verizon Wireless (2nd), Vodafone Group (3rd), AT&T (4th) and NTT DoCoMo (5th) do hold significant market shares, but this does not entirely explain their success. These carriers have aggressively hopped onto the fourth innovation wave shaping the mobile telecommunications industry – namely, IPbased value-added services. OTT players can potentially sap the revenue opportunities for incumbent mobile telecom players but carriers, such as Verizon and AT&T, are showing that it is possible to put ARPU back on an upward trajectory through the introduction of, for example, multidevice tariffs and M2M services.

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MERGERS & ACQUISITIONS

Avago Technologies announced that it has acquired **Javelin Semiconductor**. Based in Austin, TX, Javelin is a leading developer of high performance 3G CMOS power amplifiers. The acquisition of Javelin will form the foundation of Avago's RF CMOS design and development for its wireless semiconductor division. According to Avago, the acquisition is not expected to have a material effect on Avago's financial condition or results of operations in the near term.

Q-par Angus Ltd. has been acquired by **Solid State plc**. Q-par will now be known as **Steatite Q-par Antennas**. It intends to remain one of Europe's leading microwave engineering experts specializing in the design and manufacture of ultra-wideband antennas, subsystems, antenna components and consultancy.

Norsat International Inc. has closed a definitive agreement to acquire certain business assets and assume certain liabilities of a U.S.-based satellite communication systems company. Norsat will pay US\$530,170 and will finance the transaction with cash from operations. The acquired assets include new products and associated IP that align with Norsat's existing product roadmap and allow Norsat to immediately enter new and additional areas within the satellite communications markets with SSPAs, high power BUCs, SATCOM baseband kits and Microsatellite terminals.

COLLABORATIONS

NGI and Cambium Networks™ strengthened their collaboration to deploy EOLOwave access technology throughout Italy. Working collaboratively, Cambium Networks has already provided NGI with its portfolio of Canopy® Point-to-Multipoint (PMP) solutions. The two companies will work together to develop EOLOwave so that it offers ultra-broadband 30 Mb/s speeds, which have been set as a key goal by the European Digital Agenda.

In the latest round of GSM network construction, **China Mobile** Guangxi Branch and **Ericsson** have joined together to deploy City Site, an innovative radio site solution that has been put into commercial use on a trial basis. The City Site, which has been deployed with the standard RBS6601 base station, has an integrated Omni Antenna, which only covers a small area and is, therefore, easy to deploy. It could also be launched with just access to power and transmission cables. According to the test of the live network, the City Site has effectively met the capacity and quality needs of network coverage.

7Layers has selected **Anite**'s LTE device test solution for conformance and mobile operator acceptance testing in Suwon, South Korea. 7Layers has been using Anite's 2G,

3G and LTE device testing solutions at a range of its global facilities for over ten years. Increasing demand for LTE has led 7Layers to further extend its LTE test capabilities in South Korea using Anite's device test solutions.

Element Six announced, in collaboration with **Delft University of Technology**, the entanglement of electron spin qubits (quantum bits) in two synthetic diamonds separated in space. This breakthrough is a major step toward achieving a diamond-based quantum network, quantum repeaters and long-distance teleportation — changing the way information is processed and enabling new systems to efficiently tackle problems inaccessible by today's information networks and computers.

Aeris® Communications announced it has partnered with SimplyHome to launch the most innovative home care solution for independent living – specifically tailored to serve aging and disabled populations nationwide. The new assistive living solution utilizes machine-to-machine (M2M) communications to eliminate the need for just-incase staff time. By communicating with multiple sensors to observe activities of daily living, SimplyHome can proactively alert caregivers and loved ones of wellness priorities and changes in behavioral patterns. Text, email, or phone alerts can then be generated by a single event, a combination of events, or by inactivity.

NEW STARTS

Computer Simulation Technology AG (CST) has announced the incorporation of its office in Bengaluru, India. The founding of **CST India Private Ltd**. is a major milestone in the company's operations in India. CST India will organize training sessions and workshops, while also attending conferences throughout the region.

Nuvotronics has announced the opening of a new 40,000 square-foot manufacturing facility in Durham, NC. The space will integrate research, development, design and 10,000 square feet of cleanroom operations for a new 8" wafer fabrication line, assembly and test for its proprietary PolyStrata® architecture. With the company's increased capacity, it plans to grow its product areas in miniaturized next-generation phased arrays, solid state power amplifiers, and advanced microwave and millimeter wave passives such as baluns, filters, diplexers, and time delay units.

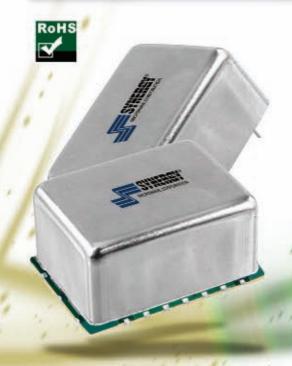
CONTRACTS

Spotsylvania County, VA, has awarded **Harris Corp.** a \$19 million contract to replace its existing public safety radio system with one that improves its coverage area and is based on the latest technology standards. The new system will improve communications for law enforcement, fire service and EMS personnel who serve one of Virginia's

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Around the Circuit

fastest-growing counties. The new Harris system includes seven new transmission sites and increases the communications capacity and extends coverage to more than 95 percent of the county.

Northrop Grumman Corp. has been awarded a \$14.1 million option to complete development of the Joint Counter Radio-Controlled Improvised Explosive Device (RCIED) Electronic Warfare (JCREW) Increment 1, Block 1 (I1B1) System of Systems. JCREW is a next-generation system to protect warfighters, vehicles, watercraft and permanent structures from RCIEDs. The award from the U.S. Naval Sea Systems Command (NAVSEA) funds Northrop Grumman to finalize the system through the development and demonstration phase in preparation for Milestone C.

Ceragon Networks Ltd. has announced that a leading mobile operator in the Southern Cone region of Latin America has placed new orders for the company's products and services valued at more than \$8 million. This network upgrade project is based on Ceragon's leading short haul and long haul solutions and will enable a range of 3G and future 4G services to millions of users across the Southern Cone. The project is expected to be completed by Q3 2013. Capacity expansion is a key

factor in this network upgrade project, as Latin America continues to experience a growing demand for broadband services.

Mercury Systems Inc. has received \$6.9 million in followon orders from **Lockheed Martin** for high performance signal processing subsystems as part of the U.S. Navy's Aegis Ballistic Missile Defense (BMD) upgrade program. The orders were booked in the company's fiscal 2013 third quarter and are expected to be shipped within its fiscal 2013 fourth quarter.

Cassidian has signed a seven-year system maintenance contract with the **Swedish Civil Contingencies Agency** (MSB) for the Rakel nationwide radio communications network. The contract includes third line support, a hardware repair service and the supply of TETRA system equipment and software, and will be effective from April 1, 2015.

A consortium of defense and security company Saab's subsidiary HITT Traffic, Ambriex and RRJ Engenharia have been awarded a contract by Brazilian airport operator Infraero to provide an A3000 Advanced-Surface Movement Guidance and Control System (A-SMGCS) at two international Brazilian airports. The system will now support air traffic controllers at Rio de Janeiro-Galeão International Airport and at Afonso Pena International Airport in Curitiba and help them guide airport traffic, especially during low visibility conditions such as fog and at night.





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Around the Circuit

ITT Exelis has been selected by Raytheon UK and the Canadian Department of National Defence to provide anti-jam GPS antenna arrays for several Canadian airborne military platforms. The N79 Controlled Reception Pattern Antenna (CRPA), which will be used on fixed and rotary-wing aircraft, prevents deliberate jamming and unintentional interference of timing signals when integrated with anti-jam GPS systems. The company has also been awarded a contract by NASA's Jet Propulsion Laboratory (JPL) to provide specialized antennas for the Constellation Observing System for Meteorology, Ionosphere & Climate-2 (COSMIC-2) program. Exelis will provide JPL with 25 high-accuracy multiband Global Navigation Satellite System (GNSS) antennas.

PEOPLE



Max H Mitche

Crane Co. announced that **Eric C. Fast**, CEO, will retire in January 2014. Fast joined Crane in 1999 as president and COO and was promoted to CEO in January 2001. He will be succeeded by **Max H. Mitchell**, currently president and COO. Mitchell, 49, joined Crane in 2004 as vice president of operational excellence, was promoted to president of fluid handling in 2005, became execu-

tive vice president and chief operating officer in May 2011, and was appointed president of Crane Co. in January 2013.



▲ Mike Farley

TMD Technologies Ltd. has opened a U.S. subsidiary and appointed **Mike Farley** as its CEO. TMD Technologies LLC, based in Baltimore, MD, will offer a significant benefit to U.S. customers, bringing local technical support, dealing with export compliance and handling classified interchanges. Farley joins TMD with an extensive background in bringing in-

ternational technological solutions to the U.S. defense market. He will implement a Special Security Agreement with the Defense Security Service, which allows TMD to execute on classified contracts with U.S. security cleared personnel.



▲ Eric Starkloff

National Instruments announced the promotion of Eric Starkloff to senior vice president of marketing. Starkloff leads the organizations responsible for strategic planning, positioning the company's innovative hardware and software platforms, marketing NI's products and corporate brand, and creating an effective eBusiness platform. Starkloff joined NI in 1997.



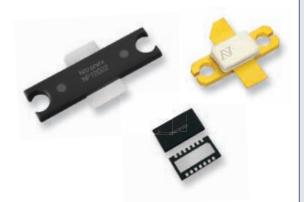
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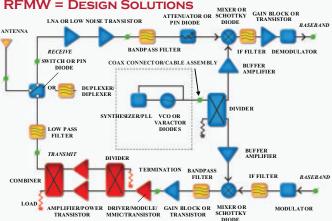
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Frequency Matters.

Around the Circuit



Mario Querner

Newtec has appointed former Technicolor, Alcatel-Lucent, and ECI Telecom executive **Mario Querner** as the company's new VP Asia. He will lead the company's business activities in Asia and the Pacific. Prior to joining Newtec, Querner worked as Head for South-East Asia at ECI Telecom, based in Singapore and he has more than 25 years of international business experi-

ence in telecommunications and media, working in both Europe and Asia.



▲ Michael McKe

Hesse Mechatronics Inc. has appointed **Michael McKeown** as senior business development manager. McKeown will be in charge of strengthening Hesse Mechatronics' position in the power electronics market. He will also focus on promoting thin wire bonder sales. McKeown carries almost three decades of experience in the automotive and power electronics industry and is the author of more than a dozen

technical papers and journal articles. He is currently working toward his PhD at Leeds Metropolitan University.



▲ Aftab Khan

Linwave Technology has appointed **Aftab Khan** as sales and marketing director. Khan, who holds an MSc in RF Communications Engineering from the University of Bradford, UK, has an accomplished track record in identifying and developing relationships with key customers and strategic partners around the world. He joins the company with several years' experience in the RF & microwave

field as a sales manager and RF applications engineer at companies such as Pascall Electronics and Mini-Circuits.

UK-based small cell backhaul developer and manufacturer **Sub10 Systems** announced a range of new global appointments as the company looked to further expand its international operations. **Frank Pauer** becomes chief sales and marketing officer having previously been global account director. **Bob Dowell** becomes global business development director with special responsibility for North American markets and partnerships. **Grant Grafton**, one of the founders of the business, moves from his sales and marketing role to become global director for regulatory affairs and compliance.

REP APPOINTMENTS

AR Europe has named **Compomill Nordic Components** to represent its products in various Nordic countries and the Baltic States.

RFMW Ltd. and **RF Circulator Isolator Inc.** (RFCI) announced a worldwide distribution agreement effective April 3, 2013. According to the agreement, RFMW will distribute RFCI's portfolio of ferrite products.

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Envelope Tracking Fundamentals and Test Solutions

There was once a time when your cell phone could go for days without needing to be recharged. Today, despite the innovations in cell phone battery technology, new demands, such as more internal radios and larger and higher resolution screens, place a greater drain on battery life than ever before. As a result, engineers must consistently innovate to reduce the power consumption as new technology is added to a cell phone. Today, envelope tracking (ET) is an increasingly popular technique used to optimize the power-added efficiency (PAE) of the RF power amplifier (PA) which is one of the primary drains on battery life. This article covers the fundamentals of ET using data gathered from an RF PA to identify crucial ET parameters. Based on these parameters, a PXI-based measurement setup is proposed and analyzed that meets the stringent requirements of ET test.

WHY ET?

PAs are most efficient when they are operated at peak output power, where the gain enters compression. For a typical W-CDMA/HSPA+/LTE PA, it is possible to obtain up to 50 percent efficiency when the device is operating at peak output power. However, much of the efficiency is reduced because modern communication standards such as W-CDMA and

LTE use modulated signals with increasingly higher peak-to-average power ratios (PAPR). Moreover, because the amplifier's magnitude response becomes highly nonlinear at compression, its output power is typically 'backed off' from the peak power by the PAPR. For LTE waveforms, the PAPR can be as high as 7 or 8 dB resulting in a PA that is operating at an average output power well below its optimum value.

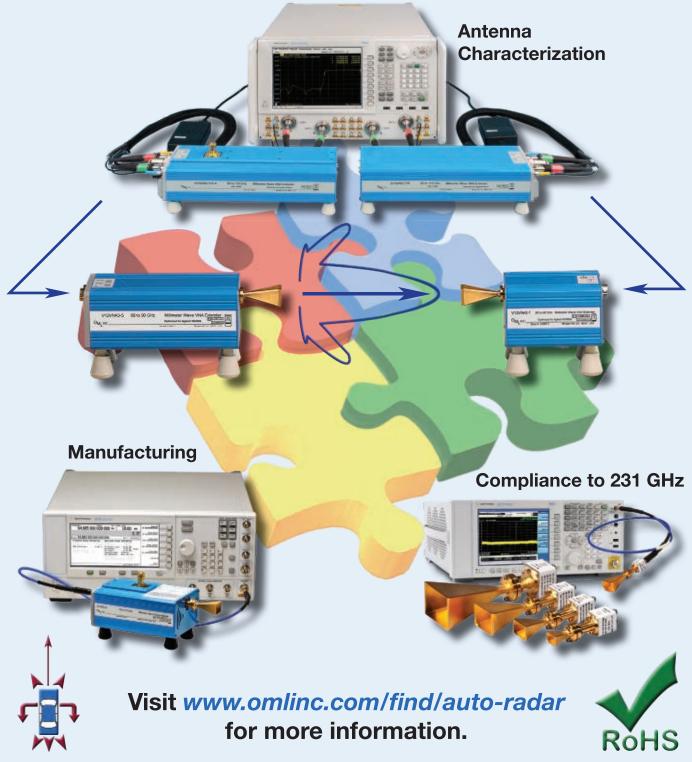
While several techniques can be used to improve the PAE of the amplifier, digital predistortion (DPD) for example, ET is quickly gaining traction amongst commercial PA vendors. In fact, base stations have been employing ET for over a decade in order to not only increase efficiency, but also to reduce cooling requirements due to energy dissipated as heat.

PRINCIPLES OF ET

The principle behind ET is to operate the amplifier in compression as often as possible. This technique makes use of the fact that both the point of peak efficiency and the point of peak output power vary as the supply voltage

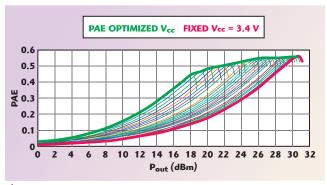
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igwedge Fig. 1 PAE vs. P_{out} across V_{cc} .

changes. To illustrate this point, Figure 1 displays PAE as a function of output power for several $V_{\rm cc}$ values. The trend we observe is that the output power of peak efficiency increases with an increase in $V_{\rm cc}$.

The basic idea of ET is to map instantaneous output power to an optimal $V_{\rm cc}$ value thereby maximizing the time the amplifier spends on the edge of compression. The theoretical PAE using ET for this particular amplifier is shown in Figure 1 as the green trace. As illustrated, the effective PAE

is substantially better than the actual PAE when using fixed supply voltage. Based on this data, we can create a simple lookup table (LUT) that maps output power to a PAE optimized V_{cc} value (as shown in **Figure 2**). Note there is a lower bound placed on the V_{cc} signal at 1 V.

This boundary has bandwidth implications explained later.

While the idea of modulating the $V_{\rm cc}$ signal to maximize PAE is good in theory, this is difficult to execute in practice. A consequence of varying $V_{\rm cc}$ as a function of output power is that the amplifier's gain will dynamically change as $V_{\rm cc}$ is changed, thus increasing AM-AM distortion. This effect can be reduced by using a smaller range of $V_{\rm cc}$ levels, which leads to a design tradeoff between PAE and AM-AM distortion. DPD algorithms can be ap-

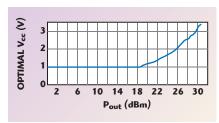
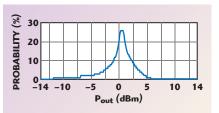


Fig. 2 Optimal V_{cc} vs. power out lookup table.



▲ Fig. 3 Test case 1 W-CDMA PDF.

plied to the baseband RF waveform in order to correct for additional distortion introduced by ET.

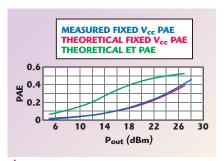
The PAE results shown in Figure 1 were based on a continuous wave signal. Using these values and the probability density function (PDF) of power $P(P_{out})$ for a particular waveform, an expected PAE for a modulated signal can be estimated, as shown in equation 1.

$$E(PAE) = \sum_{} PAE(P_{out})P(P_{out}) \qquad (1)$$

For use in this equation, *Figure* 3 shows the PDF for a test case 1 W-CDMA waveform with an average RF power of 0 dBm. By shifting this waveform to a specific average output power, we can estimate the efficiency of the amplifier with this particular modulated signal.

This calculation treats PAE as a random variable and assumes that the PAE vs. P_{out} measurements are static, i.e., they do not vary in time. While the calculation in equation 1 gives us a good approximation of PAE, actual PAE can vary slightly over time due to memory effects present in the amplifier and gain variation due to temperature. **Figure 4** shows the measured vs. calculated PAE for the test case 1 W-CDMA modulated waveform at a fixed V_{cc} as well as the expected PAE under ET conditions assuming an ideal V_{cc} modulator. Note that the expected and measured PAE curves are very close and only begin to diverge at higher output powers. The discrepancy can most likely be attributed to memory effects within the PA. Comparing the expected PAE for an ideal





▲ Fig. 4 Measured and theoretical PAE for fixed and ET V_{cc} with test case 1 W-CDMA waveform.

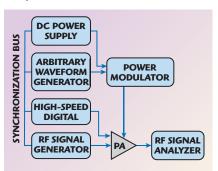
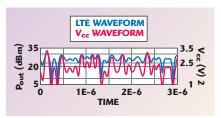


Fig. 5 Typical ET test setup.



igwedge Fig. 6 V_{cc} and PvT for 10 MHz LTE signal.

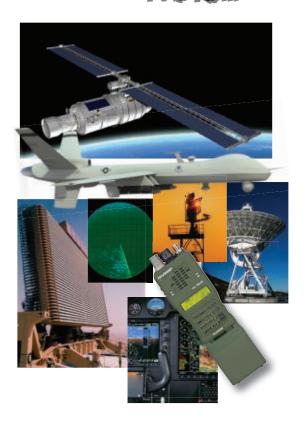
ET power supply (green curve) to the measured PAE for a fixed supply (blue curve), we see that ET could theoretically achieve twice the efficiency over a wide range of output power.

While ET promises considerable efficiency improvements, one must be aware that there are many tradeoffs involved with ET PA design. In fact, optimizing for one parameter will require tradeoffs of other parameters in the system. As a result, the design process of choosing the optimal $V_{\rm cc}$ levels for a given output power is highly iterative and necessitates the ability to quickly and reliably test design decisions.

ET TEST CHALLENGES

ET test adds another element to an already complex system. In order for a PA to successfully implement an ET scheme, careful synchronization between the RF baseband waveform and the supply voltage is required. As shown in *Figure 5*, a typical ET test

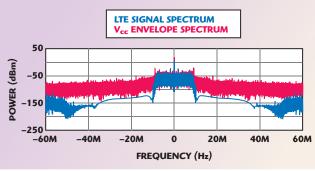
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lacktriangle Fig. 7 Spectra of 10 MHz LTE waveform and PAE optimized V_{cc} .

system uses an RF signal generator and analyzer, a high-speed digital waveform generator for controlling the PA, and a power supply to power the amplifier.

Power Supply

One significant test challenge of ET

is the high bandwidth required for the power supply waveform. The bandwidth requirements for the envelope waveform are typically far greater than those of the RF waveform. To analyze this phenomenon, consider the $V_{\rm cc}\, {\rm vs.}$ Pout LUT shown in Figure 2 and an LTE 10 MHz bandwidth signal. Figure~6 shows the PAE optimized V_{cc} waveform and the associated power vs. time plot for the corresponding LTE signal. A spectral analysis shows that the bandwidth of the V_{cc} waveform is at least three times more than that of the RF waveform. The high bandwidth requirement is due to two factors: one, \vec{V}_{cc} is a function of RF magnitude and two, clipping occurs due to the lower bounds imposed in the LUT, as seen in Figure 2.

In fact, for a 20 MHz LTE waveform, the $V_{\rm cc}$ waveform should have at least 60 MHz of bandwidth – a result shown in *Figure 7*. Moreover, in cases where wideband DPD is applied, the bandwidth requirements of the $V_{\rm cc}$ waveform are often up to five times the bandwidth of the actual RF signal. As is discussed in the next section, it is not enough that an arbitrary waveform generator (AWG) is capable of wide bandwidths, but it must also have excellent time resolution.

A second challenge with the supply voltage is that AWGs cannot supply enough current to power a PA, and power supplies do not have the bandwidth required for ET. The solution to this problem is to drive the PA with a power modulator that is driven by a DC source and modulated $V_{\rm cc}$ signal from an AWG, as shown in Figure 5.

Instrument Synchronization

The most difficult ET test challenge is ensuring instrument synchronization between the RF signal generator and the AWG. Since maximizing the PAE of the PA occurs when we choose an optimal $V_{\rm cc}$ value based on the input power, poor synchronization between these instruments will result in having a $V_{\rm cc}$ value that is either too high or too low for any given output power.

Consider what would happen if the $V_{\rm cc}$ waveform lags the RF: the power modulator will not be able to supply enough power to the device when the waveform is at peak power. As a result, the RF output would clip several dB below the desired output power. Fur-



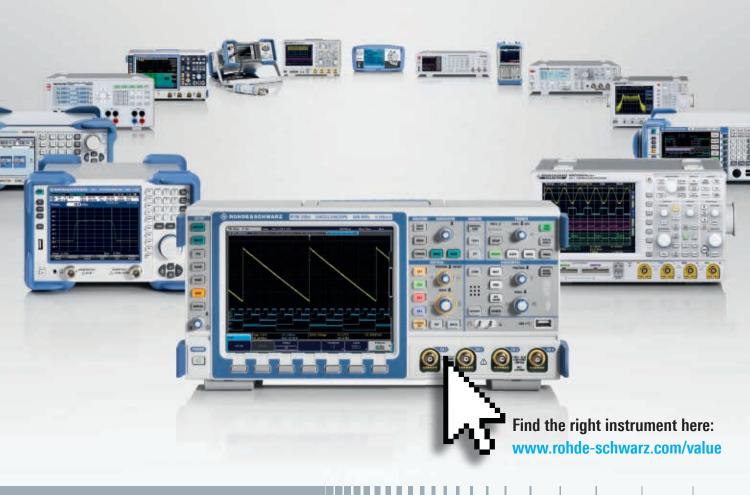
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thermore, immediately following a waveform peak, the power modulator will be supplying much more power than the amplifier requires, thus reducing efficiency. A similar situation occurs if V_{cc} leads the RF. The RF signal generator and AWG must not only be synchronized, but the synchronization should also be repeatable.

A PXI-BASED TEST SOLUTION

Instrument synchronization is a

crucial specification of an ET test setup. Because of the stringent synchronization requirements, the PXI platform is well suited to solve the challenges of ET test. In a PXI test system, modular instruments are interconnected through a chassis backplane containing a number of clock and trigger distribution lines. This single chassis integration simplifies the instrumentation setup and improves system synchronization.

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ET PAs typically have to operate with an RF signal generator and V_{cc} synchronization jitter less than 1 ns, which requires the test setup to be considerably better - preferably in the order of 100 ps. PXI allows for tight synchronization with the use of a 'T-Clock' backplane synchronization routine. 'T-Clock' is a mechanism for aligning sample clocks and starting triggers such that all devices begin generating simultaneously. For example, the NI PXIe-5451 AWG and the NI PXIe-5644R vector signal transceiver were benchmarked with maximum synchronization jitter less than 50 ps, and therefore meet this requirement.

Synchronizing the RF signal generator and AWG is only half the challenge. The modulated V_{cc} signal and RF waveforms go through different paths before reaching the amplifier and therefore experience different delays. Thus, it is also important to programmatically delay or advance the V_{cc} waveform relative to the RF signal in order for the modulated power supply and RF signal to be aligned with sub-nanosecond skew at the amplifier.

A simple way to delay the V_{cc} signal relative to the RF signal by an integer multiple of the AWG samples is to insert 'wait' cycles in the beginning of the generation script. In order to get more precise delay, the RF waveform can be shifted in software or in hardware on the vector signal transceiver's FPGA using a digital filter. The advantage of the hardware solution is that it can perform the time shift much more quickly than the equivalent software filter, thus reducing the amount of time it takes to identify the optimum alignment between the AWG and vector signal transceiver. At the nominal V_{cc} sample rate of 400 MS/s, an arbitrary delay with picosecond resolution can be attained.

The final piece of test equipment required for this measurement setup is a power supply capable of source and measurement. A battery simulator – as opposed to a standard source measure unit (SMU) is usually preferred for this application due to the high slew rates required by PAs. Note that in some instances, a high-speed digital waveform generator capable of generating patterns up to 26 MHz at 1.8 V is also required for digital control of an MIPI-capable PA.

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 \blacktriangle Fig. 8 PAE optimized V_{cc} tracking RF.

VERIFYING RESULTS

The most direct method of verifying synchronization the V_{cc} and RF signals is with a highbandwidth digitizer. In this example, the NI PXIe-5644R vector signal transceiver and NI PXIe-5451 AWG were

nected to two channels of a 2.5 GS/s digitizer. The vector signal generator generated a 10 MHz LTE FDD uplink waveform at 800 MHz using the V_{cc} vs. P_{out} LUT shown in Figure 2. On the initial run, the two waveforms are roughly 1 µs out of sync with one another due to pipeline and DSP delays within both instruments. Using the delay algorithm described in the previous section, both waveforms can be aligned through a combination of wait samples and sub-sample delays.

Figure 8 shows these results with the V_{cc} waveform scaled so that it has a magnitude comparable to the RF waveform. The graph shows the two waveforms aligned with one another but, more importantly, this relationship holds between successive runs of the application, even after power cy-

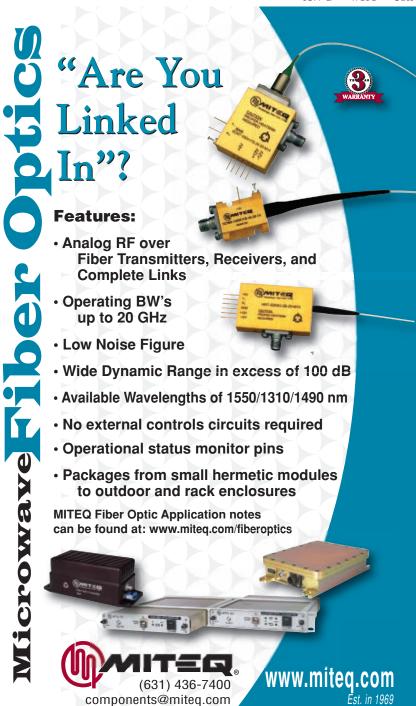
tion is optimally calibrated.

cling the system.

A high-speed digitizer is useful for visually inspecting the alignment of the two waveforms at the input of the amplifier, but it does not measure the performance of the amplifier. As we learned in the previous section about the importance of synchronization, V_{cc} and RF misalignment severely affects the linearity of the amplifier. For this reason, it is also possible to use an adjacent channel power (ACP) measurement to evaluate the optimal alignment of $V_{\rm cc}$ and RF. The amount of ACP degradation is device specific but users can expect to see a significant improvement in this measurement using an RF signal analyzer when the synchroniza-

CONCLUSION

Within the past decade, ET in cellular base stations has proven itself to be an effective means of increasing power amplifier efficiency and reducing cooling requirements due to wasted energy dissipated as heat. As wireless standards have continued to evolve, mobile handheld device manufacturers are looking to leverage ET for these same benefits as well. While ET promises considerable power savings and extended battery life over conventional fixed power supplies, it does propose significant instrumentation challenges to PA designers and test engineers. The PXI-based test solution presented here addresses the most crucial measurement challenges and, based on measured results, makes it a very compelling ET PA test solution.



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PHEMT Distributed Power Amplifier Adopting Broadband Impedance Transformer

A non-uniform drain line distributed power amplifier (DPA) employing a broadband impedance transformer is presented. The DPA is based on GaAs PHEMT technology. The impedance transformer employs asymmetric coupled lines and transforms a low output impedance of the amplifier to a standard 50 Ω transmission line. The output power of approximately 600 mW, with an associated gain of 9 dB and PAE greater than 30 percent, is demonstrated in the frequency range from 10 to 1800 MHz.

istributed power amplifiers (DPA) are known for their flat gain, linear phase response and low return losses over a wide bandwidth. The power-added efficiency (PAE) of the conventional DPA, however, does not typically exceed 20 percent. The degradation is primarily caused by the fact that the drain current is split into two branches forming waves traveling toward the output load and the

dummy termination. Several research groups have addressed the problem of DPAs' low efficiency and limited output power, suggesting solutions to overcome these limitations.^{2,3} To increase the DPA efficiency, the drain current from each transistor must be pushed toward the load termination. In this way, the effect of the drain dummy termination can be mitigated.² Another design methodology for a non-uniform DPA, employing optimal loading for each device to maximize power and efficiency, has been demonstrated.³ K. Krishnamurthy et al⁴ have described a DPA without an output synthesized transmission line, where delay equalization

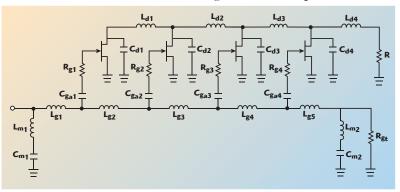
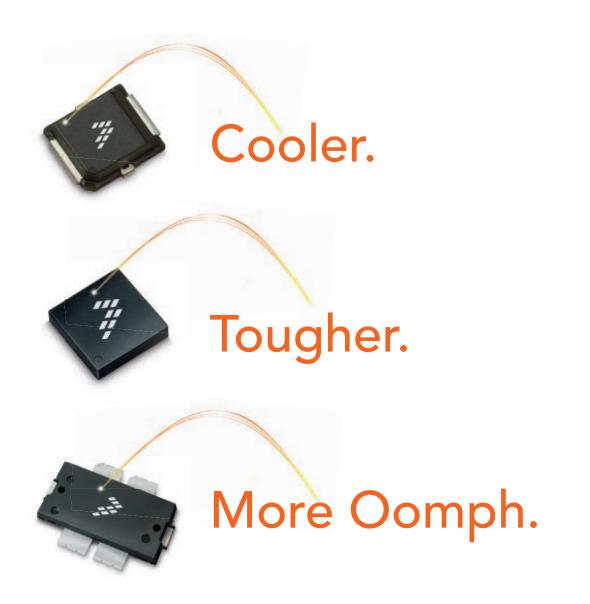


Fig. 1 Simplified four-section DPA adopting a non-uniform drain line.

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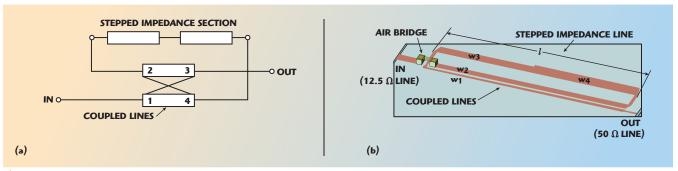
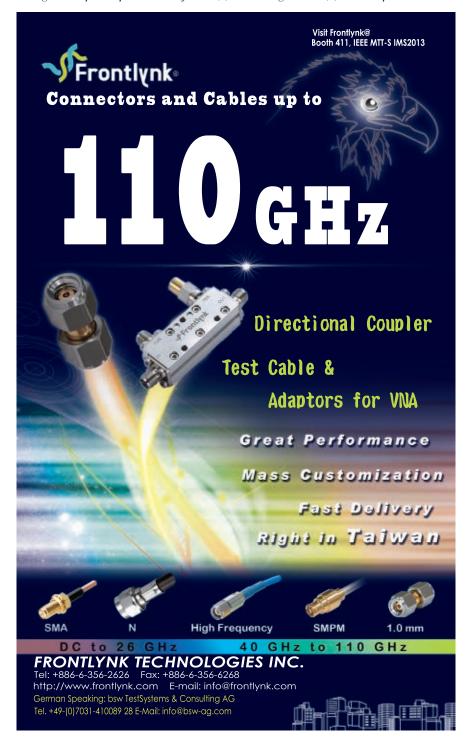


Fig. 2 Compact impedance transformer (a) circuit diagram and (b) microstrip realization.



is provided by impedance-matching sections between common-source and common-gate devices.

This article discusses an alternative design approach, based on virtual impedance analysis, considering multi-current sources and adopting a coupled line impedance transformer. The described approach leads to an increase in efficiency up to the levels required by software defined radio (SDR) driver PA applications.

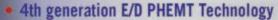
DESIGN APPROACH

In the DPA topology shown in **Fig**ure 1, each device contributes to the overall output impedance of the amplifier. The value of the load impedance R is chosen for optimal power performance across the required frequency range of the four-section PHEMT DPA with non-uniform drain line. An m-derived section is implemented at both terminations of the gate line. Each device is supplied with 5 V, while a bias voltage of 0.44 V is applied to each gate, resulting in Class AB operation for the active devices. The necessary phase velocities synchronization between the gate and drain lines is achieved by adopting a non-uniform gate line design and selecting an output load R equal to 12.5 Ω .

In order to match the entire circuit to a standard 50 Ω load over the broad frequency range of operation, a wideband impedance transformer having a transformation ratio of 1:4 has been implemented. The impedance transformer employed in this design is based on asymmetric, uniform coupled lines as shown in **Figure 2**, where the dimensions are l = 42.14 mm, $w_1 = 0.53$ mm, $w_2 = 1.57$ mm, $w_3 = 1.21$ mm and $w_4 = 1.5$ mm. Coupled transmission lines have the advantage of greater flexibility and compactness, as compared to traditional multiple quarter-wavelength transmission lines.⁵ Traditionally, cou-

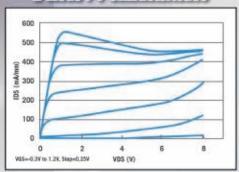


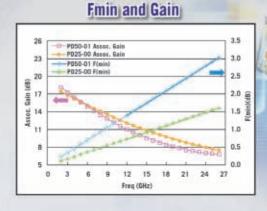




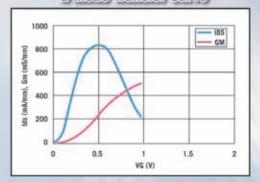
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- . E-mode device: Ultra low noise and high gain
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E-mode I-V Characteristics

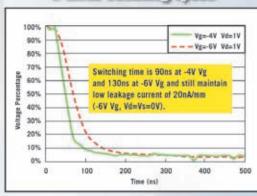




E-mode Transfer Curve



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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pled and through ports of the coupled lines are either short- or open-circuited, which is not the optimal choice from a bandwidth point of view. When loading the coupled and through ports with a stepped impedance transmission line, the operating bandwidth of the transformer can be considerably increased. The adopted configuration in this case is a quarter-wavelength long and provides a three times wider operating frequency range, compared to the traditional quarter-wave transformer.

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The performance of the broadband impedance transformer was verified with a full-wave 3D simulator. The input, (port 1) is terminated with a 12.5 Ω line and port 3 is connected to a 50 Ω SMA connector. Since port 1 will be connected to a 50 Ω SMA connector in real measurement, the two-port S-parameter data of the connector must be de-embedded for accurate results. The measured insertion loss results in less than 1.5 dB across the operating bandwidth.

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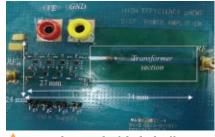


Fig. 3 Photograph of the high-efficiency DPA prototype board.

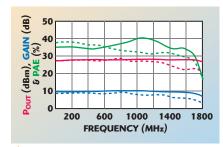


Fig. 4 Measured (dotted line) and simulated (solid line) results of the DPA as a function of frequency.

A medium power PHEMT device (ATF511P8 from Avago Inc.) is selected for amplifier realization. The drain loading effect of this device is negligible, however the reactive part of its output impedance $(X_{\rm opt}(\omega))$ plays an important role in defining the drain line cut-off frequency $f_{\rm c}.$ The value of the output capacitance $C_{\rm opt}$ is extracted (including parasitics of the package), resulting in 4 pF. The cut-off frequency of the amplifier then can be estimated by

$$f_{c} = \frac{1}{\pi \sqrt{L_{1}C_{opt,i}}}$$

Therefore, to achieve an f_c of approximately 2 GHz, the values for the drain inductances L_{di} (here i=1...4) can be selected.⁶ The dummy drain termination is omitted, improving the overall efficiency.⁶

MEASUREMENT RESULTS

In order to experimentally validate the concept of high efficiency DPA with broadband impedance transformer, a prototype circuit has been fabricated using Rogers' three-layer printed circuit board (PCB) material, with a relative permittivity $\varepsilon_{\rm r}=3.66$ and a thickness h = 0.762 mm. A series gate resistor $R_{\rm g(k)}=5~\Omega$ is used at each section for stability purposes. The top layer is used for lumped components as well as RF and DC line routing. A photograph of the fabricated DPA board is shown in





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Figure 3. The effective size of the DPA is 24×74 mm.

The measured large signal DPA characteristics are shown in *Figure 4*. An output power of ~600 mW, a gain of 9 dB and a PAE exceeding 30 percent are achieved. A good agreement between simulation and measured results is obtained. This proves that the PAE is greater than 38 percent at low frequencies. An efficiency of more than 30 percent is recorded across the bandwidth of operation. It is evident from the measurement

results that the concept to achieve high efficiency is demonstrated. Nevertheless, the DPA performance at higher frequency operation can be improved further with transformer optimization.

A transformer concept⁹ is an alternative solution to be integrated with the proposed DPA. On the other hand, a high power performance covering from 100 to 1800 MHz was demonstrated, using GaN HEMT,^{7,8} which is suitable for high output power level of SDR applications.



CONCLUSION

A DPA employing a non-uniform drain line is presented in this article. The chosen architecture exhibits improved characteristics in comparison to the traditional designs in terms of efficiency. The efficiency and output power of the amplifier is further improved by decreasing the value of the output impedance. The output impedance of the amplifier is then transformed to the standard 50 Ω termination, using a compact and broadband distributed impedance transformer based on coupled transmission lines. The proposed approach allowed increasing the efficiency of the DPA to typically better than 30 percent over a wide frequency range. The resulting circuit exhibits a power performance suitable for SDR DPA driver applications.

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Compact Triple-Band Bandpass Filter With Multimode Resonator

A compact microstrip triple-band bandpass filter (BPF), using a multimode short stub loaded resonator and two $\lambda/2$ side-coupled resonators, is proposed in this article. The characteristics of the multimode resonator are investigated by using even and odd mode analysis. This filter's three passband frequencies and their bandwidths can be designed and tuned independently. For demonstration purposes, a filter with triple-band elliptic response operating at 2.45 GHz (ISM band), 3.5 GHz (WiMAX band), and 5.75 GHz (WLAN band) was designed, fabricated and measured. The measured results are in good agreement with the full-wave simulation results.

ith the increasing demands for tripleband applications in modem wireless systems, research on innovative designs of triple-band filters has become very popular recently. Configurations of composite split-ring resonators (SRR) have been used to design a triple-band filter. A triple-band bandpass filter (BPF) has been proposed using three pairs of degenerate modes in a ring resonator. A square ring loaded resonator (SRLR) has been proven in the design of a triple-band filter.³ The SRLR can generate a triple-band response by tuning its geometric parameters to realize the high-order tri-band. The square ring short stub loaded resonators (SRSLR) have been introduced for the design of the tri-band filter.⁴ The passband frequencies can be conveniently tuned to the desired values by controlling the corresponding resonator dimensions.

Tri-band BPFs can also be constructed using several stepped-impedance resonators (SIR).⁵⁻⁷

In this article, the tri-band performance is realized by using a multimode short stub loaded resonator and two $\lambda/2$ side-coupled resonators, which are arranged in a compact structure. The passband frequencies and their bandwidths can be independently tuned to the desired values by controlling the corresponding parameters dimensions. For demonstration, a prototype is designed, fabricated and measured.

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PROPOSED SHORT STUB LOADED RESONATOR

As shown in *Figure 1*, the proposed short stub loaded resonator consists of a ring resonator with two short stubs and two open folded microstrip lines. Since the resonator is even symmetrical to the dashed line, its resonant characteristics can be examined by the even- and odd-mode method. The odd-mode and even-mode equivalent circuits are shown in *Figure 2*. The odd-mode equivalent circuit contains two resonant circuits. The two odd-mode resonant frequencies can be obtained as follows:³

$$\begin{split} f_{\text{odd1}} &= \frac{c}{4 \left(L_2 + L_3 \right) \sqrt{\epsilon_{\text{eff}}}} \\ f_{\text{odd2}} &= \frac{3c}{4 \left(L_1 + L_3 \right) \sqrt{\epsilon_{\text{eff}}}} \end{split} \tag{1}$$

where c is the speed of light in free space and $\epsilon_{\rm eff}$ is the effective dielectric constant of the substrate.

 Y_1 and Y_s are the characteristic admittances of the lines with widths W_1 and W_2 . Y_1 is set equal to $Y_s/2$ for simplicity. For the even-mode excitation, the resonant frequencies can be obtained as:

$$\begin{split} f_{\text{even1}} &= \frac{c}{4 \left(L_2 + L_3 + L_5 \right) \sqrt{\epsilon_{\text{eff}}}} \\ f_{\text{even2}} &= \frac{3c}{4 \left(L_1 + L_3 + L_4 \right) \sqrt{\epsilon_{\text{eff}}}} \end{split} \tag{2}$$

From Equations 1 and 2, it can be seen that the first passsband can be determined by L_2 and L_3 and its bandwidth is tuned by L_5 . Similarly, the second passsband may be given by L_1 and L_3 and its bandwidth is changed by L_4 . Thus, by reasonably designing the parameters L_1 , L_2 and L_3 , the dual-band frequencies are approximately allocated in the suitable passbands and their bandwidths can be independently modified by varying L_4 and L_5 , respectively. For demonstration purpose, this resonator is simulated by Sonnet 11.54 and the simulated electric current densities of the four modes are presented in ${\it Figure 3}$, with W_1 = 0.3 mm, W_2 = 0.6 mm, L_1 = 12.4 mm, L_2 = 6.5 mm, L_3 = 10.58 mm, L_4 = 0.7 mm, L_5 = 1.08 mm and $f_{\rm even1}$ = 2.50 GHz (a), $f_{\rm odd1}$ = 2.68 GHz (b), $f_{\rm even2}$ = 5.47 GHz (c), $f_{\rm odd2}$ = 5.7 GHz (d).

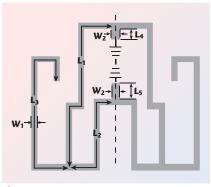


Fig. 1 Layout of the proposed short stub loaded resonator.

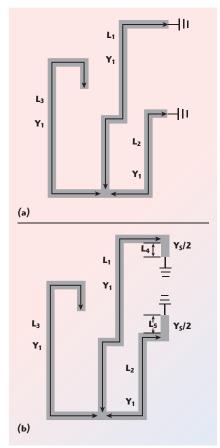


Fig. 2 Equivalent circuits (a) odd-mode and (b) even-mode.

TRI-BAND BPF DESIGN AND RESULTS

Figure 4 describes the layout of the designed filter. This filter is composed of a single short stub loaded resonator and a pair of half-wavelength (λ 2), side-coupled resonators, with length L₆ + L₇ and width W₁. The former is used to generate two passbands for dual-mode dual-band BPF design. The latter is applied to generate the third passband for two-pole BPF design and its bandwidth can be tuned by the gap g₁.8 Also, the pair of side-





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coupled resonators encircles the short stub loaded resonator and serves as part of feed lines, so that a compact size is realized.

This triple-band filter was fabricated on a substrate with a relative dielectric constant of 4.5 and a thickness of 0.8 mm. The dimensions of the filter are optimized as follows: $W_1 = 0.3$ mm, $W_2 = 0.6$ mm, $L_1 = 12.4$ mm, $L_2 = 6.5$ mm, $L_3 = 10.58$ mm, $L_4 = 0.7$ mm, $L_5 = 1.08$ mm, $L_6 = 11.6$ mm, $L_7 = 12.91$ mm, $g_1 = 0.4$ mm. **Figure 5** shows the equivalent circuit of the proposed tri-band BPF. The capacitor C_1 simulates the coupling strength

between the halfwavelength $(\lambda/2)$ side-coupled resonators and the proposed short stub loaded resonator. Figure 6 shows a comparison of the equivalent circuit simulation (Ansoft Designer) and EM simulation (Sonnet 11) for the proposed filter. The equivalent circuit simulation result is in good agreement with the EM-simu-

lation result.

A photograph of the fabricated triband filter is shown in *Figure 7*. The measured and EM simulated results are illustrated in *Figure 8*. Three pairs of transmission poles appear at 2.47/2.52, 3.4/3.49 and 5.58/5.72 GHz. The measured 3 dB fractional bandwidths for the three passbands (2.45, 3.5 and 5.75 GHz) are found to be 10.2, 11.4 and 5.56 percent, respectively. The measured minimum insertion losses are 1.1,

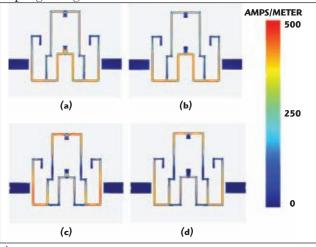
1.21 and 1.3 dB, while the return losses are better than 34.6, 24.1 and 15.2 dB, respectively. Four transmission zeros are created at 2.03, 3.15, 5.4 and 6.2 GHz, resulting in high selectivity.

CONCLUSION

In this article, a compact tripleband BPF is introduced, which has good triple passband performance at 2.45, 3.5 and 5.75 GHz. The three passband frequencies and bandwidths of this filter can be tuned independently by properly controlling the parameters dimensions of these resonators. The measured results are in good agreement with the simulations, verifying this design. This compact triple-band filter is particularly suitable for multiband and multi-service applications in communication systems.

ACKNOWLEDGMENTS

This work was supported by the National Science Foundation of Chi-



▲ Fig. 3 Simulated electric current density.

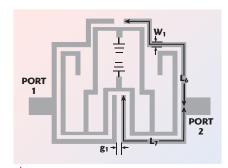


Fig. 4 Schematic of the proposed triband BPF.

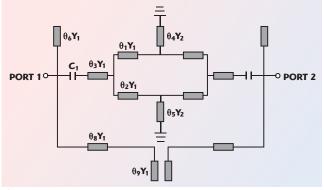
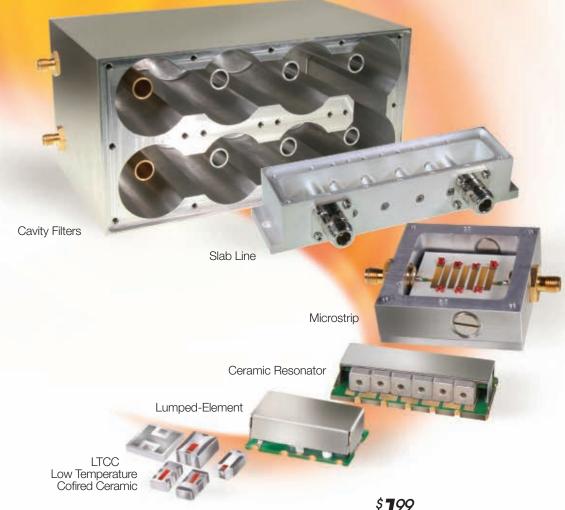


Fig. 5 Equivalent circuit of the proposed tri-band BPF.

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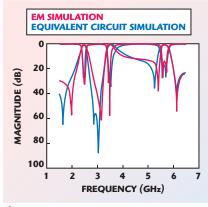


Fig. 6 Simulated responses of the proposed filter.



▲ Fig. 7 Photograph of the fabricated tri-band filter.

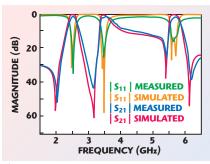


Fig. 8 Measured and EM simulated

na (No. 61061001) and the 555 Talent Program of Jiangxi Province of China.

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Haiwen Liu received his B.S. degree in electronic system and his M.S. degree in radio & remote-sensing science from Wuhan University, Wuhan, China, in 1997 and 2000, respectively. $He \ received \ his \ PhD \ degree \ from \ Shanghai$ Jiaotong University, China, in 2004. From 2004 to 2006, he was with Waseda University, Japan, as a full-time assitant professor. From 2006 to 2007, he was with the Technische Universitat Hamburg-Harburg and Kiel University, Germany, as a Humboldt research fellow. From 2007 to 2008, he was a professor at the Institute of Optics and Electronics, Chinese Academy of Sciences (CAS), Chengdu, China. Since 2009, he is a professor at the School of Information Engineering, East China Jiaotong University, Nanchang, China. His main areas of research are radio system, RF/microwave IC design.

Jiuhuai Lei received his B.S. degree in communication engineering from East China Jiaotong University, Nanchang, China, in 2011. Currently, he is studying for a Master's degree at the Electromagnetism and Information Technology Institute, East China Jiaotong University, Nanchang, China.

Yulong Zhao received his B.S. degree in electronic information engineering from PLA Information Engineering University, Henan, China, in 2010. Currently, he is studying for a Master's degree at the Electromagnetism and Information Technology Institute, East China Jiaotong University, Nanchang, China.

Wenyuan Xu received his B.S. degree in optical information science and technology from East China Jiaotong University, Nanchang, China, in 2010. Currently, he is studying for his Master's in Electromagnetism and Information Technology Institute, East China Jiaotong University, Nanchang, China.

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Wide Stopband Bandpass Filter Based on Composite Right/Left Handed Transmission Line

A compact wide stopband bandpass filter, based on composite right/left handed transmission line (CRLH-TL), is proposed in this article. The prototype filter has a wide stopband performance, a compact size and low insertion loss in the passband. A backside aperture is applied below the inter-digital part to realize a strong coupling between the fingers. The filter achieves a sharp stopband at both sides of the passband and low insertion loss within the passband. The properties of CRLH-TL enable the spurious responses to emerge far away from the passband of the bandpass filter. To further improve its upper stopband, two U-shaped defected ground structures (DGS) are placed at the input and output feed lines, respectively. Both filters are designed, simulated and fabricated. The measured results show good agreement with the simulated ones.

bandpass filter is one of the key passive components in the design of microwave communication systems and various types of bandpass filters that have been reported and investigated.¹⁻¹⁷ Recently, there has been a significant interest in composite right/left handed transmission line (CRLH-TL) and a lot of passive circuits and antennas have been designed based on this structure. 18-34 Unlike the conventional transmission line, CRLH-TL offers some unique characteristics and is very useful in practical applications. CRLH-TL has been used to design couplers; 18-20 leaky-wave antennas with backward and forward scanning capability were realized by using CRLH-TL;²¹⁻²⁴ and the concept of the zeroth- and negative-order resonance has been proposed, based on the CRLH-TL, 25-26 and were utilized to design novel antennas and filters.

CRLH-TL has provided a new way for microwave resonator design and it has been demonstrated as a good choice for size reduction both theoretically and practically. ²⁵⁻²⁹ Besides, its nonlinear electric response ensures a wide stopband. A CRLH-TL based filter using coplanar waveguide (CPW) has been proposed. ²⁸ Though a wide stopband is obtained, the high insertion loss makes it difficult for practical application. A CRLH-TL based filter has been proposed. ²⁹ The author has used a conventional CRLH-TL unit, with one side open circuited and the other side short circuited, to realize a quarter-wave type resonator. Though

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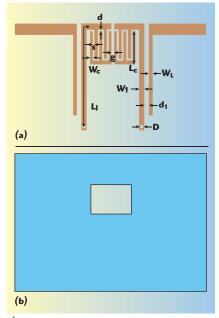


Fig. 1 Schematic view of the proposed filter (a) top view and (b) bottom view.

Fig. 2 Equivalent circuit of the proposed bandpass filter.

TABLE I							
VALUES OF THE PARAMETERS USED IN FIGURE 2							
C _c	Lo	Co	L _R	C_R	LL	C_L	C ₁
0.51 pF	6.67 nH	0.12 pF	0.1 nH	35 pF	1.59 nH	2.2 pF	0.20 pF

the quarter-wave type resonator is half the size of a half-wave type resonator in the traditional transmission line concept, the resonator implemented by

CRLH-TL does not offer size reduction, compared with a conventional CRLH-TL half-wave type resonator. Moreover, many shorted via holes are required in the structure, which increases the difficulty for fabrication.

In this article, a second order, wide stopband, bandpass filter is proposed. The modified CRLH-TL resonator is introduced to obtain a stronger electric coupling. To further broaden its upper stopband, a U-shaped slot is employed to suppress the spurious passband. Both filters are carefully designed, optimized and fabricated. The measured results show good agreement with the simulated ones.

DESIGN APPROACH

Figure 1 shows the configuration of the proposed filter. Two resonators are involved to realize two transmission poles in the passband. The resonator is composed of an interdigital capacitance and a short ended line as the shunt inductance. To realize a strong coupling between the fingers, the ground plane underneath the interdigital strips is removed to form a backside aperture. Based on the composite right/left handed transmission line theory, the resonator is open circuited at both ends. Its closed-form dispersion relation for the periodic implementation can be expressed by:35

$$\beta = \frac{1}{p} \arccos \left\{ 1 - \frac{1}{2} \left[\left(\frac{\omega}{\omega_R} \right)^2 + \left(\frac{\omega_L}{\omega} \right)^2 - \kappa \omega L^2 \right] \right\}$$

$$\begin{cases} \omega_R = \frac{1}{\sqrt{L_R C_R}} \operatorname{rad/s} \\ \omega_L = \frac{1}{\sqrt{L_L C_L}} \operatorname{rad/s} \end{cases}, \kappa = L_R C_R L_L C_L,$$

$$(1)$$

where p stands for the size of the structure, so the electric length can be expressed by:

$$\theta = \beta p \tag{2}$$

The half-wavelength transmission line resonates when

$$\theta = k\pi, k = 1, 2, 3...$$
 (3)

The equivalent circuit model for the proposed bandpass filter is depicted in *Figure 2*. The electric coupling should be the dominating coupling mechanism between the two resonators. The grounded series resonators symmetrically located near the input and output ports are used to get the transmission zero generated by the feed lines. The values of the inductors and capacitors are shown in *Table 1* and the calculated scattering parameters are shown in *Figure 3*. As shown, a second order Chebyshev response is obtained. The filter operates at 2.7 GHz and the transmission zero located at 5.6 GHz is due to the grounded series resonator, which can be explained by the resonance of the feed lines.

The filter can also be designed with the coupled resonator circuit method. The ideal [N+2] coupling matrix is derived as follows:

$$\mathbf{M} = \begin{bmatrix} 0 & 1.1478 & 0 & 0\\ 1.1478 & 0 & 1.4953 & 0\\ 0 & 1.4953 & 0 & 1.1478\\ 0 & 0 & 1.1478 & 0 \end{bmatrix}$$
(4)

The external quality value can be computed from the coupling matrix as:

$$Qe = 12.7 \tag{5}$$

SIMULATIONS AND MEASUREMENTS

The proposed filter is fabricated on a Taconic RF-35 substrate with a dielectric constant of 3.5 and a thickness of 0.508 mm. A simulation tool (Zeland IE3D) is used to

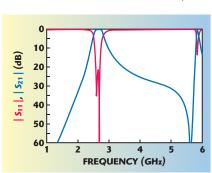
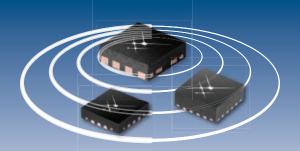


Fig. 3 Calculated S-parameters for the circuit in Figure 2.

optimize the proposed filter. The final optimized sizes and parameters of the wide-stopband bandpass filter are: $L_l=12.8~\text{mm}, W_1=0.9~\text{mm}, L_c=3.2~\text{mm}, W_c=0.2~\text{mm}, s=d=0.1~\text{mm}, W_l=0.2~\text{mm}, d_1=0.1~\text{mm}$ and D=0.5~mm.





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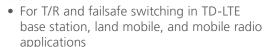


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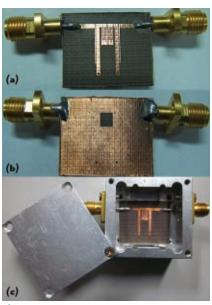






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▲ Fig. 4 Photograph of the fabricated filter (a) top view, (b) bottom view and (c) packaged.

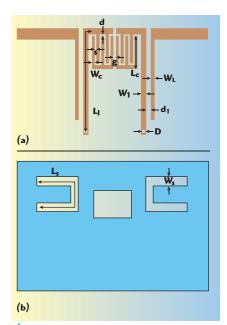


Fig. 6 Schematic view of the filter with U-shaped DGS (a) top view and (b) bottom view

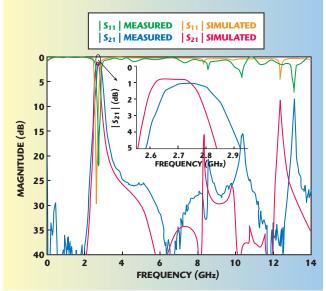


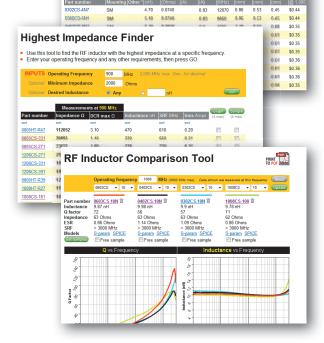
Fig. 5 Simulated and measured S-parameters of the filter.

Figure 4 shows a photograph of the fabricated filter in a metal housing. There is a 3 mm gap between the substrate and the housing. The filter has a compact size of $0.05 \times 0.21 \, \text{Ag} \, (6.1 \times 12.8 \, \text{mm})$, where λg is the guided wavelength at center frequency of the passband. The performance of the fabricated BPF was measured using an Agilent 8757D network analyzer. As shown in Figure 5, the filter operates at 2.7 GHz and has a 3 dB bandwidth of approximately 200 MHz. The fabricated bandpass filter has a wide upper stopband with more than 15 dB attenuation from 3.2 to 13.3 GHz. Besides, the measured insertion loss in the passband is only 0.99 dB, which is very remarkable in microstrip line filters.

To further broaden the upper stopband of the filter, the U-shaped defected structure ground (DGS) is employed to suppress the spurious response of the structure. The U-shaped DGS is etched below the input/output feed lines symmetrically, shown in **Figure 6**. The U-shaped DGS

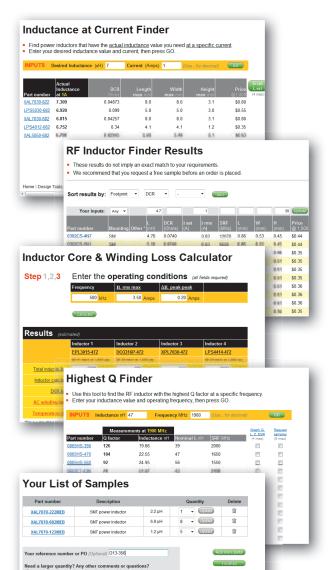
structure can generate a transmission zero at its resonance frequency and then it can be used to suppress the spurious response. The dimensions of the added U-shaped DGS are $L_{\rm s}=7.7$ mm, $W_{\rm s}=0.1$ mm. The final simulated and fabricated results demonstrate that the added U-shaped DGS works well. $\it Figure~7$ shows the photograph of the fabricated filter with DGS, also in a packaged cavity.

The measured results in *Figure* 8 (also taken with an Agilent 8757D network analyzer) show that the filter achieves a wide upper stopband with



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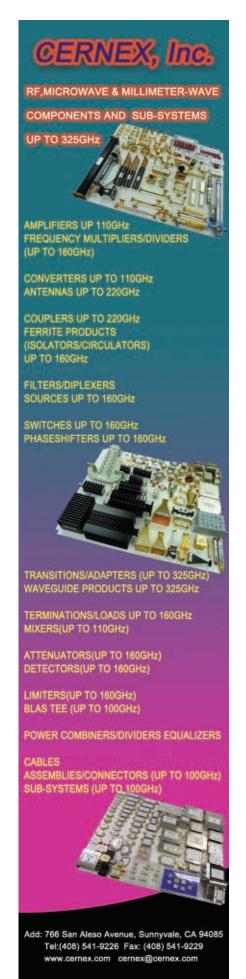


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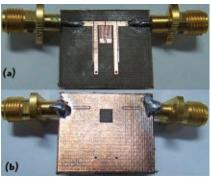


Fig. 7 Photographs of the fabricated filter with DGS (a) top view and (b) bottom view.

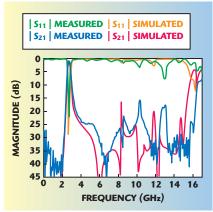


Fig. 8 Measured and simulated Sparameters of the filter with DGS.

more than 15 dB attenuation up to 16.4 GHz, and performance of the filter with U-shaped DGS is almost the same as the above filter without U-shaped DGS, except that the insertion loss is slightly worsened to 1.07 dB.

CONCLUSION

In this article, a CRLH-TL based bandpass filter is proposed. To further extend the upper stopband, a U-shaped DGS is employed. Both the equivalent circuit method and the coupled resonator circuit method have been applied for the analysis of the filter. The final fabricated filter has a compact size, wide upper stopband and low insertion loss. The good performance makes it practical for microwave applications.

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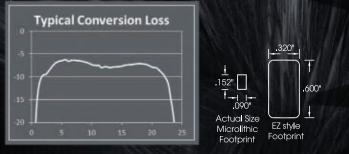
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RF Training Kit

with the migration of communication systems to higher frequencies, signal integrity plays an increasingly significant role in the design process. This in turn puts more demand on the test and measurement systems with improved capabilities. For a manufacturer of RF connectors and cable assemblies, a thorough understanding of electromagnetic phenomena is critical to establishing design rules to eliminate adverse effects. Return loss, insertion loss and the time domain behaviour of these products have to be kept under control from design, production, and assembly to final testing.

Increasingly, it is not seen as being sufficient for companies to use calibrated vector network analyzers and calibration kits for final testing to run an effective and high quality production line. The knowledge of negative effects that can arise in a production and assembly line needs to be shared with all relevant departments and subsidiaries. From this premise the idea was born to design an educational RF training kit for company internal purposes with devices that clearly and purely demonstrate the single effects supported by tutorials. However, this educational kit is not only available for internal use but also for academic and industrial customers.

The kit (order number 99M007-000) includes: coaxial devices with adapters; circuit board with 15 microstrip structures; documentation covering basic circuit theory up to sources of reflections, losses and crosstalk; guided exercises for experiencing these effects using the kit hardware on a vector network analyzer (VNA); and PowerPoint slides and field animations supporting the exercises.

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Product Feature

COAXIAL DEVICES

The primary coaxial device is a 100 mm unbeaded gold plated air line with male and female RPC-N 50 Ω connectors. It consists of one outer conductor and five inner conductors with different diameter geometries. Combining the outer conductor with an inner conductor that results in a homogeneous 50 Ω air line represents the coaxial device with the lowest reflections and the lowest specific losses available. Connected to a calibrated



▲ Fig. 1 Adapter with a damaged finger.

VNA, it shows the measurement limits for further exercises.

By replacing the inner conductor by a thinner one and adding PTFE beads over the whole length also results in a 50 Ω coaxial line. A higher insertion loss than before can be observed caused by additional dielectric losses and the line becomes electrically longer. In addition these beads can be replaced by similar ones which have a flattened outer diameter. This causes a reduction in the usable operating frequency for the quasi TEM mode.

With a set of small PTFE beads, diameters of 4, 5 and 6 mm and length of 2, 3, 5, 8 and 10 mm, discontinuities in cable assemblies can be simulated very well, e.g., regular discontinuities on a coaxial cable result in narrowband resonances. With a selection of different PTFE beads, experimentation with other bead configurations is possible. This is ideal for exploring the impact that the transformation parameters, set by the user on the VNA, have on the measurement results.

Time domain measurement is mainly limited by the rise time of

the measurement system. On VNAs, this is inversely proportional to the upper measurement frequency, often limited by the connector system or the cable material used. When measuring with a long rise time, discontinuities separated by a short distance cannot be distinguished and the real impedance of a short discontinuity can't be measured.

Besides the air line, the coaxial devices of this kit are complemented by two special RPC-N 50 Ω adapters. They were designed to demonstrate possible as-sembly problems in a production line. One adapter with a radial stub in the outer conductor, the other

with one of the six female contacts fingers lifted off, as shown in *Figure 1*. It is known as an 'adapter damaged finger' and is a nightmare for quality departments.

MICROSTRIP CIRCUITS

On the circuit board, shown in Figure 2, several circuits are implemented with female SMA interfaces. There are 50 Ω transmission lines of different length. Compared to the coaxial air line significant higher specific losses can be measured. A Π-type attenuator is realized with SMD resistors. The frequency response of the insertion loss and the return loss gives an idea of the useable frequency range. Filter structures are available as an opened stub, a shorted stub, a DC block and bandpass filters with serial/parallel coupling. Finally, three quarter-wave transformers, from first to third order, demonstrate narrow to medium bandwidth low loss transformers.

DOCUMENTATION

The included documentation covers the basics of electrical engineering: Electromagnetism, DC circuit theory, complex analysis, AC circuit theory, transmission line theory, losses, reflections and coupling.

EXERCISES

To work most effectively with the coaxial and planar devices, an extra document with comprehensive exercises is included. The document starts with handling precautions, especially for the unbeaded air line. The exercises require the user to have the necessary knowledge of the setup and handling of the VNA. Every exercise includes a description of the training kit equipment needed and gives directions for parameters to measure.

Questions regarding the measurement results aid the user in understand-

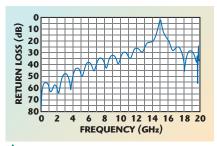


Fig. 3 Return loss for the adapter with a damaged finger.

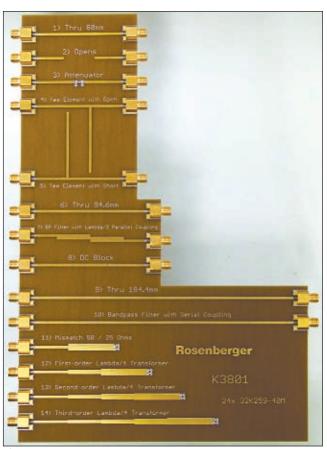
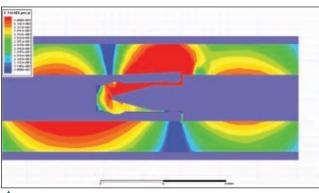


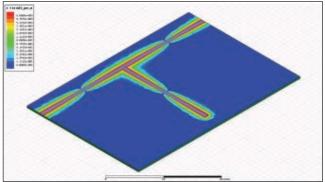
Fig. 2 Circuit board with 15 microstrip circuits.



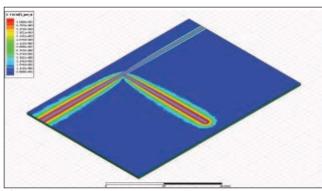
Product Feature



▲ Fig. 4 Field simulation for the adapter with a damaged finger.



▲ Fig. 5 Field simulation of a transmission line with opened stub, transmissive at 2 GHz.



▲ Fig. 6 Field simulation of a transmission line with opened stub, reflective at 1 GHz.

ing the effects. Also, with references to the single chapters of the tutorial and references to the simulations and field animations the understanding can be enhanced. Depending on the skill level and on the time available, specific exercises can be omitted.

REFERENCE SIMULATIONS AND FIELD ANIMATIONS

Every exercise is supported with reference simulations of the return loss, the insertion loss, the time domain response and an animation of the electric field for the whole device or in part when necessary. Especially for beginners it's very interesting and instructional to see what happens when the wavelength equals the distance between two or more discontinuities.

The tremendous impact discontinuities have is clearly shown in the 'adapter damaged finger' exercise. The frequency response and the field animation at 15 GHz are shown in *Figure 3* and *Figure 4*.

Figure 5 shows the field plot of the transmission line with opened stub at 2 GHz where it is transmissive. At 1 GHz the same structure becomes reflective and nearly no signal passes through the structure. The field plot, shown in Figure 6, demonstrates how the opened stub is transformed into a short at $\lambda/4$.

This kit which included special components was designed for company internal training and for academic and industrial education to enable a closer look into RF connector and cable assembly design and production. In Rosenberger's experience, this training kit is ideal for a hands-on approach to understanding the major causes of signal degradation on a system.

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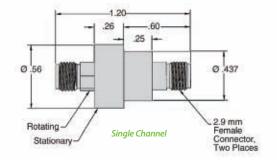
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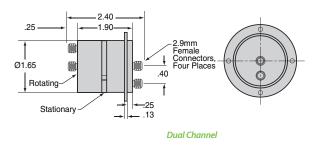
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SINGLE CHANNEL SPECIFICATIONS:

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FREQUENCY	.DC - 18 GHz	
VSWR	.DC - 10 GHz	1.20 : 1 MAX.
	10 - 26 GHz	1.35 : 1 MAX.
	26 - 40 GHz	1.75 : 1 MAX.
WOW	.1.05 MAX.	
INSERTION LOSS	.DC - 10 GHz	0.2 dB MAX.
	10 - 26 GHz	0.4 dB MAX.
	26 - 40 GHz	0.6 dB MAX.
PEAK POWER	.Equal to conne	ector rating

310 RCD 16

DUAL CHANNEL SPECIFICATIONS:

ELECTRICAL	Channel 1	Channel 2
FREQUENCY	7.0 - 22.0 GHz	29.0 - 31.0 GHz
VSWR	1.50:1 MAX.	1.70:1 MAX.
WOW	0.15	0.25
INSERTION LOSS	0.5 dB MAX.	1.0 dB MAX.
ISOLATION	Channel to Channel	50.0 dB MIN.



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Surface-Mount Ceramic Chip Antennas for UHF Applications

The UHF frequency band lies between the VHF frequencies and microwave frequencies. Due to this unique position, typical UHF band wavelengths are short enough to allow dielectric loading while their frequencies are low enough to allow effective compensation using reactive elements below their self resonance frequencies. Vishay surface-mount chip antennas use both dielectric loading and reactive compensation to provide a miniaturized antenna system for receiving/ transmitting electromagnetic radiation in the UHF 400 to 915 MHz bands. The system has two basic components: an antenna element miniaturized by the use of dielectric loading and a tuning circuit.

One approach for miniaturizing antennas is to use low-temperature co-fired ceramics (LTCC) that have a permittivity (ϵ) of about 8 and permeability (μ) of about 3.5. Using those values, LTCC-based antennas would result in a miniaturization factor of \sim 5.3. Further miniaturization of an antenna requires a high-per-

mittivity, yet with low-loss dielectric material. This ceramic material is now available from Vishay. The ability to develop chip antennas with desirable properties is enabled using Vishay Intertechnology's ceramic formulation. This proprietary dielectric material exhibits a unique combination of properties: high permittivity and low loss, a combination essential in achieving a high-gain, low-loss antenna. The newly developed material has values of ϵ of about 400 and μ of about 1.

This dielectric has opened the path for further miniaturization of chip antennas in a greater factor than is available with existing technologies. This composition can reduce the size of the antenna by a factor of 20 – a significantly larger size reduction than the 5.3 offered by LTCC materials. The formulation is RoHS compliant and allows excellent stability

VISHAY INTERTECHNOLOGY *Malvern, PA*

WIDEBAND PLL+VCOs

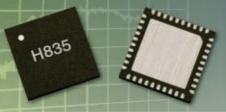
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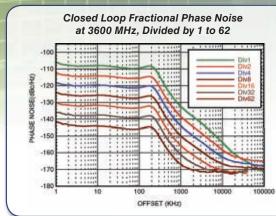


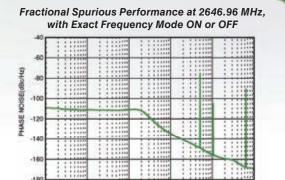




- ♦ Maximum Phase Detector Rate: 100 MHz
- ◆ PLL FOM:

 -230 dBc/Hz Integer Mode
 -227 dBc/Hz Fractional Mode
- ♦ <160 fs Integrated RMS Jitter (1 kHz 100 MHz)
- ♦ Low Noise Floor: -165 dBc/Hz
- ♦ 4 Single-Ended or 2 Differential Outputs





OFFSET (KHz)

Part Number	Frequency (MHz)	Function	Closed Loop SSB Phase Noise @ 10 kHz Offset	Open Loop VCO Phase Noise @ 1 MHz Offset	Pout (dBm)	RMS Jitter Fractional Mode (fs)	Integrated PN Fractional Mode (deg rms)
HMC829LP6GE	45 - 1050 1400 - 2100 2800 - 4200 Fo	Wideband PLL+VCO	-108 dBc/Hz @ 4 GHz	-134 dBc/Hz @ 4 GHz	4	159	0.229 @ 4 GHz
HMC830LP6GE	25 - 3000	Wideband PLL+VCO	-114 dBc/Hz @ 2 GHz	-141 dBc/Hz @ 2 GHz	6	159	0.114 @ 2 GHz
HMC832LP6GE	25 - 3000	Wideband RF VCO (+3.3V)	-114 dBc/Hz @ 2 GHz	-139 dBc/Hz @ 2 GHz	7	159	0.114 @ 2 GHz
HMC833LP6GE	25 - 6000	Wideband PLL+VCO	-114 dBc/Hz @ 2 GHz	-141 dBc/Hz @ 2 GHz	-4	159	0.11 @ 2 GHz
HMC834LP6GE	45 - 1050 1400 - 2100 2800 - 4200 Fo 5600 - 8400	Wideband PLL+VCO	-108 dBc/Hz @ 4 GHz	-134 dBc/Hz @ 4 GHz	5 2 2 -10	159	0.23 @ 4 GHz
HMC835LP6GE	33 - 4100	Wideband PLL+VCO	-105 dBc/Hz @ 4 GHz	-133 dBc/Hz @ 4 GHz	7	160	0.23 @ 4 GHz



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Product Feature

TABLE I APPLICATIONS AND FREQUENCIES OF OPERATION							
Frequency (MHz)	Antenna Part Number	Applications					
100	VJ5301M400MXBSR (3505)	Medical telemetry (internal/external) Two-way radio communication					
400	VJ5601M400MXBSR (6040)	Land mobile services Industrial and medical band applications					
433	VJ5301M433MXBSR	Medical telemetry (internal/external) Broadband transmission and reception					
433	VJ5601M433MXBSR	Automotive (TPMS, etc.) Industrial and medical band applications					
868	VJ5301M868MXBSR	Medical telemetry (internal/external) Remote sensing and control					
000	VJ5601M868MXBSR						
915	VJ5301M915MXBSR	Industrial automation, telemetry Security systems, long-range RFID Electronic water/electricity meters					
	VJ5601M915MXBSR						

TABLE II								
SINGLE FREQUENCY TUNING								
Tuning Circuit	Tuning Frequency	Evaluation Kit Part #	Typical Nominal Component Values					
	(MHz)	Part #	C1	L1	C2	L2		
VJ Chip Antenna	400	VJ5301M400MXBEK	Short	82 nH	3.3 pF			
C2 L1	433	VJ5301M433MXBEK	15 pF	82 nH	4.7 pF			
VJ Chip Antenna	868	VJ5301M868MXBEK		1.5 nH	5.6 pF	10 nH		
L2 50Ω RF Feed	868	VJ5601M868MXBEK		26.3 nH	3.9 pF	Short		
VJ Chip Antenna	915	VJ5301M915MXBEK	Short	10 nH		10 nH		
L2 SOO RF Feed	915	VJ5601M915MXBEK	Short	22 nH		29.7 nF		

The component values shown are for tuned evaluation kits. The actual values may vary depending on the printed circuit board layout.

throughout a temperature range of -40° to +85°C. A variety of different ceramic chip sizes are possible. **Table 1** contains examples for two ceramic antenna chips sizes: $3505 (35 \times 5 \text{ mm})$ and $6040 (15 \times 10 \text{ mm})$ with additional sizes under development (thickness is 1.2 mm).

THE TUNING CIRCUIT

The antenna tuning circuit functions as an impedance matching network that matches the antenna's impedance for maximum power transfer. Utilizing a tuning circuit, the antenna is tuned to a fixed center frequency in the UHF band. The imaginary part of the impedance can be either positive (capacitive) or negative (inductive) inside the desired frequency band. The imaginary impedance can be negated by adding one or more passive reactive components. Once the imaginary part is negated, only the real part remains, which is adjusted to $50^{\circ} \Omega$. Thus, the antenna is funed to 50 Ω at the desired frequency.

It is important to note that the antenna can be tuned to any desired impedance using shunt reactive elements to manipulate both the real and imaginary impedance. Using the tuning circuit, the antenna is thus tuned at a given point, thereby creating a relatively narrow band antenna, or a single-frequency antenna.

Examples of matching tuning circuits for given ceramic chips are provided in *Table 2*. Different capacitance and inductance values, in addition to circuit layout, can be applied based on the specific application. The table also lists the tuning element for a given frequency and chip antenna size.

EXAMPLES OF RADIATION PATTERNS

As explained, the antenna system is constructed of a ceramic chip and a tuning circuit. Their assembly results in a platform that allows evaluating the antenna performance at the single frequency. This assembled configuration is referred to as an antenna evaluation kit (EVK). The ceramic chip antenna radiation patterns for Vishay's EVKs are shown in *Table 3*.

To provide design engineers with the recommended circuit design layout, and to demonstrate the performance of the chip antenna, EVKs are





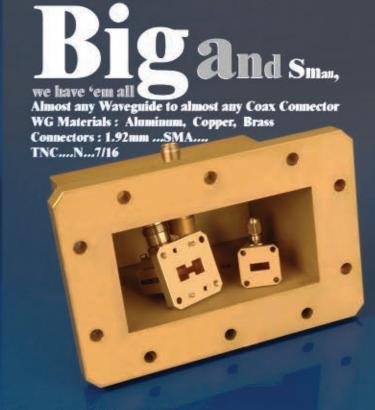
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Product Feature

Freq. (MHz)	Antenna Part Number	XZ rotation	YZ rotation	XY rotation
400[1]	VJ5301M400MXBSR	130 100 100 100 100 100 100 100 100 100		
433[1]	VJ5301M433MXBSR	100 100 100 100 100 100 100 100 100 100	137 197 197 197 197 197 197 197 197 197 19	ST S
868 ^[2]	VJ5301M868MXBSR	110 100 100 100 100 100 100 100 100 100	100 100 100 100 100 100 100 100 100 100	To the state of th
915	VJ5301M915MXBSR	19 W W W W W W W W W W W W W W W W W W W	128 - 17 - 18 - 17 - 18 - 18 - 18 - 18 - 1	100 00 00 00 00 00 00 00 00 00 00 00 00

[2] A prototype with a small footprint (8 mm by 5 mm by 1.2 mm) and high gain is available.

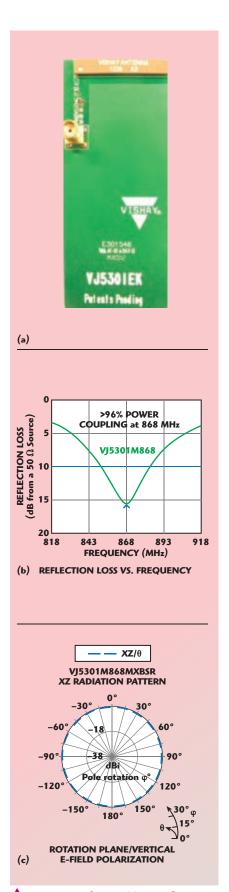
used. The EVK contains a chip antenna mounted on a 40×90 mm printed circuit board (PCB), with a 3.5 mm SMA launch connector for transmission or reception of signals. The SMA connector allows for easy connection to the designer's circuitry. Figure 1 demonstrates a peak gain of 1 dBi realized with 50 Ω impedance matching. The EVK also allows for the testing of the open field radiation emission. Open field radiation emission testing for this chip antenna demonstrates it has omni-directional radiation pat-

Miniature tunable surface-mount ceramic chip antennas that cover the UHF frequency band from 400 to 915 MHz are available. The chip antennas can be used in industrial, scientific, and medical short-range device (ISM/SRD) radio bands for applications such as medical biotelemetry receivers (400 to 433 MHz), industrial

RFID applications (868 to 915 MHz), wireless security systems, sensors and remote controls. With properly selected discrete L-C tuning components, all Vishay antennas can be tuned to any regional frequency in the 400 MHz to 1.1 GHz band.

These low-profile ceramic antennas are available in small case sizes, which makes them good solutions when instrument size and/or PCB area are limited, such as in RFID sensors, garage door openers, remote controls, wireless microphones, headphones, and more. The chip antennas are mounted onto PCBs using standard surface-mount assembly methods. Single-frequency tuning is easily achieved with just a few discrete capacitor and inductor components.

Vishay Intertechnology, Malvern, PA, chipantenna@vishay.com, www.vishay.com.



 \blacktriangle Fig. 1 Example EVK (a), S_{11} reflection loss (b) and radiation pattern of chip antenna

Amazingly Low Phase Noise SAW VCO's



Model	Frequency (MHz)	Tuning Voltage (VDC)	DC Bias VDC @ I [Max.]	Phase Noise @ 10 kHz (dBc/Hz) [Typ.]
HFSO640-5	640	0.5 - 12	+5 @ 35 mA	-151
HFSO745R84-5	745.84	0.5 - 12	+5 @ 35 mA	-147
HFSO776R82-5	776.82	0.5 - 12	+5 @ 35 mA	-146
HFSO800-5	800	0.5 - 12	+5 @ 30 mA	-146
HFSO914R8-5	914.8	0.5 - 12	+5 @ 35 mA	-139
HFSO1000-5	1000	0.5 - 12	+5 @ 35 mA	-141
HFSO1000-12	1000	0.5 - 12	+12 @ 35 mA	-141

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Tech Briefs



Digitally Tunable Capacitors

eregrine Semiconductor has expanded its DuNE™ Digitally Tunable Capacitor (DTC) product line with six second-generation devices for antenna tuning in 4G LTE smartphones. The PE623060, PE623070, PE623080, and PE623090 (PE6230x0) DTCs have a capacitance range of 0.6 to 7.7 pF and support main antenna power handling of up to +34 dBm. The PE621010 and PE621020 (PE6210x0) DTCs have a capacitance range of 1.38 to 14.0 pF and are optimized for power handling of up to +26 dBm, making them well suited for diversity antennas. All of the new DTCs are manufactured on Peregrine's UltraCMOS® technology process, with HaRP™ technology enhancements that enable the devices to meet the challenging harmonic and linearity requirements of LTE. The highly-versatile devices support a wide variety of tuning circuit topologies, with an emphasis on impedance matching and aperture-tuning applications. They extend Peregrine's high-performance tuning roadmap, which was first introduced to the market in 2008.

Smartphones are now required to support a subset of the more than 40 different LTE frequency bands, as well as MIMO and carrier aggregation. To keep up, these devices now contain multiple antennas, making it difficult to keep the end device thin and slim. Tuning the antenna solution with DuNE DTCs enables the system to support multiple bands, while at the same time reducing antenna size and providing optimal RF performance.

With PE6230x0 and PE6210x0 DTCs, all tuning functions, including bias generation, integrated RF filtering and bypassing, control interface, and ESD protection of 2 kV HBM, are incorporated into a slim, $2 \times 2 \times 0.55$ mm package. The new DTCs are available in 10- and 12-lead, 2×2 mm QFN packages.

Peregrine Semiconductor, San Diego, CA (858) 731-9400, www.psemi.com.



rtho-Mode Transducer (OMT) is an important microwave component that separates a signal into two linear orthogonal polarized signals received from a common port or, vice versa, combines two such signals from vertical and horizontal ports into a common port. The OMT supports circularly, elliptically and linearly-polarized waveforms in general. Combined with a polarizer, the OMT can support both left-hand and righthand circular polarized waveforms simultaneously. OMT is widely used in satellite data transmission and satellite television broadcasting. It also finds applications in commercial and military radar systems as a diplexer when a dual-

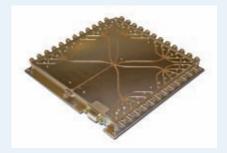
Full Waveguide Band Ortho-Mode Transducers

polarized radar antenna is used. In telecommunications, OMT plays a unique role in TDD systems where the transmitting and receiving signals are at the same frequency.

The SAT series OMTs offered by SAGE Millimeter Inc. are full waveguide band Ortho-Mode Transducers that cover entire standard rectangular waveguide bands from Ku- to W-Band in the frequency range of 12.5 to 110 GHz with eight individual models. The OMTs are configured with one square waveguide for antenna port and two rectangular waveguides, one for H-Port and another for V-Port. These OMTs exhibit low insertion loss throughout the entire waveguide band, which enables their high power handling capacity. In the meantime, the greater than 40 dB isolation between the horizontal and vertical ports and 35 dB cross-polarization make them more attractive and useful for transmitter and receiver duplexing. Unlike their counterpart, narrowband OMTs, these full waveguide band OMTs find a convenient way in antenna test setups, such as compact, near field and far field ranges as they allow two signals in orthogonal polarizations to be measured at the same time across entire waveguide bands without using multiple OMTs.

An example of the full waveguide band OMT family is a Ka-Band version with model number SAT-KA-28028-S1. The model measures 2.5"W \times 2.75"L \times 0.75"H and weighs 5.2 oz. Its antenna port is equipped with a 0.28"W \times 0.28"H square waveguide and H and V ports are with standard WR-28 waveguides. The model exhibits 0.4 dB maximum insertion loss, 40 dB minimum isolation between the H and V ports and 35 dB minimum cross-polarizations. Similar performance is achieved for all eight models.

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



SP36T Broadband Switch

icrosemi's GG-75431-64 single pole, 36 throw (SP36T) ultra-broadband absorptive switch is targeted at signal routing, simulation test equipment, communications systems and test lab equipment. The GG-75431-64 achieves low insertion loss, high isolation and fast switching over the entire 100 MHz to 20 GHz frequency range. The switch is controlled via an internal 6-bit TTLcompatible driver and operates from a single +5 V DC supply. A 9-pin D-SUB receptacle is incorporated on the device for convenient DC and control logic interface. RF connectors are field replaceable SMA female.

GG-75431-64 performance is guaranteed from -55° to 95°C and the unit is designed to withstand environmental conditions to MIL-PRF-883 including internal visual; stabilization bake thermal cycle; constant acceleration; fine leak; gross leak; external visual; and burn-in.

Key features include:

- Multi-octave frequency range
- Low-profile packaging
- Absorptive switch
- 1 W CW power handling
- 100 nsec switching speed
- 7 dB max insertion loss
- 70 dB min isolation

- Single +5 V supply
- 6-bit TTL control with enable

The GG-75431-64 is offered with a variety of options including:

- Hermetic seal
- Hi-rel screening
- Other frequency ranges
- Differential logic
- Discrete logic control
- RoHS-compliant

Microsemi Corp. Aliso Viejo, CA, sales.support@microsemi.com, www.microsemi.com.



Frequency Matters.



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Web Update

Major Web Enhancements

Agile Microwave Technology Inc. has made major web enhancements to the company's website. The include improvements more than 20 new products with complete technical datasheets available by clicking on the part num-



ber, new improved search engine and updated sales contact information.

Agile Microwave Technology Inc. www.agilemwt.com

New Products on Site

B&Z Technologies has recently updated its website with new amplifier models having 0.4 dB NF in 1 to 4 GHz, 0.7 dB NF in 4 to 8 GHz, 0.8 dB NF in 8 to 12 GHz, 1.2 dB NF in 12 to 18 GHz, and 1.4 dB NF in 18



to 26 GHz, 2.5 dB NF from 24 to 32 GHz, 2.9 dB NF in 18 to 40 GHz and 3.5 dB in 18 to 42 GHz bands. Also added to the website are its high dynamic range amplifiers with NF <3, Output-P1 >+20 dBm and typical gain of 20 dB in the 0.1 to 20 GHz band.

B&Z Technologies www.bnztech.com

Redesigned Website

Bonding Source's redesigned website includes a comprehensive, user friendly guide to epoxy pastes and films commonly used in the RF/microwave industry. It's the industry's easiest way to find data-



sheets and quick facts on various epoxies. It also offers information on a new epoxy press used for the installation of circuit boards into microwave housings. Bonding Source offers immediate, in stock delivery of epoxies, epoxy pre-forms, and bonding wire and ribbon.

Bonding Source www.bondingsource.com

COMSOL Video Center

The COMSOL website features a newly revamped video center that outlines the simulation capabilities of the 38 applicationspecific modules offered



by COMSOL Multiphysics software. Topics from product highlights to detailed explanations of simulation case studies in the electrical, mechanical, fluid, and chemical application areas can be found, and new videos are added regularly. The redesigned COMSOL blog provides engineers worldwide with stimulating content, helping to share innovative user stories, design solutions, multiphysics news and much more, on a daily basis. **COMSOL** Inc.

www.comsol.com

CST White Papers VENDORVIEW

electromagnetic simulation software is used in numerous application areas such as antennas, waveguides, and MRI coils. With the new white paper webpage, it is now easier to discover how CST STU-DIO SUITE® helps engineers overcome challenges in the design process. The white papers demonstrate techniques that simplify the development process and are available to download for free.

Computer Simulation Technology AG



FilterSolutions Website

The new website for Nuhertz Technologies presents the capabilities of FilterSolutions® 13.3.4. The design synthesis program is used for lumped and distributed element



as well as active or digital filters. Organized to enable the comparison of program features and tailoring configurations to meet specific design needs, the site describes the program interfaces with other simulation and optimization tools. Users are encouraged to evaluate the full-featured program by registration for a no-cost, 30-day license.

Nuhertz Technologies www.nuhertz.com

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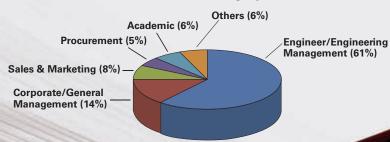


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Guy Séné, President, Electronic Measurement Group, Agilent Technologies

Attendee Demographics



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Web Update

Updated New Products Feature

RLC Electronics Inc. has launched an updated "New Products" feature to its website, adding press releases, photos, electrical information and outline drawings where available. Some of the latest



releases include a series of 18 GHz SP11/SP12T latching switches (terminated or unterminated), a 26.5 GHz micro miniature transfer switch with indicator functionality, a switch filter box and an integrated multi-switch module. RLC will continue to publish new products in this section moving forward on a monthly basis.

RLC Electronics Inc. www.rlcelectronics.com

Sensor Catalog Page



SAGE Millimeter updated its website by adding its newly released sensor catalog and product highlights recently. The new sensor



catalog is a forty page catalog, which includes K-, Ka-, V-, E- and W-Band Doppler, directional and ranging sensor product families. These sensors are designed and manufactured for traffic control, intrusion detection, level sensing, collision avoidance and many industrial and military radar system applications. Various output levels, sensitivity grades and antenna types are offered as standard products.

SAGE Millimeter

www.sagemillimeter.com

Resources Section

RF Techniques has added a new resources section on its website with helpful information on resistors, terminations and attenuators for microwaves and RF applications, and information on RFT's new soldered version



to support customers looking for a lower cost alternative. RFT continues to offer the high reliable brazed products for the high reliable and high temperature applications. RFT products are manufactured in the USA and made with "DRC CONFLICT FREE" minerals.

RF Techniques

http://rftechniques.com/resources.html

2013 Website

VENDORVIEW

Tecdia has launched its newly redesigned website for 2013. The new website offers an overview of the company's full line of products, services, capabilities and current news and events. With added search functionality this new layout simplifies the user experience. For convienience,



visitors will be able to send inquiries about specific products and services directly through Tecdia's new contact pages.

Tecdia

www.tecdia.com

Broadband RF and Microwave Solutions

Weinschel Associates announced the launch of its redesigned, state-of-the-art website. The launch is the culmination of months of market research, design and engineering. Weinschel



Associates has taken a customer-centric approach to the redesign process, determining core features based on market demand and the results of formal usability studies. This professionally built website boasts an interactive catalog with a fully integrated, easy-to-use custom quote request system. The entire catalog is searchable, and each product's specifications can be customized.

Weinschel Associates http://weinschelassociates.com

Interactive Website VENDORVIEW

Werlatone is a leading supplier of high power, broadband RF coaxial components to include (Uni, Dual, Bi) directional couplers, 90° hybrid couplers, RF combiners/dividers, and 180° hybrid RF combiners/dividers. The company's fully interactive website features detailed product search functions and new landing pages



and new landing pages highlighting its truly custom designs and DAS applications. Visit its site for additional product lines in the near future.

Werlatone

www.werlatone.com

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Solid-State Amplifiers





AR RF/Microwave Instrumentation introduced new family of solid-state microwave amplifiers that provide up to 500 W of power from 1 to 2.5 GHz. These amplifiers offer a solidstate alternative to traveling wave tube amplifiers and feature better harmonics, less noise and superior reliability. For more information please visit: www.arww-rfmicro.

com/html/12200_microwave_amplifier.asp. AR RF/Microwave Instrumentation, www.arworld.us.

RF Amplifier

COMTECH PST introduced a new high power density solid state RF module quickly becoming available in today's marketplace. Comtech's



latest development continues to expand on its proven innovative integrated RF GaN power amplifier designs by further

increasing the RF power density. Consistent with its planned technology development roadmap, Comtech introduced the latest in GaNbased 6 to 18 GHz RF amplifier. This highly integrated design is ideal for use in communication, electronic warfare and radar transmitter systems where space, cooling and power are limited.

COMTECH PST, www.comtechpst.com.

Driver Amplifier



Custom MMIC introduced the CMD158P3 a broadband driver amplifier ideally suited for mixer LO chains, passive multipliers and medium power applications. The CMD158P3 covers 6 to 14 GHz and delivers 20 dB of gain with +20 dBm of saturated power while requiring a single +5 V supply at 95 mA. Housed in a RoHS-compliant, Pb-free 3 × 3 mm QFN plastic package, the CMD158P3 offers high performance in a small footprint. The input and output ports are DC blocked.

Custom MMIC, www.CustomMMIC.com.

GaN HEMT



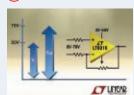
IGN3135M130 is an internally pre-matched, gallium nitride (GaN) high electron mobility transistor (HEMT). This

part is designed for S-Band radar applications operating over the 3.1 to 3.5 GHz instantaneous frequency band. Under 300 us/20 percent pulse conditions, it supplies a minimum of 130 W of peak output power with typical performance of 150 W with 12 dB gain. Specified operation is with Class AB bias. When appropriately rated, it is operable under a wide range of pulse widths and duty factors.

Integra Technologies Inc., www.integratech.com.

Operational Amplifiers





Linear Technology introduced the LT6016 and LT6017, dual and quad wide input range operational amplifiers. These am

plifiers combine high precision with the ruggedness and versatility of LTC's unique Overthe-Top® architecture. Input offset voltage is 50 μV max, input bias current is 5 nA, and low frequency noise is 0.5 μVP -P making these devices suitable for a wide range of precision industrial, automotive and instrumentation applications. Over-the-Top inputs provide true operation well beyond the V+ rail.

Linear Technology Corp., www.linear.com.

Broadband Amplifier



Microwave Solutions introduced an ultrabroadband amplifier offering low noise figures, good gain flatness and out-

put power. Model MSH-6492401 operates on 1 to 10 GHz with 28 dB gain, noise figure of 2.5 dB, \pm 20 min Pout (1 dBm), VSWR 2.0:1 and DC power of \pm 12 V/300 mA. The bandwidth makes this amplifier useful for many applications including ECM instrumentation and test sets.

Microwave Solutions Inc., www.microwavesolutions.com.

Instrumentation Amplifiers



QuinStar Technologies Inc. announced the release of the QAI family of instrumentation amplifiers in the millimeter wave

frequency range based on the most advanced device and circuit integration technology. These amplifiers can be designed to operate over a wideband or over relatively narrowband with an exceptionally high power level. Customers have used them for applications as diverse as plasma diagnostic, medical research, communication and remote sensing

and remote sensing.

QuinStar Technologies Inc.,

www.quinstart.com.

LDMOS RF Power Transistors

VENDORVIEW

Richardson RFPD Inc. announced immediate availability and full design support capabilities for five new laterally diffused metal oxide semi-



c o n d u c t o r (LDMOS) power transistors from Freescale Semiconductor Inc. The five new RF power transistors offer enhanced levels

of performance designed to boost the efficiency, peak power and signal bandwidth of next-generation base stations. With these additions, the Airfast RF power product line now includes at least one solution for each cellular band, supporting small and large (macro) cell base station applications.

Freescale Semiconductor Inc., distributed by Richardson RFPD Inc., www.freescale.com.

InGaP HBT Amplifier

RFMD's RFCA1008 is a high performance In-GaP HBT MMIC amplifier designed with the InGaP process technology for excellent



reliability. The heterojunction increases breakdown voltage and minimizes leakage current between junctions. A Darlington configuration is utilized for broadband performance. The RFCA1008 contains two amplifiers for use in wideband push-pull CATV ampli-

fiers requiring excellent second order performance; the second and third order nonlinearities are greatly improved in the push-pull configuration.

RF Micro Devices Inc., www.rfmd.com.

GaN Transistor VENDORVIEW



RFMW Ltd. announced design and sales support for TriQuint Semiconductor's T1G6003028-FL, DC to 6 GHz GaN transistor offering 30 W

P3dB at 6 GHz and up to 40 W P3dB midband. Gain at P3dB is >11 dB requiring half the power from a driver stage compared to some competitors. Linear gain is > 14 dB. The T1G6003028-FL uses a 28 V supply and only 200 mA of current. Overall efficiency is up to 60 percent. The -FL flange package offers low thermal resistance and is easily bolted down.

TriQuint Semiconductor, distributed by RFMW Ltd., www.triquint.com.



A perfect fit for almost any PCB!

RCAT/YAT ATTENUATORS DC to 20 GHz from \$299 ea.(qty. 20)

Our new tiny 2W fixed value absorptive attenuators are now available in molded plastic or high-rel nitrogen-filled ceramic packages. They are perfect building blocks for both broad and narrow-band systems, reducing effects of mismatches, harmonics, and intermodulation, improving isolation, and meeting other circuit level requirements. These units will deliver the precise attenuation you need, and are stocked in 1-dB steps from 0 to 10 dB, and 12, 15, 20 and 30 dB.

The ceramic hermetic *RCAT* family is built to deliver reliable, repeatable performance under the harshest conditions having been qualified to meet MIL requirements including

vibration, PIND, thermal shock, gross and fine leak and more, at up to 125°C!

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http://www.modelithics.com/mvp/Mini-Circuits/

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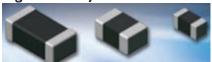
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New Products

Components

High-Reliability Ferrite Beads



AEM Inc. announced the availability of its DSCC-approved line of ferrite chip beads designed for ultra-high-reliability applications. The HRB Series is the first and only line of ferrite beads manufactured with qualified materials and tested to compliance with DSCC drawing 03024. The DSCC drawing 03024 specifications prescribe the stringent physical, electrical and operational specifications for high-reliability ferrite chip shielding beads. The series is available per EIA 0603, 0805 and 1206 package sizes with current ratings ranging from 0.2 to 4.0 A.

AEM Inc., www.aem-usa.com.

Low PIM Cable Assemblies





AtlanTecRF now has stock of low PIM cable assemblies that are designed specifically for applications

where it is essential to have a low level of PIM products. This newly launched series of high

performance and low intermodulation cable assemblies are available in two convenient diameters and a large range of lengths. To achieve the low intermodulation level of -155 dBm at 6 GHz with 2 tones of +26 dBm, the cable material consists of a silver plated copper centre conductor with PTFE dielectric and a copper/tin composite outer conductor.

Atlantic Microwave Ltd., www.atlantecrf.com.

WiFi FBAR Filter



Avago Technologies unveiled a FBAR filter for small cell applications. The ACFF-1024 is a new miniature bandpass filter optimized for

use in the 2.4 GHz ISM band. Designed with Avago's FBAR technology, the ACFF-1024 enables concurrent operation of WiFi and Bluetooth applications that coexist with other wireless standards such as PCS and LTE Bands 7 and 40 without performance degradation due to interference.

Avago Technologies, www.avagotech.com

Power Combiners





MECA Electronics Inc. introduced its H-Series, 100 W, Wilkinson high power combiner/dividers in

two-way, three-way and four-way configurations for wireless applications between 0.4 and 2.2 GHz. High isolation (25 dB), VSWR of 1.15:1 and low insertion loss (less than 0.3 dB). Available in 7/16" DIN, Type-N, SMA and TNC connectors. Essential for combining unbalanced inputs. Available stock – 4 weeks ARO. Weatherproof models (IP 65) available. Made in USA - 36 month warranty. **MECA Electronics Inc.**, www.e-MECA.com.

Hand-Flex Cables

VENDORVIEW

Mini-Circuits announced new interconnect cables, the 0.086" and 0.141" hand-flex coaxial cables. These cables are ideal replacements for



existing custom bent semirigid cable. Key features include wideband frequency coverage of DC to 18 GHz, low loss and excellent return loss, hand formable to almost any custom shape without special bending tools, antitorque nut prevents cable

stress during installation and a standard insulated outer jacket.

Mini-Circuits, www.minicircuits.com.

Quasi Drop-In Circulator





Renaissance has developed a new S-Band drop-in circulator that is designed for amplifiers used in space applica-

tions. The isolator can operate between 2.2 and 2.4 GHz with 0.5 dB insertion loss and 20 dB isolation and return loss. The design can handle 75 W over -40° to +95°C. Port 2 has an extended TNC female connector and the other two ports are coplanar drop-in tab style.

Renaissance/HXI, www.rec-usa.com.

Quadrature Mixer



Model SFQ-94394312-1010SF-SI is a W-Band quadrature (I/Q) mixer. The mixer employs high performance GaAs Schottky beamlead diodes, balanced configuration and proprietary circuitry to produce superior RF performance.



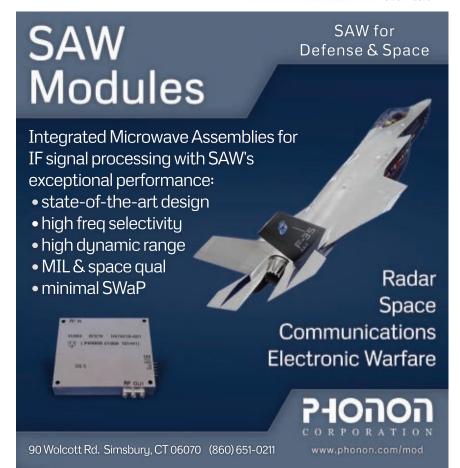
The RF and LO ports of the W-Band I/Q mixer are WR-10 waveguides and IF ports are standard SMA(F) connectors. The RF and LO operating bandwidth is up to 4 GHz

and IF frequency is from DC to 1 GHz. The mixer requires +16 dBm LO power and has 12 dB conversion loss.

SAGE Millimeter Inc., www.sagemillimeter.com.

Isolators/Circulators

VidaRF offers a wide selection of isolators and circulators designed to cover 80 MHz to 40 GHz. Configured to coaxial, drop-in, surface mount or waveguide. Standard connector





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Technology is advancing at a MILE HIGH pace and EMC testing is necessary to the success of this progress. No longer are the boundaries of EMC testing relegated to open area test sites, laboratories and text books; they are becoming part of our daily lives. The electric and hybrid vehicles and the Smart Grid, are two big arenas where EMC plays a major role.

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New Products



SMA Female, other connectors are available upon request. Magnetically shielded, clockwise or counter-clock

wise rotation (CCW), low IMD -80 dBc, reflected power from 1 to 250 W on pending models, single or double junction and RoHS compliant. **VidaBE**

www.vidarf.com.

Software

PCB Layout Software



Intercept announced a major new enhancement release of its Pantheon PCB layout software. The most notable new feature is Pantheon's 3D viewer, which displays actual stackup and dielectric layer heights, as defined by the user, with easy to use object selection and reporting. It also boasts brand new via handling. Vias and via arrays can be easily added to board, block, or component geometries, while newer capabilities allow for automatic via stitching along a manually drawn line or on the interior or exterior of selected objects.

Intercept Technology Inc., www.intercept.com.

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Power Meter Software

LadyBug Technologies' latest Virtual Power Meter V4.5 supports a broad range of RF measurement solutions. The VPM is an ideal user interface for displaying time domain scope-like



profiles of the modulated waveform. When used with Lady-Bug's Pulse Profiling Sensors, the software delivers clear and

concise pulse details. Measurements such as average power, droop, crest factor, peak and pulse power, along with statistical information such as CDF, PDF and CCDF, are also provided with full scaling control.

LadyBug Technologies, www.ladybug-tech.com.

COMPLETE Library Release

Modelithics announced the release of Modelithics COMPLETE Library version 10.0 for Agilent Advanced Design System (ADS). With this new release, the Modelithics COMPLETE Library now represents over 8600 individual microwave devices. Version 10.0 introduces over 25 new Global Models for popular surface mount RLC component families from vendors such as Passive Plus, AVX, Aeroflex, Murata and Chilisin. The Piconics conical inductor models in the CLR library have been upgraded to full equivalent circuit models validated up to 65 GHz and addressing multiple mounting configurations.

Modelithics Inc., www.modelithics.com.

Sources

OCXO

Model 122 is an ultra-high stability OCXO. The oscillator utilizes the doubleoven and IHR technologies to provide less than 1 W power consumption. It is also capable of holding high frequency stability to ± 0.2 ppb over -10° to



+60°C and ±0.2 ppb/day aging (for 10 MHz). The device is housed in a 20 × 20 mm packaging. Currently, frequencies are available from 8

to 100 MHz. Typical applications for this part includes but not limited to rubidium standard replacement, GPS disciplined frequency standards, instrumentation and communication systems.

CTS Electronic Components, www.ctscorp.com.

Rubidium Oscillator



 $\begin{array}{lll} Based & around \\ an atomic clock, \\ the & IQRB-1 \\ \pm 0.05 & ppb & rubidium & oscillator & delivers & an \\ accuracy & of \\ \pm 5E10^{-11} & irre- \end{array}$

spective of temperature fluctuations. This new Sub Miniature Atomic Clock (SMAC) is housed in a 5-pin 51 mm² package, making it compati-

New Products

ble with many existing OCXO footprints whilst offering improved performance. Operating at a standard frequency of 10 MHz, the IQRB-1 can accept supply voltages of between 12 and 18 V. Power consumption is up to 6 W with a warm-up time of typically 5 minutes.

IQD Frequency Products Ltd., www.iqdfrequencyproducts.com.

High Performance VCO

The DCSR1000-8 delivers 1 GHz output frequency signal with low phase noise performance of -122 dBc/Hz at 10 kHz. Its planar



resonator construction makes it a good solution for high vibration applications. It is an ideal building block for low

noise sources in IF converters and clock translators in high data capacity radios. Other features of this high performance VCO are supply voltage of +8 V, high modulation bandwidth and typically 15 dB of harmonic suppression.

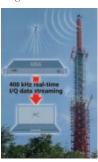
Synergy Microwave, www.synergymwave.com.

Test Equipment

Remote Spectrum Analyzer



Narda Safety Test Solutions has expanded the range of functions of its remote spectrum



analyzer. The "Scope and I/Q Data" option for the NRA-3000 and NRA-6000 analyzers deliver the data from signal sequences separated into the real (or in-phase) and the imaginary (quadrature) components. Coverage is uninterrupted up to a channel bandwidth of 400 kHz. The data are available as a gapless

stream via TCP/IP or UDP. The NRA transfers the data in blocks of up to 250,000 points for channel bandwidths of up to 32 MHz.

Narda Safety Test Solutions, www.narda-nra.com.

Temperature Sensors

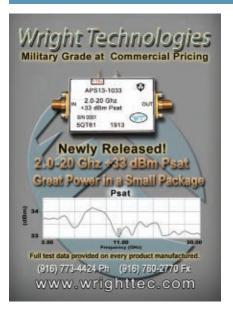


TS3 fiber optic temperature sensors control temperatures in microwave chemistry. The outer jacket of the fiber optic temperature sensor is made from Teflon

and at the sensor tip a GaAs-crystal is attached. The probe sensor is completely non-conductive and offers complete immunity to RF and microwave radiation with high temperature operating capability, intrinsic safety, and non-invasive use. The sensors are also designed to withstand harsh and corrosive environments.

OPTOcon AG, www.optocon.de.

MICRO-ADS





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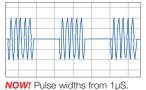


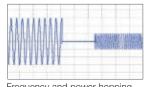
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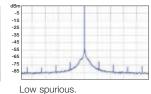
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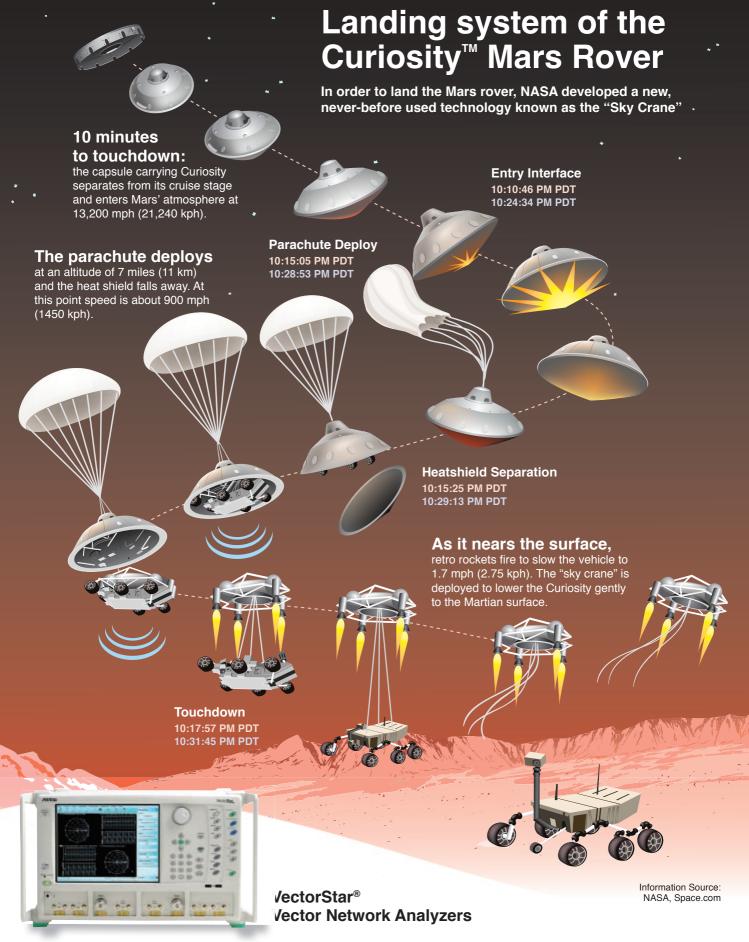
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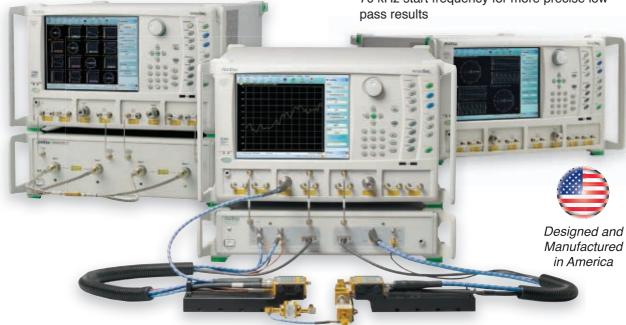
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