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November 2012

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Microwave Journal

Departments

Erratum: In last month's Technical Feature, "Design of a Passive, Broadband Equalizer for a SLED," the authors' affiliation was incorrect (October, pg 88). The correct affiliation is The College of New Jersey, Ewing, NJ.

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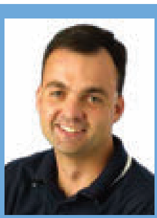

Executive Interview

Michael Keeley, director of product management, at **Spirent Communications,** talks about the commercial deployment of VoLTE and its differences from VoIP.

White Papers

Secondary Radar Transponder Testing Using the 8990B Peak Power Analyzer
Agilent Technologies

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Anritsu

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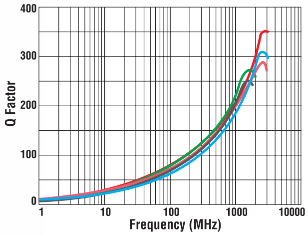

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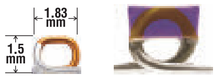

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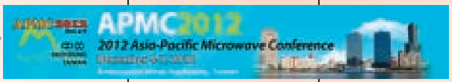
25	26	27	28	29	30	1
2	3	4 **Technical Education Webinar:** **RF PCB Design** Sponsored by AWR, LPKF	5  Kaohsiung, Taiwan **RF/Microwave Training Webinar:** **VCO Fundamentals** Sponsored by Mini-Circuits	6 **Webinar:** CST **Chip/ Package/ Board: Constraint Driven Co-Design**	7	8
9	10	11	12	13 **Webinar:** **Envelope Tracking Simulation and Analysis** Sponsored by Agilent Technologies **Webinar:** CST **Simulation of EMI in Hybrid Cabling for Combining Power and Control Signaling**	14	15
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5th International Conference on Advances in Satellite and Space Communications
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May 21–23, 2013 • Las Vegas, NV
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Technology Trends

I was recently asked to name three major global electronic industry trends from the perspective of a *Microwave Journal* editor and technical advisor to EDI CON. Sensing the need to "think big," I responded with my thoughts on 5G (the mobile Internet for all things), Near Field Communications (NFC), and the promise of GaN and CMOS to disrupt current RF semiconductor technologies. These trends were naturally influenced by the information that comes across my desk in the form of article proposals for this magazine and potential content for next year's big microwave design event in Beijing. While we haven't yet received any EDI CON papers related to 5G, our December cover story from Prof. Dr. -Ing Gerhard Fettweis of Technische Universitat Dresden does look at possible mobile telecommunication standards for the year 2020. Instead, the bulk of papers submitted to EDI CON has been concerned with more immediate communication system challenges, RF/microwave and high speed electronic design and developments in semiconductor technologies. Still, *Microwave Journal* and EDI CON have generally reinforced each other with regard to what our contributors consider to be important.

In discussing the technical program for EDI CON, I have stressed the educational nature of the event. Our goal is to bring the engineering resources of the world's leading high-frequency electronic companies together with the working engineers and researchers who need to tap into this expertise. Our goal is to provide a platform for information that is practical and relevant to the challenges of electronic component design and system integration. To achieve this objective, workshop and panel themes are being developed based on input from the event participants (sponsors), industry insiders, academic advisors from China and the EDI CON technical advisory committee. Over the past two months, several special themes have been identified and are currently in development.

The GaN Technology Panel at EDI CON 2013 will focus on the latest innovations, emerging trends and applications of this semiconductor technology. Building on the successful panel sessions organized by *Microwave Journal* at IMS 2012, including "Where are the Emerging RF Market Opportunities for GaN?", this event will focus primarily on technical issues. The panel will feature industry experts in a 90 minute session that includes individual presentations followed by a question and answer session with the audience. Freescale Semiconductor will be among the participants. Its technical team will discuss the company's new GaN hetero-junction field effect transistors (GaN HFET) for emerging high-power, high-efficiency RF applications.

The Connectivity Forum is a dedicated track focused on issues related to RF, microwave and high-speed interconnect technology, including cables, connectors, probes, harnesses, fiber optics and over-the-air methods for a wide range of applications. This forum will combine technical papers and a special panel examining emerging connector technology, the universal trend toward miniaturization, weight reduction and added functionality, mechanical, electrical and environmental requirements, phase stability, PIM and space qualifica-

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tion. Times Microwave Systems will be participating in the forum with engineering expertise on RF/microwave connectivity solutions. Other confirmed talks include Howard Hausman, CEO of MITEQ Inc., presenting “Applications of Fiber Optic Links in RF and Microwave Systems” and Wei Liu, president of MITRON, discussing “Cable Assembly Solutions for Specific Commercial and Military Applications.”

Spirent Communications will sponsor a portion of the EDI CON technical program with an hour long panel session on “The Changing Face of Testing: Moving from Conducted to OTA.” This panel will be led by Spirent and will include three additional industry participants representing various aspects of the wireless ecosystem specific to the Asia market. Spirent and the other panelists will share their perspectives on the need for Over-The-Air (OTA) test methodologies as a means to achieve a complete picture of real-world performance for mobile devices and base stations. This discussion will consider both Multiple-In-Multiple-Out (MIMO) and Assisted Global Navigation Satellite System (A-GNSS) OTA test requirements. When paired with beamforming technology, MIMO offers the ability to deliver higher data rates, greater coverage, and lower operational costs. Equally compelling is the significant role A-GNSS technology plays in enabling the next-generation Location-Based Services (LBS), resulting in a vital need to accurately quantify and benchmark the performance of A-GNSS via OTA testing. These technologies, however, present increased complexity in RF testing of base stations and mobile device receivers making MIMO OTA testing more critical than ever before. A key objective of this panel session is to clearly illustrate the pre-commercial benefits of testing per the CTIA standards for radiated OTA performance, in addition to the 3GPP industry standards for conducted minimum performance.

The GaAs foundry workshop will feature the latest information from WIN Semiconductors and OMMIC on the state of technology available from these leading compound semiconductor foundry services. III-V semiconductor ICs dominate mobile handsets where the market size is expected to hit $5 billion USD in 2016. China is one of the world’s fastest growing markets for mobile phones, and therefore a major consumer of GaAs-based switches and power amplifiers (PA), making this workshop especially relevant to our Beijing audience.

As authors, workshop sponsors and participating members of China’s RF, microwave and high-speed electronics community continue to submit content, these contributors provide shape to an event that will reflect the trends defining the future of this market; providing an indicator and guide to the next set of big microwave innovations, whatever these might be. Stay tuned. ■

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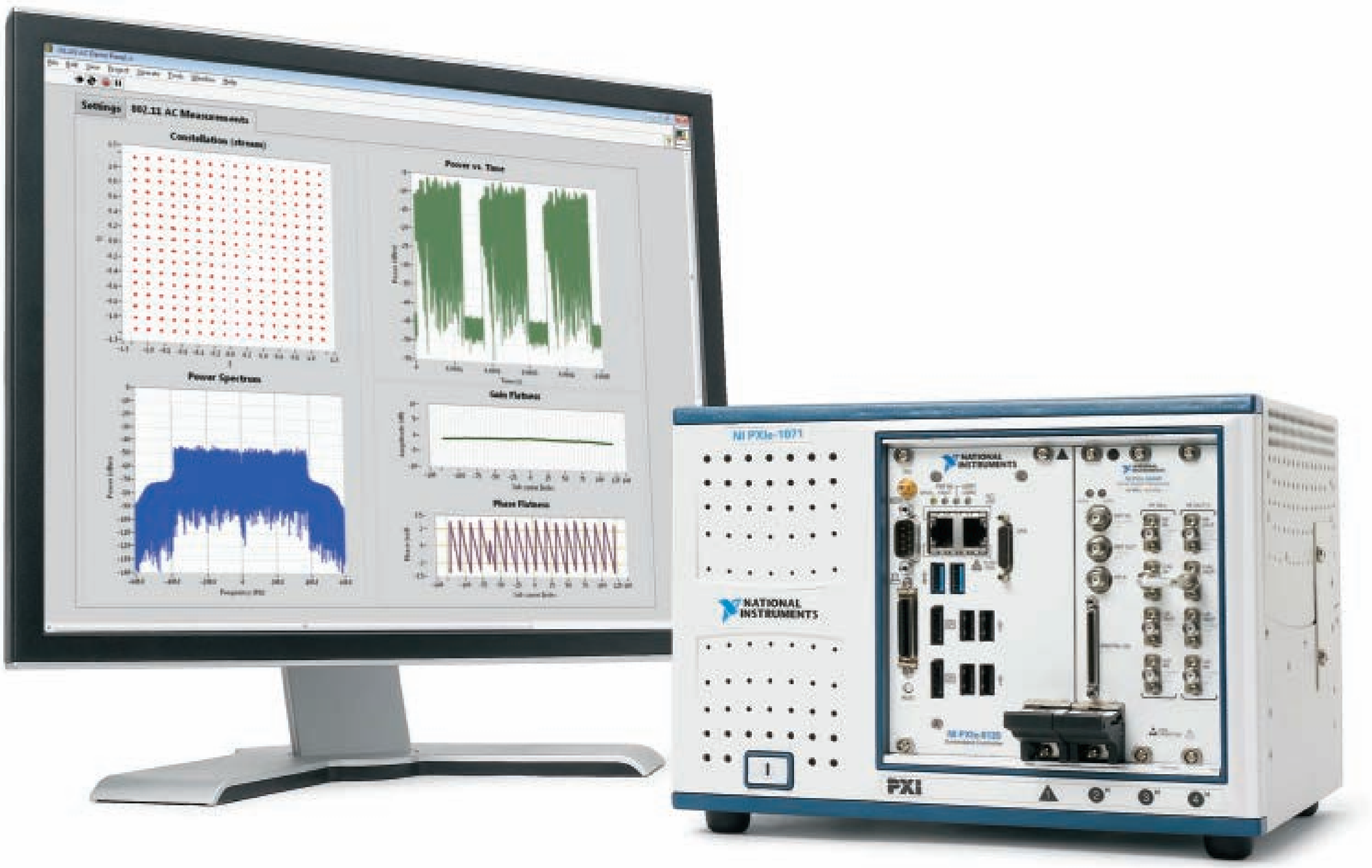

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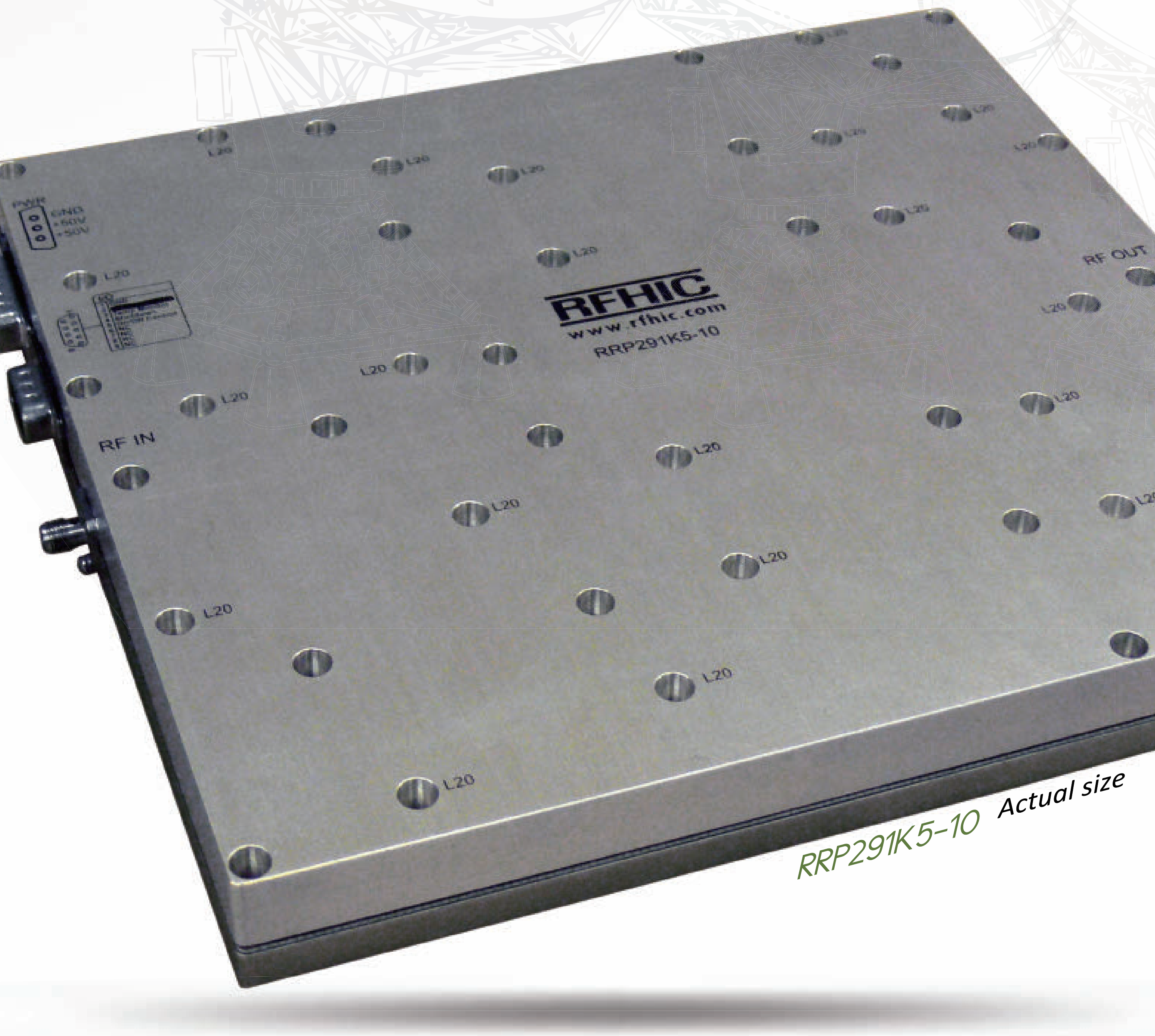

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COVER FEATURE
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Tunable RF Technology Overview

Over the past 10 years, the cellular industry has seen dramatic changes in both the requirements on, and the capabilities of the radio to support the wireless connection. The radio has evolved from a single-mode, triple-band 2G system in year 2000, to a triple-mode, 9-band (4×GSM, 5×UMTS with HSPA+), high-speed data-capable system in year 2010. And this new capability required only a third of the physical area. This evolution was driven by both: CMOS technology evolving from 0.35 µm to 65 nm, and smart integration in the front end including product innovations such as converged PAs and highly complex antenna switch modules together with more capable and compact filters.

The trend continues today with rapid deployment of 4G LTE systems, driving new bands and modes of operation. While the CMOS may continue to scale, the analog signal-conditioning RF front end and antennas pose particular challenges to scaling due to physical limits. For the front end to be able to support the continuing evolution, new enabling technologies must be introduced as we approach the limits of improvements through packaging and hybrid integration. Antenna bandwidths are highly constrained by the physical volume requirements. Tunable RF components will enable the continuation of the market requirement for significant reduction in size and total volume as the number of bands and modes increases. Additionally, tunability enables handset form-factors previously only realizable in single-mode applications, allowing for example a single antenna to cover all traditional cellular bands as well as new LTE bands.

Today, several technologies offer a useful tunable RF capability. Traditional technologies such as switched capacitor networks (RF switch plus integrated MIM capacitor), as well as newer technologies such as Barium Strontium Titanate (BST) and Micro Electro-Mechanical Systems (MEMS) are all now in use. These approaches all offer the ability to dynamically change the impedances within a RF component while introducing a minimum amount of loss. The ability of these various technologies to meet the new requirements of the rapidly-expanding RF front end is examined in detail herein.

Since the digital cellular revolution began in the early 1990s, operators and handset manufacturers alike have been striving to increase the functionality of the handset. User demands have moved from simple voice communications, to roaming across different networks, perhaps on different frequency bands, and eventually to higher data bandwidths to sup-

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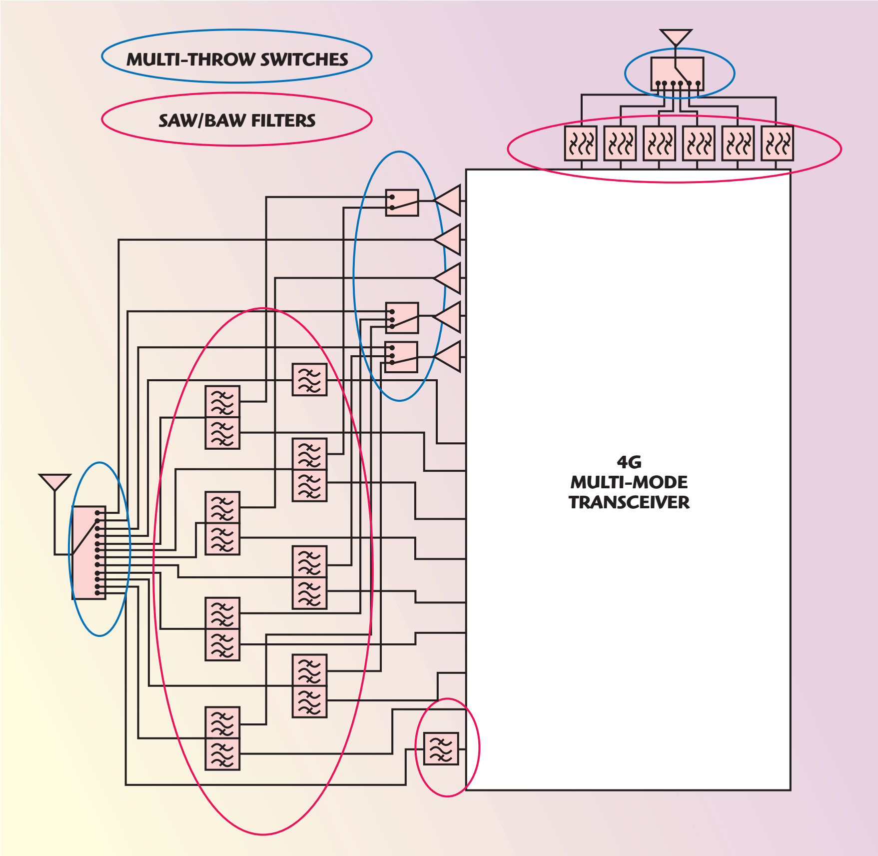
WiSpry Inc., Irvine, CA

port highly capable smartphones and other mobile computing devices.

For example, initial 2G GPRS systems could transmit data at a rate of 56 kb/s (using four time slots), while 2.5G EDGE systems increased that rate to 384 kb/s. Devices with 3G capability could achieve data rates as high as 2 Mb/s, though achieving these high speeds became more dependent upon the user environment. This trend continues with 4G, where the expected theoretical data rates are as high as 70 Mb/s. The higher data rates drive the need for additional spectrum, expanding from single-band operation in the early 1990s to over 38 bands supporting 2/3/4G worldwide bands from 700 to 3500 MHz and continuing to expand. At the same time, the mobile device itself is driving toward more compelling form-factors, with tradeoffs between screen size and overall bulk, leading to extremely thin designs. This "Thin is In" trend reduces the effective bandwidth capability of the antenna, especially at low frequencies. Thus handsets that cover both voice-capable bands, such as Band V or Band VIII as well as a low-frequency LTE band such as Band XII or XIII, have been driven to use multiple antennas.

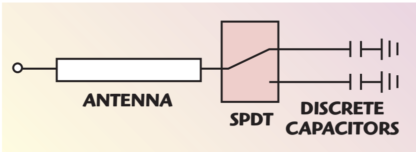
An interesting industry observation by Jan-Erik Mueller of Intel Mobile Communications captures this trend. In the past decade, we have seen the radio evolve from a single-mode, triple-band 2G system to a tri-mode, 9-band (4×GSM, 5×UMTS with HSPA+) system utilizing only a third of the physical area, and expectations are that this trend will continue. This has been coined "Mueller's Law," applying to the cellular radio as Moore's Law applies to integrated circuits.

While the digital portions of the radio continue to scale following Moore's law, the analog front end elements (filters, switches, amplifiers, antennas) have depended mostly on improved packaging and integration to support the trend while the core functional elements do not scale due to physical power and frequency limitations (see ***Figure 1***). Thus either additional elements must be included to cover the additional bands/modes or the elements must have sufficient bandwidth to cover all or groups of modes which limits their size and performance.



▲ *Fig. 1 Wireless front end complexity and challenges to scaling.*

Tunable RF technology is changing the game. In recent years, tunable RF technologies have allowed the front end designer more freedom to create configurable matching circuits. These can be used to adjust the antenna match to reduce mismatch loss and improve the overall efficiency of the antenna at frequencies other than the original design frequency, enabling a single antenna to be utilized for more modes. Tunable RF circuits can also be used for antenna load tuning, where the tunable capacitor is inserted at the antenna load (ground) to change the effective electrical length of the antenna. This was initially implemented using discrete switches and capacitors, but now can be accomplished with higher precision, multiple tuning states and lower losses. Also, these tuning elements enable a new generation of compact tunable filters along with tunable RF matching for power amplifiers and LNAs. In addition to improving the scaling of the RF front end, the availability of high Q and highly linear tunable capacitors leads to improved system performance in compact form factors and can also enable entirely new front end architectures.



▲ *Fig. 2 Traditional load switch.*

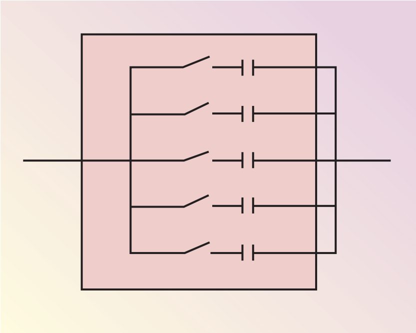
TECHNOLOGIES

Three basic technologies are currently being utilized for tunable RF, primarily focused on antenna tuning at this time. These technologies are:

Switched Capacitors

Field Effect Transistors (FET) have been used for several years to provide antenna load tuning.[1] This load-tuning approach typically used a SPDT switch to choose between two different discrete reactive networks (capacitive or inductive) to modify the resonant frequency of the antenna (see ***Figure 2***).

Switched capacitor solutions today utilize either GaAs or CMOS switching FETs with integrated metal-insulator-metal (MIM) capacitors, typically in a 4- to 6-bit configuration (see ***Figure 3***).



▲ *Fig. 3 Switched capacitor.*

FETs have an inherent tradeoff between on-resistance and off-capacitance, which can be characterized by an industry-standard figure-of-merit, $R_{on} \cdot C_{off}$. The on resistance affects the Q of the device, while the off capacitance increases the parasitic loading due to the off branches. For reasonable performance, FETs fabricated using either GaAs j-PHEMT, silicon-on-sapphire (SOS), or silicon-on-insulator (SOI) with gate lengths in the 0.13 to 0.25 µm are integrated with MIM capacitors. For high power applications, voltages as high as 40 to 100 V are encountered due to the high VSWR encountered in antennas. In many cases, the breakdown voltage of the transistors and/or capacitors will not meet the power handling requirements and must be stacked, increasing the insertion loss and cost/size accordingly.

SOS or SOI FETs approach PHEMT devices' R_{on}, in the range of 1.5 to 2.5Ω mm. These technologies have similar off capacitances leading to $R_{on} \cdot C_{off}$ figure-of-merit of 200 to 400 femtoseconds. For an overall capacitance ratio of 5:1 together with associated MIM capacitor losses and parasitics, this leads to an effective Q in the maximum capacitance state at 1 GHz of 25 to 50. For impedance matching applications, and for antennas with relatively low VSWR, this moderate Q for the switched capacitor solution may yield acceptable performance. The silicon FETs operate from standard control voltage levels, so no additional voltage levels need to be generated for operation. The digital interface can be integrated directly onto silicon switched capacitors but a separate CMOS controller is required for GaAs circuits.

Advantages:

- Low voltage operation
- Total switching cycles
- Low parasitic shunt capacitance
- Low cost, high volume, standard technology

Disadvantages:

- Low Q and/or low ratio (tradeoff)
- Low breakdown voltage
- Linearity (IP3, harmonics)

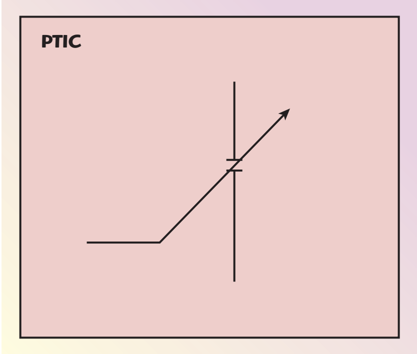
Barium Strontium Titanate (BST)

Ferroelectric and paraelectric materials provide controllable and high capacitance density utilizing their high dielectric constant which can be varied with applied voltage. BST is the most common paraelectric for RF application which exhibits about a 3:1 capacitance variation with applied voltage where the ratio is intentionally limited to provide stable temperature operation and reasonable linearity.

When the applied electric field is near zero, the unit cells in the crystal lattice are easily polarized leading to the peak dielectric constant and thus to a large capacitance value when used as a capacitor dielectric. As an electric field is applied, the resulting polariza-

tion reduces the sensitivity to additional field which lowers the effective dielectric constant. This inherently nonlinear behavior is used to build variable capacitors that are controlled by the applied voltage. Lower losses are possible than those available from switch-based systems leading to an expanded range of applications. However, the basic thermodynamics of the operation can lead to thermal stability issues. Substantial investments in improved materials and circuit operation points have mostly addressed these issues. Note that the analog control requires high voltages. The high voltage control is implemented in a separate chip that also includes a serial interface. The key limitations currently include low tuning ratio, marginal linearity and cost of the hybrid analog system.

BST capacitor fabrication is not yet compatible with monolithic CMOS integration thus requiring a separate control chip for use in a handset. This chip would provide a programmable charge pump



▲ *Fig. 4 Single BST capacitor.*

to generate the variable high voltage and may also include an integrated digital interface and other circuitry. Note that this is a smoothly varying analog capacitor as compared to the inherently digital nature of the switched capacitors.

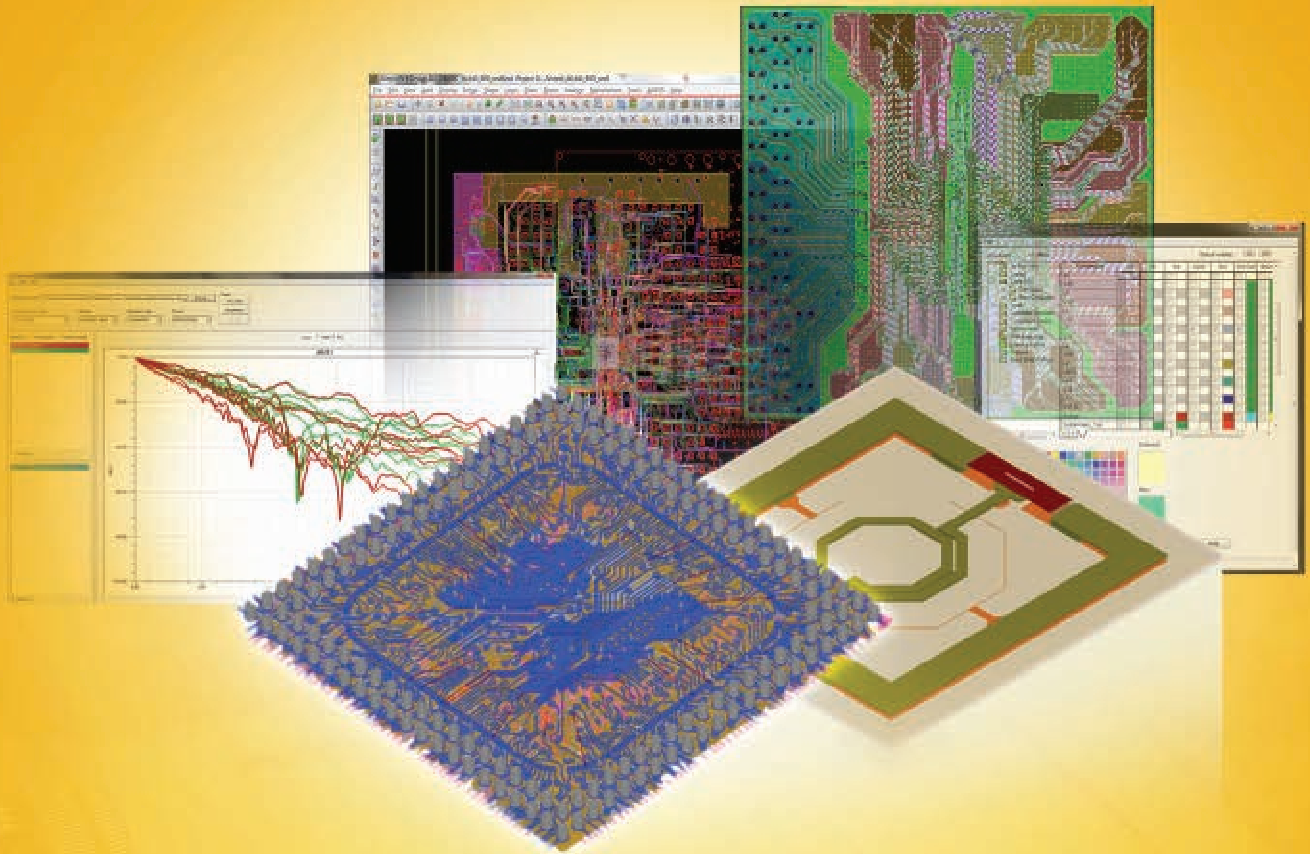
As BST provides a single variable capacitor without the need for a FET switch in series with the capacitor, the overall Q of this approach is higher (see ***Figure 4***). As the voltage is applied across the same terminals as the RF, special consideration must be taken to maintain linearity so the RF or low frequency modulation does not directly modulate the capacitance which would add spurious content. This involves stacking the capacitors to reduce the RF voltage across individual capacitors and alternating the polarity of the DC control voltage to improve linearity. However, stacking the capacitors directly reduces the effective capacitance density.

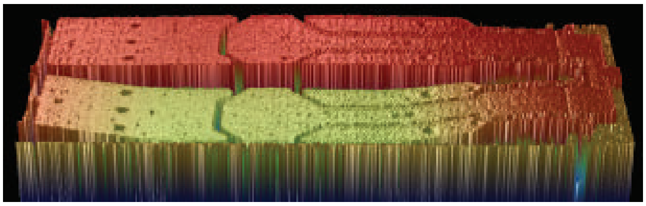
Advantages:
- Moderate Q
- Total switching cycles
- High capacitance density feasible

Disadvantages:
- Linearity
- Tuning ratio
- Analog control, requires control chip

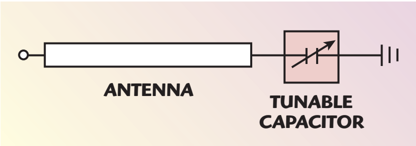
Micro Electro-Mechanical Systems (MEMS)

MEMS technology is now available for RF applications.[2] This technology consists of CMOS-integrated movable mechanical structures which provide the tunable capacitance. The small mechanical beam is actuated with electrostatic force applied through an integrated CMOS controller with the beam directly part of the RF network. Thus, the RF path for each MEMS beam is essentially a pair of metal traces with either a capacitor dielec-

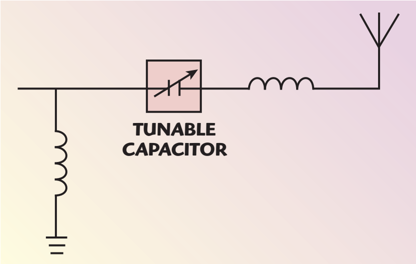




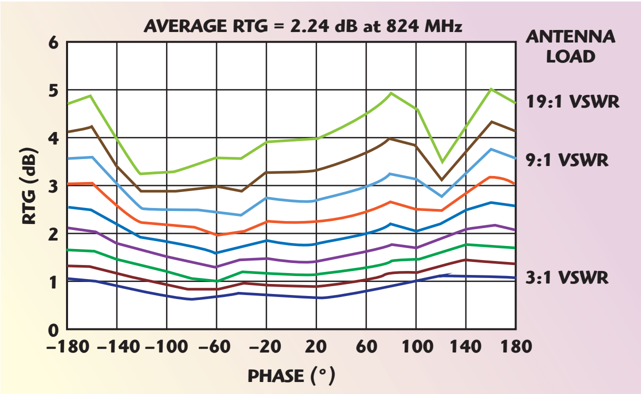
▲ *Fig. 5 MEMS capacitor elements top element "off," lower element "on."*



▲ *Fig. 6 Antenna load tuner.*



▲ *Fig. 7 Tunable impedance match (one simple topology shown).*



▲ *Fig. 8 RTG for a MEMS tuner at 824 MHz.*

tric ("on" state) or air gap ("off" state) separating the two metal traces (see ***Figure 5***). These MEMS beams are configured into an array to form a digital capacitor with many states (equivalent of 6- to 9-bits of resolution). The array can be sub-divided into series and/or shunt branches, or some combination.

MEMS provides performance enhancements to many of the aforementioned deficiencies. The RF path is through metal traces on a mechanical device (with virtually no frequency response at RF) rather than a solid-state junction, so the Q and linearity are much higher. Also, for the commercially available MEMS products, the DC voltage is physically separate from the RF path; thus, the voltage handling is quite high at well over 120 V peak. Traditionally, MEMS devices have required specialized packaging to maintain the hermetic environment around the movable structures, but the technology now allows for fully encapsulated devices at the wafer level and enables standard low-cost packaging or even wafer level chip scale packaging. As a mechanical device, however, there exists an aging effect which eventually will cause device failure, related to wearout. MEMS devices are digital devices exhibiting very little temperature dependence, with temperature coefficient of capacitance in the sub -200 ppm/°C range.

Advantages:

- High Q
- High linearity (IP3 and harmonics)
- Voltage handling
- Temperature stability
- Fully integrated

Disadvantages:

- Total cycles
- CMOS process complexity (cost)

A general summary of strengths/weaknesses for the various tunable RF technologies is presented in ***Table 1***.

TABLE I

STRENGTHS & WEAKNESSES FOR TUNABLE RF TECHNOLOGIES

	Switched Capacitors *(SOS/SOI/GaAs Switches + Integrated MIM Capacitors)*	***BST*** *(Barium Strontium Titanate)*	***MEMS*** *(Micro Electro-mechanical Systems)*
Quality Factor (Q)	Low	Moderate	High
Intercept Point	Moderate	Moderate (if stacked and ratio low)	High
Harmonics	Poor	Moderate	Excellent
Capacitance Ratio	High (for low Q) Low (for high Q)	Low	High
Voltage Handling	Low	Moderate	High
Switching Cycles	High	High	Moderate
Cost	Low	Moderate	Moderate

APPLICATIONS

Antenna Load Tuning

Today, the load-tuning method described above is being adapted to benefit from higher Q devices with less loss, and also with much greater tuning resolution to fine-tune the frequency selection. Load tuning must be incorporated into the antenna design, as it affects the effective electrical length of the antenna, as shown in ***Figure 6***. The loaded antenna typically has a narrower instantaneous bandwidth and strongly benefits from tuning components with high voltage handling and good linearity.

Antenna Impedance Matching

In addition to antenna load tuning, the Tunable Impedance Match (TIM) is enabled by the new tunable RF technologies. As shown in ***Figure 7***, this is basically a reactive tuning network at the input of the antenna (at the 50 Ω interface). If the antenna is not well matched to 50 Ω, the TIM will provide a match over some frequency range. The range of antenna impedances covered with acceptable losses will depend upon the tuner Q and capacitance ratio.

One method of characterizing the effectiveness of an antenna impedance tuner is to look at "Relative Transducer Gain, or RTG." RTG (or ΔG_T) is defined as

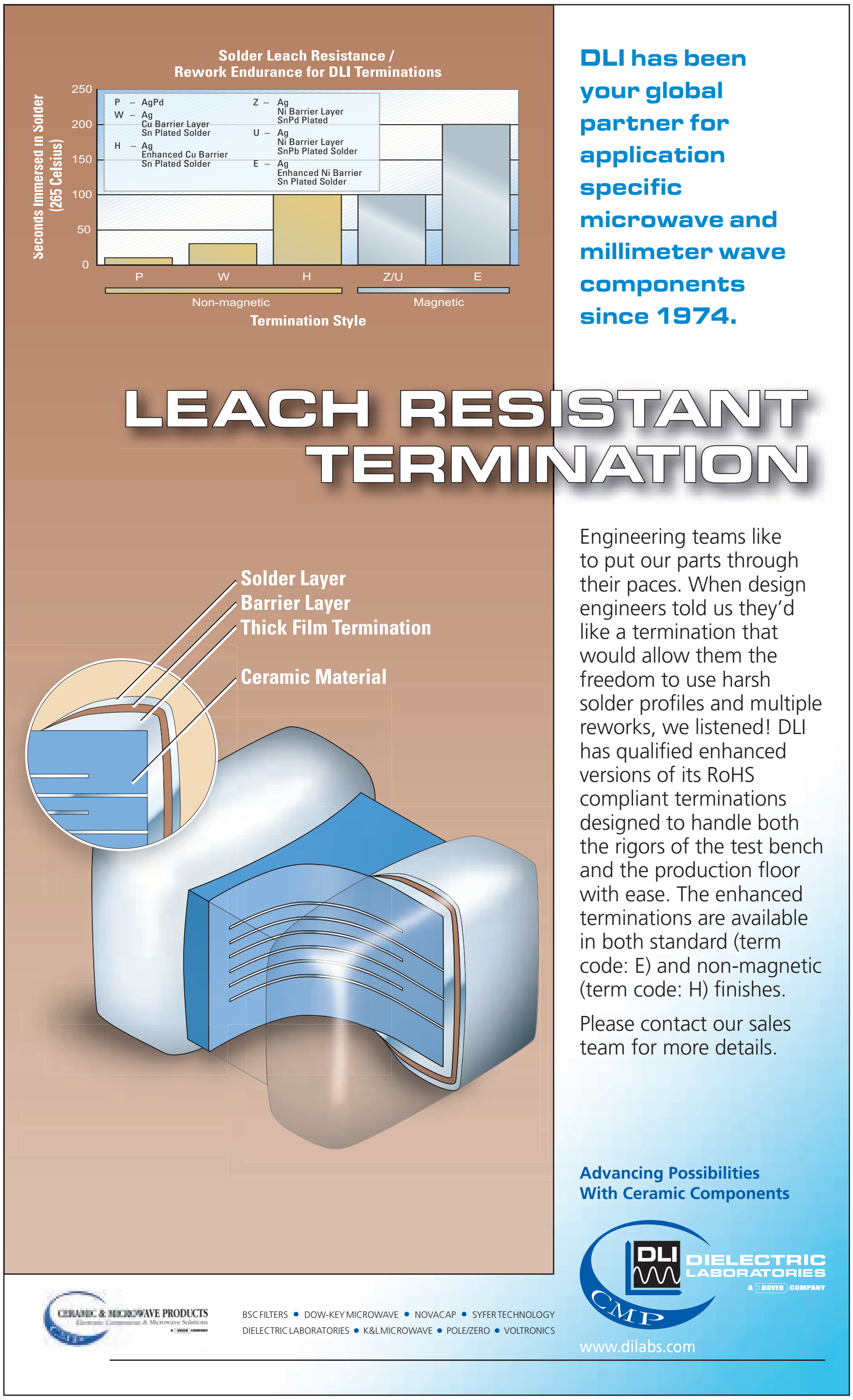
$$\Delta G_T = \frac{\text{Delivered Power to Load}}{\text{Delivered Power to Unmatched Load}} = \frac{|S_{21}|^2}{|1-S_{22}\Gamma_L|^2} \quad (1)$$

or simply, the power delivered to the antenna with the tuner relative to the power that would be delivered to the same antenna without a tuner. A typical characteristic for RTG is shown in ***Figure 8*** as a function of antenna load magnitude and phase. This figure shows 4 to 5 dB of improvement can be achieved with an antenna exhibiting a 19:1 VSWR.

OTHER APPLICATIONS

Tunable Filters

Future uses of High Q tunable capacitors are in tunable filters. These can take the form of notch filters for specific interference rejection (carrier aggregation or simultaneous voice & data applications, for example), or can provide noise rejection for a receive frequency. Requirements for Q, voltage handling and linearity are even greater in filter applications, where voltages and losses are multiplied at resonance. Small step size or resolution is also very important for tunable filters to allow precision control of the filter response.



Power Amplifier Tunable Match

Recent trends in wireless front ends have led to broadband PAs. This allows a reduction in the number of PAs while still supporting the multiple frequency bands required. A switch/filter network is then applied to properly filter the Rx-band noise and harmonics that are generated in the PA. Power Added Efficiency for the broadband PA is reduced as the harmonic frequencies cannot be as effectively terminated. High Q tunable capacitors can be used to provide narrowband matching, with inherent Rx-band noise rejection, and potentially optimized harmonic tuning/filtering. The narrowband match, combined with these other features, can enable very high efficiency PAs, stable and tunable over a wide frequency range, and equally so from CMOS as well as GaAs.

CONCLUSION

Tunable RF technologies are enabling new frontiers for wireless system RF front ends. The opportunity for smaller form-factor antennas, compensation for head- and hand-loading, and more aggressive antenna designs with higher VSWR over a broader frequency range is allowing for much more flexibility in the industrial design of the handset or tablet. As additional tunable components become available, we will see further reduction in the area and cost of the RF front end along with better RF performance and even wider frequency ranges. The projected performance of tunable RF components will eventually enable "RF Nirvana," the true software defined radio, where both digital and analog portions of the radio are fully programmable. ■

References

1. "Frequency-Tunable Internal Antenna for Mobile Phones," *12th International Symposium on Antennas (JINA 2002)*, Nice, France, November 12-14, 2002, Vol. 2, pp. 53-56.
2. "WiSpry Wins First-Ever RF-MEMS Mass-Production Handset Deal," www.reuters.com/article/2012/01/10/idUS202199+10-Jan-2012+BW20120110.

Most Valuable Product

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Fast, Reliable and Accurate EMI Test Receiver

Rohde & Schwarz's new R&S ESR EMI test receiver features comprehensive diagnostic tools such as spectrogram display, real-time spectrum analysis and IF analysis to help developers detect and eliminate electromagnetic interference. At the same time, it has all the capabilities of a full-featured, powerful signal and spectrum analyzer for lab applications and is easy to use thanks to its intuitive touch-screen interface.

The R&S ESR measures both conducted and radiated disturbances in compliance with CISPR 16-1-1 and can easily undertake EMI measurements relevant to EMC standards and product certification compliance. Like all of the company's EMI test receivers, it is based on a powerful signal/spectrum analyzer platform (R&S FSV). With the internal pre-selection activated, it also performs standard-compliant EMI measurements in spectrum analyzer mode.

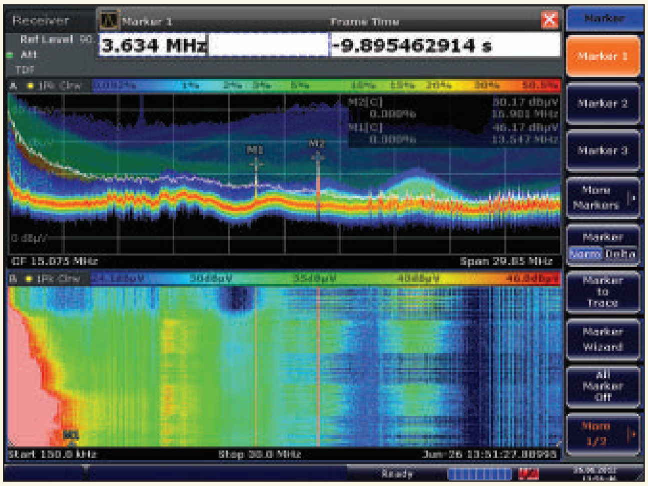
The test receiver is available in two models for frequencies ranging from 9 kHz to 3.6 or 7 GHz. An option extends the range down to 10 Hz. EMI bandwidths in decade steps from 10 Hz to 1 MHz are optionally available for measurements in line with MIL-STD-461, DO-160 and ICNIRP guidelines on exposure limits.

The R&S ESR also features time-domain scan, which is an FFT-based receiver technology that is claimed to enable it to perform measurements up to 6000 times faster than conventional EMI test receivers. In the time-domain scan mode, the instrument achieves level measurement accuracy in line with CISPR 16-1-1.

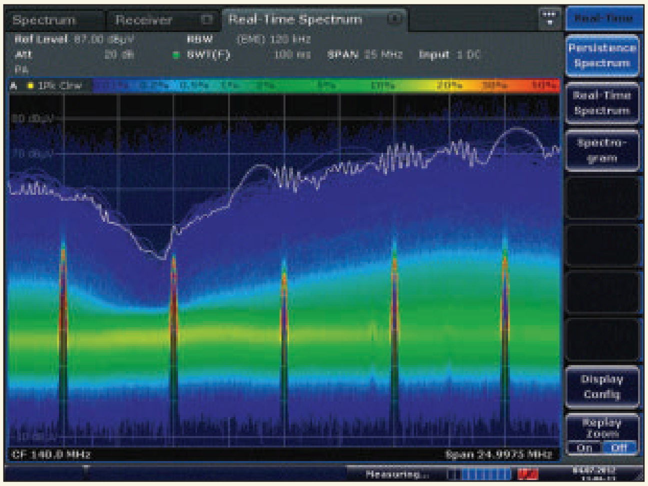
Standard-compliant measurements that took hours can now be completed in seconds. Speed is crucial when testing equipment that can be operated or measured only during a short period of time. The automotive and lighting industries are good examples because: the DUT can change its EMI characteristics during operation; extended operation might be destructive; or, the DUT may have a short operating cycle. A shorter measurement time lets users increase the dwell time per frequency segment and more reliably detect intermittent interferers with low repetition rate or isolated pulses.

The R&S ESR can measure a disturbance signal in both modes, the time domain scan mode and the conventional stepped frequency scan mode. Users decide which method is best for their ap-

Rohde & Schwarz
Munich, Germany



▲ *Fig. 1 Display showing disturbance spectrum in a split screen — persistence mode at the top and as a real-time spectrogram below.*



▲ *Fig. 2 In persistence mode, the R&S ESR can reveal narrowband disturbances that would otherwise be hidden by a high level broadband interference.*

plication, or they can compare the results of both methods in one diagram.

DISTURBANCE MEASUREMENT

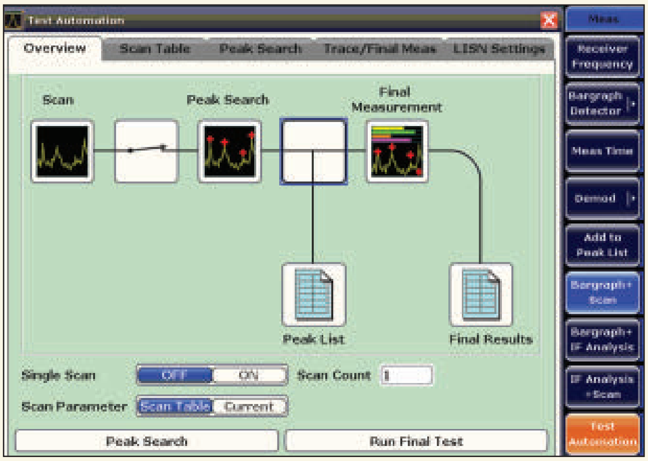
With its real-time analysis function, the R&S ESR opens up totally new diagnostic capabilities for measuring disturbances caused by sporadic events in the frequency domain or for determining the spectral behavior of devices under test during switching operations. The spectrogram function displays the analyzed spectrum over time and records measurements for up to five hours to detect sporadic interferers. The frequency mask trigger is another useful feature. If the mask is violated, a trigger is activated, the measurement is stopped, and the user can analyze the exact cause and effect of the interferer.

In persistence mode, the R&S ESR writes a pre-defined number of seamless spectra into a single diagram and displays a color-coded probability distribution of frequencies and amplitudes. This allows users to differentiate between continuous disturbances and pulse interferers present for very brief periods. It also makes it possible to detect narrowband interferers hidden by broadband signals and to identify specific pulsed disturbances, as shown in ***Figures 1*** and ***2***.

For quick, accurate tuning to the signal of interest, the R&S ESR's IF analysis function provides a spectral display of the RF input signal in a selectable range up to ± 5 MHz around the EMI receive frequency (see ***Figure 3***). This provides a detailed overview of the spectrum occupancy around the measurement channel, allowing signals to be quickly classified as disturbance signals or wanted signals. AM or FM audio demodulation can be activated in parallel, making it even easier to identify detected signals.

The time-domain display function of the R&S ESR allows users to assess the disturbance's timing behavior on a fixed frequency – comparable to using an oscilloscope. The level versus time on the set receive frequency can be measured from 50 µs to 100 s resolution. This feature can help determine the pulse repetition frequency (PRF) of a broadband disturbance or for click rate analysis to product standard CISPR 14-1.

▲ *Fig. 3 IF analysis using a split screen: RF input signal centered at the EMI receive frequency (a) and a stored trace of the preview measurement (b).*



▲ *Fig. 4 Users can configure automatic test sequences such as preview, data reduction, and final measurement very easily and execute them by the touch of a finger.*

The instrument is also easy to operate. Its 21 cm touch-screen has an 800 × 600 pixel resolution, measurement modes are distinctly separated, and the operating mode can be switched directly. Automated test sequences (preview measurement, data reduction and final measurement) are quickly configured on a single touch-screen (see ***Figure 4***).

INTERACTIVITY

If required, the final measurement can be done interactively. With up to four million values per trace, the R&S ESR performs seamless frequency scans with narrow IF bandwidths across very wide frequency ranges. This high-frequency resolution means the disturbance frequency is measured with high accuracy – a major advantage over spectrum analyzers or test receivers that use fewer test points.

The EMI test receiver includes a set of typical transducers for test antennas and a selection of important limit lines compliant with commercial product RF emission standards. Users can also create their own limit lines and correction tables. Multiple correction factors can be combined in transducer sets.

The test receiver's application spectrum is as versatile as its diagnostic capabilities. The R&S ESR makes it easy to perform acceptance testing (conducted or radiated) in line with EN/CISPR/FCC on modules, assemblies, household appliances, IT equipment, TVs, radios, etc. In the automotive sector, the EMI test receiver is suitable for acceptance testing in line with automobile manufacturer guidelines – including mobile applications thanks to the DC operation option.

Using the optional, rechargeable battery pack, the R&S ESR can record measurements for up to two hours on a single charge. Finally, R&S EMC32 software can remotely control the R&S ESR and integrate it into complex EMC systems for automated measurements.

VENDORVIEW

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

High Performance...

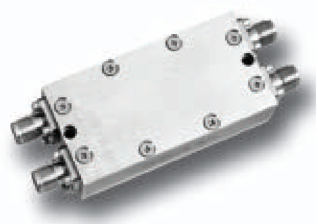
Mixers

Model Number	RF/LO Frequency (GHz)	IF Frequency (GHz)	LO Power (dBm)	Conversion Loss (dB) Typ./Max.	LO-to-RF Isolation (dB) Min.
DOUBLE-BALANCED VERSIONS					
DM0052(L)A2	0.5 - 2	DC - 0.5	7 - 13	6.5/8.5	25
DM0104(L)A1	1 - 4	DC - 1	7 - 13	5.5/7	30
DM0208(L)W2	2 - 8	DC - 2	7 - 13	7/8	30
DM0408(L)W2	4 - 8	DC - 2	7 - 13	5/6	30
DM0812(L)W2	8 - 12	DC - 4	7 - 13	4.5/6	30
DM0416(L)W2	4 - 16	DC - 4	7 - 13	7/8	30
DB0218(L)W2	2 - 18	DC - 0.75	7 - 13	6.5/8.5	22
DB0226(L)A1	2 - 26	DC - 0.5	7 - 13	9/10	20
DB0440(L)W1	4 - 40	DC - 2	10 - 15	9/10	20
TRIPLE-BALANCED VERSIONS					
TBR0058(L)A1	0.5 - 8	0.05 - 3	10 - 15	10.5/12.5	15
TB0218(L)W2	2 - 18	0.5 - 8	10 - 15	7.5/9.5	20
TB0426(L)W1	4 - 26	0.5 - 8	10 - 15	10/12	20
TB0440(L)W1	4 - 40	0.5 - 20	10 - 15	10/12	18

DYNAMIC RANGE OPTIONS

(*) Add Letter	LO/IF Power Range	Input 1 dB C.P. (dBm) (Typ.)
L	10 - 13 dBm	+6
M	13 - 16 dBm	+10
H	17 - 20 dBm	+15

Image Rejection Mixers



Model Number	RF/LO Frequency (GHz)	Conversion Loss (dB) Max.	Image Rejection (dB) Min.	LO-to-RF Isolation (dB) Min.
IMAGE REJECTION MIXERS				
IRM0204(*)C2(**)	2 - 4	7.5	18	20
IRM0408(*)C2(**)	4 - 8	8	18	20
IRM0812(*)C2(**)	8 - 12	8	18	20
IRM1218(*)C2(**)	12 - 18	10	18	20
IRM0208(*)C2(**)	2 - 8	9	18	18
IRM0618(*)C2(**)	6 - 18	10	18	18
IR1826NI7(**)	18 - 26	10.5	18	20
IR2640NI7(**)	26 - 40	12	18	20

Model Number	RF/LO Frequency (GHz)	Conversion Loss (dB) Max.	Balance Phase (±Deg.) Typ./Max.	Balance Amplitude (±dB) Typ./Max.	LO-to-RF Isolation (dB) Min.
I/Q DEMODULATORS					
IRM0204(*)C2Q	2 - 4	10.5	7.5/10	1.0/1.5	20
IRM0408(*)C2Q	4 - 8	11	7.5/10	1.0/1.5	20
IRM0812(*)C2Q	8 - 12	11	5/7.5	.75/1.0	20
IRM1218(*)C2Q	12 - 18	13	10/15	1.0/1.5	20
IRM0208(*)C2Q	2 - 8	12	7.5/10	1.0/1.5	18
IRM0618(*)C2Q	6 - 18	13	10/15	1.0/1.5	18
IR1826NI7Q	18 - 26	13.5	10/15	1.0/1.5	20
IR2640NI7Q	26 - 40	15	10/15	1.0/1.5	20

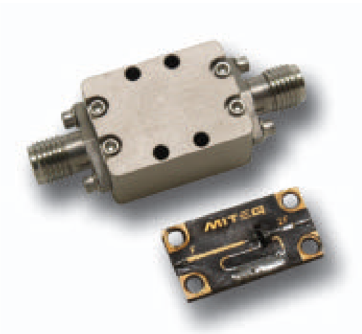
IF FREQUENCY OPTIONS

(**) Add Letter	IF Frequency Range (MHz)
A	20 - 40
B	40 - 80
C	100 - 200
Q	DC - 500 (I/Q)

Mixer Products

Passive Doublers

Model Number	Input Frequency (GHz)	Input Power (dBm)	Output Frequency (GHz)	Conversion Loss (dB) Typ./Max.	Rejection (dBc) Typ. Fund.	Rejection (dBc) Typ. Odd Harm.
DROP-IN VERSIONS						
SXS01M	0.5 - 3	8 - 12	1 - 6	13/16	-20	-25
SXS04M	2 - 9	8 - 12	4 - 18	13/15	-20	-25
SXS07M	3 - 13	8 - 12	6 - 26	13/18	-18	-25
CONNECTORIZED VERSIONS						
SXS2M010060	0.5 - 3	8 - 12	1 - 6	13/16	-20	-25
SXS2M040180	2 - 9	8 - 12	4 - 18	13/15	-20	-25
SXS2M060260	3 - 13	8 - 12	6 - 26	13/17	-18	-25
MX2M130260	6.5 - 13	8 - 12	13 - 26	11/13	-15	-15
MX2M004010	0.02 - 0.5	8 - 12	0.04 - 1	10.5/13	-25	-25



SSB Upconverters or I/Q Modulators

Model Number	RF Frequency (GHz)	Conversion Loss (dB) Max.	Carrier Suppression (dBc) Min.	Carrier Suppression Carrier - Fundamental IF (dBc) Min.
IF DRIVEN MODULATORS				
SSM0204(*)C2MD(**)	2 - 4	9	20	20
SSM0408(*)C2MD(**)	4 - 8	9	20	18
SSM0812(*)C2MD(**)	8 - 12	9	20	20
SSM1218(*)C2MD(**)	12 - 18	10	20	18
SSM0208(*)C2MD(**)	2 - 8	9	20	18
SSM0618(*)C2MD(**)	6 - 18	12	20	18

For full data sheets on the products shown, please visit www.miteq.com/mixers
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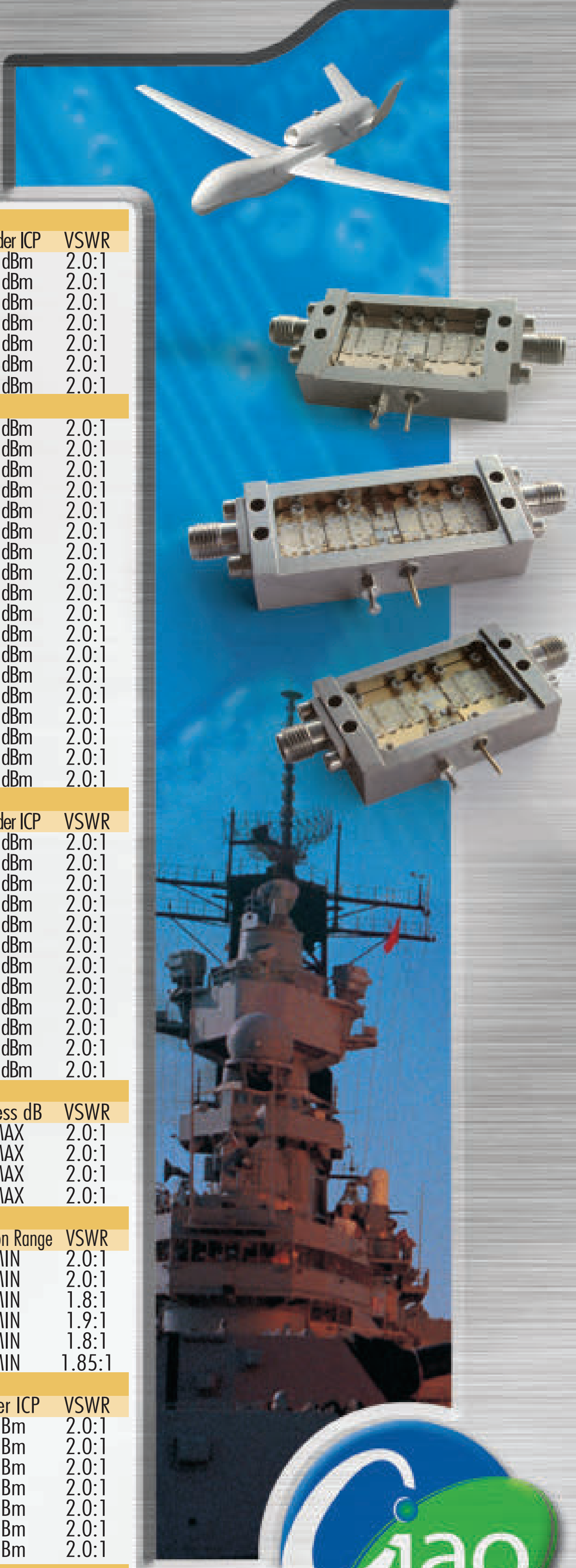

OCTAVE BAND LOW NOISE AMPLIFIERS

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

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

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

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

LIMITING AMPLIFIERS

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

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

LOW FREQUENCY AMPLIFIERS

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

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Lockheed Martin Conducts Successful PAC-3 Missile Flight Test

Lockheed Martin's PAC-3 Missile successfully detected, tracked and intercepted an aerodynamic tactical ballistic missile (TBM) target in a test at White Sands Missile Range, NM. The test included a ripple fire engagement, utilizing two PAC-3 Missiles against a single target. The first interceptor destroyed the target and the second PAC-3 Missile self destructed as planned.

"We continue to demonstrate the effectiveness of the PAC-3 Missile in tests that duplicate the kinds of operational scenarios our soldiers and our allies may face," said Richard McDaniel, vice president of PAC-3 Missile programs in Lockheed Martin's Missiles and Fire Control business. "We are constantly improving the PAC-3 Missile, increasing its capabilities and expanding the missile's ability to handle the growing number of potential threats."

The PAC-3 Missile is one of the world's most advanced, capable and reliable theater air defense missiles. It defeats advanced tactical ballistic and cruise missiles, and fixed- and rotary-wing aircraft. As the most technologically advanced missile for the PATRIOT air defense system, PAC-3 significantly increases the PATRIOT system's firepower, allowing 16 PAC-3 Missiles to be loaded in place of just four legacy PATRIOT PAC-2 missiles on the launcher.

Northrop Grumman Begins Production of EHF SatCom System for B-2 Bomber

The U.S. Air Force's fleet of B-2 stealth bombers will begin receiving new high-speed processing subsystems under a $108 million low rate initial production contract awarded to Northrop Grumman Corp. The new hardware and software, which include an integrated processing unit, a high-capacity disk drive and a network of fiber optic cable, will allow the aircraft to perform advanced communications and weapons delivery missions in the future. The new subsystems are being produced as part of Increment 1 of the Air Force's B-2 extremely high frequency (EHF) satellite communications program. Northrop Grumman is the Air Force's prime contractor for the B-2 Spirit, the flagship of the nation's long-range strike arsenal and one of the world's most survivable aircraft systems. The B-2 is the only combat-proven stealth platform in the current U.S. inventory.

"Every current and future upgrade program for the jet will benefit from the quantum leap in processing power and data handling capacity provided by this new hardware and software."

"The EHF Increment 1 upgrades provide a smart, cost-effective way to enable future combat capability on the B-2," said Ron Naylor, director of B-2 modernization and transformation for Northrop Grumman. "Every current and future upgrade program for the jet will benefit from the quantum leap in processing power and data handling capacity provided by this new hardware and software."

In late July, the EHF Increment 1 hardware and software successfully completed a series of operational tests conducted by the Air Force, Naylor said. The company is also beginning to install the new subsystems in a limited number of aircraft as part of the current EHF Increment 1 system development and demonstration contract.

Each new EHF Increment 1 hardware kit includes:

- An integrated processing unit developed by Lockheed Martin Systems Integration, Owego, NY, that will replace up to a dozen current stand-alone avionics computers on the B-2
- A disk drive unit developed by Honeywell Defense and Space Electronic Systems, Plymouth, MN, that will enable transfer of EHF data onto and off of the B-2
- A network of fiber optic cable that will support the high-speed data transfers within the aircraft

The B-2 is the only long-range, large-payload U.S. aircraft that can penetrate deeply into access-denied airspace. In concert with the Air Force's air superiority fleet, which provides airspace control and the Air Force's tanker fleet, the B-2 can help protect U.S. interests anywhere in the world. It can fly more than 6000 nautical miles unrefueled and more than 10,000 nautical miles with just one aerial refueling, giving it the ability to reach any point on the globe within hours.

Raytheon Awarded $349 M U.S. Army Contract for TOW Missiles

Raytheon Co. received a $349 million five-year, multi-year contract to provide heavy anti-tank, wireless precision-assault missiles for the U.S. government. Raytheon received the award during its third quarter. Under this contract, Raytheon will deliver 6676 of the new wireless tube-launched, optically tracked, wireless-guided (TOW) missiles that receive commands from the gunner through a wireless guidance link, eliminating the wire connection in early generations of the missile.

"TOW has been one of the most fired weapons in history and the upgrade to wireless gives our warfighters an improved capability," said Michelle Lohmeier, vice president of Land Combat for Raytheon Missile Systems. "With this contract, we are partnering with the U.S. Army to ensure our warfighters continue to have this life-saving weapon for years to come."

With the wireless system built into the missile and the missile case, the next-generation TOW works with exist-

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ing launch platforms, including the Improved Target Acquisition System, Improved Bradley Acquisition System, TOW2 Subsystem and M220 Ground TOW. The system performs exactly like the wire-guided version, enabling soldiers and Marines to continue using the proven weapon without changing tactics or incurring additional training.

"TOW remains the U.S. Army and Marine Corps' primary heavy anti-tank and precision-assault weapon," said Scott Speet, Raytheon Missile Systems' TOW program director. "It is currently deployed on more than 4000 TOW launch platforms including the Army Stryker, Bradley Fighting Vehicle System and High Mobility Multipurpose Wheeled Vehicle."

Harris Awarded $331 M Contract by FAA

Harris Corp. has been awarded a seven-year, $331 million contract to provide highly reliable air/ground data communications services for a key Federal Aviation Administration (FAA) program. The contract has 10 one-year options that could extend the duration of the program to 2029. Under the Data Communications Integrated Services (DCIS) contract, Harris and its teammates will provide integration and engineering services for the end-to-end DataComm system, including management and delivery of data communications services leveraging commercial air-to-ground digital data link networks to connect FAA air traffic control (ATC) sites and data communications-equipped aircraft. Harris will also establish an outreach initiative to encourage and incentivize aircraft operators to equip their aircraft with DataComm-compatible avionics.

DCIS is a key component of the FAA's DataComm program, which ultimately will automate many of today's routine ATC and en route voice communications with specialized data messaging equivalents. The goal of DataComm is to ensure more reliable ATC communications; enable trajectory-based routing; and improve arrival and departure routes — saving fuel and reducing emissions. DataComm is an essential element of the FAA's Next Generation Air Transport System initiative to transform the U.S. air traffic control system to meet future requirements.

"DCIS lays the groundwork for the move from traditional air traffic control to more active air traffic management," said John O'Sullivan, vice president, Mission Critical Networks, Harris Government Communications Systems. "Our approach to this effort reflects the same high standards that Harris adopted during the successful FAA Telecommunications Infrastructure (FTI) program, which the FAA has called a model of government and industry partnership."


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ITU Report Tracks Global Growth of ICT

The International Telecommunication Union's (ITU) annual report titled *Measuring the Information Society 2012*, revealed that information and communication technology (ICT) uptake continues to grow worldwide, spurred by a steady fall in the price of telephone and broadband Internet services.

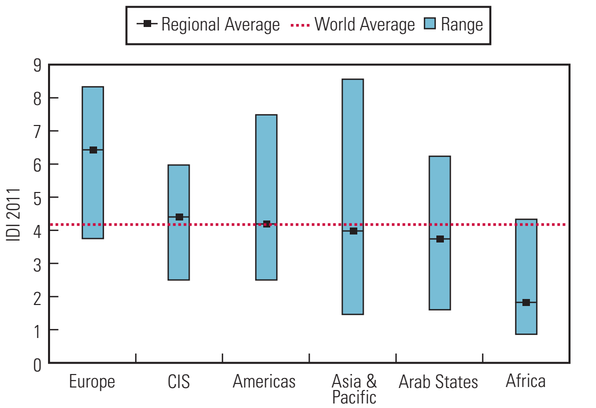
The new data ranks the Republic of Korea as the world's most advanced ICT economy, followed by Sweden, Denmark, Iceland and Finland. Of the ten top-ranked countries, eight are from Europe. The two remaining countries both come from the Asia-Pacific region, with the Republic of Korea in first place, and Japan ranked 8th.

ITU's ICT Development Index (IDI) ranks 155 countries according to their level of ICT access, use and skills, and compares 2010 and 2011 scores. All countries in the IDI top 30 are high-income countries, underlining the strong link between income and ICT progress. There are large differences between developed and developing countries, with IDI values on average twice as high in the developed world compared with developing countries.

One promising development is the growth of mobile-broadband services. In developing countries, mobile-broadband services are more widely accessible and, in the case of low-volume packages, less costly than fixed-broadband Internet services. Mobile broadband is expected to boost Internet use, which stood at 32 percent globally and 24 percent in developing countries at end 2011.

"The past year has seen continued and almost universal growth in ICT uptake. The surge in numbers of mobile-broadband subscriptions in developing countries has brought the Internet to a multitude of new users. But despite the downward trend, prices remain relatively high in many low-income countries. For mobile broadband to replicate the mobile-cellular miracle and bring more people from developing countries online, 3G network coverage has to be extended and prices have to go down even further," said Brahima Sanou, director of ITU's Telecommunication Development Bureau, which produces the annual report.

IDI Ranges and Averages, by Region, 2011



Source: ITU

Astrium is First Provider of SATCOMs to EDA for EU MoDs

Astrium has been awarded a three year contract by the European Defence Agency (EDA) to provide commercial satellite communications (SATCOM) capacity for European military needs. This contract will be managed by the EDA's newly established procurement cell, the European Satellite Communications Procurement Cell (ESCPC).

Astrium Services will provide the EDA with satellite communications in commercial bands (C, Ku and Ka) for European military needs, and associated value added services including lease of terminals, anchoring and backhauling, worldwide. The ESCPC will allow the European Union member states to pool their needs, purchase, and even switch satellite communication capacity between themselves, in a coordinated manner, ultimately ensuring the best and most cost effective access to SATCOM services.

> *"Astrium Services is fully engaged in making a significant contribution to European defence."*

To date, five contributing member states (France, Italy, Poland, Romania and the United Kingdom) have joined the ESCPC to benefit from cost savings for their commercial SATCOMs needs. Astrium Services will offer its one-stop-shop 24/7 expertise to manage and execute a complete service catalogue for the delivery of the upcoming orders placed by EDA on behalf of the contributing member states.

Eric Béranger, CEO of Astrium Services, said: "As a commercial company and a pioneer in providing MILSATCOMs to governments and defence ministries, we are very proud to be the first to provide commercial satellite communications to the European Defence Agency through such an innovative scheme. Being European, Astrium Services is fully engaged in making a significant contribution to European defence."

UK Government Secures £1 B for Research

World leading science projects are receiving a £1 billion joint industry, university and Government boost, following the announcement that the UK Government will add £200 million of new money to the UK Research Partnership Investment Fund (UK RPIF), supporting long-term university capital projects.

The fund, which launched with a government investment of £100 million in March 2012, was heavily oversubscribed and received an overwhelming number of high quality bids. This additional support will more than double the number of projects that will benefit.

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To access the money, universities must match the funding by at least double from private companies or charities – taking the total investment, including universities' own contributions, to at least £1 billion. As well as supporting the best proposals already submitted by universities, the fund will now reopen for further bids.

Subject to final due diligence from the Higher Education Funding Council for England (HEFCE), successful projects from the first round of bidding included: A more than £35 million partnership between the University of Surrey and industry consortium including many of the mobile communications global industry leaders to build new collaborative international research centre which will support the development of 5th Generation cellular communications. The 5G Centre will provide real-time experimental facilities to underpin the development of new mobile broadband Internet products and services.

As well as supporting the best proposals already submitted by universities, the fund will now reopen for further bids.

The fund is managed by HEFCE, working with its counterparts in the devolved administrations. Universities bid for between £10 million and £35 million per project. Applications are judged on value for money and must build on existing strong research capability.

European Commissioner Supports Eurostars

Acknowledging that SMEs in many Member States are severely hit by the economic crisis, Máire Geoghegan-Quinn, European Commissioner for Research, Innovation and Science, has presented the different measures that will be taken by the EU in the coming years to help this particular sector of the economy.

Geoghegan-Quinn recognised that the European Commission has previously failed to encourage SMEs to exploit its Framework Programme (FP) for research "for strategic business innovation," explaining that the programme had not "been conceived with a strong enough business logic from the perspective of SMEs." She mentioned EUREKA's joint Eurostars Programme as one that will help the EU to reach the budgetary target for SMEs within the future Horizon 2020 scheme of 15 percent of its total budget – a target that had not been reached within the current FP.

Eurostars is the first European funding and support programme to be specifically dedicated to research-performing SMEs and a joint programme between EUREKA member countries and the European Commission.

Besides a strategic redirection of funding towards innovative and commercially-driven projects, as opposed to purely academic ones, other features commonly associated with the Eurostars Programme should be part of Horizon 2020: simplification, association with private investors and ensuring that "SMEs receive the right financial support at the right time," said the commissioner.

Dan Massé, Associate Technical Editor

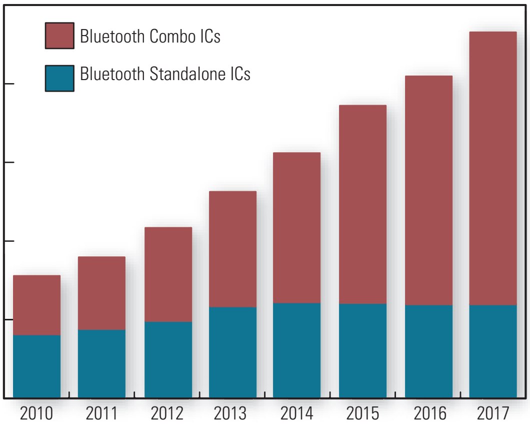
Bluetooth IC Market to Exceed $4 B in 2012

The total Bluetooth IC market (including stand-alone and combo ICs) is expected to reach $4.3 billion in 2012 — an increase of 21 percent on 2011. Revenues are forecast to grow at a compound growth rate of over 20 percent to reach almost $12 billion by 2017.

"Bluetooth market growth continues to be driven largely by the smartphone sector, with an extra push coming from other major markets such as laptops and media tablets," said Peter Cooney, wireless connectivity practice director. "The emergence of Bluetooth Smart and increasing Bluetooth adoption in new markets will be a major driver in future growth."

These findings are part of ABI Research's Bluetooth Research Service, which includes research reports, market data, insights and competitive assessments.

Bluetooth Single-Mode vs. Combo Chipset Revenue World Market, Forecast: 2010 to 2017



Source: ABI Research

Mobile Handset IC Market Expected to Exceed $35 B in 2012

The market for mobile handset IC, including platform and connectivity ICs, surpassed $32 billion in 2011 and is forecast to grow a further 11 percent in 2012 to reach $35.7 billion. Growth is being led largely by the smartphone segment, with ultra-low end handsets also growing strongly. "Qualcomm stands out as the market leader with 26 percent overall share in 2011," stated Peter Cooney, practice director, of semiconductors, "its continuing focus on the handset market and in particular its efforts to increase platform integration look set to further strengthen Qualcomm's hold on the market in the near term."

"Qualcomm stands out as the market leader with 26 percent overall share in 2011…"

Looking at the two main sections of the market — platform ICs and wireless connectivity — there are a number of suppliers that are strong across the board; these include Qualcomm, Broadcom, Texas Instruments and MediaTek. "For all handset IC suppliers, their future fortunes in the market will be bound by their ability to embrace integration and supply the market with compelling solutions that enable high functionality whilst keeping costs down," continued Cooney, "Qualcomm has continued to embrace this and its Snapdragon 4 platform takes this to a new level."

MediaTek is following hot on Qualcomm's heels with its MT6575 platform for low- to mid-end smartphones; it continues its transition from a lower-end handset to a smartphone-focused supplier.

Broadcom continues to lead the handset wireless connectivity market with almost 40 percent revenue market share, due largely to its strength in the combo IC market. Its long-term future in this market will be determined by its ability to match Qualcomm, MediaTek and others, in the integrated platform ICs market.

Texas Instruments is also strong in wireless connectivity being the second largest combo IC supplier but its withdrawal from the baseband IC (modem) market puts it at a disadvantage as platform solutions (whether fully integrated or not) — which include wireless connectivity — start to become the norm.

These findings are part of ABI Research's Mobile Device Semiconductors Database, which includes market data and insights.

One-Third of Households Worldwide Now Subscribe to Fixed Broadband Services

Worldwide fixed broadband market continues to grow across different regions to reach 618.7 million subscribers at the end of 2012, increasing 7.3 percent from 2011. In terms of penetration, more than one-third of the world's total households will have a fixed broadband connection at the end of 2012. The growth has come from all the fixed broadband platforms: DSL, cable and fiber-optic broadband. In Q2 2012, DSL broadband subscription grew 1.2 percent from Q1 2012, adding 4.3 million subscribers. The quarter-on-quarter (QoQ) growth rate was 1.5 percent in the first quarter. A slower QoQ growth rate indicates that DSL subscribers are shifting to other alternative platforms such as fiber optic. "Development of next generation broadband networks is creating opportunities to upgrade customers to fiber optic. Fiber optics broadband market-share is expected to increase to 13.2 percent by YE-2012 from 12 percent in

North America has the highest fixed broadband penetration around the world, with 72.4 percent of households using broadband services.

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2011, while DSL market-share will decline nearly 1 percent point from 64 percent in 2011," said Jake Saunders, vice president and practice director of core forecasting.

North America has the highest fixed broadband penetration around the world, with 72.4 percent of households using broadband services. By the end of second quarter, Western Europe had almost caught up with the penetration rate of North America. The region added 1.2 million subscribers in Q2 2012 resulting in a penetration rate of 72 percent. Subscriber base of key broadband operators in Western Europe such as British Telecom, Deutsche Telecom and Iliad Telecom increased more than 1 percent from the first quarter. The majority of the North American operators grew about 0.8 percent from the first quarter except Cox Communications which grew approximately 3 percent.

Increasing penetration of connected devices, applications and services over broadband access continue to drive adoption of high-speed broadband services. "As broadband operators upgrade their networks, customers are snapping up the faster services. At the end of Q2 2012, more than 44 percent of total customers subscribe to a broadband service of 10 Mbps and above," noted Khin Sandi Lynn, research analyst.

ABI Research's "Broadband Subscriber" market data, which is updated quarterly, profiles ARPU and service revenue by operator, country, and technology.

$389 M Mobile Application Security Market Set to Explode as Threats Increase

Games, social networking, productivity apps, financial tools are flocking to the mobile platform and along with it, malware. Loss, theft, spam, Trojans, spyware, data breaches and aggressive advertising are some of the few threats facing vulnerable devices. Between Q1 2011 and Q2 2012 ABI Research found that unique malware variants grew by 2180 percent reaching 17,439.

ABI Research shows that the global market for mobile application security will be worth $398 million by the end of 2012. This includes revenues for paid apps, partnerships with manufacturers and operators, white label deals and dataset sales. To date, ABI Research calculates that there have been over 130 billion downloads of mobile security apps. And these threats are set to increase significantly.

"With the increasing popularity of smartphones, mobile threats are on the rise. This has implications for security at the corporate level as well as for individual privacy," says Michela Menting, senior cyber security analyst. "The mobile application security market is rife with vendors offering their wares. The priority now for end-users is understanding the issue at hand and finding the right offering that best suits their needs."

Around the Circuit

Laura Glazer, Staff Editor

INDUSTRY NEWS

Cornell Dubilier Electronics Inc. has acquired the Orange Drop® film capacitor product lines and all other radial product lines from capacitor maker **SBE Inc.** (dba SB Electronics) of Barre, VT. Orange Drop capacitors, made with film dielectric and metallized or foil electrodes, are known for their excellent performance in pulse DC and AC circuits. The Orange Drop line consists of roughly 20 series.

Mindspeed Technologies and **China Mobile Research Institute** (CMRI), the research institution of China's largest mobile operator, have signed a memorandum of understanding to collaborate on multiple initiatives related to Nanocell research in China. To accelerate the adoption and deployment of the small cell network in China, Mindspeed will collaborate with CMRI in Beijing to accelerate the field trial of TD-LTE small cell systems across the China Mobile Communications Corp.'s (CMCC) network in China. Further, the company will work closely on such key research issues as SON technologies, synchronization methods and network topology.

Agilent Technologies Inc. announced a memorandum of understanding has been signed with the **China Academy of Telecommunication Research** (Telecommunication Metrology Center), or CATR (TMC). The two organizations have agreed to work together on TD-LTE MIMO over-the-air (OTA) test research. A nonprofit, public legal body under the Ministry of Industry and Information Technology, CATR has a broad set of responsibilities in setting national public metrology standards and telecommunication standards. The MIMO OTA standard for TD-LTE is one of the standards that CATR is driving for the wireless industry. Agilent and CATR will focus their collaboration on MIMO OTA standardization using an innovative TD-LTE MIMO OTA two-stage test method.

The **French National RFID Centre** (CNRFID) and **NRFLab** announced their collaboration and ability to offer neutral testing of ultra-high frequency (UHF) RFID tags and early comparisons of different EPC tag-compliant options. As a result of the collaboration, RFID UHF solutions developers can access CNRFID's expertise and network, and use NRFLab's UHF RFID test platform to compare and choose the best solutions for their applications before further development or production.

Constant Wave Inc. announced it has become an **Agilent** Solutions Partner. The program provides access to specialized Agilent training events and collaborative marketing activity.

Nanjing Ericsson Panda Communications Co. Ltd. (ENC) celebrated its 20^{th} anniversary and inaugurated a new 11,700 m^2 Research & Development Centre in Nanjing, China. Founded in 1992 as a production unit, ENC has developed vigorously and matured into Ericsson's largest production supply centre. In 2008, the company invested to expand the total area of factory buildings and ancillary facilities to approximately 13,000 m^2. The expansion, completed in 2009, increased the ENC's production area by 50 percent and doubled its production capacity, which is mainly devoted to 3G equipment.

MBDA Germany has opened a new simulation and integration center for air defense systems at its Schrobenhausen site. With approximately 4,000 m^2 of usable space, this building offers a modern infrastructure and sufficient space for integrating large end items such as radar systems, launchers and command posts, and for installation in vehicles. The building also houses a new simulation center enabling, amongst other things, the simulation of air defense scenarios.

Peregrine Semiconductor Corp. announced the expansion of its European operations with the opening of a design, manufacturing and sales facility in Reading, UK. The company's UK facility focuses on developing dedicated RFIC products of European content. The facility will also provide design services for Peregrine Semiconductor's next-generation UltraCMOS® RFIC portfolio.

Intercept Technology Inc. is the recipient of the 2012 New Product Introduction (NPI) Award from *Printed Circuit Design & Fab Magazine* in the PCB Design Tools category. Intercept's Pantheon layout software underwent a complete user interface overhaul over the course of 2011-2012, introducing major new productivity and ease of use enhancements

The **Saab**-coordinated **Seventh Framework Programme** project, the Integrated Mobile Security Kit (IMSK) started in 2009 and due to be delivered in 2013, has reached a significant milestone. The project entails a complete security solution for Olympic Games, EU summits and other medium to large scale events requiring temporary enhanced security. A large-scale demonstration simulating an EU summit went ahead at Hylands House, Chelmsford, UK on September 20^{th}. The demonstration presented a fully integrated security concept, including new sensor technologies, and proved that the solution offers an effective security overview of the situation at the event. Demonstrations at the simulated exercise included technologies such as 3D facial recognition, chemical detection, radar sensors, tracking and knowledge fusion.

Skyworks Solutions Inc. announced that it has received the Best Vendor and Outstanding Delivery awards from **ZTE** for supporting their growing RF business without a single part shortage in the last three years. Skyworks is now ZTE's leading front-end solution supplier and has supported several major product launches.

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PRODUCTS

POWER DIVIDERS

Model #	Frequency (MHz)	Insertion Loss (dB) [Typ./Max.] ◊	Amplitude Unbalance (dB) [Typ./Max.]	Phase Unbalance (Deg.) [Typ./Max.]	Isolation (dB) [Typ./Min.]	VSWR (Typ)	Input Power (Watts) [Max.] ·	Package
2-WAY								
CSBK260S	20 - 600	0.28 / 0.4	0.05 / 0.4	0.8 / 3	25 / 20	1.15:1	50	377
DSK-729S	800 - 2200	0.5 / 0.8	0.05 / 0.4	1 / 2	25 / 20	1.3:1	10	215
DSK-H3N	800 - 2400	0.5 / 0.8	0.25 / 0.5	1 / 4	23 / 18	1.5:1	30	220
P2D100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	5	329
DSK100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	20	330
DHK-H1N	1700 - 2200	0.3 / 0.4	0.1 / 0.3	1 / 3	20 / 18	1.3:1	100	220
P2D180900L	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	5	331
DSK180900	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	20	330
3-WAY								
S3D1723	1700 - 2300	0.2 / 0.35	0.3 / 0.6	2 / 3	22 / 16	1.3:1	5	316

◊ In excess of theoretical split loss of 3.0 dB
· With matched operating conditions

HYBRIDS

Model #	Frequency (MHz)	Insertion Loss (dB) [Typ./Max.] ◊	Amplitude Unbalance (dB) [Typ./Max.]	Phase Unbalance (Deg.) [Typ./Max.]	Isolation (dB) [Typ./Min.]	VSWR (Typ)	Input Power (Watts) [Max.]	Package
90°								
DQS-30-90	30 - 90	0.3 / 0.6	0.8 / 1.2	1 / 3	23 / 18	1.35:1	25	102SLF
DQS-3-11-10	30 - 110	0.5 / 0.8	0.6 / 0.9	1 / 3	30 / 20	1.30:1	10	102SLF
DQS-30-450	30 - 450	1.2 / 1.7	1 / 1.5	4 / 6	23 / 18	1.40:1	5	102SLF
CSDK3100S	30 - 1000	0.8 / 1.2	0.05 / 0.2	0.2 / 3	25 / 18	1.15:1	50	378
DQS-118-174	118 - 174	0.3 / 0.6	0.4 / 1	1 / 3	23 / 18	1.35:1	25	102SLF
DQK80300	800 - 3000	0.2 / 0.4	0.5 / 0.8	2 / 5	20 / 18	1.30:1	40	113LF
MSQ80300	800 - 3000	0.2 / 0.4	0.5 / 0.8	2 / 5	20 / 18	1.30:1	40	325
DQK100800	1000 - 8000	0.8 / 1.6	1 / 1.6	1 / 4	22 / 20	1.20:1	40	326
MSQ100800	1000 - 8000	0.8 / 1.6	1 / 1.6	1 / 4	22 / 20	1.20:1	40	346
MSQ-8012	800 - 1200	0.2 / 0.3	0.2 / 0.4	2 / 3	22 / 18	1.20:1	50	226
180° (4-PORTS)								
DJS-345	30 - 450	0.75 / 1.2	0.3 / 0.8	2.5 / 4	23 / 18	1.25:1	5	301LF-1

◊ In excess of theoretical coupling loss of 3.0 dB

COUPLERS

Model #	Frequency (MHz)	Coupling (dB) [Nom]	Coupling Flatness (dB)	Mainline Loss (dB) [Typ./Max.]	Directivity (dB) [Typ./Min.]	Input Power (Watts) [Max.] ·	Package
KDS-30-30	30 - 512	27.5 ±0.8	±0.75	0.2 / 0.28	23 / 15	50	255 *
KFK-10-1200	10 - 1200	40 ±0.75	±1.0	0.4 / 0.5	22 / 15	150	376
KBS-10-225	225 - 400	10.5 ±1.0	±0.5	0.6 / 0.7	25 / 18	50	255 *
KDS-20-225	225 - 400	20 ±1.0	±0.5	0.2 / 0.4	25 / 18	50	255 *
KBK-10-225N	225 - 400	10.5 ±1.0	±0.5	0.6 / 0.7	25 / 18	50	110N *
KDK-20-225N	225 - 400	20 ±1.0	±0.5	0.2 / 0.4	25 / 18	50	110N *
KEK-704H	850 - 960	30 ±0.75	±0.25	0.08 / 0.2	38 / 30	500	207
SCS100800-10	1000 - 8000	10.5 ±1.5	±2.0	1.2 / 1.8	8 / 5	25	361
KBK100800-10	1000 - 8000	10.5 ±1.5	±2.0	1.2 / 1.8	8 / 5	25	322
SCS100800-16	1000 - 7800	16.8 ±1.5	±2.8	0.7 / 1	14 / 5	25	321
KDK100800-16	1000 - 7800	16.8 ±1.5	±2.8	0.7 / 1	14 / 5	25	322
SCS100800-20	1000 - 7800	20.5 ±2.0	±2.0	0.45 / 0.75	12 / 5	25	321
KDK100800-20	1000 - 7800	20.5 ±2.0	±2.0	0.45 / 0.75	14 / 5	25	322

* Add suffix - LF to the part number for RoHS compliant version.
· With matched operating conditions

Unless noted, products are RoHS compliant.

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Around the Circuit

7Layers has been recognized by **MetroPCS Communications** as an approved test lab for LTE device certification. The cooperation expands the options available to mobile phone manufacturers who are preparing to introduce LTE devices. 7Layers is now able to help manufacturers to certify devices in a timely manner for MetroPCS' network.

DragonWave Inc. has concluded field tests and confirmed the functionality of higher modulation modes of up to 2048 QAM on its Horizon packet microwave products. The field tests were conducted in Odessa, Ukraine, the nation's south Bay City. Deployments and analysis for the field test were done in coordination with DragonWave's in-country partner UKRCOM and their customer, Intertelecom, one of the largest wireless service providers in the country.

Emerson Network Power Connectivity Solutions launched its new Chinese language website on emerson-connectivity.com. The Chinese translated site went live on September 17, 2012 and is intended to provide product and brand awareness throughout China, a target and rapidly developing market for Emerson Connectivity Solutions. The new site houses product features, news and events, product search functionality, press releases, availability to product literature, datasheets and installation instructions.

CONTRACTS

Harris Corp. has received a $297 million Indefinite Delivery/Indefinite Quantity (IDIQ) contract to deliver Falcon® tactical radio systems to the **U.S. Department of the Navy**. The five-year contract, awarded by the **Space and Naval Warfare Systems Command**, enables the Navy to acquire Harris Falcon tactical radios and accessories for ground personnel and small craft tactical requirements. The contract is part of Portable Radios Program (PRP), which procures and fields radios for the Office of the Chief of Naval Operations for secure/non-secure voice and data communications, satellite communications, and emergency communications for ships. Harris has been a provider to the PRP program since its inception in 2007.

The **U.S. Air Force** has awarded **Northrop Grumman** a contract to demonstrate technologies for its Three-Dimensional Expeditionary Long-Range Radar (3DELRR) program. Designed to replace the current AN/TPS-75 radar systems, 3DELRR will be the primary Air Force ground-based, long-range radar for detecting airborne threats. The pre-engineering and manufacturing development contract, valued at $34.7 million, will last 15 months.

Comtech Xicom Technology Inc. has been awarded a contract totaling more than $1.3 million from a major system integrator to supply klystron power amplifiers (KPA). The KPAs will be deployed internationally to relay military satellite communications to facilities in the U.S.

Raytheon Co. has been awarded its second contract from **Boeing Co.** for low-rate initial production (LRIP) of active electronically scanned array radar systems for the **U.S. Air Force** F-15E Radar Modernization Program. Raytheon's APG-82(V)1 AESA radar can detect, identify and track multiple air and surface targets at longer ranges than the APG-70 radar it replaces. Raytheon is scheduled to begin delivery of the LRIP-2 radar systems in February 2014.

The **NASA Goddard Space Flight Center**, Greenbelt, MD, awarded a SBIR Phase II program to **Tahoe RF Semiconductor Inc.** for developing a miniaturized radiation hardened beam-steerable GPS receiver front end for NASA spacecrafts. This product is designed to improve the signal sensitivity by 10 dB to 25 dB-Hz and improve performance against multipath interferences. This product will provide NASA with the ability to track GPS signals above GPS Constellation regions, including all Geostationary Earth Orbit (GEO), Highly Elliptical Orbit (HEO) and cis-lunar missions.

Astrium has been awarded a three year contract by the **European Defence Agency** (EDA) to provide commercial satellite communications capacity for European military needs. This contract will be managed by the EDA's newly established procurement cell, the European Satellite Communications Procurement Cell (ESCPC). Astrium Services will provide the EDA with satellite communications in commercial bands (C, Ku and Ka) for European military needs, and associated value added services including lease of terminals, anchoring and backhauling, worldwide. The ESCPC will allow the European Union member states to pool their needs, purchase, and even switch satellite communication capacity between them, in a coordinated manner, ultimately ensuring the best and most cost effective access to SATCOM services.

French defense procurement agency, **Direction Générale de l'Armement** (DGA) has awarded **Thales Alenia Space** a design contract to study military space communications capacity to be available by 2019. This study falls within the scope of preparations for the replacement of two Syracuse III satellites built by Thales Alenia Space, and as a complement to the two Sicral 2 and Athena Fidus satellites, also developed by the company and built in cooperation with Italy.

PERSONNEL

e2v aerospace and defense has appointed **Robert Brevelle** into the role of president, based at the Milpitas, CA facility. Brevelle joins e2v from Advanced Reconnaissance Corp., where he held the role of vice president of business development and marketing. He has previously been accountable for building business opportunities and strategic partnerships in the aerospace and defense industry. He will design and lead e2v's work toward developing strategic relationships and driving further growth in the U.S. mil/aero market.

Altair Semiconductor has appointed **Chee W. Kwan** as vice president of worldwide sales and **Uri Yaffe** as vice president of business development. Kwan brings more than 27 years of industry experience to the position, having most recently served as the vice president of worldwide marketing and sales at BroadLight Inc., a company acquired by Broadcom in April 2012. Yaffe, with more than 20 years of experience as a C-Level executive, previously founded and served as the CEO of Cellular Bridge, a business develop-

ment and consulting company focused on the telecom and Internet industries.


▲ Rajinder Rai

Endicott Interconnect Technologies Inc. (EI) announced the promotion of **Rajinder Rai** to the position of CTO reporting to James J. McNamara Jr., president and CEO. In his new position, Rai will be responsible for monitoring new technologies, overseeing the selection of research projects, generating a technology roadmap and ensuring its progress and assessing the potential of new product introduction. Rai holds a BS in materials science and engineering from the University of Notre Dame and an MS in materials science from Stevens Institute of Technology. He has been issued six U.S. patents and authored more than 25 technical papers over the course of his career.

REP APPOINTMENTS

Aeroflex/Inmet has appointed **MMS Technical Sales** of Rochester, NY as its new sales representative for upstate New York. MMS will represent Inmet's broad product line of surface mount resistive products and high performance coaxial components and provide support to strategic customers in the region.

L-com Inc. finalized an agreement with an Argentinean electronics company **ISECOM S.A.** Through ISECOM, customers in Argentina can purchase L-com's wireless products without foreign shipping. ISECOM will be adding L-com's HyperLink products to a list of manufacturers including HP Networking, Eaton, AMP, Fayser and VISIONxIP.

MITEQ Inc. announced the appointment of **AR Benelux BV** as the company's exclusive sales representative in the Netherlands. AR Benelux BV will represent MITEQ's component and SATCOM divisions.

Pasternack Enterprises Inc. announced that it has appointed **Spur Microwave Inc.** as Pasternack's exclusive distributor for India.

Peregrine Semiconductor Corp. and **RFMW Ltd.** announced they have finalized a worldwide distribution agreement for Peregrine's UltraCMOS® RFICs. According to the agreement, RFMW will stock, distribute and provide applications engineering support for Peregrine's product portfolio.

RFMW Ltd. and **EMC Technology/Florida RF Labs** announced a distribution agreement adding Europe, the Middle East and Africa (EMEA) to franchised RFMW territories.

Wenzel Associates Inc. announced the appointment of **Associated Technical Sales** as its representative to the Southern California area. Wenzel's low phase noise product line will be an addition to their line card that includes industry leaders in RF/microwave, mmWave, and LightWave markets.

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488 rev M

Recovery Time of the Schottky-PIN Limiter

In wireless receivers, limiters prevent large incoming signals from momentarily overdriving or permanently damaging the sensitive front end stages such as the low noise amplifier (LNA) and the mixer. In a transmitter, the limiter is used to curtail modulation peaks from exceeding the power amplifier's input limit. The simplest limiter circuit consists of a PIN diode and a parallel inductor for DC return – the "self-biased limiter." When the incoming signal amplitude exceeds the PIN diode's turn-on voltage, rectification occurs, and the resultant circulating current biases the diode to a low impedance state that reflects the signal back to the source. The input power at which the limiter has a 1 dB higher loss than its quiescent state is defined as the limiting threshold. Using a PIN diode with 1.5 µm thick I-layer in this limiter achieves a limiting threshold of approximately 10 dBm,[1] but this is higher than what many LNA devices can tolerate. Adding a Schottky diode in anti-parallel to the PIN diode creates the Schottky-enhanced PIN limiter, which favorably lowers the limiting threshold by approximately 8 dB[2-3] because of the Schottky diode's lower turn-on voltage. Moreover, the addition of the faster Schottky diode speeds up the limiter's turn-on time.[4] The Schottky-PIN limiter does not require a shunt inductor because the anti-parallel diodes form a complete DC path. Consequently, the absence of the shunt inductor is encouraged to improve both bandwidth and loss in the anti-parallel configuration.[5]

The recovery time is the period during which the limiter gradually returns to a low-loss state following the cessation of overdrive. This transitory state, which is also known as the blind/dead time, disrupts communication and causes information loss. In nuclear magnetic resonance and magnetic resonance imaging, slow recovery in the "crossed diodes" RF-actuated switch – which is essentially a limiter – creates imaging artifacts.[6-7] The recovery time of the self-biased PIN limiter is extensively described in the literature – it is proportionate to the PIN diode's I-layer thickness[8] and is approximately equal to the diode's minority carrier lifetime Tau.[9-10] In contrast, there is a dearth of information pertaining to the recovery time of the PIN-Schottky limiter despite this topology's increasing popularity, as shrinking transistor dimensions necessitates lower limiting thresholds than before. This study of the PIN-Schottky limiter's recovery characteristics was performed because quantitative data

Chin Leong Lim
Avago Technologies, San Jose, CA

was not found elsewhere. This article documents the results of measurements on the most popular form of the PIN-Schottky limiter and also proposes a simple modification to speed up the recovery time.

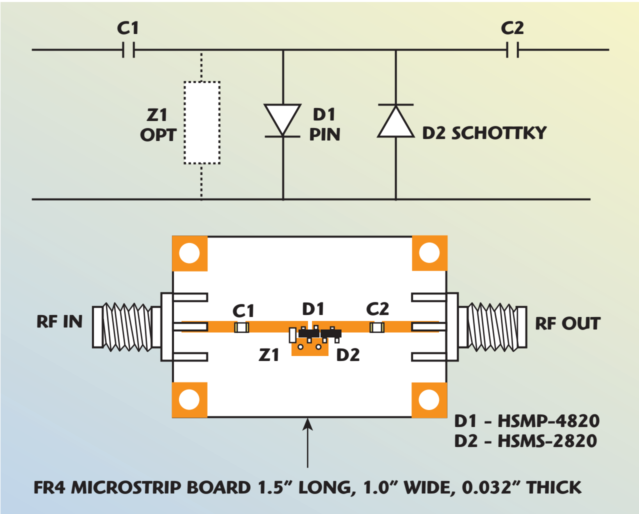
MATERIALS AND METHODS

This section describes the components that form the evaluated limiter and then the measurement setup. The prototype for the recovery time evaluation, shown in ***Figure 1***, follows a circuit arrangement intended for reducing high frequency losses caused by the diode parasitic capacitances.[2] The PIN limiter diode D1 was chosen for the following reasons: a relatively thin 1.5 µm I-layer to achieve fast transient response and 100 µm diameter to handle up to 10 W incident power.[11-12] The detector diode D2, formed of a Schottky and a PIN hybrid, was chosen for a compromise of robustness (>15 V breakdown voltage) and sensitivity (250 mV barrier height at 1 mA bias).[13] The diode chips are connected by bond wires at the top and conductive epoxy at the bottom to their lead-frames. The lead-frames are then epoxy molded to form SOT-23 packages. The packaged diodes and two DC blocking capacitors (C1, C2) are soldered to 50 Ω microstrip traces on a FR4 printed circuit board measuring 1.5" × 1" × 0.032." Following the previous authors' assertion that the anti-parallel arrangement eliminates the low frequency limit imposed by the shunt inductor, a relatively large capacitance value of 1 nF was initially chosen to enable operation down to the tens of MHz range. RF connections to the PCB are made via two edge-launch SMA connectors (Johnson 142-0701-881).

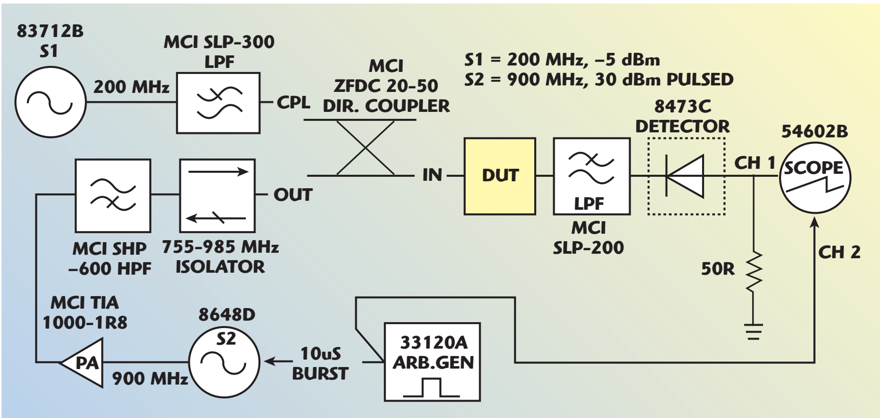
The limiter's recovery from an overload pulse is measured using a two frequency method first proposed by Goldie in 1967[14] and subsequently re-discovered and updated with modern test accessories by Looney, et al. in 2004.[15] In this method, the separation of the overdrive pulse and the much weaker desired signal in the frequency domain allows the limiter's response to the latter to be isolated using simple filters (see ***Figure 2***). The original X-Band test frequencies were transposed to the VHF-UHF range to suit the plastic packaged diodes' lower useable frequency range. The desired signal S1 is a 200 MHz, –5 dBm continuous wave. The incident overdrive S2 consists of a 10 µsec burst of 900 MHz, 30 dBm carrier. The frequency spacing between S1 and S2 is arbitrary – it is chosen to ensure the 200 MHz low pass filter (Mini-Circuits SLP-200) in front of the detector has sufficient rejection of the 900 MHz pulse. Both signals are combined in a directional coupler, because the isolation between its main and coupled branches can prevent cross modulation – a hybrid combiner can also be used in the same slot, if available. Since PIN junction heating is known to significantly increase the measured recovery time,[9-10] the overdrive signal is pulsed at 10 µsec bursts and the incident power is roughly one-tenth of the limiter's maximum power handling. To permit visualization of the limiter's output waveform on an available 150 MHz oscilloscope, the waveform's envelope is extracted using a commercial low barrier Schottky diode detector (Agilent 8473C). The detector output terminal is loaded with a 50 Ω resistor in order to achieve a sufficiently fast response time[16] as required by this test.

RESULTS AND DISCUSSION

This section first presents the results obtained from the standard PIN-Schottky limiter circuit and then the results following different modifications. The PIN-Schottky limiter's recovery from overload is extremely slow because it is dependent on surrounding components, which have relatively large RC time constants. The results reveal that the DC blocking capacitances are the primary determinant of the limiter's recovery time. For the 1 nF and the 27 pF capacitances evaluated, the corresponding recovery times are 2000 and 130 µsec, respectively (see ***Figure 3***). These results are several orders of magnitude larger than the < 70 nsec recovery time of a self-biased PIN limiter using the same diode type. The self-biased PIN limiter owes its fast recovery to the requisite shunt inductor. On the other hand, the inductor absence from the PIN-Schottky limiter means the positive voltage stored in the capacitors can continue to bias the PIN diode long after the overdrive has ended. The observation of slower recovery with larger capacitances is due to the larger stored charge. Therefore the bandwidth im-



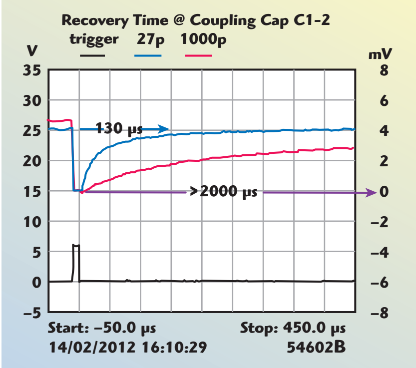
▲ *Fig. 1 PIN-Schottky limiter circuit diagram and printed circuit board assembly.*



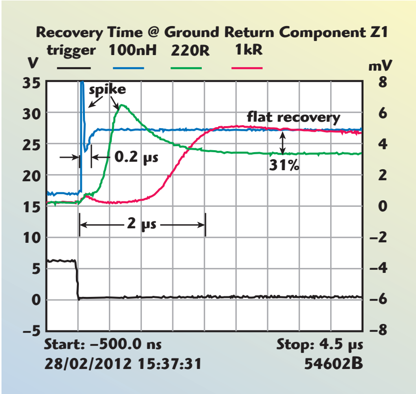
▲ *Fig. 2 Test setup for recovery time.*

provement in the anti-parallel topology is a double edged sword, because it can only be achieved at the expense of a very slow recovery. The unacceptably slow recovery may have escaped previous authors' attention because the two-frequency measurement method was not well known prior to 2004. Additionally, wireless traffic before 2G was mostly voice-based – so, a recovery period of a few milliseconds may have been below the audibility threshold. In radar applications, the recovery period corresponds to echoes from nearby targets and so a higher insertion loss may be tolerated.[10]

The PIN-Schottky limiter's recovery time can be reduced by three orders of magnitude or more by the addition of a ground return path in the form of either an inductor or a resistor (Z1 in Figure 1). Of course, reintroducing the ground return cancels the anti-parallel diode configuration's bandwidth advantage. Retaining the 1 nF capacitors in the evaluated



▲ *Fig. 3 PIN-Schottky limiter recovery time as a function of blocking capacitance value.*



▲ *Fig. 4 Limiter recovery time as a function of ground return component Z1.*

limiter, the recovery times are reduced to 0.2 nsec and 2 μsec with the addition of a 100 nH inductor and a 1 kΩ resistor, respectively (see ***Figure 4***). These component values are chosen to provide sufficient choking at the test frequencies. However, the inductor's speed advantage is marred by a large spike at the leading edge of the recovered waveform. Because the spike peak has almost twice the amplitude of the flat recovery, the inductor's under-damped solution may be unacceptable to sensitive applications. The 1 kΩ shunt resistor achieves critical damping – resulting in a spike-free leading edge although at the cost of a ten times slower recovery than the inductor. A 220 Ω resistance has a recovery time in between that of the inductor and the 1 kΩ resistor, but it is not recommended because the flat recovery voltage is 31 percent lower (3.4 vs. 4.9 mV), and this portends to a higher small signal loss.

CONCLUSION

The PIN-Schottky limiter's recovery time is determined by its external components rather than by the di-

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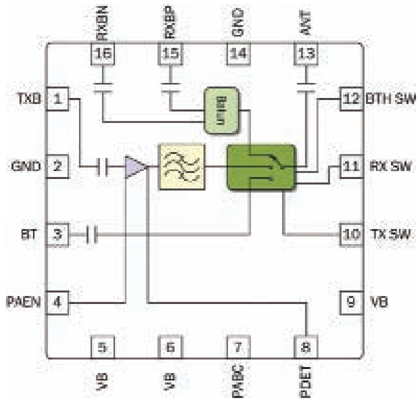
SPECIFICATIONS

Freq Range (Min) (MHz)	*Freq Range (Max) (MHz)*	*Gain (dB)*	*Operating Power 802.11g (dBm)*	*V_{CC} (V)*	*I_{CC} 802.11g (mA)*	*Package*	*Part Number*
2.4	2.5	33.0	17.0	3.3 to 4.2	160	QFN-16 Pin	RFFM3842Q



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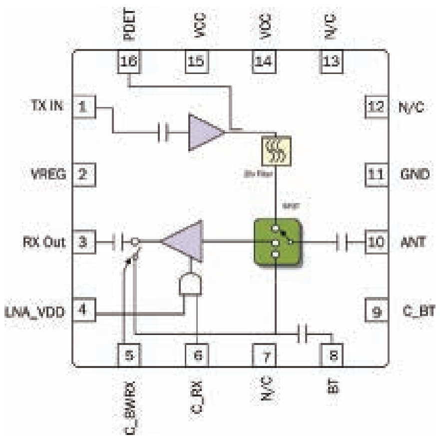
SPECIFICATIONS

Freq Range (Min) (MHz)	*Freq Range (Max) (MHz)*	*Gain (dB)*	*Operating Power 802.11g (dBm)*	*V_{CC} (V)*	*I_{CC} 802.11g (mA)*	*Package*	*Part Number*
2.4	2.5	30.0	19.0	3.0 to 4.8	215	QFN-16 Pin	RFFM5765Q



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ode minority charge carrier as in the self-biased PIN limiter. The recovery process is extremely slow because the PIN-Schottky limiter lacks the shunt inductor that allows the self-biased PIN limiter to quickly discharge the remnant charge in the blocking capacitors. Limiters that are designed for low frequency operation are the worst affected because recovery time is proportional to the capacitance.

It is probable that the other two members of the anti-parallel diode family, the all Schottky limiter and the "crossed diodes," should also exhibit slow recoveries though its existence has been only confirmed in the latter. As the results demonstrate, the standard form of the PIN-Schottky limiter is unsuitable for high-speed communication and NMR/MRI imaging applications because of the slow recovery. Since there is a need for sensitive limiters that are also fast responding, the standard circuit can be retrofitted with an appropriate shunt inductor or resistor to improve the recovery time by at least three orders of magnitude. It is anticipated that the modified PIN-Schottky limiter will lead to improvements in NMR/MRI imaging and wireless data rate. ■

ACKNOWLEDGMENT

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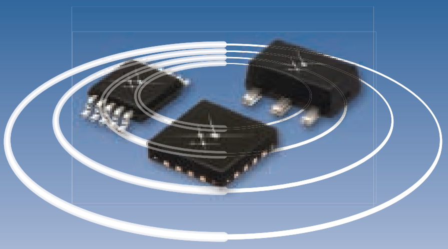

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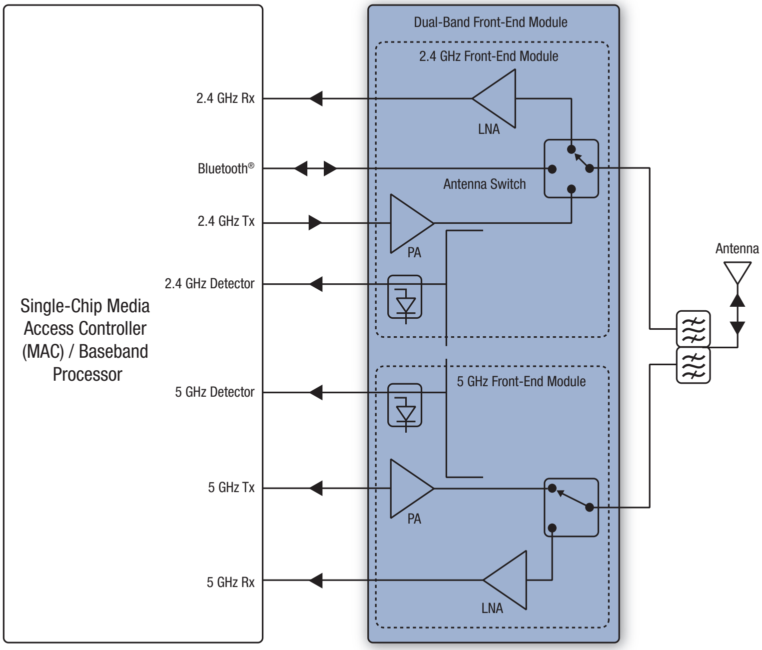

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Carrier Aggregation: A Key Enabler for LTE-Advanced

By the end of 2012, 150 LTE networks will be on air in 64 countries worldwide. Compared to previous technology rollouts (2G, 3G, 3.5G), this is by far the wireless industry's fastest. Despite marketing claims by network operators advertising LTE deployments as 4G, from a strictly technical perspective, they are not. LTE as defined by 3GPP Release 8 does not meet all IMT-Advanced requirements set by ITU for a true 4G technology[1] (ITU-R M.2134). 3GPP (3rd Generation Partnership Project), the standardization body behind LTE, is addressing and exceeding these requirements, while standardizing LTE-Advanced as part of its Release 10. This article describes one of the most requested features of LTE-Advanced in greater detail: carrier aggregation.

TABLE I

IMT-ADVANCED REQUIREMENTS

		IMT-Advanced	LTE 3GPP Rel. 8	LTE-Advanced 3GPP Rel. 10
Transmission Bandwidth (MHz)		≤40/≤100 MHz	≤20	≤100
Peak Data Rate (DL/UL) (Mbps)		1000 (low mobility) 100 (high mobility)	300/75	1000/500
Peak Spectral Efficiency (bps/Hz)	DL (4×4/8×8)	15/-	15/-	16/30
	UL (2×2/4×4)	6.75	3.75	8.4/16.8 (FDD) 8.1/16.1 (TDD)
Latency (ms)	User Plane	<10	<6	<6
	Control Plane	<100	50	50

CARRIER AGGREGATION AND LTE-ADVANCED

While the industry still faces challenges with LTE (that is providing circuit-switched services, such as SMS and voice via the "All-IP"-based network architecture) standardization is enhancing LTE to meet the IMT-Advanced requirements outlined in ***Table 1***. Two steps are required to achieve the spectral efficiency and requested peak data rates for downlink and uplink. First, enhancing the multi-antenna capabilities in downlink (up to 8×8 Single-User MIMO[2]) and allowing multi-antenna support in the uplink (up to 4×4 Single-User MIMO); second, applying carrier aggregation. LTE-Advanced as specified by 3GPP Release 10

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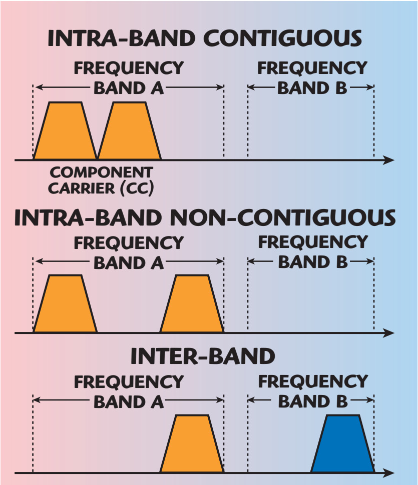


▲ *Fig. 1 Modes of carrier aggregation.*

(Rel-10), allows the aggregation of up to five component carriers, with up to 20 MHz of bandwidth to attain a total transmission bandwidth of up to 100 MHz. However, 3GPP's RAN Working Group 4 (RAN4) presently limits aggregation to two component carriers for a maximum aggregated bandwidth of 40 MHz – still in line with IMT-Advanced requirements. To assure backward compatibility, each carrier is configured to be 3GPP Release 8 (Rel-8) compliant. Each of the aggregated component carriers can use a different bandwidth. In fact, one of the six supported bandwidths within LTE: 1.4, 3, 5, 10, 15 or 20 MHz. This is dependent on each network operator's spectrum availability. Currently RAN4 discusses constellations with 5, 10, 15 and 20 MHz channel bandwidth. Since no service provider owns continuous spectrum of 100 MHz, three carrier aggregation modes are possible within LTE-Advanced: intra-band contiguous and non-contiguous as well as inter-band carrier aggregation (CA). Rel-10 already comprises intra-band contiguous and inter-band CA but intra-band non-contiguous CA must wait for Rel-11. Intra-band describes the aggregation of component carriers within the same frequency band in a contiguous or non-contiguous way. For inter-band carrier aggregation, the two component carriers reside in different frequency bands. ***Figure 1*** shows the different modes of carrier aggregation.

Inter-band carrier aggregation has resulted in many band combinations requests by network operators worldwide. Especially in the U.S., there is a competitive situation among carriers over how much spectrum is available to each of these service providers: contiguous, non-contiguous as well as in different frequency bands. Carrier aggregation is clearly considered as the best possible way to combine frequency allocations and therefore is often referred to as spectrum aggregation. ***Table 2*** shows the band combination that RAN4 is currently considering. As mentioned above, U.S. operators have submitted the majority of band combinations. Most combinations call for aggregation of currently deployed LTE networks at 700 MHz or, in general, lower frequencies with frequency blocks around 2 GHz, mostly in the so-called Advanced Wireless Services (AWS) spectrum. In 3GPP terminology, AWS corresponds to frequency band 4. The Federal Communication Commission (FCC) auctioned AWS frequencies in 2006, whereas 700 MHz frequency band licensing occurred in February 2008.

TABLE II

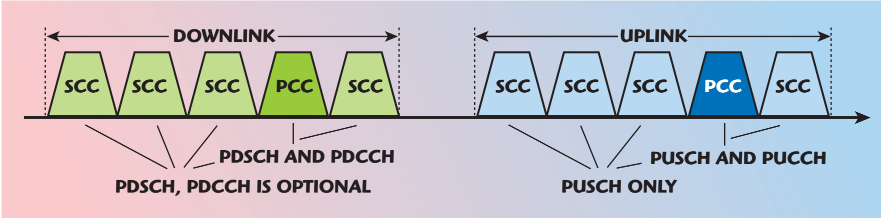
FREQUENCY BAND COMBINATIONS FOR INTER-BAND CARRIER AGGREGATION (RAN4)

Acronym	Mode	Work Item	Work Item Rapporteur
LTE_CA_B3_B7	FDD	RP-100668	TeliaSonera
LTE_CA_B4_B17	FDD	RP-111750	AT&T
LTE_CA_B4_B13	FDD	RP-111678	Ericsson (Verizon)
LTE_CA_B4_B12	FDD	RP-111316	Cox Communications
LTE_CA_B7_B20	FDD	RP-110403	Huawei (Orange)
LTE_CA_B2_B17	FDD	RP-110432	AT&T
LTE_CA_B4_B5	FDD	RP-110433	AT&T
LTE_CA_B5_B12	FDD	RP-120111	US Cellular
LTE_CA_B5_B17	FDD	RP-110434	AT&T
LTE_CA_B1_B7	FDD	RP-111357	China Telecom
LTE_CA_B3_B5	FDD	RP-111603	SK Telecom
LTE_CA_B4_B7	FDD	RP-111358	Rogers Wireless
LTE_CA_B3_B20	FDD	RP-120372	Vodafone
LTE_CA_B8_B20	FDD	RP-111213	Vodafone
LTE_CA_B11_B18	FDD	RP-111634	KDDI
LTE_CA_B1_B19	FDD	RP-111765	NTT DoCoMo
LTE_CA_B1_B21	FDD	RP-111764	NTT DoCoMo
LTE_CA_B3_B5 With 2 Uplink	FDD	RP-120364	SK Telecom
LTE_CA_B3_B8	FDD	RP-120388	KT

ARE ALL COMPONENT CARRIERS EQUAL?

The single most important question is: How does the network activate carrier aggregation? The answer is simple: only in connected mode. Before this can actually happen, a Rel-10 supporting mobile device must execute the generic access procedures defined for LTE as of Rel-8: cell search and selection, system information acquisition and initial random access. All these procedures are executed on the so-called primary component carrier (PCC) for downlink and uplink. Secondary Component Carrier (SCC) – in total up to four, initially two – are considered as additional transmission resources. The basic linkage between the PCC in downlink and uplink is signaled within system information block type 2 (SIB Type 2). The PCC is device-specific, not cell-specific. That means, for instance, two terminals of the same network operator could have

their PCC on different frequency bands. If one sticks with the U.S.-based example, terminal #1 could have its PCC in the AWS spectrum, whereas terminal #2's PCC could be at 700 MHz. However, the most likely initial deployment scenario is that the PCC is configured for 700 MHz because the carriers' initial LTE deployments are in the lower frequency bands. Nevertheless, the network can change the PCC for a terminal while executing the handover procedure. Besides being used for initial access, only the PCC in the uplink can carry the Physical Uplink Control Channel (PUCCH), for uplink control information transmission. Any additional SCC in the uplink provides only the Physical Uplink Shared Channel (PUSCH).

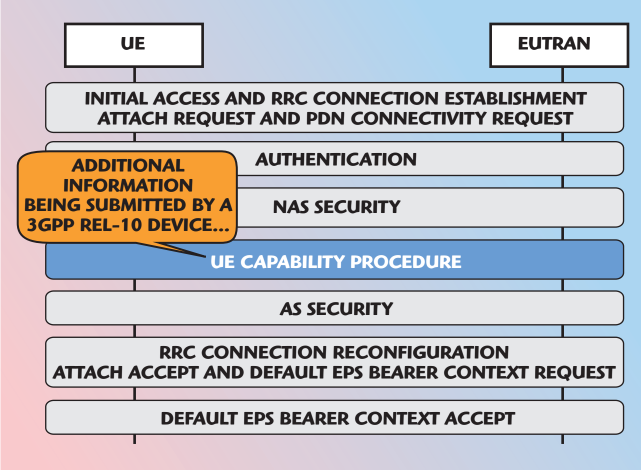


▲ *Fig. 2 Symmetric carrier aggregation.*

However, even if carrier aggregation in the uplink is defined with Rel-10, it is most likely that initial LTE-Advanced deployments for FDD make use of carrier aggregation only in the downlink. That means there is an asymmetric aggregation of component carriers: two in the downlink and only one in the uplink, for example. For TD-LTE, carrier aggregation typically results in a symmetric aggregation. But first systems may feature two DL and one UL CA for TDD as well. In FDD systems, which are the majority of current LTE deployments, symmetric carrier aggregation with up to five CCs, as shown in ***Figure 2***, as well as intra-band non-contiguous CA, is supposed to be rolled out in a second step. Reasons are quite simple. Uplink carrier aggregation, for inter-band, requires a second transmit chain,[1] which leads to a more complex device design and higher power consumption. In addition, things like power control per (uplink) component carrier, related power head room reporting, buffer status reports as well as timing advance are more challenging to implement and must be thoroughly tested and verified, which results in longer time to market. This would not be in line with the aggressive roadmaps of some network operators for carrier aggregation. Therefore, this two-step deployment approach seems plausible and is backed up with the submitted work items (WI) to RAN4, where only one network operator requested inter-band carrier aggregation for FDD including aggregation of two uplink component carrier[3] [RP-120364, Rapporteur: SK Telecom (South Korea)].

WHAT TYPE(S) OF CARRIER AGGREGATION DOES A DEVICE SUPPORT?

It is important to note that there are certain limitations to which fre-



▲ *Fig. 3 Default EPS bearer establishment procedure.*

quency band combination a Rel-10-capable terminal can support. A device enabled for global roaming and with multi-technology support must at least support four GSM frequency bands, five 3G/WCDMA frequency bands and three LTE bands, if just support of technologies defined by 3GPP is considered. In addition, support of GPS, FM, Bluetooth, WiFi and, eventually, Near Field Communications (NFC)[4] are important. Each technology requires its own transmit-receive (TRX) chain and space is limited due to the size of today's smartphones. The more TRX elements, the higher the power consumption. Because of these limitations, a device that supports LTE-Advanced will submit additional information to the network during the UE capability procedure. The UE capability transfer is part of the Default EPS bearer establishment – shown in ***Figure 3*** – that takes place after contention resolution of the initial random access procedure. The submitted UE capabilities, already enhanced with Rel-9, have been extended by Rel-10.

With regards to the supported band combinations, the RF-Parameters-v1020 information element provides this important detail to the network. Capabilities are signaled per frequency band, separately for downlink and uplink. Furthermore, so-called bandwidth classes are indicated on a per band basis, including the support of either intra-band (contiguous or non-contiguous) and inter-band carrier aggregation. ***Table 3*** shows supported bandwidth classes for LTE-Advanced as defined by the actual version of the related 3GPP specification. ***Figure 4*** provides an example of which terminology the device uses to indicate carrier aggregation support for a particular frequency band or frequency band combination (R4-122764, CA configuration acronyms for non-contiguous intra-band CA, Nokia Corp.).

Let's take the intra-band non-contiguous case with CA_25A_25A as an example. It tells the network that this device can receive (or transmit) two separate carriers in frequency band 25, each with a maximum bandwidth of 100 RB, or in other words 20 MHz. If this device could aggregate two carriers in that frequency band, but continuously, the acronym would change to CA_25C. Bandwidth

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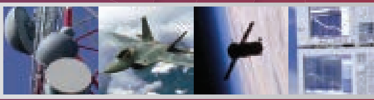

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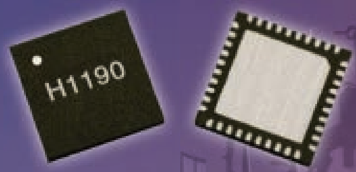

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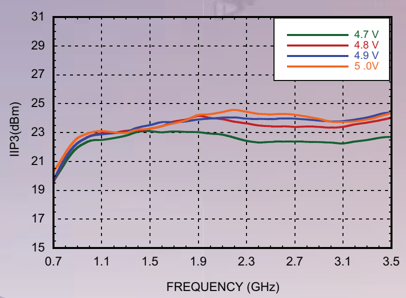
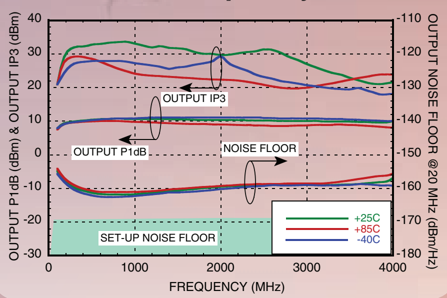
Input IP3 vs. Vg



P1dB, OIP3 & Noise Floor vs. Frequency



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Rx RFICs

	Frequency (GHz)	Function	Input IP3 (dBm)	NF (dB)	Conv. Gain (dB)	PLL FOM (dBc/Hz) (Int./Frac.)	Package	ECCN Code	Part Number
NEW!	0.7 - 3.5	Wideband Dual-Downconverter w/ Frac-N PLL/VCO	+24	9	8	-230 / -227	LP6G	5A991.b	HMC1190LP6GE

Tx RFICs

	Frequency (GHz)	Function	Output IP3 (dBm)	Output P1dB (dBm)	Output Noise Floor (dBc/Hz)	PLL FOM (dBc/Hz) (Int./Frac.)	Package	ECCN Code	Part Number
NEW!	0.4 - 4	Wideband Direct Modulator w/ Frac-N PLL/VCO	+30	+11	-160	-230 / -227	LP7F	5A991.b	HMC1197LP7FE

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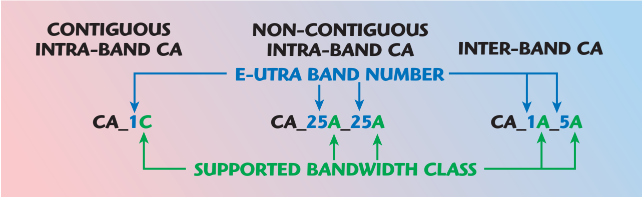
class C defines an aggregated transmission bandwidth between 100 and 200 RB, allocated to two component carriers. Obviously, 3GPP has work to do for bandwidth classes D, E and F, which are marked FFS – For Further Studies. It is fair to say that, initially, an aggregated bandwidth of 200 RB maximum, equal to 40 MHz as required by IMT-Advanced using two separate component carriers, will be used. Once the network is aware of the carrier aggregation capabilities of the device, it can add, modify or release SCC by means of the *RRC-ConnectionReconfiguration* message that has been enhanced with Rel-10. But, let us take a step back.



▲ *Fig. 4 Notation of carrier aggregation support (type, frequency band, bandwidth).*

IMPACT OF CARRIER AGGREGATION ON LTE SIGNALING PROCEDURES

Generally speaking, carrier aggregation signaling affects only certain layers of the protocol stack. For instance, the device is permanently connected via its PCC to the serving Primary Cell (PCell). Non-Access Stratum (NAS) functionality such as security key exchange and mobility information are provided by the PCell. All secondary component carriers, or secondary cells, are considered additional transmission resources. For the Packet Data Convergence Protocol (PDCP) and Radio Link Control (RLC) layer, carrier aggregation signaling is transparent. The latter, compared to Rel-8, needs only to support higher data rates with a larger buffer size. The buffer size is defined by the UE category the device belongs to. With Rel-10, three new categories have been added (see ***Table 4***).

Carrier aggregation is not limited, however, to these new categories. Rel-8 device categories 2 to 5 can be also capable of carrier aggregation. A terminal is configured on the Radio Resource Control (RRC) layer to handle secondary component carriers provided by secondary cells. Moreover, on RRC the parameters of the SCell(s) are set, that is configured. The Medium Access Control (MAC) layer is the multiplexing entity for the aggregated component carriers as they are activated or deactivated by MAC control elements. In case of activation in subframe n, then 8 subframes (8 ms) later, the resources are available to the device and it can check for scheduling assignments. At this moment, a newly introduced timer (SCellDeactivationTimer r-10) will be started. Assuming an SCC has been configured for a device using RRC signaling and has been activated via MAC, but no scheduling information in a certain period via the PDCCH is received, this SCell will be deactivated on MAC after the timer expires. The timer can be set to infinity, however, to override deactivation. When the MAC acts as

TABLE III

CARRIER AGGREGATION (CA) BANDWIDTH CLASSES

CA Bandwidth Class	Aggregated Transmission Bandwidth Configuation	Maximum Number of CC	Nominal Guard Band BW_{GB}
A	$N_{RB,agg} \leq 100$	1	$0.05BW_{Channel(1)}$
B	$N_{RB,agg} \leq 100$	2	FFS
C	$100 < N_{RB,agg} \leq 200$	2	$0.05 \max(BW_{Channel(1)}, BW_{Channel(2)})$
D	$200 < N_{RB,agg} \leq [300]$	FFS	FFS
E	$[300] < N_{RB,agg} \leq [400]$	FFS	FFS
F	$[400] < N_{RB,agg} \leq [500]$	FFS	FFS

$BW_{Channel(1)}$ and $BW_{Channel(2)}$ are channel bandwidths of two E-UTRA component carriers

TABLE IV

NEW DEVICE CATEGORIES WITH 3GPP RELEASE 10

UE Category	Maximum Number of DL-SCH Transport Block Bits Received Within a TTI	Maximum Number of Bits of a DL-SCH Transport Block Received Within a TTI	Total Number of Soft Channel Bits	Maximum Number of Supported Layers for Spatial Multiplexing in DL
Category 6	301504	149776 (4 layers) 75376 (2 layers)	3654144	2 or 4
Category 7	301504	149776 (4 layers) 75376 (2 layers)	3654144	2 or 4
Category 8	2998560*	299856	35982720	8

UE Category Transmitted	Maximum Number of UL-SCH Transport Block Bits Transmitted Within a TTI	Maximum Number of Bits of an UL-SCH Transport Block Transmitted Within a TTI	Support for 64QAM in UL	Total Layer 2 Buffer Size [Bytes]
Category 6	51024	51024	No	3 300 000
Category 7	102048	51024	No	3 800 000
Category 8	1497760**	149776	Yes	42 200 000

*~ 3 Gbps peak DL rate for 8×8 MIMO, 64QAM
**~1.5 Gbps peak, UL data rate, 4×4 MIMO, 64QAM

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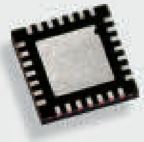
- Limiters & Detectors
- Log Amplifiers
- Pulse & Bi-Phase Modulators
- Phase Shifters
- Rack & Chassis Mount Products
- Receiver Front Ends
- Single Sideband Modulators
- SMT & QFN Products
- Solid-State Switches
- Switch Matrices
- Switch Filter Banks
- Threshold Detectors
- USB Products

Limiters & Limiter Detectors



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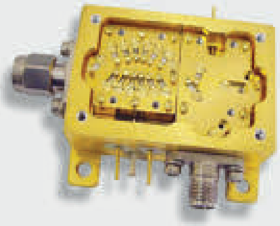

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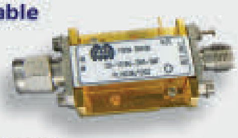

◆ DD-50-218-10PF-1-N

Frequency Range: 2.0-18.0 GHz, 3.5:1 VSWR, Frequency Flatness ±1.5dB Typical, Speed: 5nS, +17dBm Max RF Input, Voltage Sensitivity 700mV/mW Typical.
Size: 0.5" x 0.5" x 0.22"

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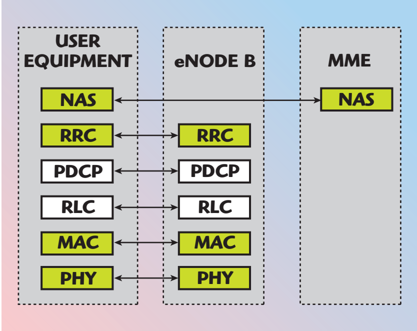
multiplexer, each component carrier has its own Physical Layer (PHY) entity, providing channel coding, HARQ, data modulation and resource mapping. On the primary and each secondary component carrier, both types of synchronization signals are transmitted to allow the device detection and synchronization. ***Figure 5*** shows the control plane signaling, highlighting the layers involved in activating carrier aggregation for a particular handset. Returning to the extension of the *RRCConnectionReconfiguration* message at RRC layer, a maximum of four secondary cells can be activated. For each cell, its physical cell identity is sent, the explicit downlink carrier frequency as an Absolute Radio Frequency Channel Number (ARFCN) as well as common and dedicated information. For the two latter ones, the transferred information is separated for downlink and uplink. Common



▲ *Fig. 5 Carrier aggregation signaling involved protocol layers (control plane).*

information (That is information applicable to all devices to which this carrier will be added) includes its bandwidth, PHICH and PDSCH configuration and, in case of TD-LTE, the UL-DL configuration and special subframe configuration. Further, the MBSFN subframe configuration is part of the downlink information. With Rel-9, broadcast/multicast capabilities have been fully defined for LTE and summarized as enhanced Multimedia Broadcast Multicast Services (eMBMS). With this feature, a mixed mode is possible, where certain subframes of an LTE radio frame are used for broadcast purposes. In terms of carrier aggregation, this is important information to the device, because it need not check subframes, which are assigned to MBSFN. Similarly, for the uplink, carrier frequency and bandwidth information are signaled, as well as power control-related information and uplink channel configuration (PRACH, PUSCH).

Dedicated information (That is information applicable to a particular terminal) includes the activation and use of so-called cross-carrier scheduling, which is an optional device feature. Its support is also indicated to the network during the UE capability transfer procedure. The use of cross-carrier scheduling is linked to Heterogeneous Network (HetNet) deployment scenarios with carrier aggregation, where it is used to measure interference reduction. In brief, HetNet's aims to improve spectral efficiency per unit area, using a mixture of macro-, pico-, femto-cell base stations and relays. In these deployment scenarios, interference control and management is introduced. The question remains of how to schedule resources when carrier aggregation is activated for a

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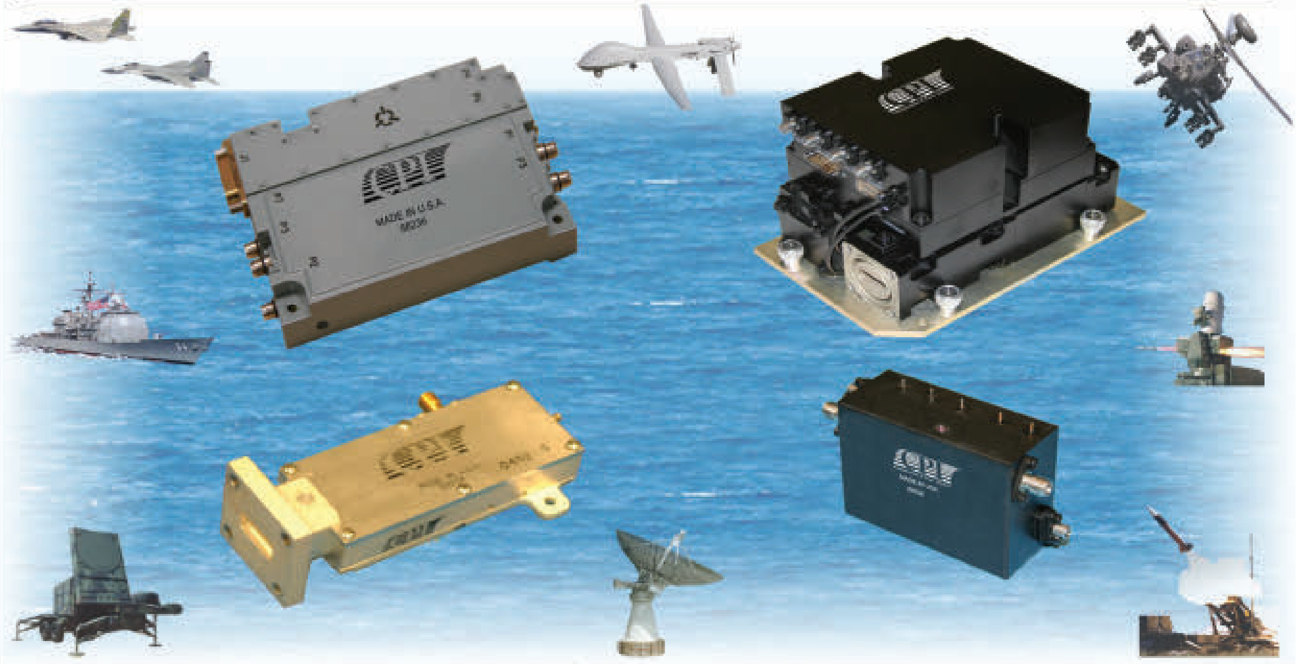

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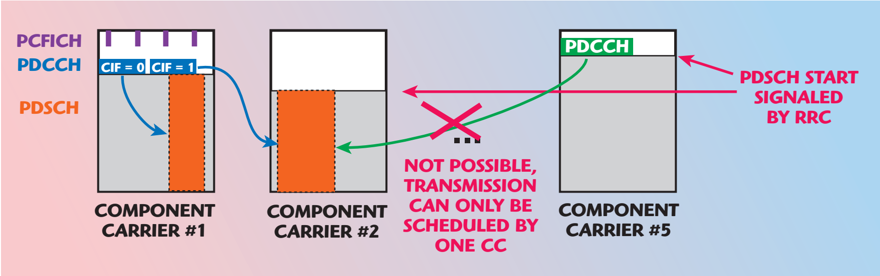
device. The answer is in the definition of cross-carrier scheduling. Instead of decoding Physical Downlink Control Channel (PDCCH) on each associated component carrier, the device just decodes the PDCCH on one carrier, presumably the PCC, to identify allocated resources on associated SCC. This is implemented by extending the Downlink Control Information (DCI) formats (which carry scheduling assignments) with a so-called Carrier Indicator Field (CIF). This new 3-bit field enables the terminal to clearly identify the component carrier intended by the decoded scheduling decision. ***Figure 6*** illustrates this principle. As previously noted, cross-carrier scheduling is enabled by RRC signaling. Since the terminal no longer decodes the PCFICH on the associated (secondary) component carrier, it does not know how many OFDM symbols at the beginning of each subframe are for control data. Thus this information, referred to as PDSCH-Start, must be signaled to the device during activation of cross-carrier scheduling and is therefore part of the related information element. Dependent on the bandwidth of the component carrier, this could be 1 to 4 OFDM symbols. It is also important to point out that for cross-carrier scheduling, when resources on a component carrier are scheduled via another carrier (Such as the PCC), no resources on that SCC for that terminal can be scheduled by any other component carrier.



▲ *Fig. 6 Cross-carrier scheduling.*

However, initial deployments with carrier aggregation will utilize resource allocation according to Rel-8. This means that the terminal will check on the PCC as well as on all activated SCC's for the PDDCH to decode the associated DCI format and demodulate the assigned PDSCH resources. HetNets with cross-carrier scheduling will be deployed in a second phase.

TESTING REQUIREMENTS FOR CARRIER AGGREGATION AND LTE-ADVANCED

LTE-Advanced is a complex and powerful technology enhancement. The variances permitted in carrier aggregation increase mobile device complexity. The major design challenge is at the transceiver front end, which must support multiple band combinations. This requires the use of highly flexible switches, wideband power amplifiers and tunable antenna elements. That places exceptional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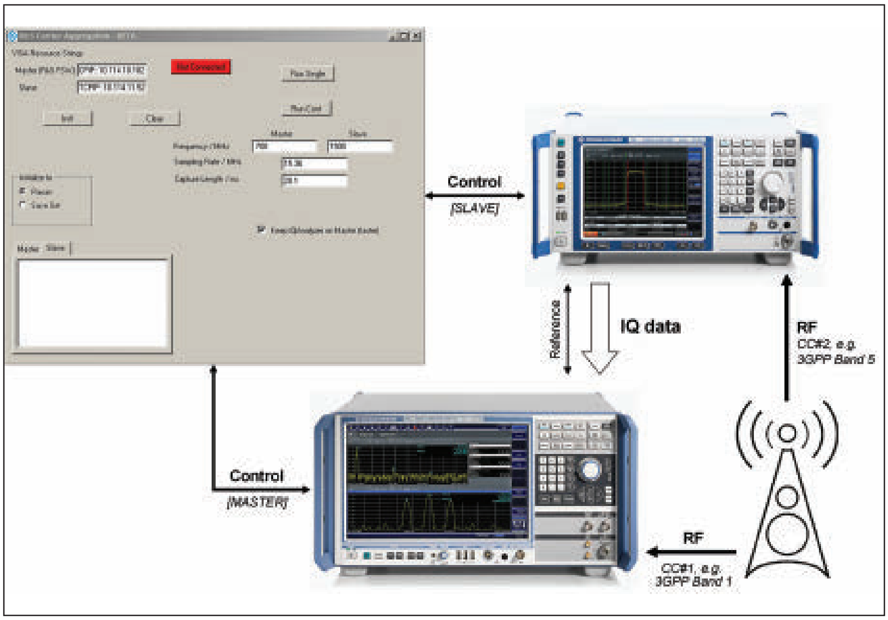
▲ *Fig. 7 Multi-CMW setup for testing carrier aggregation mobility with 2×2 MIMO.*



▲ *Fig. 8 Setup measuring TAE for inter-band carrier aggregation.*

performance requirements on test and measurement equipment. Without adequate planning during the selection process, test equipment can prove inadequate or quickly become obsolete. The introduction of intra-band (contiguous, non-contiguous) and inter-band aggregation with two component carriers, for instance, calls for a single instrument that supports all 3GPP frequency bands that LTE can utilize. The tester should also be capable of handling all combinations of inter-band carrier aggregation, including 2×2 MIMO and support of different bandwidths per component carrier (up to 20 MHz each). Other test design challenges are at the PHY layer, signaling and mobility. Testing these functions requires a comprehensive set of test scenarios best provided by a T&M company with broad experience in physical-

layer testing. Complexity increases additionally, when talking about mobility testing for carrier aggregation including multi-antenna technology, known as MIMO that is 2×2. In today's test labs, often multi-box setups are used to simulate multiple cells of different technologies (such as LTE, 3G/WCDMA or 2G/GSM) for various types of mobility testing, PLMN and cell selection scenarios or neighbor cell measurements. Such setups will pay off another time, while being used testing mobility for carrier aggregation. Such a multi-box setup using the R&S CMW500 Wideband Radio Communication Tester is illustrated in ***Figure 7***.

Vector signal generators also play an initial, critical role in testing carrier aggregation functionality at the PHY layer. Ideally, the instrument combines two complete signal generators – each with baseband section and RF up-conversion. As carrier aggregation signals can be exceptionally complex, an intuitive configuration is essential. Configuring cross-carrier scheduling and the PDSCH, start offset of the secondary component carriers is also supported in addition to the generation of AWGN, fading and MIMO support.

Time alignment error (TAE) measurement presents additional test challenges. Frames of LTE signals at a base station antenna port are not perfectly aligned, but must fulfill certain timing requirements. The test setup in ***Figure 8*** shows how this can be accomplished. A high-end signal and spectrum analyzer acts as master and is controlled by a software application inside the instrument. The program synchronizes the capture of IQ data from master and slave (a midrange spectrum analyzer).

CONCLUSION

Carrier aggregation is a key enabler for LTE-Advanced to achieve the peak data rates of the IMT-Advanced requirements. It is highly desired by network operators, because it enables the aggregation of spectrum fragments and offers a way out of the spectrum crunch. The major design challenge is on the terminal side. Support of higher bandwidths and aggregating carriers in different frequency bands tremendously increases transceiver circuit complexity, including the design of components such as wideband power amplifiers, highly efficient switches and tunable antenna elements. The additional functionality provided to PHY/MAC layer and the adaptations to the RRC layer must be thoroughly tested. ■

References

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2. 3GPP TS 36.141 E-UTRA Base Station (BS) Conformance Testing, V11.1.0.
3. 3GPP TS 36.321 Medium Access Control (MAC) Protocol Specification, V10.5.0.
4. 3GPP TS 36.331 Radio Resource Control (RRC) Protocol Specification, V10.5.0.

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Taming the Smartphone Power Consumption Vicious Cycle

Consumer appetite clearly demonstrates the demand for feature-rich, portable, communication devices that provide always-on connectivity, content and communication, or what we call c^3. This c^3 demand fuels the disruptive smartphone revolution and dramatically alters the cellular handset space in many ways. One fundamental outcome of this revolution has been the creation of an almost perfect power consumption vicious cycle. The cycle begins with the quest for c^3 propelling increased data bandwidth, which enables greater baseband processing power and display sophistication. The cycle repeats as increases in processing power and display sophistication have driven improved mobile applications to take advantage of c^3. Battery power consumption demands mushroom at each step in the cycle and in each smartphone generation.

POWER CONSUMPTION TRENDS

Smartphone power consumption trend analysis yields insightful drivers and results. Clearly, each successive smartphone generation significantly increases power consumption. In the past, inclusion of the latest radio link technologies (2G/2.5G/3G/4G) predominately drove handset power consumption. Radio link power consumption increases were modest when compared to relative bandwidth gains. Handset bandwidth gains, however, resulted in explosive overall power consumption, driven by high resolution displays and sophisticated applications processors. For example, during the last three years, RF power consumption increased by 11 percent, while processor and display power consumption each increased more than 200 percent.

The increasing overall power consumption curve encourages innovative approaches to power management. Power management starts with the battery. Most smartphones use a Lithium polymer battery with an energy density of approximately 0.13 mAh/mm^3 at a nominal 3.7 V. Growing smartphone power demands have traditionally been met by increasing battery capacity through increasing physical battery size and, as a result, battery capacity has increased approximately 10 percent per year for the last several years. The rate in battery capacity increase has been unable to keep pace with the power demands resulting from the vicious power cycle driven by c^3. ***Table 1*** shows the increased power demand for the different functions in the past two years.

Until recently, the RF cellular power amplifier (PA) significantly drove the handset power consumption curve. As such, the RF PA has been a significant target for efficiency gains. The latest 3G-generation of cellular PAs average more than 45 percent efficiency. A reasonable rule of thumb in current smartphone generations is that 1 percent point of PA efficiency improvement translates to approximately 35 mAh of battery capacity. Looked at another way, a 1 percent point improvement in PA efficiency translates to approximately 50 mm^2 of recoverable footprint area in today's ubiquitous

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TABLE I

POWER CONSUMPTION CHANGES FOR DIFFERENT FUNCTIONS OVER THE PAST TWO YEARS

Function	2009	2011	% Change
Display	300 mW	900 mW	300%
Peripherals	400 mW	1500 mW	275%
Processor	800 mW	1620 mW	200%
Audio	300 mW	400 mW	30%
RF	1200 mW	1330 mW	11%
TOTAL	3000 mW	5750 mW	92%

smartphone form factor. As the smartphone form factor has generally stabilized, due to ergonomic form-factor limitations, the efficiency driven footprint reductions translate into additional features, increased battery size, or both.

RF POWER MANAGEMENT

From an outside perspective, the cellular PA appears a relatively simple device. It takes energy from the battery and directs it to the antenna. The PA has traditionally been directly connected to the battery without significant power management. As the battery voltage rose and fell (based on its charged capacity), the voltage available to the PA essentially followed. The 3.9 to 2.5 V range of the standard Lithium polymer battery (over full to empty capacity) results in design-related efficiency tradeoffs of direct battery connected PAs. The inclusion of PA power management DC-DC conversion allows PA efficiency design gains. The simplest converter uses a buck topology. The buck converter bucks high battery voltage to a lower, regulated level. Not surprisingly, this regulated bucked voltage level (typically targeted at 3.4 V) matches the average voltage (nominally 3.7 V) found over the significant portion of a Lithium polymer battery capacity profile. The buck regulator compensates for the high voltage level found on a fully charged battery. Once the battery voltage falls below the regulated level, the buck converter "drops out" and the PA is once again essentially directly connected to the battery. A buck converter allows the PA designer to maximize the efficiency of the PA by minimizing the need to deal with the higher end of a relatively wide battery voltage dynamic range. PA linearity performance suffers, however, as the voltage level drops on the battery as capacity is exhausted.

PA designers prefer a constant and relatively high supply voltage. The constant and high voltage leaves the PA designer with a reduced set of design tradeoffs between gain, linearity, efficiency, stability and ruggedness. This is where the newer boost/buck power management topology comes into play. The boost/buck converter operates in two modes. When the battery is nearly full (voltage level near maximum), the regulator operates in the buck mode providing a lower stabilized voltage. As the battery capacity diminishes, the battery voltage declines through an inflection point, where the regulator switches from buck mode to boost buck mode. As the name implies, the boost mode boosts the available PA supply voltage to a regulated voltage level above the currently available battery voltage. A typical boost buck PA DC-DC converter is essentially a high efficiency dedicated switching power supply. In order to minimize the size of the inductors needed (saving both space and cost), highly efficient boost buck converters operate at very high switching rates. The boost buck converter provides a tightly controlled voltage source allowing the PA designer to optimize the PA design without highly dynamic battery voltage constraints.

CELLULAR POWER AMPLIFIER ARCHITECTURE

The cellular PA architectural topology constantly evolves to keep pace with the vicious power cycle. Traditional, high-performance, smartphone PA designs used quadrature balanced architectures. The balanced architecture was implemented for multiple generations, primarily because it balanced the need for efficiency against the need for voltage standing wave ratio (VSWR) tolerance. Remember that most PAs are typically directly connected to the handset antenna through a switch/filter network, which means that PA efficiency is directly tied to the quality of the impedance match between the output of the PA and the input of the antenna (or switch/filter network front end module). A better impedance match yields better efficiency. Handset antennas and their environment, however, routinely and dynamically change impedance. A tremendous number of both static and dynamic variables, including antenna material, location, and proximity/orientation to the human body, influence this pronounced impedance change. Impedance mismatch is measured by VSWR. Traditionally, PAs have been designed to meet high VSWR requirements to deal with the unpredictable environment.

Unfortunately, the quadrature, balanced architecture is not the most efficient PA architecture. If the VSWR requirement was relaxed, PA designers would take advantage of the higher efficiency single-ended (SE) architecture. The SE architecture gains efficiency at the expense of limited VSWR tolerance. Fortunately, the ability to control the antenna mismatch through traditional passive design approaches has nearly reached its limit. Several factors drive the inability to control antenna mismatch, but new active antenna control solutions generally result. Active antenna control solutions (ACS) essentially eliminate impedance mismatch. More importantly, the SE topology unlocks efficiency gains as ACS significantly reduces VSWR. ACS obviously comes at a cost, but other unrelated factors in handset design may encourage ACS. Of course, SE will work with passive impedance matching solutions as long as the VSWR range can be guaranteed through design. SE PA solutions are another weapon for combating the vicious power cycle.

ENVELOPE TRACKING FOR CELLULAR POWER AMPLIFIER

Both boost/buck power management and SE architecture improvements are relatively transparent to the system designer and independent in nature. Both approaches provide reasonable efficiency improvements

to the handset system designer, with a defined cost/benefit tradeoff. Of course, the vicious power cycle continues driving new, innovative, approaches to efficiency improvements. Envelope tracking (ET) is the latest emerging technique and a dramatic shift to the handset RF PA design approach. The ET solution relies heavily on the tightly interwoven coordination of power management and PA architecture. In traditional PA architectures, using average power tracking (APT), PA energy consumption remains relatively stable regardless of the content of the transmitted data. To transmit, the PA is turned on and fed a steady amount of energy that is either dissipated in the PA (generating wasteful heat), passed to the antenna, or a combination of both. ET turns this convention on its head. In an ET system, the amount of energy provided to the PA dynamically changes as the content to be transmitted changes. Instead of dissipating significant amounts of energy in the PA, the PA is only provided with the energy that it will pass directly to the antenna.

An oversimplified analogy is as follows: In a traditional architecture, the amount of energy needed to transmit four bits of data is constant, regardless of the value of each individual bit. The ratio of energy dissipated in the PA versus provided to the antenna does vary as the makeup of the four bits varies, but the overall average power consumption is constant. In an ET system, the amount of energy needed to transmit four bits of data varies as the value of each individual bit varies. Most of the energy in an ET system is provided directly to the antenna with very little energy dissipation occurring in the PA. Now imagine a stream of bits creating a constant envelope of data. In a traditional system, the PA is provided constant average power for the duration of the envelope. In an ET system, the PA is provided with power that closely tracks the envelope. The amount of envelope tracking power is dynamic and depends upon the makeup of the data. Less power for the same result equates to increased system efficiency.

While the concept is straightforward and well understood, the level of coordination required between power management and PA in an ET architecture is significant and unprecedented in handset design. This coordination requires hardware-level design optimization and interaction to insure each component of the system contributes appropriately within an ET-optimized system. The ET-related system efficiency improvements are another arrow in the quiver to battle the vicious power cycle.

CONCLUSION

Each of the three described design techniques approaches system efficiency and power management from different angles. Cellular PA power conversion, cellular PA design architecture and envelope tracking focus on reducing the cellular PA impact on smartphone power consumption. Of course, each degree of power management sophistication comes with increasing costs in both footprint and component BOM costs. These are cost tradeoffs available to the smartphone system designers to choose from, in their never-ending quest to balance the vicious power cycle. ■

E/D GaAs PHEMT Core Chips for Electronically Steerable Antennas

Despite great progress in silicon-based microwave integrated circuits, III/V technologies continue to demonstrate improved capabilities, offering optimum trade-offs in terms of noise figure (NF), gain, power and linearity for various applications, including wireless telecommunication infrastructure, security scanners, radars and instrumentation. Historically, a weakness of III/V technologies has been their limited level of integration. This article demonstrates how E/D PHEMT processes now facilitate analog functions like phase shifters and attenuators, with state-of-the-art performance, on the same chip as digital control functions, such as serial to parallel converters to produce highly integrated Core Chips for electronically steerable antennas – from C- to Ka-Band today and even E-Band in the near future.

Due to higher electron mobility and velocity, III/V technologies provide higher frequency cut-off F_t, F_{max} and also lower noise and higher gain than silicon RFICs. The wide bandgap produces higher breakdown voltage (V_b), higher power and better linearity. The $F_{max} \times V_b$ product is between two and five times better than that of silicon, which means high power at high frequency. Examples include 4 W power amplifiers up to 31 GHz, low noise amplifiers from 75 to 110 GHz and 2.8 dB noise figure.

At first sight, this leading-edge performance only seems possible for single-functions, such as power amplifiers or low noise amplifiers, with no digital circuitry, like digital phase shifters or digital attenuators, on the chip. However, the example of Core Chips for electronically steerable antennas will be used to show that III/V processes are not limited to high performance simple single-functions.

Electronically steerable antennas are widely used in both military and civilian applications, such as military radar, earth observation equipment for satellites, radio astronomy and mobile radio. These antennas avoid the noise, reliability and maintenance issues of mechanically steerable systems, by receiving and/or transmitting using a matrix of independently parameterized radiating elements to form a directed beam. The orientation of the beam is obtained by the use of variable phase shifters attached to each radiating element (see ***Figure 1*** and the associated equation).

The side lobes of the beam may then be controlled by variable attenuators also linked to

F. Robert, R. Leblanc, J. Moron, A. Gasmi, N. Santos and M. Rocchi
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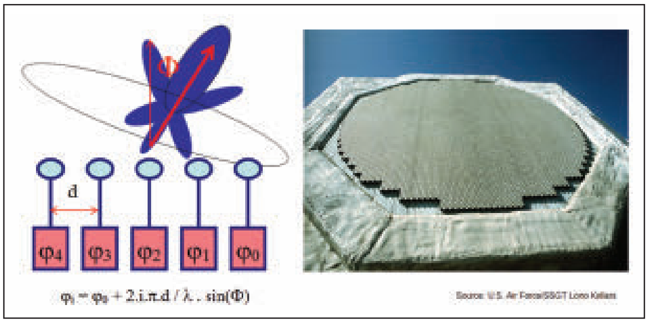
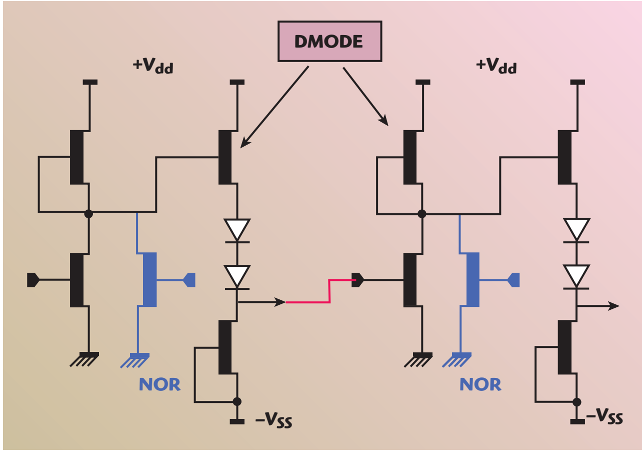


▲ *Fig. 1 Phased array antenna principle.*



▲ *Fig. 2 SIPO cell based on D-mode transistors.*

each radiating element. As the same antenna is often used for transmission and reception, each radiating element may be linked to a power amplifier, a low noise amplifier and some T/R switches. This makes at least six circuits per radiating element and the number of elements per antenna can easily be several thousand.

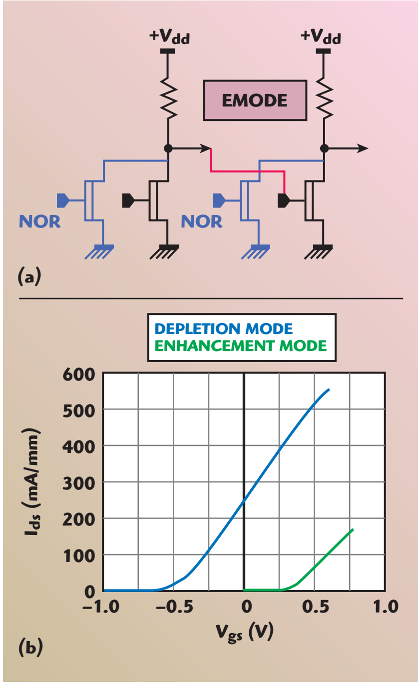
Small, cost-effective solutions must have high levels of RF integration, but comprehensive digital control of each element is vital. The concept of the Core Chip was introduced to integrate all these functions in a single chip at reduced complexity and cost, to allow electronically steerable antennas to address both high-end and low-end markets.

So, a Core Chip is a complete control function for electrically steerable antennas with phase shifters, attenuators, switches, low noise amplifiers and medium power amplifiers, on the same chip as their digital control circuits. Such multifunction microwave circuits are very challenging – they must minimize noise in Rx mode, maximize amplifier gain in Tx mode, and at the same time compensate losses in phase shifters, attenuators and switches that vary by as much as 15 dB. This is where III-V PHEMT technology has an advantage over silicon by combining high gain and low noise at high frequency, with an extremely limited DC consumption (hundreds of mW).

The need for digital control of all these analog functions also brings a considerable interconnection problem. For high resolution, twelve bit accuracy, a circuit may need up to 24 pads, with a large number of control lines routed across the chip so that the digital switching signals do not interfere with the analog RF functions. For an antenna with thousands of radiating elements, this is hardly feasible. Integrating a digital Serial Input Parallel Output (SIPO) converter block directly on to the Core Chip is a cost effective solution, which reduces a maze of interconnection to one serial data input.

One way to design a SIPO is to use only some depletion mode transistors for power functions and digital control functions as depicted in ***Figure 2***. However, the complexity of the SIPO structure and particularly the transistor voltage supply present problems. As shown in the figure, the biasing of gates must be done using a negative voltage supply and DC level shifting using diodes. This complicates the structure and substantially increases the area the SIPO occupies on the chip. Depletion mode transistors are well suited for power and noise performance, but enhancement mode transistors provide a much more efficient SIPO design for on-chip integration.

The structure of an enhancement mode SIPO block is depicted in ***Figure 3***. Unlike depletion mode transistors, enhancement mode transistors are pinched off at a gate voltage of 0 V and deliver current while the gate voltage supply is positive. One advan-

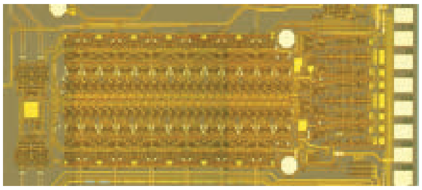


▲ *Fig. 3 SIPO cell based on E-mode transistors (a) and comparison between D-mode and E-mode transistors DC characteristics (b).*

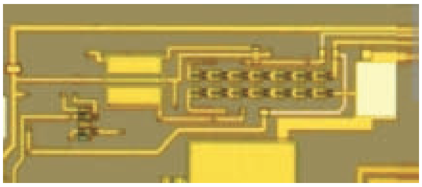
tage of this is called "direct coupling," where the second stage gate voltage supply can be fed by the first stage drain voltage supply. A second advantage is the low consumption due to low knee voltage of enhancement mode transistors.

One of the enhancement/depletion processes, suitable for highly integrated Core Chips for steerable antennas, is composed of enhancement and depletion transistors with F_t approximately 60 GHz, making it a good candidate for single-chip integration of digital circuits, such as SIPOs, low noise amplifiers, medium power amplifiers (20 dBm and above) and several on-chip switches. As an example, ***Figure 4*** shows a 26-bit SIPO using 1200 enhancement transistors which is only 46 transistors per bit. This consumes an exceptionally low overall power of 60 mW (2.3 mW/bit).

For an antenna comprising hundreds or thousands of elements, DC consumption for each Core Chip must be as low as possible. On-chip DC regulation, using an E/D GaAs PHEMT process, helps to minimize the overall mmW/bit, process deviation effects, reduce design margins (layout corners) and also reduce system complexity, since no tuning is necessary. So if the voltage supplies are not well regulated in the user's system, the



▲ *Fig. 4 Die photography of a 26 bit SIPO.*



▲ *Fig. 5 Die photography of a DC regulation block.*

on-chip DC regulation, as shown in ***Figure 5***, enables Core Chips across normal process variations to work in optimum conditions of noise, gain and phase and attenuation consistency.

Core Chips are already used in several applications such as space systems in C-Band, civilian Internet by satellite in X- and Ku-Bands and military missile guidance in Ka-Band. Some real-world examples are highlighted below.

The first 5.4 GHz chip[1] integrates a 6-bit digital phase shifter (2.5° rms error over 4096 states), a 6 bit digital attenuator (0.25 dB rms error over 4096 states), six switches, a 12-bit SIPO and amplifiers with DC regulation providing 20 dBm of output P1dB. The overall die is shown in ***Figure 6***, and the dashed lines highlight each function embedded on the chip.

The topology of the chip is arranged to separate the phase shifters and attenuators with SIPO in the middle. These two areas are also separated by the ground wall. This avoids phase distortions at high attenuation states due to coupling between RF input and output. Such design rules are a trade-off between chip size (and cost) and electrical performance such as very low phase and amplitude rms error over all states.

The second example shows a high volume civilian application, a broadband Internet by satellite for cars or planes, which have a phased array antenna on the roof.[2] A single antenna includes 150 Core Chips. Without such a highly integrated single chip, the larger size, mounting and routing of each element and higher cost would make such an antenna impossible.

In this example, a single chip integrates a 4-bit phase shifter (180°, 90°, 45° and 22.5°) cascaded with a two-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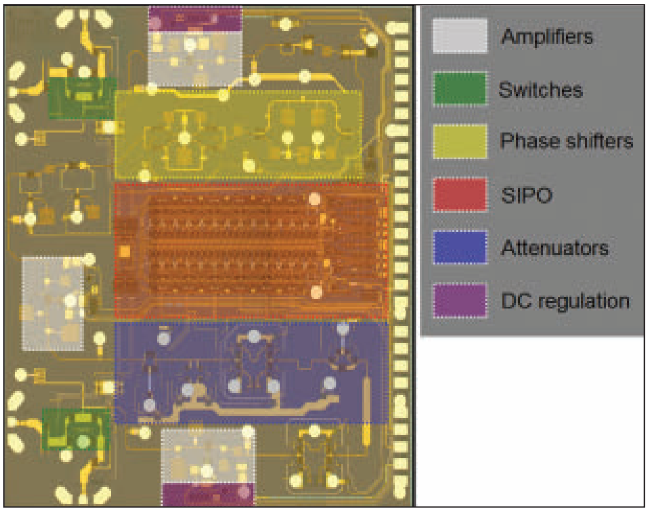
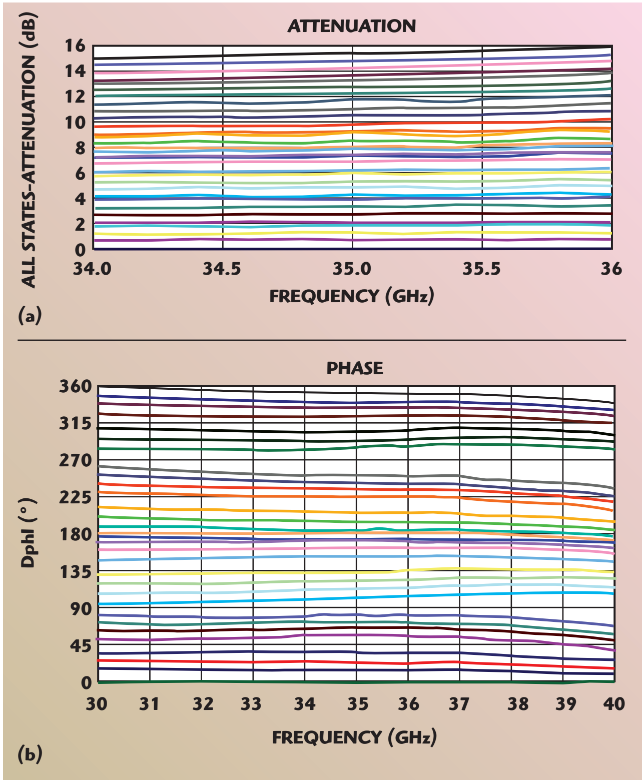


▲ *Fig. 6 Die photography of a C-Band 6-bit core chip.*



▲ *Fig. 7 Ka-Band core chip phase and attenuation control response.*

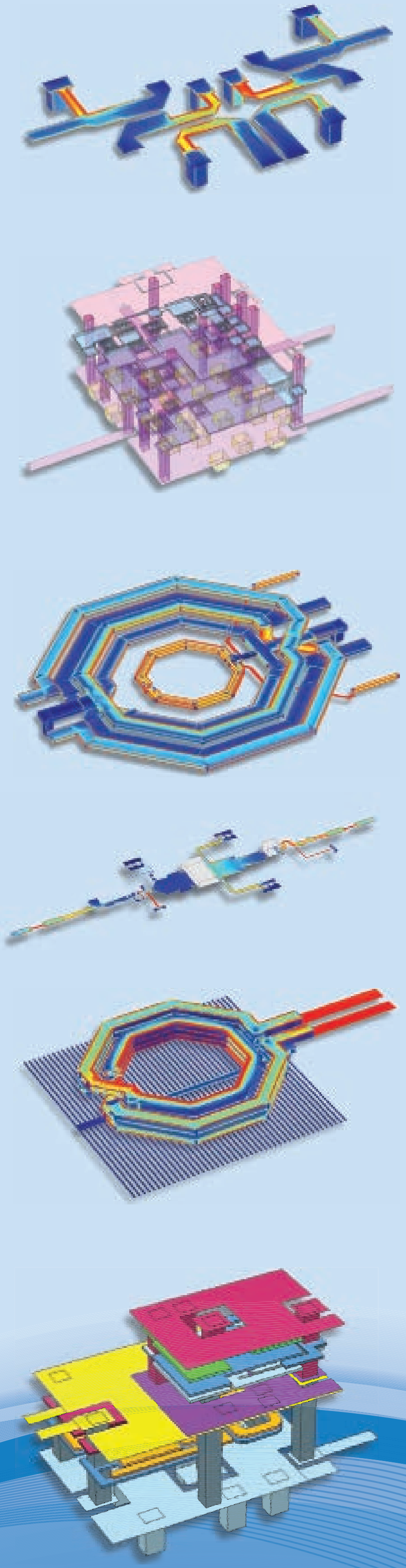
stage low noise amplifier and a SIPO. Since this antenna only operates in Rx mode, this example does not integrate switches and medium power amplifiers. High integration reduces space, complexity and overall cost.

The third example highlights the capability to design and use Core Chips in E/D processes, up to Ka-Band (34 to 36 GHz) and at $F_t/2$ of the process. As previous examples, this Core Chip is composed of phase shifters, attenuators, a 12-bit serial to parallel converter and a low noise amplifier (noise factor below 8 dB in reception mode). Unlike the previous example, this chip also includes a medium power amplifier (P1dB of 10 dBm), with less than 350 mW consumption.

Figure 7 shows the phase and attenuation control of the chip over the 34 to 36 GHz band. Note the flatness of phase and attenuation over the bandwidth. This characteristic is mandatory for electronically steerable antennas. If the phase is not constant across the overall bandwidth, then pointing the beam in the same direction at different frequencies would demand dynamic phase changing for each radiating element, depending on the frequency.

This would make the system far too complex and would effectively close the door to large bandwidth applications. In fact, each Core Chip in this antenna array is programmed with a phase value, so the combination of each single radiating element points the overall beam in one precise direction.

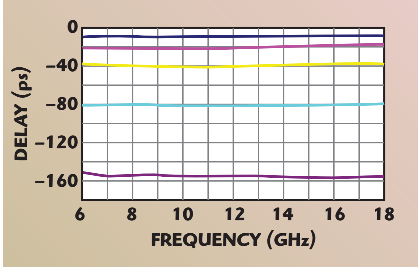
While using a phase shifter, it is common to give 15 percent of bandwidth as a maximum value of use range. As an example, at 35 GHz, the maximum bandwidth will be approximately 5 GHz. At Ka-Band, the phase shifter response, from 30 to 40 GHz (see Figure 7), exhibits a phase deviation of 20°, whereas between 32.5 and 37.5 GHz the deviation is less than 5°, which is the smallest phase shifting step. When the beam pointing error due to phase steering is smaller than



half the antenna beam width, then the phase shifters cannot be used anymore.

To achieve higher beam pointing accuracy, True Time Delay (TTD) functions are a solution.[3] Instead of changing the phase of each radiating element, the trick is to change the true time delay between each radiating element to obtain the same differential phase shifting between two elements, whatever the frequency. A constant time delay on a large bandwidth is possible using different lengths of switched lines, since phase variation is proportional to frequency. Switches can be used to modify the overall line length.

A 5-bit TTD has five different line lengths making possible 64 different length combinations and 64 different time delays. ***Figure 8*** shows a 5-bit true time delay chip and its performance from 6 to 18 GHz. One can see the five delay line blocks with increasing lengths that are combined under digital control. The graph highlights the flat behavior over a wide frequency range.



▲ *Fig. 8 6 to 18 GHz 5-bit True Time Delay Chip measured results.*

The III/V process nevertheless limits the range of frequencies that Core Chips can operate over. To develop Core Chips with on-chip SIPO control to work at 60 GHz and up to E-Band, designers must use a process with an F_t of approximately 200 GHz. A 100 nm true E-mode process, using a metamorphic layer,[4] will be available next year. It offers an F_t of 200 GHz and F_{max} of 300 GHz, which unlocks the technology for Core Chips up to 100 GHz.

This device provides enough RF power and performance, even using only enhancement mode transistors. The maximum stable gain of one stage at 30 GHz is 15 dB, showing that E-mode gain is no longer an issue even at these higher frequencies. The large average gate voltage swing of 0.62 V and the 100 mV threshold voltage also supports the integration of switches.

In conclusion, it can be said that E/D III/V processes enable the integration of high performance amplifiers, phase shifters and attenuators, on the same chips with serial to parallel converters, to achieve state-of-the-art Core Chips. This level of high performance integration makes the implementation of large electronically steerable flat antennas possible at minimum cost and size, from C-Band to Ka-Band, today, and at E-Band in the near future. ■

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Design of Miniature RF Transceivers for Broadband MIMO Systems in Ku-Band

In this article, the development of low cost, miniature, four-way RF transceivers in Ku-Band for MIMO wireless communication systems is presented. The RF transceiver operates with an FDD duplexing scheme, to obtain high bidirectional data throughputs and a simple network arrangement. The transceiver operates from 13.6 to 14.4 GHz, which is an experimental band for the next generation wireless communications in China. The RF bandwidth is up to 100 MHz, which makes it possible to support very high data rates (more than 1 Gbps). The whole four-way RF transceiver is fabricated on a single high-frequency multilayer PCB board, realizing a low cost transceiver with miniature size. A demonstration wireless communication system in Ku-Band has been successfully set up with the proposed RF transceivers.

Currently, wireless communication systems with over 1 Gbps data rates are of great interest in both research and industry areas. According to the definition of IMT-Advanced (4G) systems by the International Telecommunication Union (ITU), the next generation network should support approximately 1 Gbps data rates for low mobility. To meet this requirement, many advanced techniques, such as broad channel bandwidth, high-level modulation scheme (QPSK or higher level), orthogonal frequency division multiplexing (OFDM) and multiple-input multiple-output (MIMO) configurations, should be employed.[1-3] Compared to a TDD communication system, an FDD scheme helps to obtain higher bidirectional data throughputs, simpler network arrangement for the RF transceiver and larger cell coverage, which is an attractive choice to support the high data rate communications.

However, the frequency arrangement for an FDD system is more difficult than for a TDD system. In order to support data rates up to 1 Gbps or more, the channel bandwidth will be at least 100 MHz.[1] Thus, two continuous 100 MHz transmission bands are needed for a Tx and an Rx channel, respectively. A guard band of several hundred MHz, for Tx/Rx frequency separation, is necessary for feasible duplexer design with high isolation. The low RF frequency band (that is less than 6 GHz) is too crowded today to provide the required band

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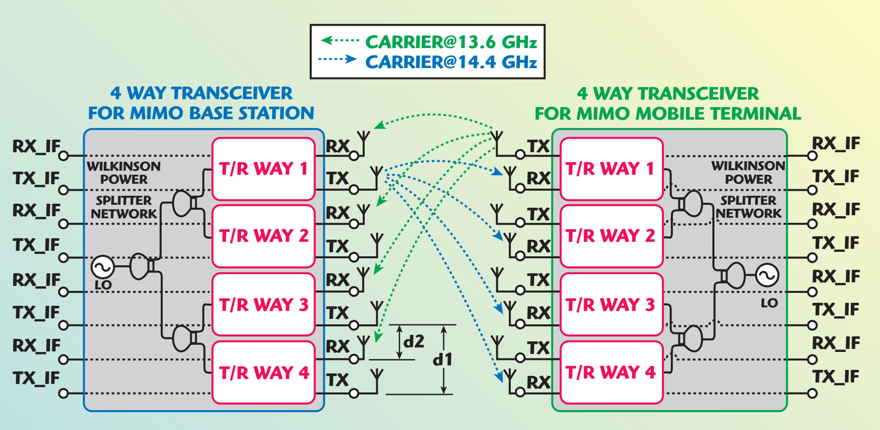


▲ *Fig. 1 Ku-Band transceivers for MIMO base station and mobile terminal.*

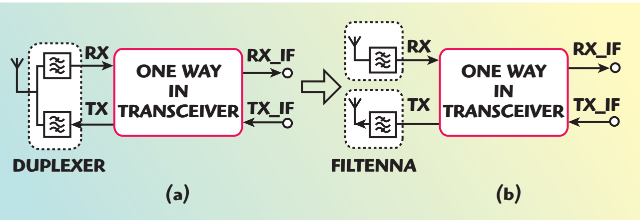
resources. Besides, in a MIMO system, antenna elements are usually fed with uncorrelated signals and typically have a substantial spacing of at least half a wavelength from each other.[4,5] This results in a bulky antenna array working with a low carrier frequency. More and more attention is focused on a higher RF frequency band of 6 to 15 GHz for future wireless communication systems.[6] In this article, 13.6 to 14.4 GHz is the chosen RF frequency band for the transceiver, which is an experimental band for the next generation of wireless communications in China.

The transceiver in this article is developed for a 4×4 MIMO wireless communication system. After careful design and optimizations, a pair of low cost miniature four-way transceivers in Ku-Band is fabricated on a single PCB board. The RF performance of the transceiver is measured and provided in detail. In addition, a Ku-Band wireless communication demonstration system is set up successfully with the transceivers.

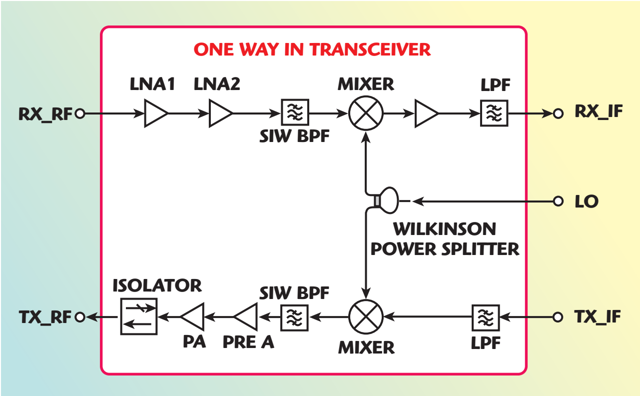
DESIGN AND IMPLEMENTATION OF A FOUR-WAY TRANSCEIVER IN KU-BAND

Systematic Design

The block-diagram of the four-way transceivers in Ku-Band for the MIMO base station and MIMO mobile terminal are shown in ***Figure 1***. For a MIMO communication system to work properly, the RF signal in each Tx/Rx channel has to be as uncorrelated as possible, which means the space between antenna elements (denoted as d1 the figure) should be large enough. Normally, in order to ensure uncorrelated fading characteristics of the wireless channel, the adjacent antenna elements should have a substantial spacing of at least a half wavelength,[4,5] which is approximately 10 to 12 mm for a 13.5 to 14.5 GHz signal. The cable between the antenna and the RF transceiver will introduce a considerable insertion loss at Ku-Band, and thus degrade the overall performances of the transceiver. Here, the Tx/Rx antennas are directly connected to the RF ports with SMA connectors, avoiding the cable loss.



▲ *Fig. 2 Conventional antenna arrangement (a) and filtenna arrangement (b) of the receivers.*



▲ *Fig. 3 Schematic of one way in the transceiver.*

In the design, d1 is equal to 110 mm (approximately 5 wavelengths of the carrier frequency), which makes the coupling between two adjacent antennas very weak. For FDD transceivers, the isolation between transmitting and receiving path is also very important. The relatively large d1 provides enough space to utilize two antennas for transmitting and receiving, respectively, instead of one in conventional FDD transceivers. Better isolation between the Tx and Rx paths can be reached with two filtennas,[7] as shown in ***Figure 2***. The conventional duplexer is no longer needed. The distance between the Tx and Rx antennas for one way in the transceiver, denoted as d2 in Figure 1, is equal to half d1 (that is 55 mm, or approximately 2.5 wavelengths at the carrier frequency), thus ensuring good balance between weak coupling and high isolation between Tx and Rx antennas.

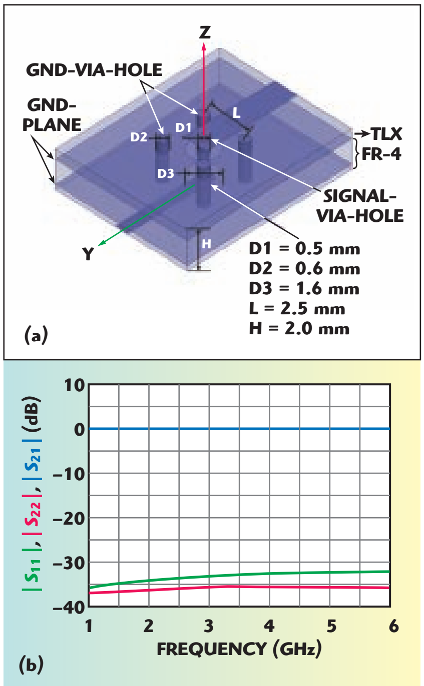
The schematic of one way in the transceiver is shown in ***Figure 3***. ***Table 1*** gives the RF specifications. The classic super heterodyne architecture is utilized for this Ku-Band transceiver. A GaAs HEMT MGF4941AL is used for the low cost two-stage low noise amplifier (LNA) with ultra-low noise and reasonable gain to suppress the noise of the following stages. SIW image-rejection filters[8,9] are employed for better performance than with the microstrip type. A high linear passive mixer is used, which demands +13 dBm LO pump power. FMM5061VF with 27 dB linear gain and +33 dBm P1dB power output is needed as the LO driver before the Wilkinson[1-8] power splitter network. System-level simulation for one TRX way is performed with Agilent Advanced Design System (ADS) 2009. Table 1 also gives the system-level simulation results for the transceivers in MIMO base station and mobile terminal, respectively. The simulation result shows adequate margin, ensuring a promising measurement performance.

Implementation Considerations

Several methods are utilized to realize the low cost transceiver with miniature size. A high-frequency

TABLE I
RF SPECIFICATIONS AND SYSTEM-LEVEL SIMULATION RESULTS FOR ONE WAY IN THE TRANSCEIVER FOR MIMO BASE STATION (A) AND MIMO MOBILE TERMINAL (B)

Items	Specifications	Sys-level Simu. Result
(a)		
Duplex Scheme	FDD	–
Carrier of Tx (GHz)	14.4	–
Carrier of Rx (GHz)	13.6	–
RF Bandwidth (MHz)	100	–
Rx Conv. Gain (dB)	>25	28.9 - 29.6
Rx NF (dB)	<4.5	2.5 - 2.9
Rx Gain-Flatness (dB)	<2.0	0.7
Tx Conv. Gain (dB)	>22	26.3 - 27.2
Tx Gain-Flatness (dB)	<2.0	0.9
Tx Output P1dB (dBm)	>+30	33.8
Tx Output IM3	<–40 dBc @ P_{out}=+20 dBm	–46 dBc @ P_{out}=+20 dBm
(b)		
Duplex Scheme	FDD	–
Carrier of Tx (GHz)	13.6	–
Carrier of Rx (GHz)	14.4	–
RF Bandwidth (MHz)	100	–
Rx Conv. Gain (dB)	>25	27.3 - 28.0
Rx NF (dB)	<4.5	3.0 - 3.3
Rx Gain-Flatness (dB)	<2.0	0.7
Tx Conv. Gain (dB)	>22	24.9 - 25.8
Tx Gain-Flatness (dB)	<2.0	0.9
Tx Output P1dB (dBm)	>+25	28.5
Tx Output IM3	<–40 dBc @ P_{out}=+15 dBm	–45 dBc @ P_{out}=+15 dBm



▲ *Fig. 4 3D structure (a) and simulation results of the IF port configuration.*

multilayer PCB board is used for the integration of the four-ways of the transceiver, the PLL module, LO power splitter network, power and control module, etc. The top-layer material is a Taconic TLX, with ε_r = 2.55 and a height of 0.508 mm. The other layers are all FR-4. In order to get rid of "metal jumpers" for crossing signal-transmission lines, a wideband microstrip-to-microstrip via transition[10] for the IF signal is used to get a simple circuit layout. IF signals (below 4 GHz) are transmitted from the top layer microstrip line to the bottom PCB layer through the signal-via-hole, as shown in ***Figure 4***. Several GND-via-holes, acting as current return-path, are necessary for impedance matching. After design and simulation with Ansoft HFSS, excellent RF performance could be obtained with this transition. The simulation results show S_{11} and S_{22} below –30 dB and S_{21} above –0.1 dB from

1 to 6 GHz. Compared to low RF frequency transceiver, severe cross coupling is a critical issue in Ku-Band. Different function blocks, including passive/active RF blocks, DC power and control blocks, are separated by metal frameworks, in order to suppress cross coupling and shield interferences from other blocks and the environment. ***Figure 5*** shows the pictures of the pair of four-way transceivers in Ku-Band.

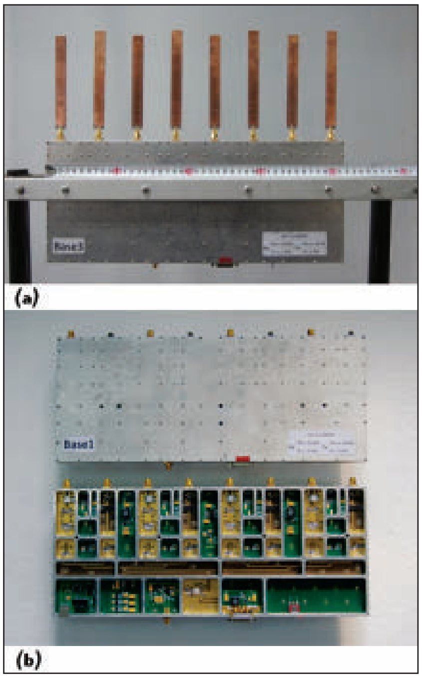
MEASUREMENTS AND RESULTS

Measured Performance of the Four-Way Transceiver in Ku-Band

Table 2 gives the detailed frequency conversion scheme for the pair of transceivers. The RF frequency is within 13.55 to 14.45 GHz. Brief measured results are given for key blocks of the transceiver in ***Table 3***.

Figure 6 gives the measured return loss of the transceivers for the MIMO base station and MIMO mobile terminal. A low return loss is obtained at the RF ports of the transceivers, ensuring a good matching with antennas.

Figure 7 shows the measured Rx gain and Tx output power of the four-way transceivers. Cable insertion loss has been calibrated. Detailed comparison between the RF specifications, simulation and measured results are listed in ***Table 4.***



▲ *Fig. 5 The four-way transceivers with filtennas in Ku-Band (a) and six-way transceivers without cover (b).*

Demonstration of a Ku-Band Wireless Communication System

Finally, to evaluate the overall performance, a Ku-Band wireless communication demonstration system is set up for error vector magnitude (EVM) measurement, with a pair of the proposed transceivers. ***Figure 8*** gives the schematic and photograph of the wireless system under test. The desired IQ baseband signals are first generated with Agilent N8241A and then modulated with Rohde & Schwarz SMBV100A to output the IF signals. The transceiver for the MIMO base station up-converts the IF signal and then the transceiver for the MIMO mobile terminal down-converts the IF signal, which is demodulated and analyzed by Agilent

TABLE II

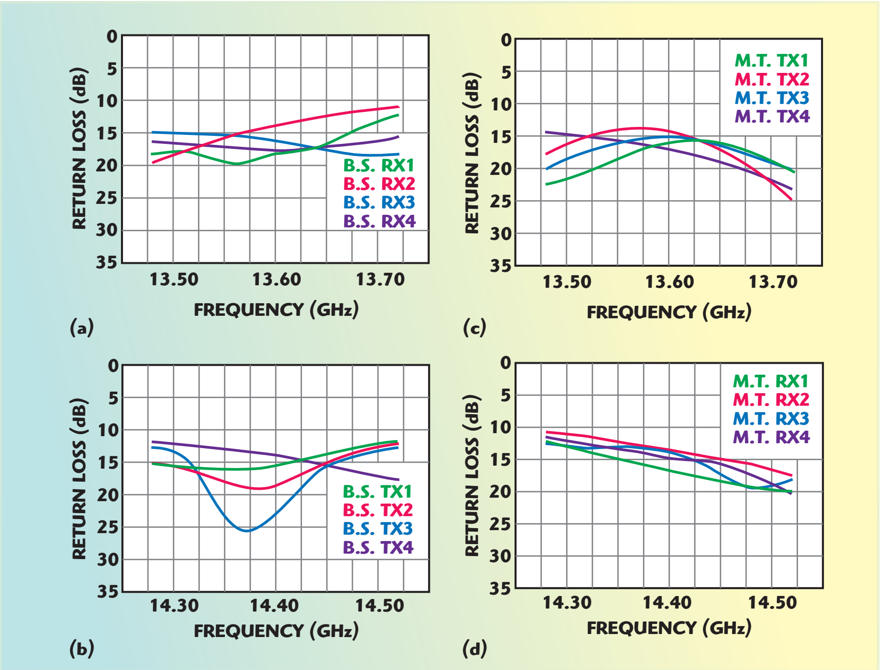
FREQUENCY CONVERSION SCHEME FOR THE PAIR OF TRANSCEIVERS

RF Frequency of Rx in MIMO Base/Tx in MIMO Mob	13.55 - 13.65 GHz
RF Frequency of Tx in MIMO Base/Rx in MIMO Mob	14.35 - 14.45 GHz
IF Frequency of Rx in MIMO Base/Rx in MIMO Mob	2.19 - 2.29 GHz
IF Frequency of Tx in MIMO Base/Tx in MIMO Mob	2.99 - 3.09 GHz 1.39 - 1.49 GHz

TABLE III

MEASURED RESULTS FOR KEY BLOCKS IN ONE TRX WAY

Blocks	Measured Results
2-stage LNA	Gain: 21.2±0.5 dB @ 13.55 - 14.45 GHz NF: 1.1±0.1 dB @ 13.55 - 14.45 GHz
IF Amplifier	Gain: 14.3±0.5 dB @ 2.19 - 2.29 GHz NF: 1.5±0.1 dB @ 2.19 - 12.29 GHz
Mixer	CL: 9.5±1.5 dB @ RF13.55 - 14.45 GHz P1dB_in: +5 dBm @ 13 dBm LO
Preamplifier	Gain: 8.6±0.8 dB @ 13.55 - 14.45 GHz P1dB_out: +10.5±0.3 dBm @ 13.55 - 14.45 GHz
Ku-Band Power Amplifier	Gain: 26.3±0.5 dB @ 13.55 - 14.45 GHz P1dB_out: +35.5 dBm @ 14.35 - 14.45 GHz +32.4 dBm @ 13.55 - 13.65 GHz



▲ *Fig. 6 Measured return loss of RF ports for MIMO BS receiver (a), BS transmitter (b), MT transmitter (c) and MT receiver (d).*

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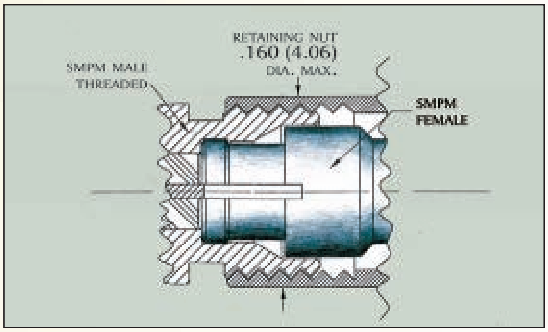

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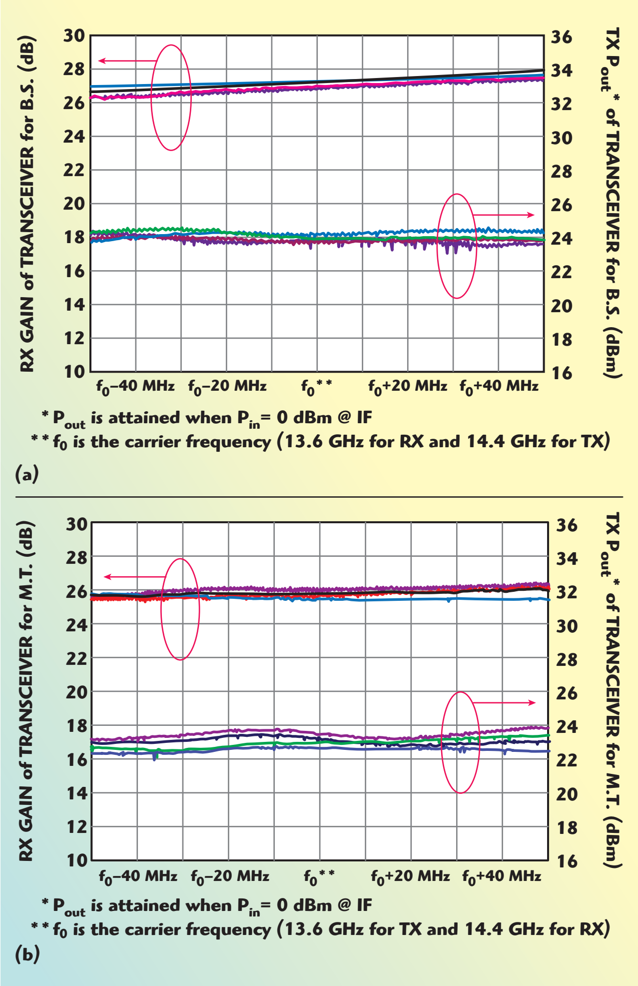

▲ *Fig. 7 Rx gain and Tx output power of the four-channel transceivers for MIMO base station (a) and mobile terminal (b).*

89600VSA for EVM. The carrier frequency is 14.4 GHz.

For demonstration, the input power at the TX_IF port is set to –30 dBm, and the distance between Rx and Tx antennas is set to 0.80 m. Other unused RF and IF ports are all terminated with matching loads. In the measurement, the baseband signal with 100 M symbol/s under QPSK and 16QAM modulation is applied to the wireless system. The signal constellation and other results are depicted in ***Figure 9***. The measured EVM is 4.7 percent rms and the SNR is 26.5 dB for a 100 M symbol/s QPSK signal; the measured EVM is 5.2 percent rms and the SNR is 23.2 dB for a 100 M symbol/s 16QAM signal.

TABLE IV

COMPARISON OF RF SPECIFICATIONS, SIMULATIONS AND MEASURED RESULTS FOR TRANSCEIVER OF MIMO BASE STATION (A) AND MOBILE TERMINAL (B)

Items	Specifications	Simulation Results	Measured Results
(a)			
Rx Conv. Gain (dB)	>25	28.9 - 29.6	26.3 - 27.9
Rx Gain Flatness (dB)	<2.0	0.7	1.7
Tx Conv. Gain (dB)	>22	26.3 - 27.2	23.8 - 24.5
Tx Gain Flatness (dB)	<2.0	0.9	0.7
Tx Output P1dB (dBm)	>+30	+33.8	+31.5
Tx Output IM3	<–40 dBc @ P_{out}=+20 dBm	–46 dBc @ P_{out}=+20 dBm	–42.8 dBc @ P_{out}=+20 dBm
(b)			
Rx Conv. Gain (dB)	>25	27.3 – 28	25.3 – 26.2
Rx Gain Flatness (dB)	<2.0	0.7	0.9
Tx Conv. Gain (dB)	>22	24.9 - 25.8	22.5 - 24
Tx Gain Flatness (dB)	<2.0	0.9	1.5
Tx Output P1dB (dBm)	>+25	+28.5	+26.2
Tx Output IM3	<–40 dBc @ P_{out}=+15 dBm	–45 dBc @ P_{out}=+15 dBm	–42.2 dBc @ P_{out}=+15 dBm

CONCLUSION

In order to support very high data rates (more than 1 Gbps) and bandwidth of up to 100 MHz for next generation MIMO wireless communication system, a pair of four-way transceivers in Ku-Band, with an FDD scheme, have been developed. For highly integrated transceivers, a low-cost high-frequency multilayer PCB technique has been utilized during fabrication. The experimental results have proved the excellent RF performance of the transceivers. All of the measured results fully meet the design requirements. Finally, the overall performance of one complete RF channel is evaluated with a Ku-Band wireless communication system. Measured results show that the demonstrated Ku-Band wireless system successfully supported wireless communication in Ku-Band with 100 Ms/s QPSK and 100 Ms/s 16QAM signals with low EVM. ■

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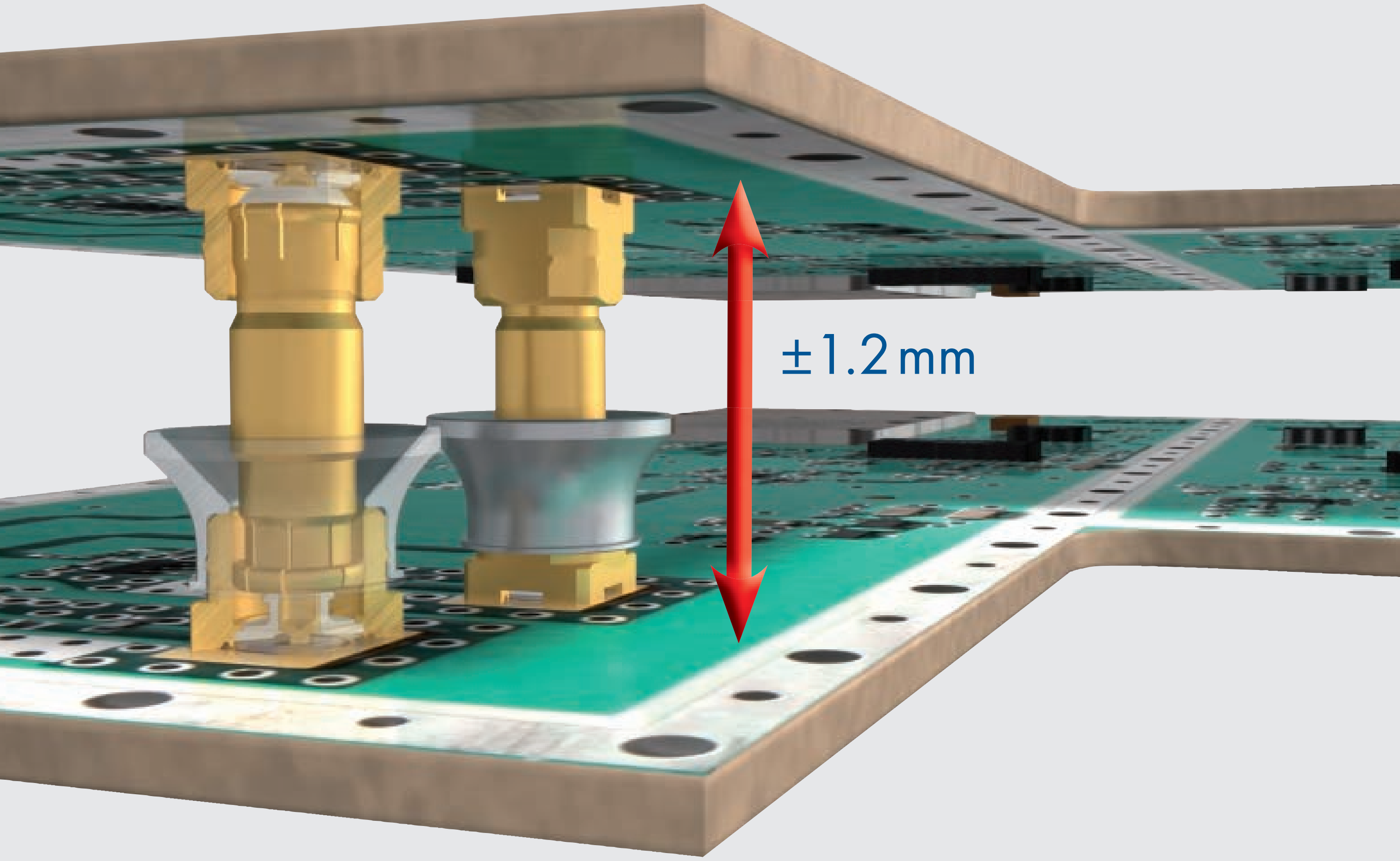

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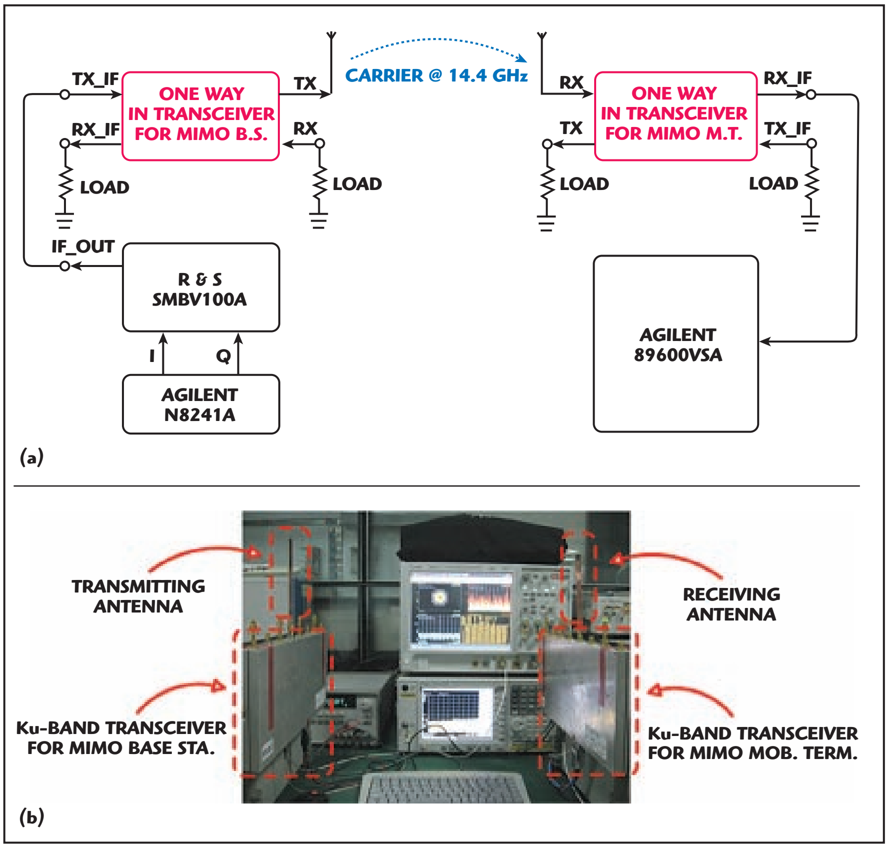
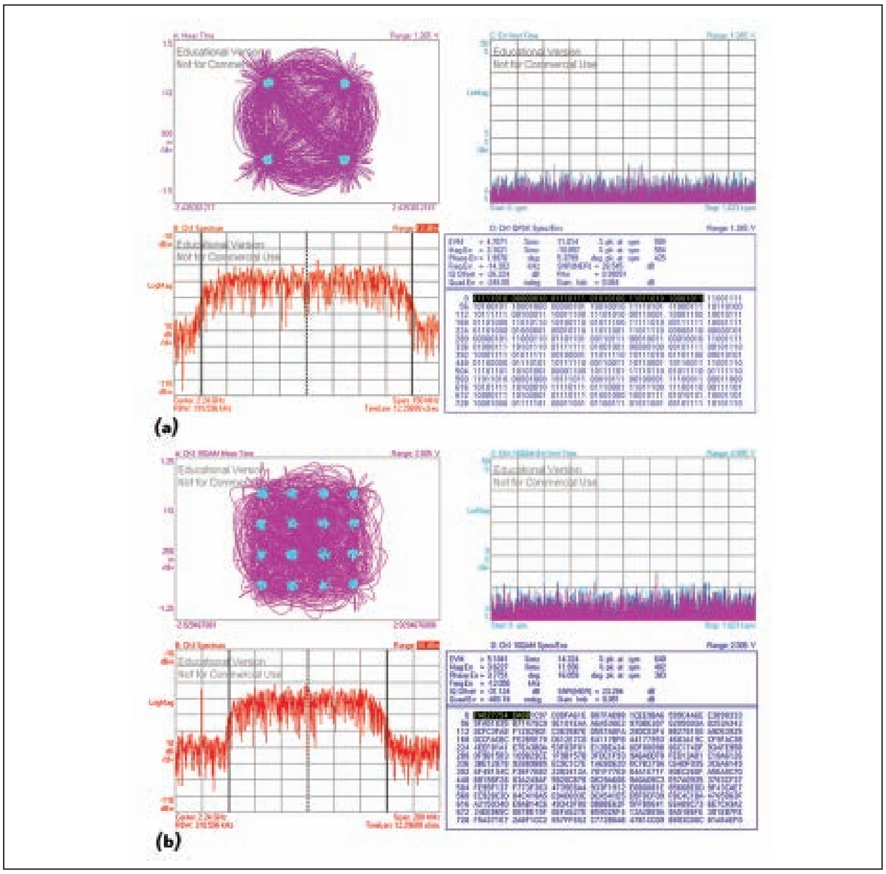


▲ *Fig. 8 Schematic (a) and photograph of the wireless communication system under test (b).*



▲ *Fig. 9 Ku-Band wireless communication system measured results for a 100 Ms/s QPSK signal (a) and a 100 Ms/s QAM signal (b).*

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A Cascaded Triplet SIW Bandpass Filter

A substrate integrated waveguide (SIW) bandpass filter is proposed in this article, which uses proximity coupling structures and slot loaded quarter SIW resonators to implement a cascaded triplet (CT) filter. Electrical coupling is realized with the novel proximity coupling structure, while the size of a quarter SIW resonator (QSIWR) is reduced by 43 percent, when loaded with a slot. By introducing magnetic cross coupling into the electric main coupling path, a C-Band CT filter is designed, which has a transmission zero at the upper stopband. The measured results show good performance and agree well with the simulated results.

Since the proposal of the substrate integrated waveguide (SIW) technique, many kinds of SIW filters have been designed, among which SIW cavity coupled filters are in the majority.[1-3] Such filters have the advantages of high Q, light weight, easy fabrication and simple integration with planar circuits. However, they are relatively large in size, compared with their microstrip counterparts, especially in the lower microwave frequency band. To alleviate this problem, some miniaturized SIW filters have been proposed based on half mode substrate integrated waveguide (HMSIW),[4] substrate integrated folded waveguide (SIFW)[5] and their variants.[6-11] The quarter SIW resonator (QSIWR) is one of these miniaturized structures, first proposed by Zhang,[9] whose size is only a quarter of an SIW cavity resonator. The electric field distribution of a QSIWR's fundamental resonant mode is shown in ***Figure 1***, compared with that of a rectangular SIW cavity.

In this article, it will be shown that the size of a QSIWR can be further reduced when loaded with a carefully designed slot. In addition, a proximity coupling structure will be proposed. Unlike traditional magnetic coupling between SIW resonators, which are mostly realized by

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MSW2002–200	SP2T T-R Switch	+V Only	2000–6000	0.6	1.5:1	34	+50
MSW2022–202	SP2T T-R Switch	+V & -V	10–1000	0.2	1.5:1	45	+52
MSW2050–205	SP2T T-R Switch	+V Only	20–1000	0.2	1.5:1	50	+52
MSW2051–205	SP2T T-R Switch	+V Only	200–4000	0.3	1.5:1	34	+52
MSW2030–203	Symmetrical SP2T	+V Only	20–1000	0.3	1.5:1	52	+50
MSW2031–203	Symmetrical SP2T	+V Only	200–4000	0.5	1.5:1	35	+50
MSW2032–203	Symmetrical SP2T	+V Only	2000–6000	0.6	1.5:1	35	+50
MSW2040–204	Symmetrical SP2T	+V Only	20–1000	0.2	1.5:1	50	+52
MSW2041–204	Symmetrical SP2T	+V Only	200–4000	0.5	1.5:1	33	+52
MSW2060–206	Symmetrical SP2T	+V & -V	20–1000	0.25	1.5:1	53	+50
MSW2061–206	Symmetrical SP2T	+V & -V	400–4000	0.5	1.5:1	35	+50
MSW2062–206	Symmetrical SP2T	+V & -V	2000–6000	0.7	1.5:1	34	+50
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an aperture in the common wall of two neighbored SIW cavities, electrical coupling is adopted and can be readily realized by the proximity coupling structure. With electrical coupling in the main path and magnetic coupling in the cross coupling path, a CT filter is designed, which operates at 5.9 GHz, with a fractional bandwidth of 7 percent and has a transmission zero point at approximately 7 GHz.

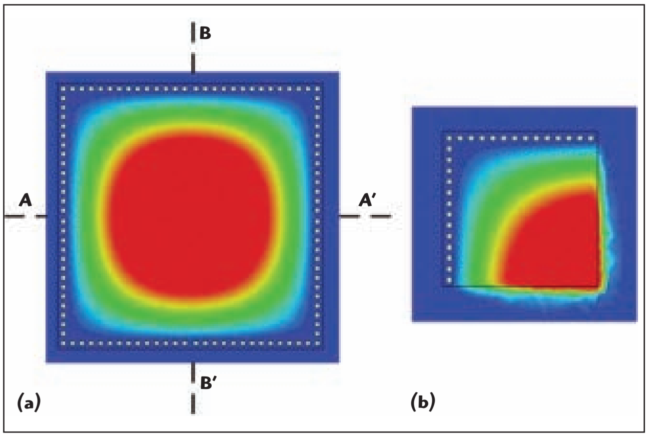

Fig. 1 *Electric field distribution in a conventional rectangular SIW cavity (a) and QSIWR (b).*

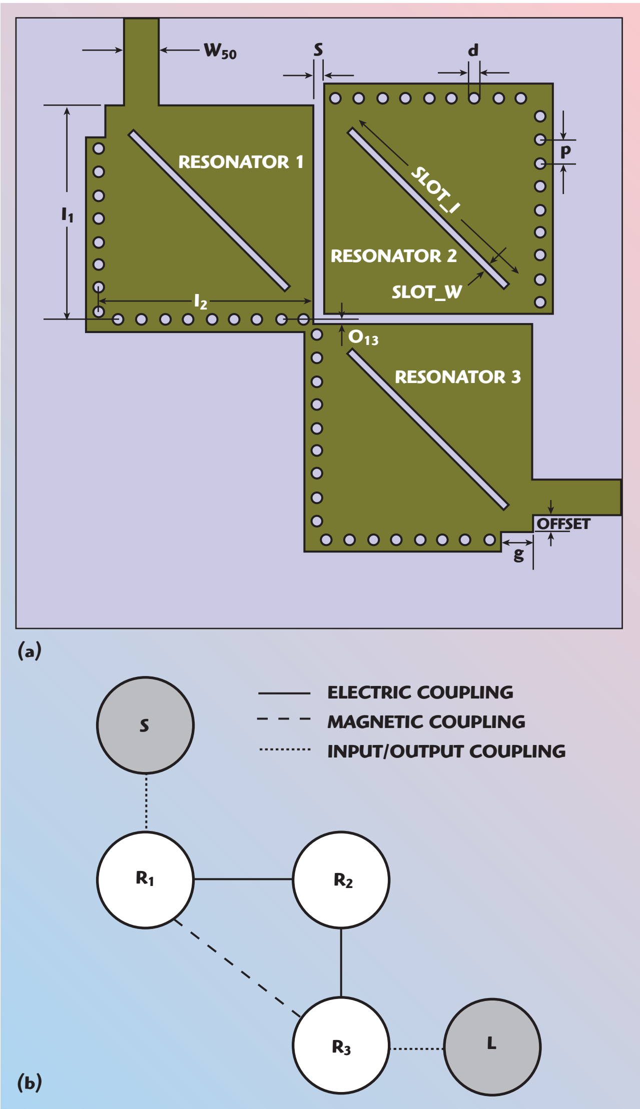

Fig. 2 *Configuration of the proposed CT filter (a) and the coupling technology (b).*

FILTER DESIGN

The configuration of the proposed CT filter is shown in ***Figure 2***. It is a cross coupled filter with three slot loaded QSIWRs. The center frequency of the filter is determined by the resonant frequency of the constitutional resonators, while the bandwidth is mainly affected by the coupling strength. Besides, the cross coupling between resonator 1 and resonator 3 determines the location of the transmission zero point. The input and output ports are two tapped 50 V microstrip lines, which determine how the filter is coupled with external circuits. The filter is specified to work at 5.9 GHz with a fractional bandwidth of 7 percent and a transmission zero at 7 GHz. Thus the coupling matrix and external quality factors are synthesized to be:[12]

$$M = \begin{bmatrix} -0.0195 & 0.0737 & -0.0158 \\ 0.0737 & 0 & 0.0737 \\ -0.0158 & 0.0737 & -0.0195 \end{bmatrix} \qquad (1)$$

$$Q_{e1} = Q_{e3} = 11.7143$$

where M_{ij} denotes the coupling coefficient between resonator i and resonator j, M_{ii} denotes the fractional frequency deviation of resonator i from the center frequency of the filter, Q_{e1} and Q_{e3} represent the input and output external quality factors.

Slot Loaded QSIWR

A slot loaded QSIWR has a slot etched off along the diagonal of its upper metal plane. Due to the effect of the slot, the resonant frequency of a slot loaded QSIWR is affected not only by l_1 and l_2 (in our design $l_1 = l_2$) but also by the dimensions of the slot. A parametric dependence of the resonant frequency is shown in ***Figure 3*** for a slot loaded QSIWR built on a Rogers 5880 substrate with $\varepsilon_r = 2.2$ and $\tan\delta = 0.0009$. It is observed that the resonant frequency decreases as the slot becomes longer and wider, which means that to achieve the same resonant frequency, the cavity length l_1 of a slot loaded QSIWR can be shorter than that of a QSIWR and thus the size of the filter is further reduced.

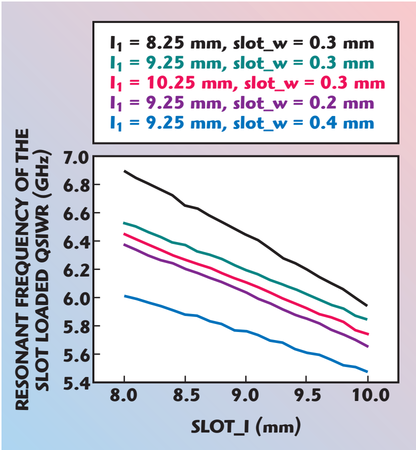

Fig. 3 *Resonant frequency of the slot loaded QSIWR with $l_1 = l_2$.*

To explain the effect of the slot on lowering the resonant frequency of a QSIWR, an analysis on the surface current distribution is done by HFSS. As shown in ***Figure 4***, the surface current of a slot loaded QSIWR has to detour around the slot, which stretches the effective current path in contrast to QSIWR


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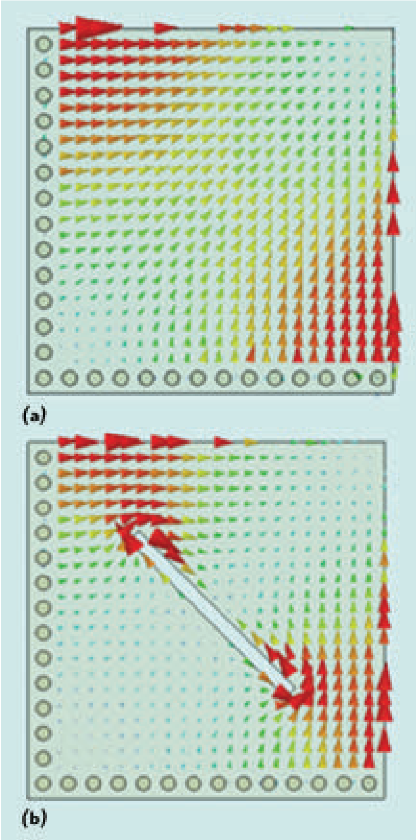

Fig. 4 Surface current distribution of a QSIWR (a) and a slot loaded QSIWR (b).

and results in a lower resonant frequency. To implement an asynchronous resonance, as required by the coupling matrix, a gap is opened in the grounded via wall of both resonator 1 and resonator 3, as denoted by g in Figure 2 (a).

Proximity Coupling in the Main Coupling Path

An SIW resonator is closed by grounded vias on all sides and the inter-resonator coupling is generally realized through an aperture in the common via wall between neighbor SIW cavities.[1,2] QSIWRs and slot loaded QSIWRs have two additional open boundaries by contrast and thus may have different coupling structures besides aperture coupling. ***Figure 5*** illustrates the configuration of the proposed proximity coupling structure. Since the resonant frequency of the odd mode is lower than that of the even mode, the coupling is electric in nature.[12] Aperture coupled SIW resonators implement magnetic coupling easily, but have difficulty implementing electric coupling.[2] However, with the proposed proximity coupling structure, electric coupling is readily

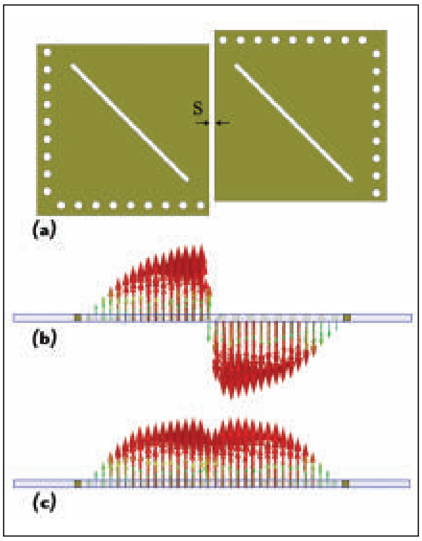

Fig. 5 Configuration of the proposed proximity coupling structure (a) and the electric field distribution of the low mode (b) and high mode (c).

realized, which facilitates the design of cross coupled SIW filters.

The coupling coefficient is primarily determined by the space between two resonators and can be extracted by the following formulation.[12]

$$M = \pm\frac{1}{2}\left(\frac{f_{01}}{f_{02}}+\frac{f_{02}}{f_{01}}\right)\cdot\sqrt{\left(\frac{f_1^2-f_2^2}{f_1^2+f_2^2}\right)^2-\left(\frac{f_{01}^2-f_{02}^2}{f_{01}^2+f_{02}^2}\right)^2} \qquad (2)$$

Where f_1 and f_2 correspond to the resonant frequencies of the odd mode and the even mode, while f_{01} and f_{02} correspond to the resonant frequencies of uncoupled resonators.

Cross Coupling

Figure 6 shows the cross coupling structure when the resonators are apart, $o_{13}<0$ (a) or overlap, $o_{13}>0$ (b). The cross coupling is weak when the resonators are apart from each other, whereas it gets stronger when they are overlapped. However, in both cases, the resonant frequency of the even mode is lower than that of the odd mode, indicating the cross coupling to be magnetic in nature.[12] The cross coupling strength is dependent on the parameter o_{13}, which is defined to be negative in Figure 6a and positive in Figure 6b. As demonstrated in ***Figure 7***, the transmission zero point gets closer to the passband as the cross coupling grows stronger.

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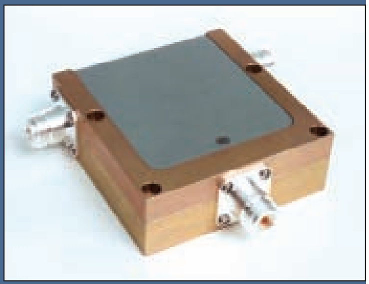

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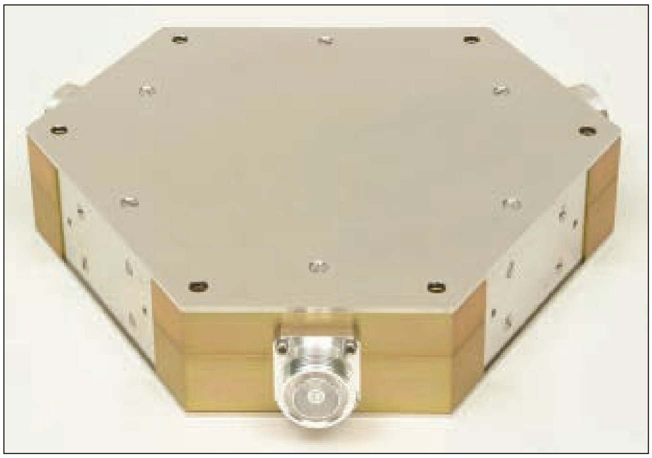

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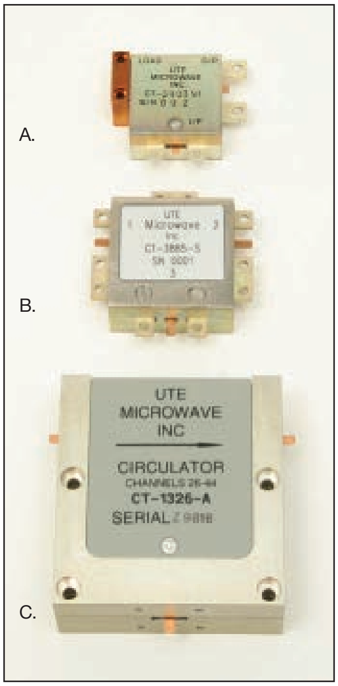

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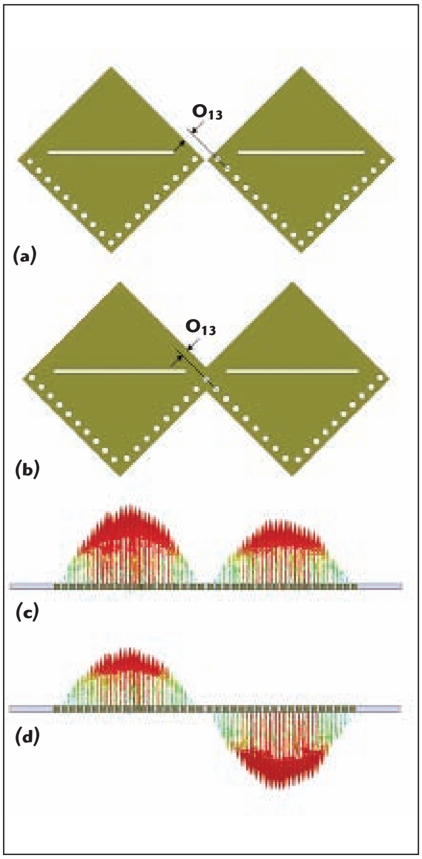
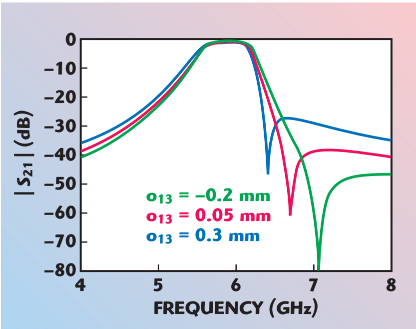


▲ *Fig. 6 Configuration of the cross coupling structure when the resonators are apart (a) or overlap (b) and the field distribution of the low mode (c) and high mode (d).*



▲ *Fig. 7 Simulation filter responses with different cross coupling.*

External Coupling

The external quality factors are influenced by the offset distance of input and output microstrip lines, which can be extracted from the group delay of S_{11} at resonance:[12]

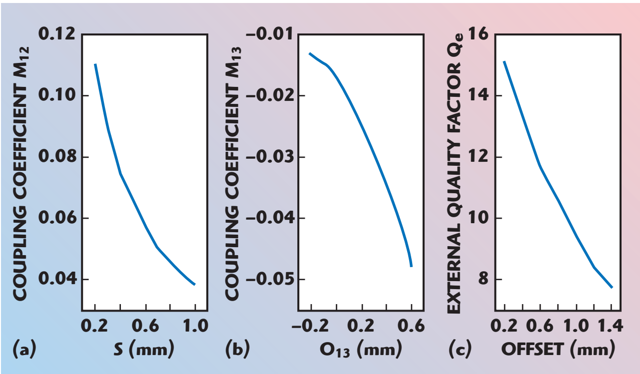
$$Q_e = \frac{\omega_0 \tau_{S_{11}}(\omega_0)}{4} \qquad (3)$$

Filter Synthesis

The coupling coefficient and the external quality factor are extracted according to Equations 2 and 3, as demonstrated in ***Figure 8***. Then the initial dimension parameters of the filter can be determined, which are tuned afterward for better performance. The final dimensions are $l_1 = l_2 = 9.25$ mm, slot_l = 9.5 mm, slot_w = 0.3 mm, s = 0.4 mm, $o_{13} = -0.15$ mm, g = 1.4 mm, offset = 0.8 mm, w_{50} = 1.5 mm, d = 0.5 mm, p = 1 mm. It is noticed that the size of a slot loaded QSIWR ($l_1 = l_2$ = 9.25 mm) is further reduced by 43 percent, compared with that of a QSIWR ($l_1 = l_2$ = 12.25 mm).

EXPERIMENTAL RESULTS

The filter was fabricated by a single layer printed circuit board (PCB) process on a 20 mil thick Rogers 5880 substrate with permittivity of 2.2 and loss tangent of 0.0009. The total size of the filter including feeding lines is 31 by 31 mm. A photograph of the filter is shown in ***Figure 9***. ***Figure 10*** shows the measured results from 4 to 8 GHz compared with the simulated results by HFSS and the ideal responses synthesized by the coupling matrix. The measured insertion loss is approximately 1.77 dB and the return loss is better than 23 dB from 5.7 to 6.03 GHz. The transmission zero point, at approximately 7 GHz, considerably improves the selectivity of the upper stop band. ***Figure 11*** shows the measured results from 3 to 20 GHz. It is observed that the spurious passband is far above the operating band.



▲ *Fig. 8 Coupling coefficients (a) and (b) and external Q factor (c) vs. filter dimensions.*

CONCLUSION

A proximity coupling structure for QSIWRs is proposed in this arti-

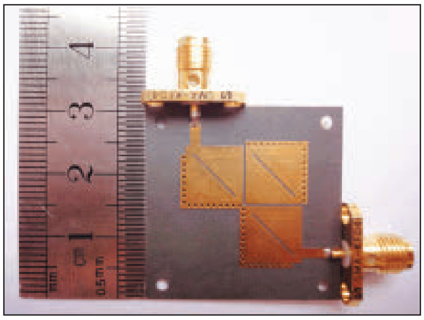


Fig. 9 Photograph of the fabricated CT filter.

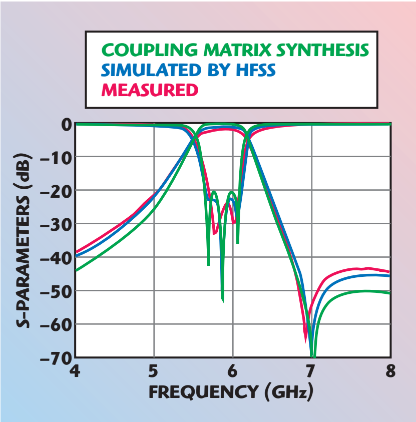


Fig. 10 Measured results compared with simulated results of the CT filters.

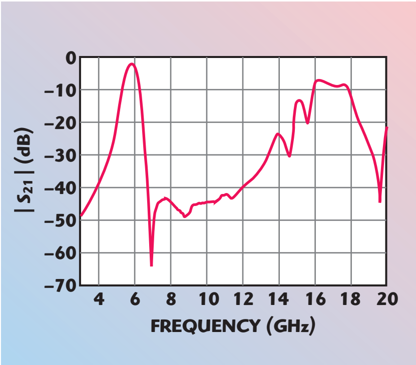


Fig. 11 Measured results of the CT filter over a wide band.

cle, which readily realizes electrical coupling and facilitates the design of cross coupled filters. To further reduce the filter size, slot loaded QSIWRs are utilized and a 43 percent reduction in size is achieved, compared with QSIWRs. With electrical coupling in the main path and magnetic coupling in the cross coupling path, a compact C-Band CT filter has been designed, which shows good performances of low insertion loss, high selectivity and wide-spaced spurious passband. ■

ACKNOWLEDGMENT

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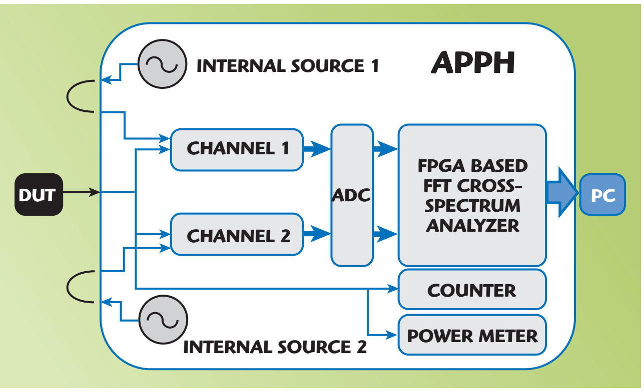

Fig. 1 APPH system block diagram.

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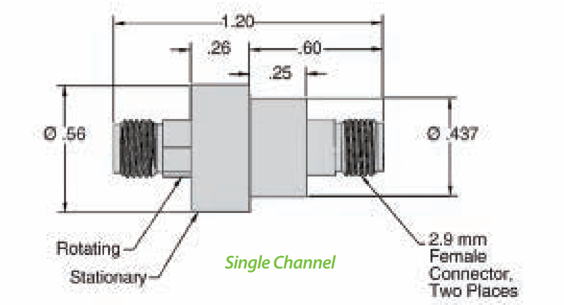
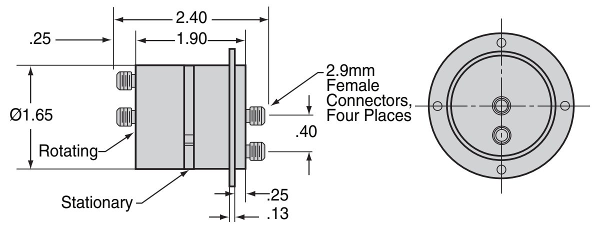


Single Channel



Dual Channel

SINGLE CHANNEL SPECIFICATIONS:

ELECTRICAL		
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 connector rating	

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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displays, which minimizes product costs while increasing reliability. The LAN or USB controlled instrument is 'plug-and-play' with any standard computer.

ACCURATE CALIBRATION

The entire test system is enclosed in a compact, fanless chassis. Developing the product on a fully integrated, low power platform has avoided fan cooling, further eliminating spurious signals and ground and power line loops. Two chassis are available, a 2.5 kg portable version, and a 4.5 kg, 19 inch rack mountable version.

A very important consideration is precise calibration. Before shipment, each instrument is carefully calibrated against a traceable noise standard to guarantee high precision, consistent and repeatable results. Optionally, a calibration standard can be supplied with the instrument to enable a user's on-site performance verification at any time.

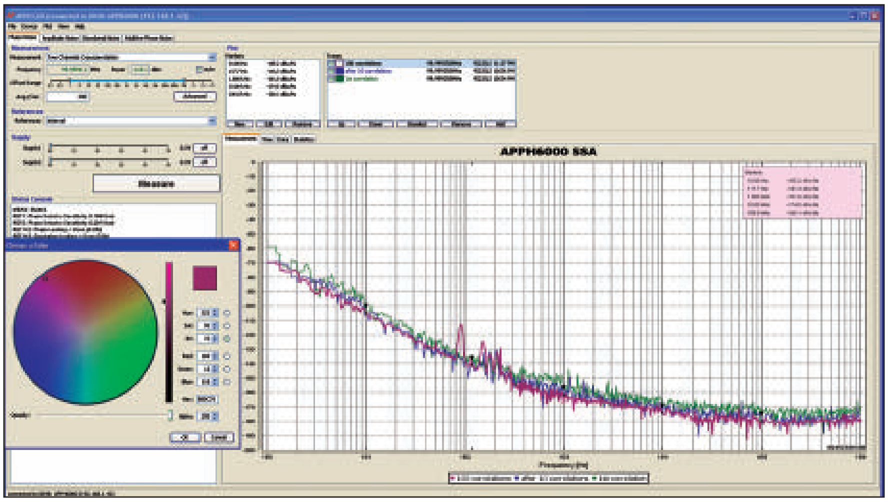

Fig. 2 APPH Graphical User Interface (GUI).

MEASUREMENT CAPABILITY

The APPH instruments are phase noise measurement systems that are designed to consistently provide clean, accurate absolute and additive phase noise data. The standard RF unit has an operating range of 2 to 400 MHz or 6.2 GHz. The microwave model extends the frequency range up to 21 GHz. The user may want to bypass the internal sources and work with their own reference sources to achieve improved phase noise floors with even shorter measurement times.

The phase noise data shown in ***Figure 2*** is data gathered from a low noise 100 MHz OCXO reference. The three traces shown are after first correlation (green, after 12 s measurement time), 10 correlations (blue, after 120 s) and 100 correlations (red, after 20 min), respectively. The noise floor of the DUT at –180 dBc/Hz is reached just after 10 correlations or two minutes. For this ultra-low noise measurement, even faster results can be obtained with external references sources.

The sensitivity of the system operated with the internal references is dependent on both the carrier frequency of the DUT and the frequency offset range. ***Figure 3*** shows the typi-

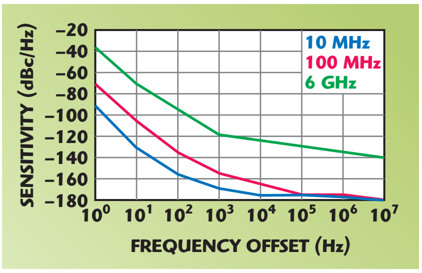

Fig. 3 Sensitivity of APPH with internal reference sources (after 24 s measurement time).

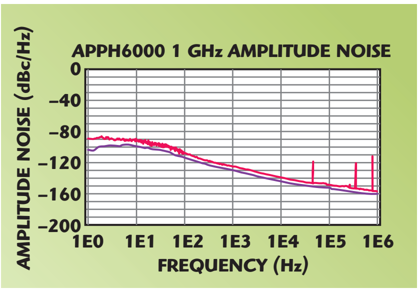

Fig. 4 Amplitude noise measurement with noise and spurious marker lists.

Fairview Microwave Inc.
ADAPTERS
SM5250 $58.16 SMA SWEPT 27 GHZ
SM4979 $38.77 SMA 27 GHZ
SM4923 $97.25 SMA FLANGE 27 GHZ
SM3224 $226.17 2.92 BULKHEAD 40 GHZ
SM3221 $148.48 3.5-3.5 34 GHZ
SM3935 $440.50 1.85-1.85 65 GHZ
SM8867 $195.00 SMP-2.4 40 GHZ
SM2927 $138.94 GMS-SMA 23 GHZ
SM3358 $226.17 7mm-3.5 18 GHZ
SM3397 $51.76 7/16 90° 6 GHZ
SM4531 $172.00 N 90° 18 GHZ
SM3547 $38.77 TNC-BNC 8 GHZ
SM5514 $145.40 ZMA-SMA 18 GHZ
SMW75ACN $297.95 WR75-N 10-15 GHZ
28AC206 $363.60 WR28-2.92 26-40 GHZ
SM4835 $172.53 SSMA-2.92 40 GHZ
ATTENUATORS
SA18N5WA $60.17 N 5W 18 GHZ
SA18N25WA $232.24 N 25 W 18 GHZ
SA18N507 $343.09 N 50 W 18 GHZ
SA3015 $13.55 SMA 2 W 3 GHZ
SA18S50W $337.81 SMA 50 W 18 GHZ
SA3N511 $162.41 N 50 W 3 GHZ
SA4020 $738.96 2.92 10 W 40 GHZ
SA5074 $274.47 2.4 1 W 50 GHZ
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MC0618 $341.38 SMA COUPLER 6-18 GHZ
MC4061 $757.50 N-SMA COUPLER 1-12 GHZ
SMC4037 $52.52 N COUPLER 700-2700 MHZ
MP0218-4 $600.95 SMA 4-WAY 2-18 GHZ
MP1540-2 $1,045.15 2.92 2-WAY 15-40 GHZ
MP8769 $472.68 N 2-WAY 2-8 GHZ
MP8758-4 $82.98 N 4-WAY 800-2500 MHZ
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ST3D-50 $206.96 7/16 50 W 3 GHZ
ST1831 $19.57 SMA PUSH ON 1 W 18 GHZ
ST2671 $51.11 SMA 2 W 27 GHZ
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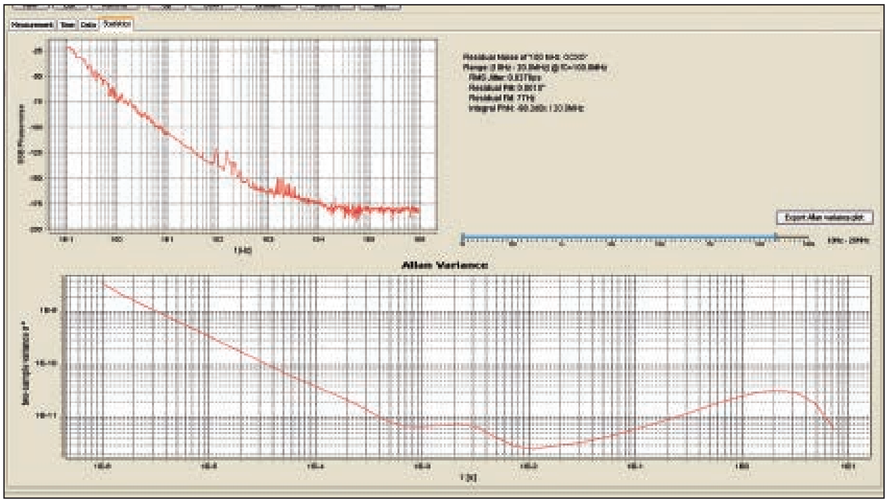


Fig. 5 Statistic tab provides jitter, residual FM; integral phase noise, or Allan Variance.

cal sensitivity when using the internal sources to make a measurement, assuming an approximate 24 second measurement with an offset from 1 Hz to 10 MHz.

However, the APPH signal source analyzers can do more than just absolute phase noise tests of oscillators and synthesizers. They can also measure additive phase noise of amplifiers under different drive conditions, and of frequency translating devices like prescalers or mixers. Additionally, amplitude noise measurements are also supported. ***Figure 4*** shows the amplitude noise obtained from one of Anapico's signal generators at 1 GHz, showing a trace with user defined markers and spurious list.

The APPH also offers direct access to the FFT analyzer, which enables noise analysis of supply and control voltages. The APPH6040 with extended offset range as well as the APPH20G provide bandwidth beyond 40 MHz and transient measurement capability.

REMOTE CONTROL

It is known that efficient conduction of noise measurements requires high quality user interfacing. All Anapico instruments are supplied with a dedicated interface GUI that is easy to navigate and operate (see Figure 2) and allows simple 'one-click' measurements. There are simple indicators for DUT power, frequency and frequency stability, as well as lock status and indicators relating to the validity of the results. Embedded diagnostic hardware provides the information the software needs to auto-detect, lock, calibrate, acquire data and post-process data.

Important features include:

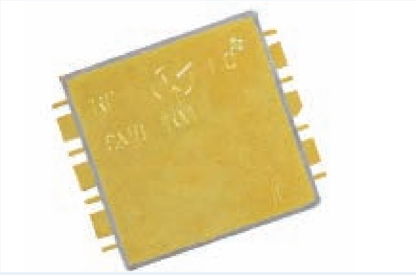
- DUT power level and frequency and drift indicator
- Dedicated plot window with autoscale and versatile zoom functions, scaling and smoothing
- Drag and drop multiple markers
- Spurious detection, list and suppression
- Data export to CSV, Excel and ASCII data formats
- Single or multi plot traces export to bitmap or re-loadable APPH format
- Multiple post-processing data such as random jitter over defined bandwidth, Allan Variance, integral phase noise (see ***Figure 5***).

While this GUI provides powerful features to the user, the APPH instruments are also optimized for direct control via user software. Programming libraries as well as standard SCPI command language allows direct access and control to the instrument and allows maximum measurement speed and test throughput. Single spot noise measurements can be performed at maximum speed per tested DUT.

The APPH series of signal source analyzers provides fast, accurate and easy to operate measurements beyond 20 GHz and with offset from 0.1 Hz to 40+ MHz at extremely attractive costs. Customers are supported with user and programmer manuals and direct support is provided through an instant email support hotline.

Anapico Ltd.,
Zurich, Switzerland
+41 44 515 55 01,
sales@anapico.com,
www.anapico.com.


www.pivotone.com



Space Qualified Image Reject Mixer

Crane Aerospace & Electronics Microwave Solutions introduces a newly developed surface-mount image rejection mixer designed for space-flight applications. This mixer, operating in a selected segment of L-Band, provides greater than 25 dB rejection of the image frequency, while supporting an insertion loss performance of 8.5 dB maximum.

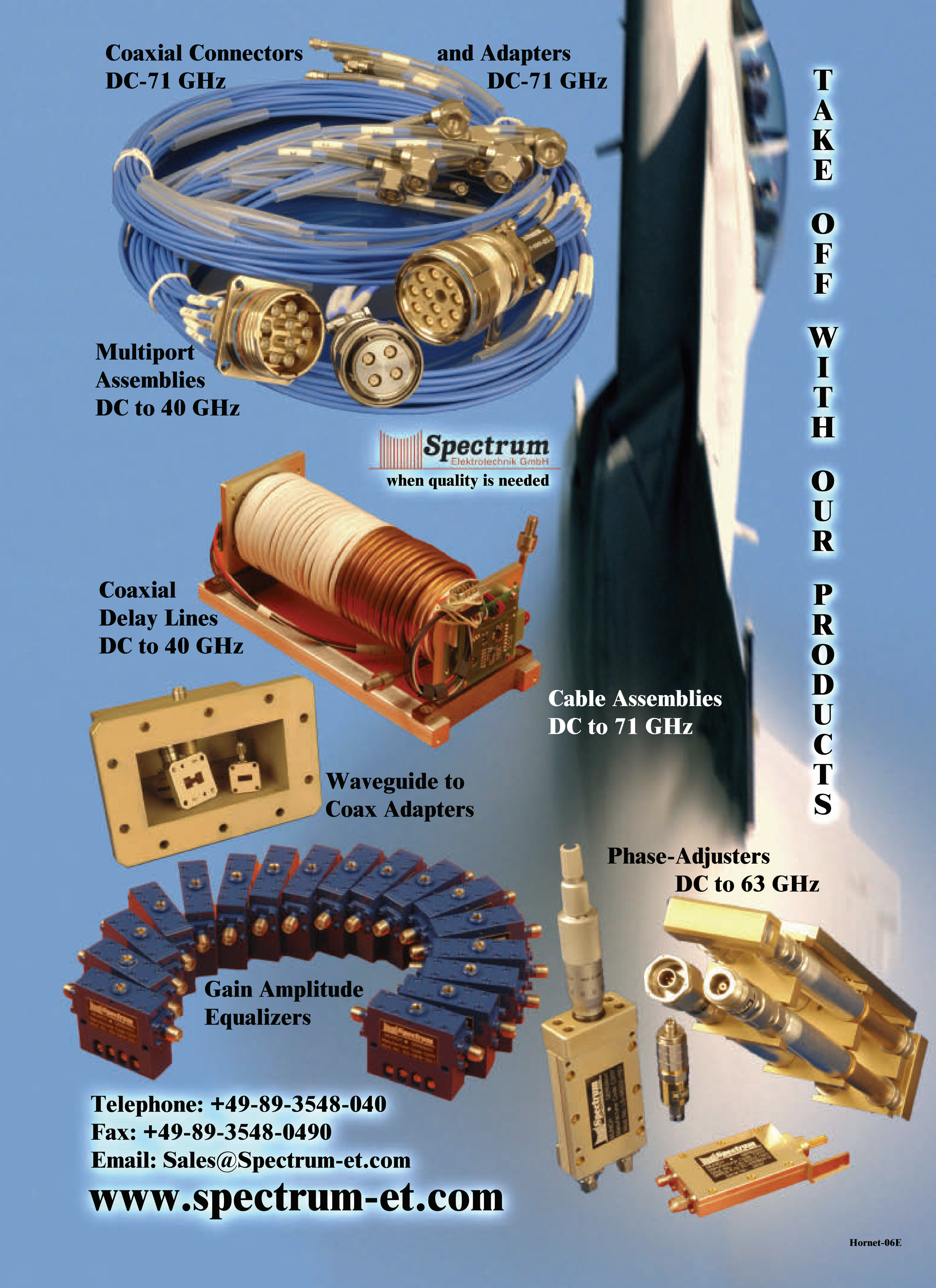
The units are constructed using a combination of toroid transformer and stripline technology. The mixers are built using Crane's considerable experience in complex, high-performance double-balanced mixer technology. Carefully selected monolithic Schottky diode quads are used so that both the diode junctions within the diode quads and the two quads are matched allowing the mixer to meet the required isolation and image rejection. The device is housed in a resistance welded, hermetically sealed Kovar and ceramic based surface-mount package.

The specifications for this unit include RF and LO frequency range from 1745 to 1785 MHz; IF frequency of 2 to 42 MHz; conversion loss of 8.5 dB maximum; LO to RF isolation of 30 dB minimum; and image rejection of 25 dB minimum.

In order to ensure that the unit is appropriate for use in space flight, it is critical that the pedigree and quality of the underlying components and overall construction technology is held to high standards. The individual components are qualified and screened to meet the rigors of the space flight environment. Additionally, the devices themselves are both screened and qualified to the appropriate requirements.

This product is representative of the custom design and manufacturing capabilities of Crane Aerospace & Electronics Microwave Solutions Space Product Line. Additional product areas supported for space flight applications include power dividers, hybrids and directional couplers, beamformers, mixers, circulators and isolators, filters and oscillators.

Crane Aerospace & Electronics, Beverly, MA, www.craneae.com/mw.



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MaxGain Cables

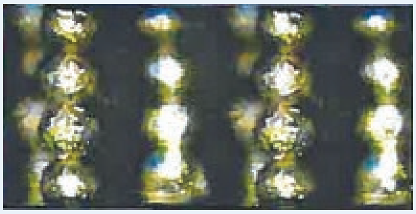
Achieving a combination of ultra low loss, flexibility and stable, repeatable, long-life performance has always been a major challenge in the world of microwave cables. Generally some of these requirements can be satisfied, but seldom are all achieved in one cable. Now, Times Microwave Systems introduces MaxGain™ ultra low loss, flexible microwave coaxial cable. Ideally suited for applications where the absolute lowest loss and exceptional long life stability are required, MaxGain cable assemblies are designed for general microwave applications in both field and laboratory conditions.

MaxGain cables are available as fully tested custom cable assemblies using specially designed passivated stainless steel connectors, or in cable form for use by skilled assembly facilities. Note that Times only recommends termination of MaxGain cable by skilled technicians in a suitable manufacturing environment. MaxGain cable assemblies are readily available directly from Times Microwave Systems, built and tested to exacting customer specifications.

Years of effort have gone into developing the mix of component and construction details necessary to achieve the MaxGain performance levels. Especially important is a proprietary outer conductor geometry that mimics the performance of a solid and smooth tubular conductor, to provide stable, repeatable and unmatched long life performance.

Features and benefits include: lowest insertion loss available, DC to 18 GHz; insertion loss of 20 dB/100 ft at 18 GHz for MaxGain-300 cable; ultra stable and repeatable insertion loss, VSWR loss tracking performance with wide temperature range (-65° to +150°C); superior flexibility, low minimum bend radius; and outstanding shielding effectiveness (> 100 dB).

Times Microwave Systems,
Wallingford, CT
(800) 867-2629,
www.timesmicrowave.com.



High Performance Contact System

Paricon Technologies provides a state-of-the-art family of high performance contact materials specially designed for the advanced needs of the electronics industry. At the core of these products are specially designed anisotropically conductive materials that are referred to as PariPoser Interconnects. PariPoser Interconnects make electrical connections uniformly between opposing contact areas using conductive columns that are regularly distributed within a sheet of advanced polymer.

This advanced contactor structure has been demonstrated as being a cost effective means of providing very low loss interconnection at frequencies from DC to well above 60 GHz. The material has excellent thru-conductance and high in-plane isolation resistance. The integration of the PariPoser contact into applications and fixturing that addresses the customer's needs has resulted in the development of a wide range of interconnection products for use in both production and test applications. These include virtually every level of interconnection, including test and burn-in sockets, production level sockets, cable-to-board connectors and mezzanine connectors. It is well suited for non-destructive test and measurement of devices and modules.

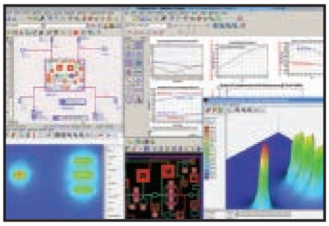
The capability of PariPoser Interconnects to withstand long life cycle applications in real factory test environments to one million cycles has been repeatedly demonstrated using hard gold plating system on all contacts. In addition, the product was subjected to the 40 year life cycle demands of the telecommunications industry at Bell Labs. The self sealing behavior of the PariPoser contact makes it an ideal choice for use in HAST testing.

Paricon Technologies Corp., Taunton, MA, www.paricon-tech.com.

Software and Mobile Apps

Electronic Design Automation Software

VENDORVIEW



Agilent unveiled ADS 2012, the next major release of its Advanced Design System (ADS) flagship RF and microwave EDA platform. ADS 2012 features a number of new user interface enhancements designed to improve design efficiency and productivity. Dockable windows, for example, enable users to quickly access frequently used dialog boxes, such as component information and layer visibility in layout. New component search and net navigator functions make it easy to work with larger designs, and a new archive/un-archive utility makes sharing designs and workspaces easier.

Agilent Technologies Inc., www.agilent.com.

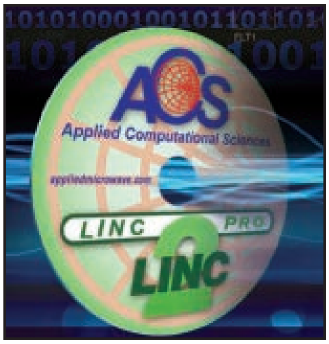
LTE Advanced Carrier Aggregation Software

VENDORVIEW

Anritsu announced the industry's first call-based LTE advanced carrier aggregation testing capability that can be integrated into its MD8430A LTE Signaling Tester. The software-only upgrade leverages the four available RFs in the MD8430A, and provides 300 MB/s downlink throughput using two 2×2 MIMO Component Carriers. When configured with this option, the MD8430A can test advanced wireless devices at twice the rate available on today's most advanced LTE networks. The LTE Carrier Aggregation option for the MD8430A is available now for testing LTE Category 6 wireless devices.

Anritsu Co., www.anritsu.com.

Design, Synthesis and Simulation Software

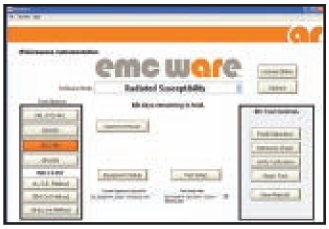


ACS released a new version of the LINC2 Pro RF and microwave design, synthesis and simulation software suite. Version 2.72 release R adds many new component models to the program's extensive model library. These include more than 600 new capacitor models, 350 inductor models and new active models including GaN power devices. The latest edition of LINC2 also offers enhanced schematic capture. Circuits can be entered manually or created automatically by a number of circuit synthesis modules.

Applied Computational Sciences (ACS), www.appliedmicrowave.com.

EMC Test Software

VENDORVIEW

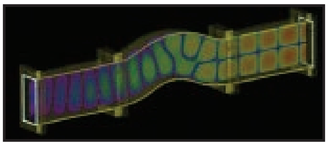


AR's EMC test software combines radiated susceptibility, conducted immunity and emissions testing into one package allowing more control and a more intuitive interface. Built-in standards include IEC, MIL-STD, DO160, automotive standards and the ability to create your own test standards. Download your copy at www.arworld.us. The software has the ability to control more equipment and the report generating feature has been enhanced to offer more control and customization.

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

EM Simulation Software

VENDORVIEW



Remcom announces a major upgrade to XFdtd® Release 7 (XF7), with waveguide ports, additional XStream® GPU acceleration coverage (for magnetized ferrite materials, thin wire materials and periodic boundary conditions), multi-core meshing, a dramatic reduction in overall time to prepare a simulation and other significant performance improvements in simulation creation. The static solver has been enhanced to calculate and assign static potentials to uninitialized conductors in the problem space. The point release updates XFdtd to Release 7.3.

Remcom, www.remcom.com.

Power Calculator App

VENDORVIEW

30 dBm + 30 dBm = 60 dBm? It is well known that it is not that easy. With the dBCalculator app from Rohde & Schwarz, engineers can add or subtract an arbitrary number of power or voltage levels – correlated or uncorrelated. In addition, the app allows them to convert units from the logarithmic to the linear scale or linear ratios to dB and vice versa, as well as a VSWR to other reflection quantities. The dBCalculator is available free of charge for iOS in iTunes and for Android in the Google play app store.

Rohde & Schwarz GmbH & Co. KG, www.rohde-schwarz.com.

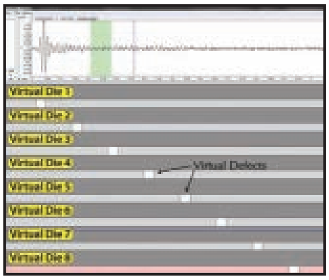
Software and Mobile Apps

Online Design Tool

Samtec has released Solutionator®, a new online tool that allows customers total design flexibility with their AccliMate™ IP67 and IP68 dust and water sealed cable products. Users are able to design a complete sealed assembly from over 350,000 design permutations comprised of mix-and-match options on bundled cable, shell size and material, contact size and quantity, contact placement, wire gauge and keying options. In minutes, Samtec customers are able to design a solution to their exact specification, see real time performance simulations of their design, download a spec sheet and request a free sample or quote.

Samtec,
www.samtec.com.

3D IC and Die Stacks Acoustic Imaging



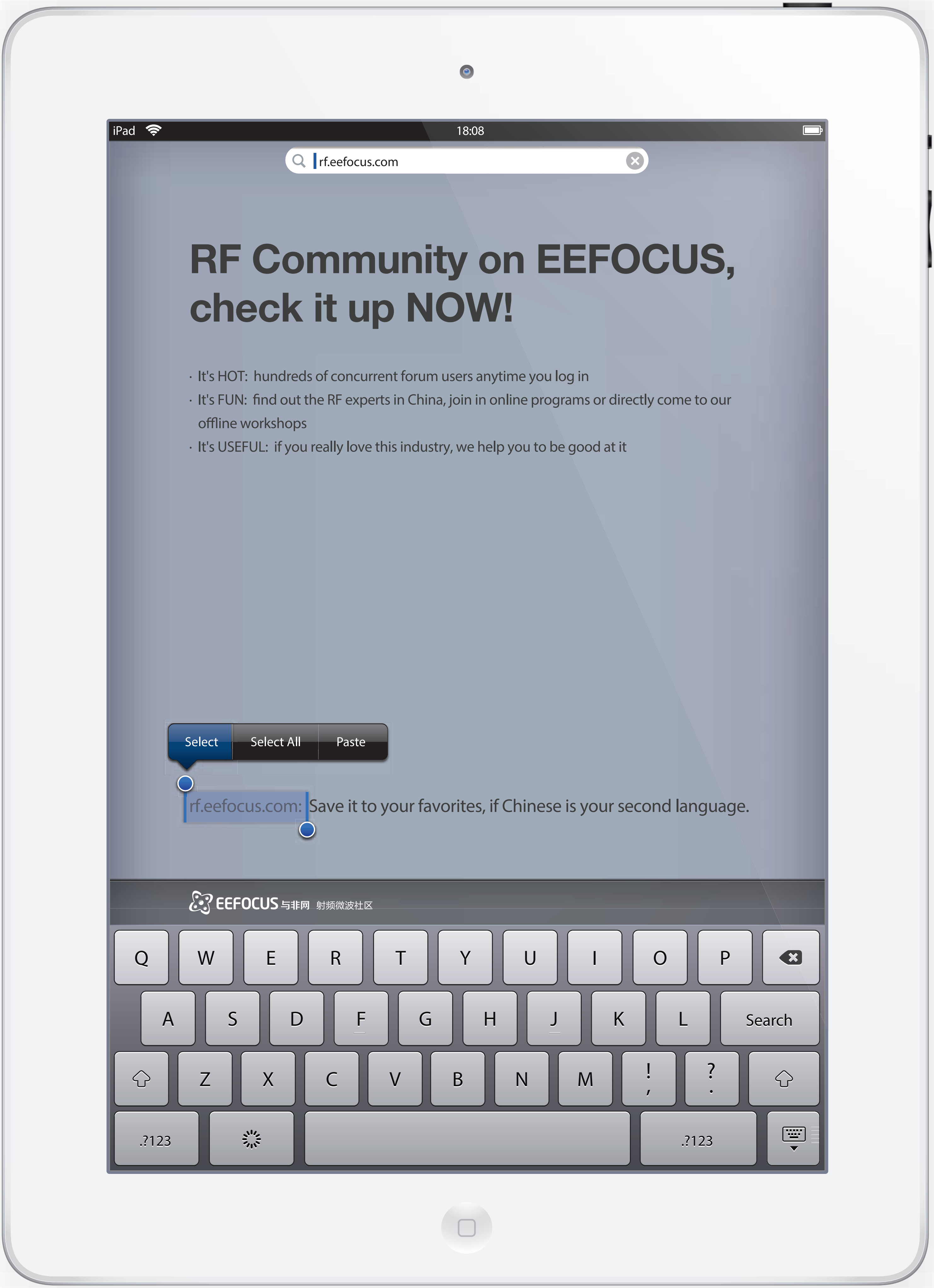
Sonoscan has introducted its SonoSimulator™ software, which is now a standard feature on the Gen6™ C-SAM® acoustic microscope. The SonoSimulator determines optimal gate positions and other parameters with far less effort than is possible with the physical stacked parts alone. It also results in higher quality acoustic images. This powerful new software allows the operator to create a virtual die stack that matches the characteristics of the physical 3D IC or die stack to be inspected, including defects at specified layers.

Sonoscan,
www.sonoscan.com.

Graphical RF Editor

X-COM introduced Version 3.0 of its RF Editor Graphical software for modifying and building custom RF signal waveform files for use in defense, commercial and system verification applications. RF Editor Version 3.0 is more intuitive, faster, and adds useful features that expand its capabilities. The software runs on Windows 7 and uses .xiq and .tiq (I&Q) files or waveform segments created in MATLAB and other third-party scientific programming languages. RF Editor is integrated with X-COM's Spectro-X signal analysis and visualization software.

X-COM Systems LLC,
www.xcomsystems.com.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Innovations in EDA
Presented by: Agilent Technologies
RF Module Design Using Amalfi CMOS PA
Live webcast: 11/15/12, 1:00 PM ET

RF/Microwave Training Series
Presented by: Besser Associates
Passive Components: Couplers, Dividers and Combiners
Sponsored by: Mini-Circuits
Live webcast: 11/20/12, 11:00 AM ET

CST Webinar Series 2012
Multiphysics Approach for a Magnetron and Microwave Oven Design
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Presented by: Agilent Technologies
Calibration and Alignment Techniques for Precise Field Measurements
Live webcast: 11/28/12, 1:00 PM ET

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Live webcast: 11/29/12, 11:00 AM ET

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Presented by: COMSOL
Introduction to Antenna Simulation with COMSOL Multiphysics
Live webcast: 11/29/12, 11:00 AM ET

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- Device Characterization Methods & Advanced RF/Microwave Design

RF/Microwave Training Series
Presented by: Besser Associates
- Spur-Free Switching Power Converters for Analog and RF Loads
- Mixers and Frequency Conversion

Technical Education Training Series
- Radar Fundamentals II - Pulse Doppler Radar
- Improving GaN HEMT PA Design with Cree's Large Signal Models and AWR's Microwave Office™

CST Webinar Series 2012
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FieldFox Handheld Analyzers Series
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- Techniques for Precise Cable and Antenna Measurements in the Field
- Techniques for Precise Interference Measurements in the Field

Register to attend at mwjournal.com/webinars

Microwave Journal
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Components

SMA Connectors

Amphenol Connex announced new and improved versions of its end launch SMA connectors. The company re-engineered its edge mount SMA connectors to ensure contact stability and to improve electrical performance from DC to 18 GHz. The connectors feature gold plated bodies, precision machined from brass. Dielectrics are PTFE. Male contacts are machined from brass. Female contacts are machined from beryllium copper. All contacts are plated with cost-saving gold over high-phosphorous nickel plating, ensuring a durability of 500 mating cycles minimum.

Amphenol Connex,
www.amphenolconnex.com.

Digital-to-Analog Converters

The AD9114/AD9115/AD9116/AD9117 are pin-compatible dual, 8-/10-/12-/14-bit, low power DACs that provide a sample rate of 125 MSPS. These TxDAC® converters are optimized for the transmit signal path of communication systems. All the devices share the same interface, package and pinout, providing an upward or downward component selection path based on performance, resolution and cost. The flexible power supply operating range of 1.8 to 3.3 V and low power dissipation of the AD9114/AD9115/AD9116/AD9117 make them well suited for portable and low power applications.

Analog Devices Inc.,
www.analog.com.

Surface Mount Couplers

VENDORVIEW

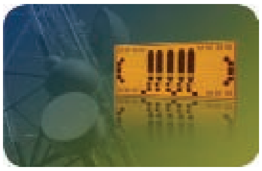
Florida RF Labs expanded the HybriX® coupler product line with new 0805-styled hybrid couplers. Built with advanced low temperature co-fired ceramic (LTCC), the HVx3F series outperforms existing miniature couplers in operating temperature range and power handling. These latest additions to the largest selection of surface mount couplers in the world are optimized for operation in major commercial wireless spectrums from 700 to 3700 MHz. They feature low insertion loss, excellent amplitude and phase balance, and high isolation in a space-efficient 2 × 1.25 mm package.

Florida RF Labs,
www.emc-rflabs.com.

Bandpass Filter Chip

VENDORVIEW

The center frequency of the HMC897 bandpass filter chip is adjustable from 9 to 19 GHz by applying an analog tune voltage between 0 and 14 V with a tuning speed of 200 ns. The HMC897 also provides a 3 dB filter bandwidth of approximately 18 percent, while the 20 dB filter band



width is approximately 35 percent. Return loss is typically better than 10 dB across the operating frequency and wideband rejection is at least 30 dB out to 40 GHz.

Hittite Microwave Corp.,
www.hittite.com.

Highpass Filter

Integrated Microwave Corp. offers a high-frequency true elliptic function highpass filter. This small-profile filter offers a nominal passband insertion loss of 0.7 dB at 5.2 to 13 GHz. This superior rejection provides 20 dB at 4.9 GHz, and -40 dB nominal DC to 4.8 GHz, with a 3 dB cutoff at 5.15 GHz. Performance is comparable to a suspended substrate, but at one-quarter the size and cost.

Integrated Microwave Corp.,
www.imcsd.com.

Attenuators

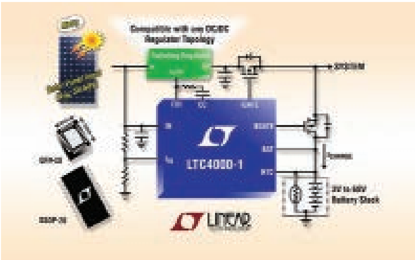
IMS announced the availability of its cost-effective 0404 size attenuators. The IMS2479 attenuators are available in 1 to 10 dB attenuation

values in 1 dB increments with attenuation accuracy starting at ±0.3 dB. Operating frequency for the IMS2479 is DC to 3 GHz and it is rated at 40 mW. These attenuators are especially suited, but are not limited to, consumer electronics, commercial communication devices and low-power wireless monitoring and sensing applications such as smart meters.

International Manufacturing Services Inc.,
www.ims-resistors.com.

Controller and Power Manager

VENDORVIEW



Linear Technology introduced the LTC4000-1, a high voltage controller and power manager with input maximum power point control (MPPC) that converts virtually any externally compensated DC/DC power supply into a full-featured battery charger. The LTC4000-1 is capable of driving typical DC/DC converter topologies, including buck, boost, buck-boost, SEPIC, flyback and forward. The device offers precision input current monitoring and charge current monitoring and regulation. It operates across a wide 3 to 60 V input and output voltage range.

Linear Technology Corp.,
www.linear.com.

Injector-Diplexer Combiners

Microlab launched a new product line of WiFi and WiMAX combiners: BK-28N. These "Tuned-by-Design" components combine or

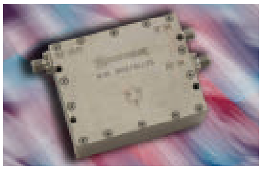
separate WLAN and WiMAX in the frequency range 2.4 to 3.8 GHz with frequencies between 5.15 and 5.85 GHz. With a signal loss of only 0.3 dB in the lower bands and 0.5 dB in the higher bands, BK-28N guarantees very efficient signal handling. Special low-loss strip lines achieve excellent loss values.

Microlab,
http://fxr.com.

Image Rejection Mixer

VENDORVIEW

MITEQ's new model IR0618LC4E, broadband image rejection mixer design has an ultra-wide IF bandwidth. This image rejection mixer is useful for downconverting and receiving high data rate bandwidth signals as well as for



wideband test equipment needs. Features include image rejection: 18 dB min.; RF/LO frequency: 6 to 18 GHz; IF frequency: 10 to 1000 MHz; conversion loss: 12 dB; LO-to-RF isolation: 18 dB; LO-to-IF isolation: 20 dB; LO port power: 10 to 15 dBm; RF VSWR: 2.0:1; LO VSWR: 2.5:1; and IF VSWR: 1.5:1. Applications: radar and test equipment.

MITEQ,
www.miteq.com.

Phase Shifter

VENDORVIEW

Model number PS-9G11G-3609-A-SFF is an analog controlled phase shifter that operates over the 9 to 11 GHz frequency range. This

model utilizes a phase shift control voltage ranging from -7.5 to +7.5 V for a corresponding phase shift of 0 to 360°. The insertion loss is 7 dB typical with a typical phase shift accuracy of ±10 degrees and a speed of 150 nsec. The required DC voltage is a single +15 V supply and only draws 30 mA. The size is 4.95" × 3.38" × 1.02". Other frequency ranges are available.

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

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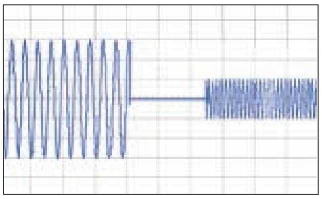
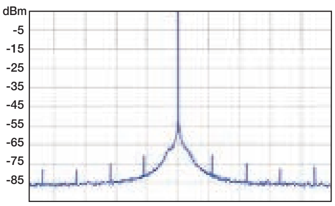


Frequency and power hopping.



Low spurious.

Model	Frequency (MHz)	Power (dBm)	Harmonics (dBc typ.)	Price ($ ea.)
SSG-4000HP	250-4000	-50 to +20	-40	1995.00
SSG-4000LH	250-4000	-60 to +10	-66	2395.00

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New Products

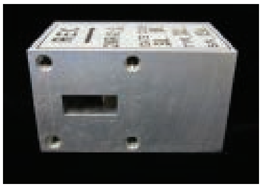
Liquid/Water Cooled Load

High power liquid/water cooled load fits a WR159 waveguide and has a CPR159G flange. It operates at 4.90 to 7.05 GHz with an average power of 10 kilowatts max. and 1.8 megawatts peak power at 30 PSIG. Additional specifications include: 1.10:1 VSWR, 4 gallons per minute flow rate. Coolant inlet temperature 150°F max., test pressure 50 PSIG, operating coolant pressure 150 PSIG, length 16" max., finish iridite and black.

RADITEK,
www.raditek.com.

Waveguide Isolator

VENDORVIEW



Targeting the receive side requirements for a low loss waveguide isolator, Renaissance has developed a product with less than 0.2 dB insertion loss over 20.1 to 21.2 GHz from -40° to +85°C. Ensuring more than 26 dB isolation, the unit improves system performance considerably. With a size of 1.5" × 0.88" × 0.5", it can handle up to 50 W of forward and 5 W of reverse power. Visit www.rec-usa.com for datasheet and specifications.

Renaissance Electronics Corp.,
www.rec-usa.com.

Transmit/Receive Module

VENDORVIEW

Designed for 868 MHz and 902 to 928 MHz AMR solutions, RFMD's new RF6549 features separate ports for Rx and Tx paths, and two ports on the output for connecting a diversity solution or a test port. The PA section includes a nominal output power of 28 dBm. The device comes in a 6 × 6 mm, 32-pin package. It features a single 50 Ω bi-directional transceiver interface, thru path insertion loss of 1 dB, antenna diversity switch, and LNA with bypass mode.

RF Micro Devices,
www.rfmd.com.

Multi-Throw Switches

RFMW announced design and sales support for two new single-pole, multi-throw switches. The SKY13414-485LF is a SP4T and the SKY13418-485LF is a SP8T. Both parts cover a broad frequency range of 100 and 3000 MHz and are pin compatible with each other. The SP8T offers 0.65 dB typical insertion loss with >20 dB of isolation while the SP4T provides 0.55 dB insertion loss and >25 dB isolation. Integrated decoder logic and high linearity make them ideal for switching applications commonly used in LTE-based data cards and tablets.

RFMW Ltd.,
www.rfmw.com.

DC Link Capacitors

VENDORVIEW

Richardson RFPD announced availability of new metalized polypropylene DC link capacitors from Kendeil™. The devices are rated from 600 to 1300 V. Key features of the general purpose K31 devices, designed for frequencies less than 15 kHz, include a high ripple current (max.) of 100A and a capacitance range of 120 to 1000 µF. Key features of the K32 devices, designed for frequencies exceeding 15 kHz, include a high ripple current (max.) of 100A and a capacitance range of 100 to 1000 µF.

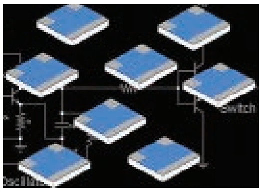
Richardson RFPD Inc.,
www.richardsonrfpd.com.

Band Reject Filters

RLC Electronics now provides band stop filters that can be re-adjusted by the customer to new center frequencies. These filters are tunable over a ±7.5 percent center frequency range with minimal change in bandwidth. They have a power rating of 2 W, 50 Ω impedance, VSWR 1.5:1 fc to 2 × fc and a temperature range of -55° to +85°C. They offer a Mil-E-5400, Class 1A Environment and female connectors.

RLC Electronics Inc.,
www.rlcelectronics.com.

Temperature Variable Attenuators



State of the Art (SOTA) introduced a new line of temperature variable attenuators for both high reliability and commercial applications. They are available in a 1512 case size (0.150" × 0.125" × 0.020") with single surface solderable or wire bondable terminations. The attenuation of the TVA decreases with increasing temperature allowing it to passively compensate for the amplifier's drop in gain with temperature. This kind of signal compensation can be used for various amplifiers, circulators, mixers, power dividers, and other temperature sensitive devices.

State of the Art (SOTA) Inc.,
www.resistor.com.

SP4T Switch

VENDORVIEW

Skyworks has a new 0.02 to 4 GHz, GaAs-based high isolation, single-pole four-throw switch with integrated 50 Ω terminations in a small 3 × 3 mm

New Products

quad flat no-lead plastic surface mount technology package. The SKY13384-350LF is ideal for designs where low insertion loss (< 1 dB), high isolation (> 40 dB) and broadband return loss (15 dB) are required, such as in critical filtering and band switching applications. Markets for this wideband high isolation switch include wireless infrastructure, military communications and test and measurement.

Skyworks Solutions Inc.,
www.skyworksinc.com.

Type N Connectors

Times Microwave Systems announced its new non-solder two piece EZ 7/8 EIA flange, 716DIN and type N connectors for LMR-1200-DB and LMR-1200-FR flexible low loss 7/8" 50 Ω coaxial cables. These high quality connectors utilize a non-solder spring finger center conductor contact and clamp-style outer contact attachments. The total number of connector parts has been reduced from six pieces to two pieces making these the perfect connectors for field installations. Non-solder EZ style connectors are also available for most LMR® cable types and sizes.

Times Microwave Systems,
www.timesmicro.com.

Frequency Hopping Filters

Trilithic introduced a new series of frequency hopping filters that enable users to address interference issues in environments crowded with RF signals. The VTF series of frequency hopping filters is designed to help mitigate the issues that commonly occur in shipboard, airborne and ground vehicle applications with an RF crowded environment. The VTF series filters offer drop-in second source capability for existing programs, while being versatile enough for new programs. They are rugged and durable, and work across multiple frequency ranges and bandwidths.

Trilithic,
http://rfmicrowave.trilithic.com.

Low PIM Connectors

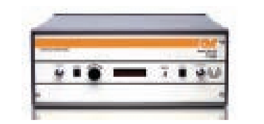
VidaRF is offering low PIM versions of the popular 7/16, Type N, and SMA connector that can deliver PIM performance as low as -170 dBc. Just like with all of the RF components that VidaRF offers, the company is happy to build to your specifications and provide delivery in as little as 2 to 3 weeks.

VidaRF,
www.vidarf.com.

Amplifiers

Solid State Amplifiers

VENDORVIEW



AR recently introduced a new family of solid state amplifiers that cover 1 to 6 GHz and provide up to 50 W of power. This family highlights a class A design with low harmonic distortion and excellent noise figure. These models are small and lightweight but provide superior reliability for your most demanding applications.

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

Four-Stage Amplifier

VENDORVIEW

ZVA-183W+ is a class-A, four-stage, unconditionally stable amplifier. It features a ruggedized case, available with and without a heat sink/fan, and has the capability to withstand accidental open or short at output and is protected against reverse bias protection for added reliability under difficult conditions. This wideband, 0.1 to 18 GHz amplifier has a high IP3, 36 dBm typ. It features a high power output of +26 dBm and a high flat gain of 27±2 dB typ.

Mini-Circuits,
www.minicircuits.com.

Power Transistor

M/A-COM Tech introduced a highly efficient 40 W pulsed power transistor optimized for civilian and military pulsed radar applications between 2.7 and 3.5 GHz. The MAGX-002735-040L00 is a gold metalized, internally matched, GaN on SiC, RF power transistor that exhibits excellent performance when operated at +50 V, class AB operation, 40 W peak output, using a 300 μs pulse and 10 percent duty cycle pulsed signal. Leveraging wafer fabrication processes, the transistor provides high gain, efficiency, bandwidth and ruggedness over a wide bandwidth.

M/A-COM Technology Solutions Inc.,
www.macomtech.com.

Driver Amplifier

The TQP7M9105 is a 1 W, 5 V high-linearity driver amplifier in a standard SOT-89 surface-mount package. At 0.9 GHz, the TQP7M9105 offers 19.4 dB gain, ultra-high 49 dBm OIP3, and +30 dBm of compressed 1 dB power while drawing a very low 220 mA current. Internal

circuitry allows the amplifier to offer 'Class A' linearity performance with 'Class AB' efficiency. The TQP7M9105 contains added patented features implemented on-chip that differentiates it from other products in the market.
TriQuint Semiconductor,
www.triquint.com.

Antennae

Flat Panel Antennas

L-com Inc. offers a Hyper-Link brand 900 MHz flat panel antenna that offers 9 dBi gain with a heavy duty all weather plastic radome. The new antenna is designed for indoor or outdoor 900 MHz ISM band applications, 900 MHz cellular applications, SCADA, and RFID applications. The heavy duty radome uses thick UV-stable plastic to provide a reliable 60° vertical or 70° horizontal beam width no matter what the outdoor conditions. It features direct ground lightning protection and comes with a tilt and swivel mast mount kit for easy alignment in either polarization.
L-com Inc.,
www.l-com.com.

Sources

Magnetron Transmitter

The model 337 power MOSFET modulator, magnetron transmitter is designed to operate magnetrons up to 500 kW. The continuously variable pulse width range is 0.15 to 2.0 microseconds, or greater, at PRF up to 5 kHz. Maximum pulse width is determined by the pulse storage capacitor value and the magnetron capability. Model 337 is not damaged by magnetron arcs. Arc energy to the magnetron is limited which helps clean up an arcing magnetron. The modulator HVPS is a very efficient, duty cycle regulated DC to DC converter design.

Applied Systems Engineering Inc.,
www.applsys.com.

Voltage Controlled Oscillator

Crystek's CVCO33BE-1662-1708 VCO operates from 1662 to 1708 MHz with a control voltage range of 0.5 to 4.5 V. This VCO features a typical phase noise of -106 dBc/Hz at 10 KHz offset and has excellent linearity. Output power is typically +2 dBm. Engineered and manufactured in the USA, the VCO is packaged in the industry-standard 0.5" × 0.5" SMD package. Input voltage is 5 V, with a maximum current consumption of 20 mA. Pulling and pushing are minimized to 5 MHz and 5 MHz/V, respectively.

Crystek Corp.,
www.crystek.com.

Phase-Locked Oscillator

The CLX-1020-XA phase-locked oscillator operates at 1020 MHz and features exceptionally low phase noise (<-109 dBc/Hz at 10 KHz). The unit is locked to an internal reference and offers +7 dBm output power with low power consumption (+5 VDC at < 65 mA) and low spurs (<-80 dBc). Custom units are available in fixed frequencies from 50 MHz to 4.5 GHz in a surface-mount package of just 0.75" × 0.75" × 0.25".

EM Research Inc.,
www.emresearch.com.

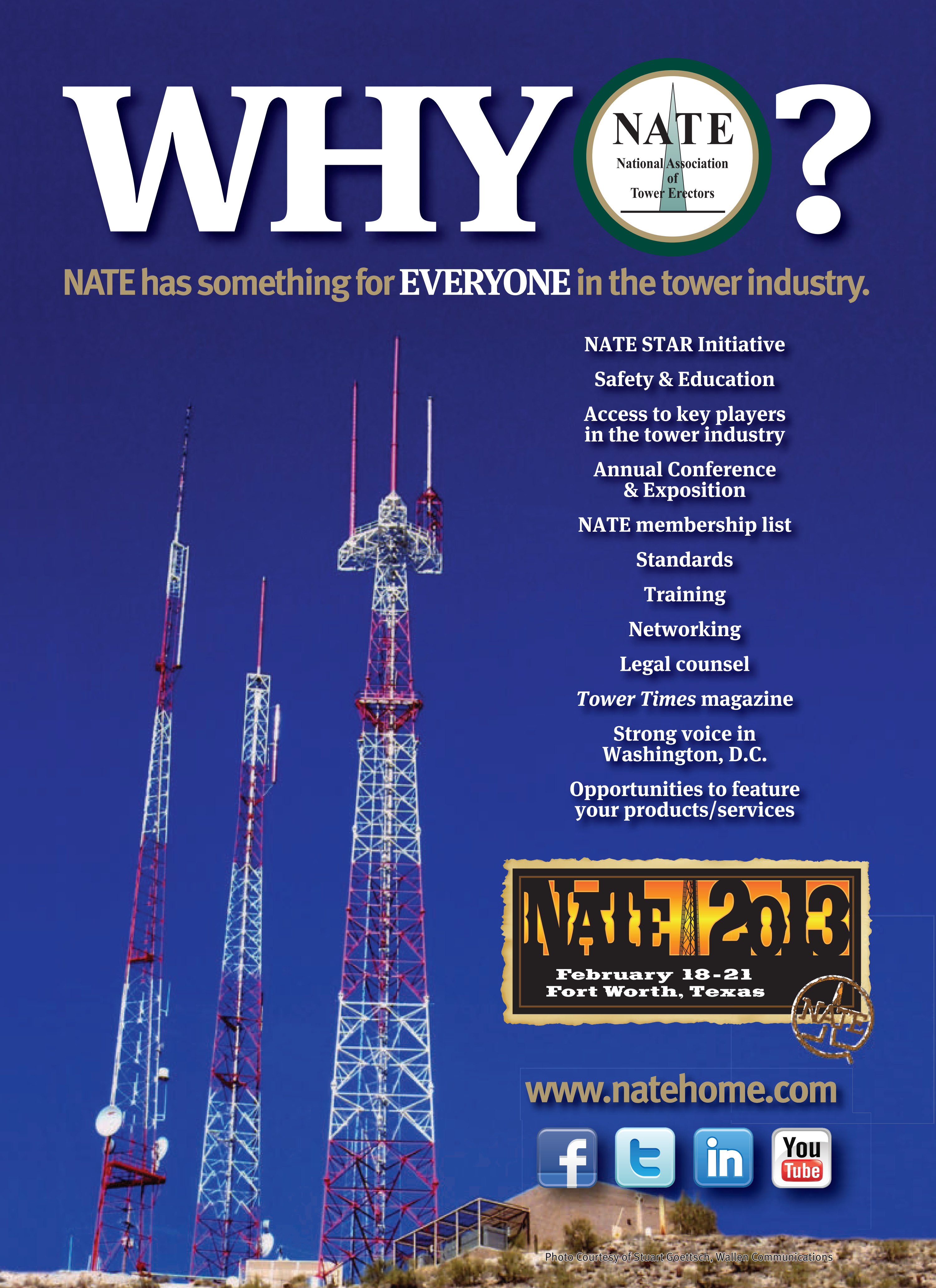
Voltage Controlled Oscillator

Z-Communications announced a new RoHS compliant VCO model USSP1217-LF in the L-Band. The USSP1217-LF operates at 1210 to 1230 MHz with a tuning voltage range of 0.5 to 3.0 VDC. This miniaturized VCO features phase noise of -102 dBc/Hz at 10 kHz offset while operating off a 3.3 VDC supply and typically drawing only 13 mA of current. The USSP1217-LF provides the end user an output power of 3±3 dBm into a 50 Ω load while operating over the industrial temperature range of -40° to 85°C.
Z-Communications Inc.,
www.zcomm.com.

Processing Equipment

Bondhead

Hesse & Knipps added the HBK08 Loop Former Bondhead to its BONDJET BJ935 and BONDJET BJ939 fully automatic heavy wire bonders to support growing requirements for high density module bonding. Offering highly precise die pattern recognition and bonder positioning precision, this heavy wire bondhead enables extremely long wire loops (up to 40 mm), special wire loop formations and minimal wire distances for fine pitch bonding in addition to multi-stitch bonding. It allows for low loop heights with higher wire stability than previously possible.
Hesse & Knipps Inc.,
www.hesse-knipps.com.



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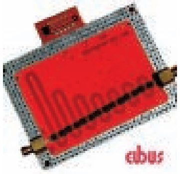
PS Form 3526, September 2007 (Page 2 of 3)

New Products

Software

MIMO Simulators



Custom and standard MIMO simulators are offered to ease system optimization efforts and these simulators are available for mobile communication bands up to 6 GHz. All transmitter signals are routed to all receivers and link loss for every path can be individually modeled for phase and attenuation. Digital control – via Ethernet interface – enables the rapid steering of attenuators and phase shifters over 95 dB dynamic range and over any phase desired.

eubus GmbH,
www.eubus.net.

Test Equipment

Step Probe

The new Step Probe series T-785 M with a splayed tip enables, for the first time, reliable testing of clips and jacks. The wear-free contacting is achieved via the outer wall of the contacting cage and the splayed tip. The splayed tip opens up as soon as the collar of the probe rests against the casing of the clip. Different variants are available for round and square cross-sections depending on the shape of the opening to be contacted. Assembly is carried out by means of a receptacle.

Ingun Prüfmittelbau GmbH,
www.ingun.com.

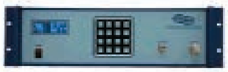
Oscilloscope System

VENDORVIEW

Agilent introduced a 60 GHz remote sampling head oscilloscope module. The Agilent N1045A 2/4-port electrical remote sampling head module provides the most economical solution for accurately characterizing multilane designs used in today's new and emerging standards such as IEEE 802.3 ba/bj/bm (40Gb/100Gb Ethernet) and Optical Internetworking Forum CEI 3.0. Users can configure up to four N1045A modules in a single Agilent 86100D DCA-X wide-bandwidth oscilloscope mainframe to create a system with 16 channels.

Agilent Technologies Inc.,
www.agilent.com.

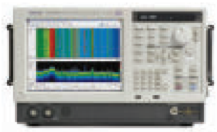
Noise Generator



The NoiseWave NW-ATE series, an economical and rugged programmable noise generator, now covering from 10 MHz up to 40 GHz, is ideal for military and SATCOM applications including Ka-Band tests such as BER vs. E_b/N_o, interference and jamming. The instrument is fully programmable from the front panel and remotely via GPIB and Ethernet. The output level is controlled by an internal broadband variable attenuator in 1 dB steps. Many other options are available including finer attenuation resolution, an internal signal combiner and custom frequency ranges.

NoiseWave,
www.noisewave.com.

Spectrum Analyzer



Tektronix introduced SPECMON, a spectrum analyzer with swept DPX technology that automatically scans the entire frequency range in real time to find transient interferers. With density and frequency mask triggers, SPECMON can capture infrequent transients and intelligently save only events of interests. It offers up to 110 MHz real-time bandwidth, widest in its class, and can capture events as short as 3.7 µs with 100 percent POI. Other built-in features further simplify spectrum management applications including time-saving mapping, interferer locator, signal demodulation and automated field measurements.

Tektronix Inc.,
www.tektronix.com.

The Book End

Passive RF Component Technology: Materials, Techniques, and Applications

Guoan Wang and Bo Pan, Editors

This book focuses on the introduction to integration of novel materials and new technologies in RF passives to design smart wireless communication systems and to develop low-cost, high performance smart components/systems for military and commercial applications. Instead of using traditional semiconductor materials, these novel materials-based smart components enable higher performance. Smart passives in this book not only refer to passive components that can be electronically tuned or reconfigured, but also to all state-of-the-art materials and integration techniques that enable these smart passive components.

The book specifically covers passive materials and integration technologies for smart sensors such as carbon nano tubes, paper-based RFID sensors and flexible magnetic composites for such things as wearable body sensors. Multifunctional materials and associated integration techniques for all-in-one package platforms using materials such as liquid crystal polymer or micromachining technologies are reviewed. Reconfigurable and tunable RF passives such as MEMS switches, reconfigurable antenna arrays and ferrite thin film-based components are also covered. Metamaterial and on-wafer millimeter wave passives for smart RF passive systems and low-cost paper based RF passive structures using an ink-jet printing process for RFID applications for eco-friendly solutions are addressed.

The book is made up of selected articles that cover these topics as state-of-the-art processes and manufacturing techniques. It provides up-to-date information on novel materials, new manufacturing techniques and device design for these new types of devices and packaging systems. Readers who want to learn about these novel devices and materials will benefit from reading this book, but it does not cover any traditional passive devices technologies. It is a good compilation of articles on novel passive devices and materials.

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Math and Logic Puzzles for the 'Enginerd' in All of Us

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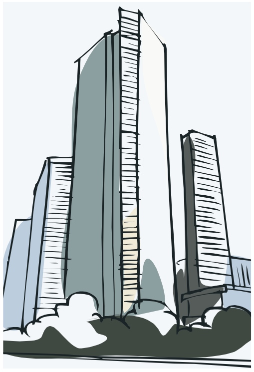
Bob and John

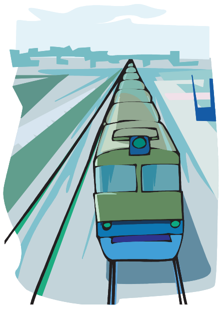
Bob and John form a team together. Bob is as old as John will be when Bob is twice as old as John was when Bob was half as old as the sum of their current ages. John is as old as Bob was when John was half as old as he will become in ten years.

How old are Bob and John?



A Moving Tale (Find a word containing "city" for each line)

I lived in a city that held as much as it could,
So I moved to another that repaid what it should.
The third had very little, with not much to be found,
The fourth was very boring, with no change in the sound.
The fifth was a jungle; wild beasts roamed in the street,
The sixth was so foggy you could not see past your feet.
The seventh was on the move; I could barely keep the pace,
The eighth was so evil; a whole city in disgrace.
The ninth was off-center; the people were bizarre,
The tenth was quite truthful; where honesty is par.
The eleventh was so wise; the acumen hurt my brain,
So I settled in a twelfth, because it was so plain.



The Smith Jones Robinson Riddle

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

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

Bullish on Barcelona

A Preview of Mobile Technologies

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Mobile Communications 2012

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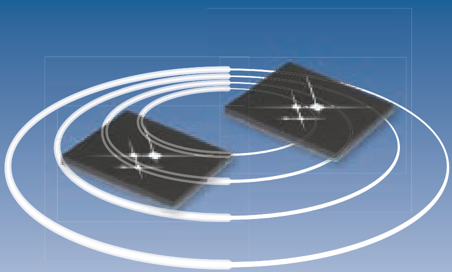

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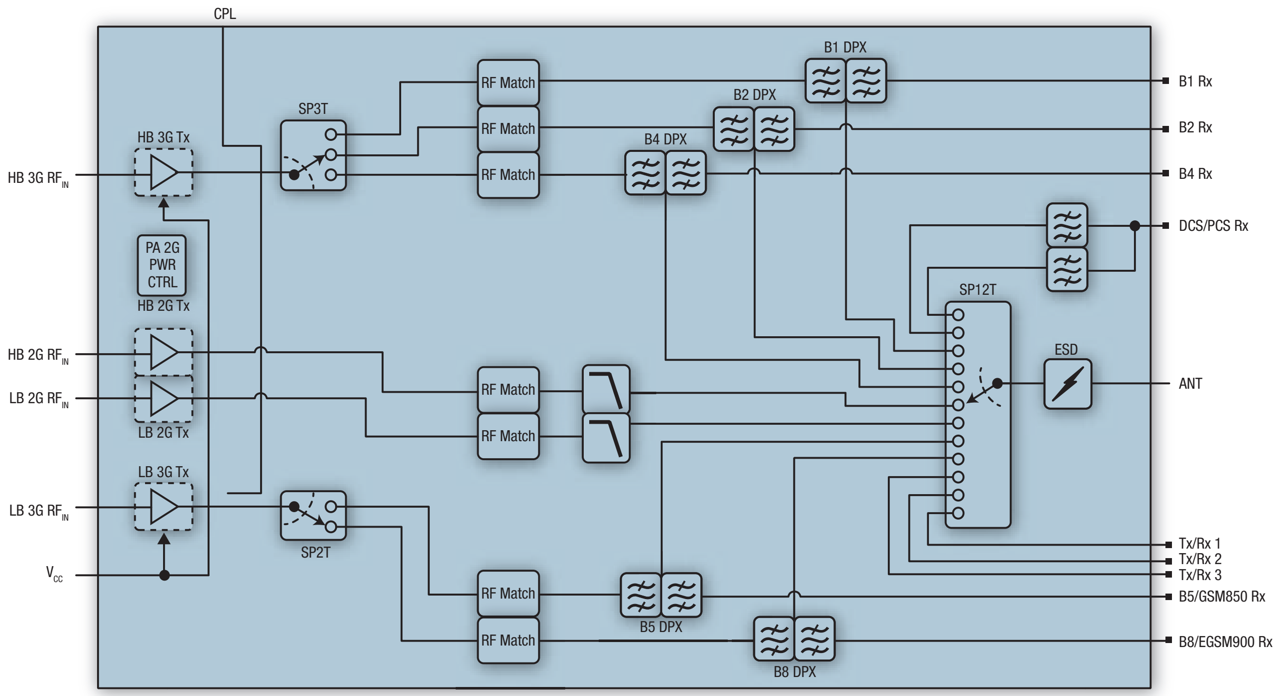

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Wireless Trends to Look for at MWC 2013

What technologies will increase capacity and address the network constraints that are a reality with the ballooning demand for data and video services? How soon will test equipment and RF modules be needed to support the rollout of LTE and other 4G services? What infrastructure changes will be needed to increase capacity and how will those affect testing needs? What other network options are available to address these challenges?

This year *Microwave Journal* asked some of the leading test & measurement and semiconductor device manufacturers what they think will be the hot topics and key technologies for GSMA Mobile World Congress 2013 in Barcelona. Participating on the test & measurement side are Agilent Technologies, Anritsu and Rohde & Schwarz. On the semiconductor device side are articles from RFMD, Skyworks and TriQuint Semiconductor.

The number of cellular bands is ever increasing and having a world phone with all the LTE bands plus compatibility with older generation networks becomes a challenge. Supporting all these bands in a small form factor also consumes more and more power. What are some of the solutions to reduce power consumption while still reducing the cost and size of RF modules? The device manufacturers will address this challenge along with ways to increase integration and improve time to market, including key trends in passive and active solutions for future handsets.

These are some of the challenges and questions that will be answered by these leading companies in the RF/microwave industry as we look forward to Mobile World Congress 2013. As you will read, there are some definite trends that each company mentions and key technologies to watch out for next year.

Patrick Hindle
Microwave Journal *Technical Editor*

MORE DATA, MORE ANTENNAS AND MORE CELLS

Agilent Technologies

The explosion of data traffic will continue in 2013. One of the main concerns for mobile operators is to optimize the use of the available frequency bands. It drives the industry to continue rapid deployment of new technologies and network infrastructures to face the ever growing need for greater capacity. There are three areas of focus that will challenge the industry in the coming year.

LTE-A & Carrier Aggregation

2013 will see an acceleration in development of LTE-A and carrier aggregation techniques. Wireless equipment manufacturers and chipset manufacturers will face more and more complex RF tests to develop further modems supporting those techniques. To address these challenges, there is a need to test components with an LTE-Advanced downlink and uplink signals compliant to the 3GPP Release 10 standard. Signal generation software must generate up to five component carriers simultaneously in both contiguous and non-contiguous carrier configurations and to place them anywhere within the modulation bandwidth of the signal generator — up to 100 MHz. For analysis, the LTE-Advanced application needs to support carrier aggregation for both FDD and TDD, UL and DL and contiguous and non-contiguous allocations. So test software needs to provide for analysis of up to five component carriers simultaneously and independent measurement setup for each component carrier, including varying bandwidths, for individual component carriers (CC).

LTE Infrastructure Volume Deployment

For network development, 2013 will see a massive LTE infrastructure deployment which will lead to a growing demand for system capacity enhancement tests (MIMO OTA testing, MIMO beamforming, WiFi fallback) and LTE conformance tests.

Operator Acceptance and Roaming:

Each operator has dedicated requirements and a feature set on the LTE network that need to be addressed in mobile device testing. Moreover, in 2014, all LTE devices will need to go through certification and GCF and PTCRB in order to ensure roaming capability between all service providers. Agilent is addressing these compatibility requirements with a product line that delivers RF, RRM and protocol certification with the most integrated and cost effective product platform on the market.

On the user equipment side, the future test challenges in the LTE Releases 9, 10 and 12 includes energy saving, battery drain and user profiling. Agilent provides solutions such as interactive functional test (IFT) software with an automated and simplified interface to qualify and characterize battery drain and user profiling that meets operator acceptance criteria and allows mobile device power management unit optimization.

Microcells, Picocells & Metrocells

Finally the third challenge next year is to increase capacity while reducing cost. There will be a growing use of microcells, picocells and metrocells. Those cells will need to be produced at a much lower cost than traditional ones and the test in manufacturing will need to be much faster. The challenge here is to perform more and more complex RF tests in less time and with lower cost than in the past. Vector signal generator (VSG) manufacturers need to increase the speed of testing to achieve lowest cost of test. Through exclusive baseband-tuning technology innovation, Agilent VSGs have enabled frequency and amplitude switchin g speeds as fast as 10 μs.

Source: Agilent Technologies

GETTING MORE CAPACITY

Anritsu

At MWC this year, Anritsu expects strong interest in measurement solutions addressing manufacturing and field testing, as LTE networks and devices become more prominent worldwide. Anritsu also expects attendees to look for test instruments that address a growing concern – Passive Intermodulation (PIM).

LTE

Rel 8 current deployments are focused on tuning and optimizing data rate throughput, managing coverage expansion (interference issues), and handovers. In addition, voice services (VoLTE) and supporting technologies like SRVCC will have a major push. On the applications side, the company expects to see the launch of new services that really begin to use LTE features such as capacity, peak rates and low latency.

Carrier aggregation offers up to 300 MB/s download rates, but importantly, allows operators with several small frequency band licenses to aggregate them together to offer

Source: Anritsu

customers high capacity and higher data rates. The other key technology is enhanced Inter Cell Interference Co-ordination (eICIC) to help interference in "full coverage" deployments. Currently, most LTE networks are "hotspot" coverage, and do not provide full coverage with no requirement for legacy networks to fill the gaps. When LTE is used with full coverage, interference can be a problem. This enhanced technology will reduce the problem and help operators provide full coverage.

Anritsu's LTE Signaling Tester has call-based LTE Advanced Carrier Aggregation testing capability. It can be used with its Rapid Test Designer (RTD) to create automated measurements, execute multiple test cases continuously, and generate test reports automatically. Also for LTE is another Signaling Tester that supports multiple formats, including LTE, W-CDMA, GSM/(E)-GPRS and CDMA2000. Optional VoLTE test capability has been added, with an internal CSCF server capable of authenticating and establishing loopback VoLTE calls, as well as providing the capability to select various server responses, including ignore and reject.

Vector signal generators today can generate test signals based on all leading technologies, including LTE and LTE Advanced, as well as W-CDMA/HSPA, CDMA2000, GSM and PDC, WLAN, Bluetooth® and ISDB-T. Anritsu's spectrum analyzer/signal analyzer is also well suited for multiple standards, as it offers advantages in measurement speed, dynamic range and ±0.3 dB (typical) total level accuracy.

WiFi

Offload and carrier WiFi are also key words being discussed. These are first steps in Heterogeneous Networks (Het Net), together with a big push for Home NodeB/picocells to help operators manage network capacity, and offload data from a 3GPP network to a WiFi network without affecting the user quality or experience.

To measure LTE and WiFi – as well as all other major wireless signals – in the field, some test and measurement manufacturers offer handheld analyzers. Anritsu's PIM analyzer incorporates patented Distance-to-PIM™, which shows the location of PIM problems within the antenna system, as well as distance to external PIM sources outside the antenna systems. Also available is a cost-efficient tool for tower contractors, installation and maintenance contractors, and wireless service providers to ensure optimum deployment, installation and maintenance of wireless networks.

LTE WILL RULE BUT DON'T FORGET 3G

Rohde & Schwarz

By mid-2011, the number of operators investing in LTE technology rose to 338 in 101 countries. Although growth was concentrated in U.S. and Asian markets, European (e.g., German) operators are also pushing on their LTE network deployments with the goal of reaching nationwide coverage. At roughly the same time, LTE became a true 4G technology according to the ITU definition. By adding features summarized in 3GPP Release 10 – also known as LTE-Advanced – the technology achieved IMT-Advanced performance requirements. The dominant feature of LTE-Advanced is carrier aggregation that provides a means of driving data rates up to 1 Gbps. The real driving force behind carrier aggregation, however, is to obtain much more efficient use of the fragmented spectrum allocations available to operators. Commercial introduction of carrier aggregation will start by the end of 2012. It will undoubtedly be a popular subject for many demonstrations at the Mobile World Congress in Barcelona 2013. This includes carrier aggregation testing solutions from R&S, which will be focused on R&D applications.

Although LTE has become the most popular technology, there are still plenty of improvements being added to 3G, mainly for data services based on HSPA. Therefore, achieving efficient operation of multiple technologies in heterogeneous networks remains a critical challenge. Data consumption will continue to grow exponentially and this will drive the development of strategies to move specific types of data services to WLAN on top of 3G/4G networks. This requires a closer integration of WLAN in mobile communication systems because the goal is to route mobile traffic based on the type of service that originated it. A particular operator, for example, may want to supply video services via LTE and e-mail services via WLAN whenever possible. This development will underscore the need for testing solutions that provide all relevant technologies and all required test scenarios – preferably in a single test device to shorten test time as much as possible. This is another important trend to look for at MWC 2013.

In addition to the need to verify that the technology is working as expected, there is the continuous trend to judge the performance on application layer. Network operators mostly care about their customers. Customer experience is just as important as verifying that a certain data rate is achieved. The discussion about how best to support voice-over-LTE – a technology that relies on packet switching – is a good example. Luckily, voice quality has been well understood in mobile communication since the early days of GSM and that makes testing voice-over-LTE a bit easier. On the other hand, video will be the main service driving data rate consumption. Its quality metrics are not nearly as well understood, particularly when the goal is to predict the end user's experience in a varying environment (for example, watching a YouTube video in a car in contrast to IP TV at home). Furthermore, there are several Internet services that people have become accustomed to using almost habitually. We are already well aware of so-

Source: Rohde & Schwarz

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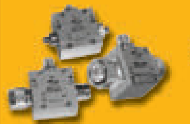

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cial networking and online gaming, for example, but new applications will undoubtedly emerge. Consequently, the service experience as judged by a customer will matter more and more even though it may well be translated into KPIs like data rate, latency and (signaling) capacity.

The continuing strong growth in the smartphone and tablet market as well as M2M applications are the main drivers of the company's business for testing products in development and production. Although the economic situation in Europe must be taken into account by all multinational companies, Rohde & Schwarz is an independent company with a strong global presence.

EFFICIENCY, GLOBAL, MOBILE BROADBAND

RFMD

Key themes during MWC 2013 will likely be that mobile data usage continues to grow as rapidly as expected and mobile data creation is definitively on the rise. Additionally, cloud-based services will be larger than ever, providing access to streaming content, along with the security and convenience of not having files resident on an individual mobile device.

Consumer market demands inevitably have an effect on the RF platforms that suppliers create, and the combined changes ongoing in the cellular space are the most impactful seen over the last decade of cellular market growth. The RF-related topics most prominently displayed at MWC 2013 will be carrier aggregation (CA), envelope tracking (ET) and antenna control solutions (ACS).

The consumer's insatiable demand for data consumption is driving the rapid adoption of LTE at mobile operators (MO) across the globe. As discussed at past MWC events, the fragmented nature of LTE frequency bands across the world forces a tremendous increase in cellular RF content. With these LTE bands present, the mobile operators' aim is to maximize their operating frequency allocation to serve increasing consumer needs. CA helps address this MO need by maximizing utilization of available LTE frequencies. On the surface, CA is simply using the current frequencies in a different way; in practice, a highly complex CA implementation requires switch and filter innovation to effectively manage new functionality with minimal size and battery current penalty. Various solutions for CA, from discrete to highly integrated, will be prominent at MWC 2013.

Mobile devices are increasing their data creation capability — both video and picture — which has an RF impact by placing renewed emphasis on the efficiency of transmitting data up to base-stations. Unfortunately, the migration to higher order modulations (HOM) such as LTE to support higher upload speeds, combined with the move to multi-band power amplifiers, is having a negative influence on current consumption. ET has been discussed as the best way to lower current consumption, but remained an investigative technology — until 2013, when it becomes real. Multiple ET solution providers and multiple ET implementations will be available and leading the discussion on the ever-present topic of cellular RF current consumption reduction techniques.

The trend that will have the most dramatic impact on RF is the proliferation of cloud-based services. Increased demand for mobile download drives the need for receive diversity, MIMO, and CA technologies, while the increased need for upload extends the need for ET solutions to counter the increased transmit current consumption and perhaps extend battery life. In a mirror example, RFMD has an up-and-coming innovation in RF, which has a broad, positive impact on the ability to provide the best quality of service (QOS) for consumers — antenna control solutions. ACS, which includes the well-publicized antenna tuning technologies, seeks to provide much improved RF performance in the face of changing environmental conditions, such as antenna mismatch, and multiple antennas configurations, all while providing OEMs the ability to optimize antenna loading for both receive and transmit. Consumers should see direct impact of CA, ET and ACS though improved QOS and longer battery life.

Business, regardless of the market, is driven by consumer demand, and MWC 2013 promises to be rich with solutions and innovations for the RF industry.

PUT IT ALL IN ONE SMALL MODULE

Skyworks

Skyworks believes there are several important trends that mobile device manufacturers will be looking for at MWC 2013. These include higher levels of integration, envelope tracking and carrier aggregation.

With regard to higher levels of integration, manufacturers are seeking ways to incorporate all popular 2G, 3G and 4G bands, as well as switches and filters, into a single module for an unprecedented level of integration

Source: RFMD

and carrier coverage. These types of solutions will enable customers to design country-specific versions of a phone using the same printed circuit board (PCB) and simply changing several other components. In other words, no PCB change is required to offer multiple versions of the same model. This integrated approach will significantly reduce the amount of required design resources, enabling OEMs to utilize a single core design team to simultaneously release multiple handsets for multiple markets.

Manufacturers will also be seeking solutions that condense multiband power amplifiers (PA) and high throw switches along with all associated filtering, duplexing and control functionality into a single, ultra-compact package in an extremely small area. At the same time, they will require best-in-class linearity and power added efficiency (PAE) for smart RF integration — equating to significant board space savings, ease of implementation, performance and time-to-market advantages.

Envelope tracking, which improves the efficiency of PAs carrying high peak-to average-power-ratio signals, is yet another important trend. The drive for OEMs to attain high data throughput within limited spectrum resources requires the use of linear modulation with high peak to average power. Unfortunately, conventional fixed-supply PAs working in this environment have low efficiency.

Source: TriQuint Semiconductor

Opportunities remain, however, to improve the PA efficiency by varying the amplifier's supply voltage in synchronism with the envelope of the RF signal.

Finally, given the need to achieve high data rate solutions that boost transmission bandwidths versus those that can be supported by a single carrier or channel, or carrier aggregation, this will be another topic of discussion at MWC. By using LTE advanced carrier aggregation, it is feasible to use more than one carrier and augment the overall transmission bandwidth.

ARE BRICK PHONES MAKING A COMEBACK?

TriQuint Semiconductor

The first cell phones were roughly the size of a two-liter soda bottle and weighed two pounds. They offered less than an hour of talk time, and the cellular radio required hundreds of RF components. It is absurd to think we would carry such unwieldy contraptions today, but as next-generation smartphones become increasingly complex, phone engineers face a daunting challenge: trying to squeeze ever more functionality and bigger batteries into sleek, lightweight form factors without compromising performance.

As multimedia applications like video streaming drive demand for faster connections through LTE and 802.11ac networks, RF content is increasing significantly. High-end super phones house a growing number of cellular and Wi-Fi bands to support 2G/3G/4G voice and data services, as well as global roaming. Because smartphones operate within the world's crowded RF spectrum, they also require more and better performing filters to ensure a satisfactory user experience.

TriQuint is taking on this design challenge to simplify RF design and optimize performance by providing more capability in less space for their customers. They have made significant advancements in miniaturization, power efficiency and system performance leveraging active and passive process technologies to integrate the growing number of puzzle pieces into a few tiny modules — while conserving precious battery life.

TriQuint is seeing high demand for multi-band, multi-mode power amplifier modules (MMPA) so OEMs can support numerous cellular bands in less space. This gives them a common RF footprint to limit the proliferation of regional phones and speed design time. By streamlining their bill of materials, they can reduce costs and offer more affordable phones to spur greater adoption.

In addition to highly integrated amplifiers, TriQuint is seeing significant demand for filters. The filter market is expected to grow 10.5 percent annually, reaching $1.7 billion in 2016, driven by the adoption rate of WCDMA, LTE and Wi-Fi. SAW filters are a mainstay in today's smartphones, while BAW technology provides the only feasible means to meet the most demanding requirements for many LTE and Wi-Fi coexist filters.

As the company's engineers collaborate to optimize the RF front-end, TriQuint's operations and manufacturing teams are making packaging innovations to deliver better products faster. Newer technologies such as flip-chip use copper 'bumps' to replace wire bonds, which speeds assembly and improves performance along with wafer level packaging that enables smaller RF solutions with reduced height to help reduce cost and size.

TriQuint increased its manufacturing capacity by 40 percent in 2011 to support the one billion annual smartphone shipments forecast by 2016. TriQuint will utilize its integration capabilities to reach further and faster, to prevent the return of the brick phone. ■

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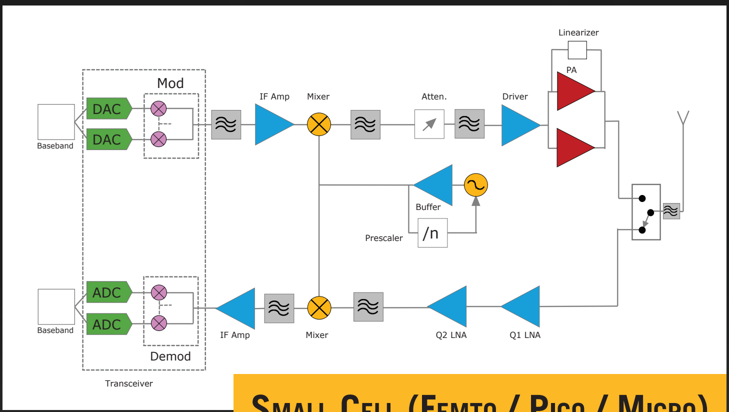

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Toward Full Coverage Voice Over LTE

As an all Internet Protocol (IP) packet environment, the Third Generation Partnership Project's (3GPP) Long Term Evolution (LTE) cellular radio standard was intentionally designed without support for existing circuit-switched voice services. The idea was that mobile operators would simply adopt this entirely new, IP-based infrastructure to replace their legacy 2 and 3G networks.

The industry may eventually move to LTE-only networks, with full coverage and all services – data, voice, SMS and Internet-enabled applications – being transported via IP on LTE. However, such an ideal could be 10 years or more in the future. Moreover, with devices available for use in both the home network and roaming situations, the cost to the operators of providing full LTE network coverage and the cost of legacy radio components being relatively low, it is unlikely that LTE-only devices will be made available any time soon, or that they would prove acceptable to consumers. Given the reality of this gradual migration to LTE, it is necessary to look at how LTE will interwork with voice services in 2G/3G. ***Figure 1*** illustrates how network technologies have evolved.

LTE uses a newer air interface technology based on Orthogonal Frequency Division Multiplex (OFDM) modulation, briefly considered for 3G, but available chipsets were considered too power-hungry for mobile devices at the time. Developments of other OFDM applications, such as digital TV broadcast and wireless LAN, have advanced chipset design so that this is no longer the case. To support its all-packet structure, a project concurrent with LTE defined Evolved Packet Core (EPC), a network architecture that simplifies signaling and moves more responsibility for in-session data management to the

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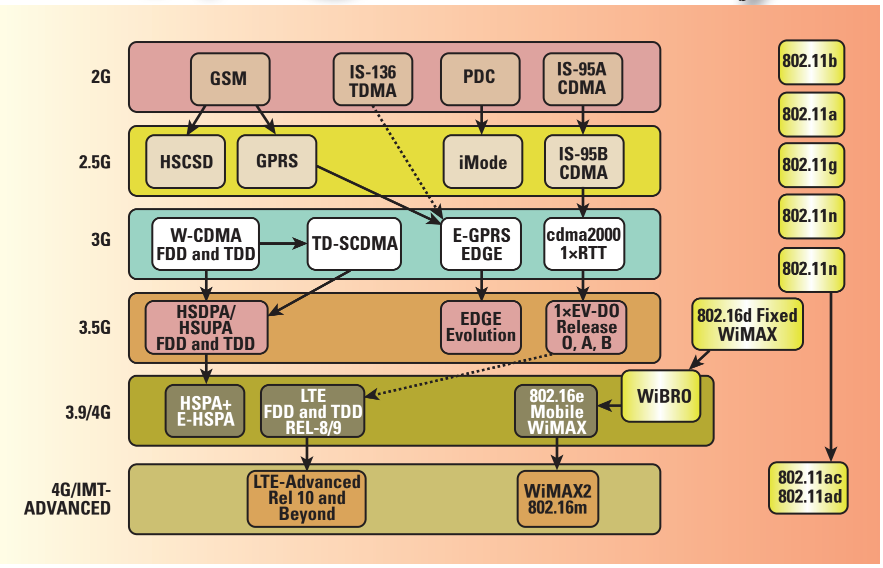
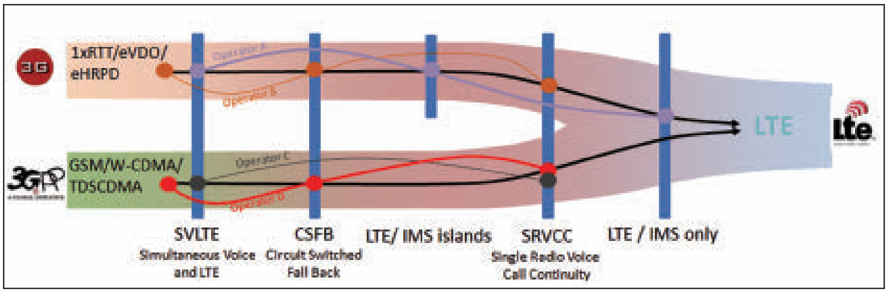


▲ *Fig. 1 Technology evolution from 2G to today.*



▲ *Fig. 2 Progress toward full voice service over LTE.*

Evolved Node B (eNB) or base station. The resulting reduced latency makes packet-based voice services and high-speed data services, such as streaming video, possible.

Until voice service on LTE is generally available, there are two development paths. For operators in much of the world, where current networks are 3GPP GSM/W-CDMA/HSPA, there is a natural evolution to LTE and standards-based support for full backward and forward compatibility, both in the radio access network and the core network that lies behind it. Until LTE voice service is implemented, making or receiving a voice call will cause an automatic fall-back to the best 3G or 2G bearer available, where both voice and data service can be provided. Voice service is then provided by the inherent circuit-switched mechanism and continuing data service managed by radio resource release and re-assignment messages. This technique is known as Circuit-Switched Fall Back (CSFB). Fallback scenarios all the way to basic 2G GSM voice and GPRS data are defined.

In countries where current networks are 3GPP2 (cdma2000/1xRTT/1xEV-DO), integration issues are harder to resolve. Without exception, operators have chosen 3GPP LTE as their next-generation technology. While there is support in LTE for the discovery and measurement of neighbor 3GPP2 cells, the core LTE and 3GPP2 networks have major differences. The first LTE implementations will support only "non-optimized" data handovers where, when the client device (technically "User Equipment" or UE) loses LTE service, it has to acquire 1xEV-DO service. In idle mode this is not really an issue, but during an active data session it will cause some disruption. Later implementations will support "optimized" data handovers, where the UE will be directed to a new serving cell and have much more information about it. Voice service in both cases is supplied by a separate cdma2000 radio in the UE and known as simultaneous voice and LTE (SV-LTE); there is no integration of voice and data services and battery power consumption is compromised. ***Figure 2*** shows the steps to full voice service over LTE for both 3GPP and 3GPP2 networks.

VOICE SERVICE OVER LTE

Voice over LTE (VoLTE) provides a standardized system for transferring voice traffic over an LTE air access network and involves the use of Voice over IP (VoIP) and a core network, based on an IP Multimedia Subsystem (IMS), to provide rich voice services, including video calling. IMS provides the framework for delivery of IP multimedia. The main protocol for setup and connection control of these services is Session Initiated Protocol (SIP), which was designed to work with generic open IP networks. SIP provides the call setup and high level call controls and also provides extended services (in 2G/3G sometimes called supplementary services) such as call hold, multi-party calls, delivery of SMS, video calling, etc.

A number of operators worldwide have stated their intention to use the introduction of this technology to refocus attention on voice services and voice quality rather than on data connection speeds and have already set an expectation of the introduction of "premium quality" or "high definition" voice services. The preferred solution is Single Radio Voice Call Continuity (SRVCC), an approach that enables operators to deploy voice over LTE, seamlessly handing over to existing GSM W-CDMA and CDMA 1x installed coverage as needed, to provide a robust voice service with global reach to their LTE Smartphone users. (It is also possible that an operator may choose to confine such a premium voice service to LTE coverage areas only and simply disconnect the call if the quality of service cannot be maintained.)

Once VoIP/IMS service is available in an LTE network, there remains the challenge of moving a voice call to a legacy network if, for instance, the UE moves out of an LTE coverage area. SRVCC provides the ability to transition a voice call from the VoIP/IMS packet domain to the legacy circuit domain, when no LTE coverage is available. Variations of SRVCC are defined to support both the GSM/UMTS and CDMA 1x circuit-switched domains. If the legacy circuit-switched network also has an associated packet capability and is capable of supporting concurrent circuit/packet operations, the subscriber's data sessions can be handed over to the legacy network, in conjunction with switching the voice call from the packet to the circuit domain. In this case when the voice call finishes and the mobile re-enters LTE coverage, these packet sessions can be handed back to LTE. While SRVCC does not require modifications to the legacy radio access network (RAN), it does require a significant modification of the operator's legacy core and full deployment of IMS circuit-packet continuity services.

BUT (AND THERE IS ALWAYS A BUT...)

While the industry hype is all about LTE, many 3GPP-based operators have chosen HSPA+ (or evolved HSPA) as a more cost-effective short-term upgrade strategy. For these operators, most of whom have already deployed HSPA, HSPA+ is a software upgrade – ideal in these days of tight budgets. The option to have the HSPA+ network operate fully in packet mode for both voice and data updates the backhaul network to make future LTE deployment simpler: only the physical (base station radio) layer would need major upgrade.

The major goals of HSPA+, as defined by the 3GPP standards organization include:

- Exploiting the full potential of the CDMA physical layer before moving to the OFDM physical layer of LTE
- Achieving performance comparable with LTE in a 5 MHz channel bandwidth
- Providing smooth interworking between HSPA+ and LTE
- Achieving co-existence of both technologies in one network
- Allowing operation in a packet-only mode for both voice and data
- Being backward compatible with earlier user devices

Current visions show "HSPA+ Advanced" supporting over 300 Mbps downlink and almost 70 Mbps uplink – easily high enough to give a similar user experience to LTE – in proposed 3GPP Specification Release 11, scheduled late in the decade. It remains to be seen how the trade-offs between the further developments of HSPA+ and LTE will evolve.

An emerging industry term, "Voice over Mobile Broadband" refers to the end-to-end routing of VoIP/IMS voice service over not just LTE, but also over HSPA+. Whichever air interface technology is used, VoMBB allows carriers the opportunity to manage and optimize the flow of mobile VoIP traffic generated by Over the Top (OTT) applications and services (that is Internet-enabled Smartphone applications and services provided by third parties). This can potentially open up new models for charging of voice services and even possible relationships between carriers and OTT application developers.

IT IS MOBILITY THAT MAKES THE DIFFERENCE

Voice over Internet Protocol (VoIP) is not new – it has been around for many years in the fixed network and is the backbone behind much of today's landline voice traffic. Nor are many of the other technologies involved with packet-based networks – the IPv6 device addressing standard is probably the most recent – but there are new challenges in applying them to mobile networking.

We still see the landline as an analog copper pair, but in reality once it reaches the local exchange the network is all-digital. Designed initially for high-speed data services and adapted for voice, VoIP is a packet-switched environment that breaks transmission into manageable chunks and routes them from end to end in the most efficient way for the network. In the fixed network, effects such as error rate and latency are virtually zero and can be ignored, whereas in the mobile air interface environment they are major issues. Typical error rate in a fiber backbone is of the order of 1×10^{-20} where mobile devices make do with a threshold of 1×10^{-3}, so coding algorithms, error correction and re-transmission of failed packets absorb much more of the mobile network's time and bandwidth. Inherent latency in 2 and 3G systems means that packet-based voice services are impossible: a circuit-switched architecture with its built-in waste of resources, with either the forward or back channel silent part of the time, had to be provided. (Typical conversations are half-duplex, unless there is an argument going on!)

When VoIP packets are small, signaling overhead may be as high as 60 percent. Again, this is not an issue in high-speed fiber networks, where ultimate bandwidth is virtually limitless, but the same is not true in the mobile air interface. A single base station radio (eNB) may be communicating with many UEs at the same time – some idle, some in voice calls and others in data sessions – and has a finite total data bandwidth available to it. Consumers pay only for their net data usage, the operator absorbs the cost of the overhead and so would like it to be the least possible percentage of the traffic. Two of the mechanisms defined in the LTE standards to alleviate this signaling burden are semi-persistent scheduling (SPS) and transmit time interval (TTI) bundling.

Semi-Persistent Scheduling

In true dynamic scheduling, each sub-frame SF (1 ms) has to be allocated individually, leading to a high usage of the Physical Downlink Control Channel (PDCCH), a shared logical channel in the 3GPP LTE structure, where allocation information for each UE is carried. Voice by its nature involves lots of small resource allocations to many users, which, in a truly dynamically allocated network, leads to possible scheduling conflicts if everyone wishes to speak at once.

Fully Persistent Scheduling

Fully persistent scheduling – equivalent to a circuit switched call, where resources are permanently assigned to a UE – would waste valuable network resources, but would dramatically reduce the requirement on PDCCH resources. Semi-persistent scheduling (SPS) provides temporary but regular allocations, reducing load on the PDCCH without over-committing Physical Downlink Shared Channel (PDSCH) resources.

SPS is a compromise between fixed and dynamic scheduling, where a user is allocated a small amount of resource for a fixed period at regular intervals. It enables radio resource to be semi-statistically configured and allocated to a UE for a longer time period than one sub-frame, avoiding the need for specific downlink assignment messages or uplink grant messages over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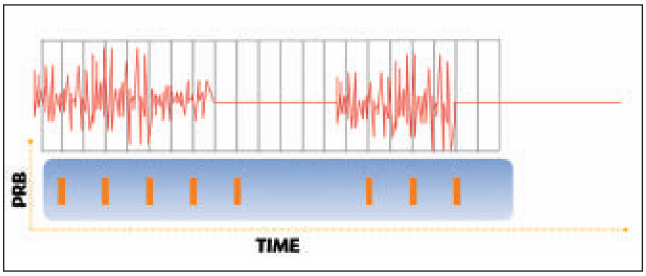
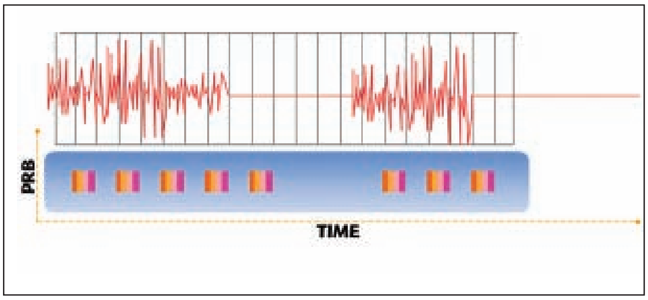


▲ *Fig. 3 Semi-persistent scheduling.*



▲ *Fig. 4 Transmit time interval bundling.*

the PDCCH for every sub-frame. It is useful for services such as VoIP, for which the data packets are small, periodic and semi-static in size; that is for the kind of service where the timing and amount of radio resources needed are predictable. Thus, overhead of the PDCCH is significantly reduced, compared to the case of dynamic scheduling. ***Figure 3*** gives an illustration. There are several studies available online discussing the various benefits of SPS versus Dynamic scheduling.

Transmit Time Interval Bundling

If it is at the cell edge, a UE can either increase power or increase coding rate to ensure good reception at the eNB. However, if a UE at the cell edge has reached its maximum available transmission power, it may not be able to transmit an entire VoIP packet during one TTI, since the required coding rate may make the instantaneous source data rate too high for the necessary relatively-well-protected transmission.

The eNB gets power headroom status reports from each UE, telling the network when the UE is at its power limit. The UE can also provide buffer status reports to say how much information the UE has in its stack. Using these pieces of information, the UE may be instructed by the eNB to use TTI bundling.

In TTI bundling, a VoIP packet is transmitted as a single packet data unit (PDU) during a bundle of subsequent TTIs, without waiting for the HARQ feedback. HARQ feedback is only expected for the last transmission of the bundle. Downlink signalling is reduced (less ACKs/NACKs) and round trip delay is minimized, but Uplink Shared Channel (ULSCH) capacity is slightly reduced. ***Figure 4*** shows an example.

MEASURING VOICE QUALITY

When testing the voice quality of a VoIP device, whether by Perceived Evaluation of Speech Quality (PESQ) or a Perceptual Objective Listening Quality Assessment (POLQA), there is a long list of test needs. The testing can be performed using audio analysis, signaling test (including connections to servers, conformance testing, radio aspects, and handovers for fall back support), battery drain analysis and SMS/video call testing. Operator-specific test plans and field testing may also be necessary. ***Figure 5*** shows a typical test setup for parametric audio quality and noise suppression test.

CONCLUSION

Regardless of the history and route to full packet-based voice services, the result is the same – a whole new slew of challenges for developers tasked with creating a range of different, more complex and more capable devices. Testing handovers between different radio access technologies (RAT) is becoming ever more important in the verification of LTE UEs. When out of the LTE service area, the UE will typically fall back to the network's 2G or 3G infrastructure. For a positive end-user experience, UEs need to transition smoothly between these technologies. Many of these test challenges will stem from the needed interoperability between legacy 3GPP or 3GPP2 technologies and LTE. Addressing these challenges and ensuring VoLTE delivers the standard of voice call the network operators want to provide, will require developers and operators to increase their focus on testing real-world performance, before deploying a new device on a live network. ■

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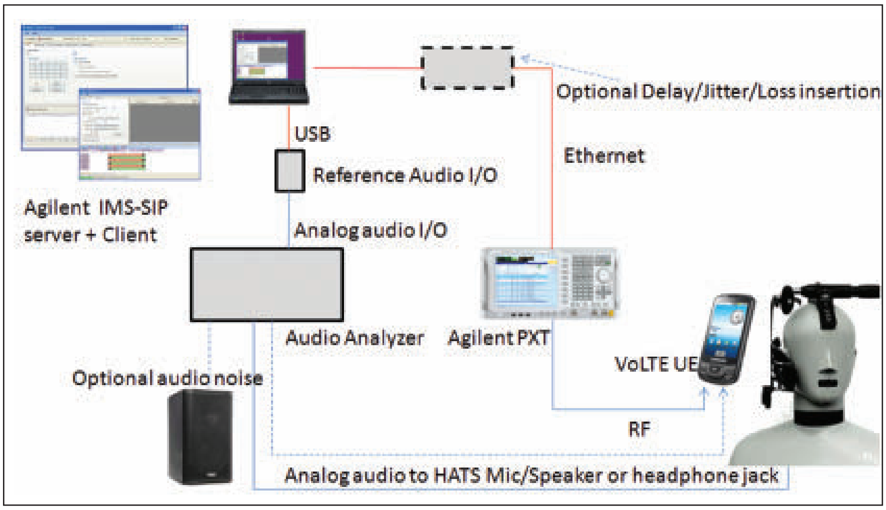

▲ *Fig. 5 Typical parametric and noise suppression test setup.*

AMPS
WiFi
TX
DCS
WLL
MMDS
VHF
UHF
CDMA
GSM
Wireless
Microcell
&
Reactel, Incorporated
Mobile
EGSM
UMTS
RX
WLAN
C1
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LTE-Advanced: The Challenges and Opportunities of "True 4G"

The cellular industry today is patiently looking forward to the deployment of LTE-Advanced, also known as Release 10 of the 3GPP's Long-Term Evolution (LTE) technology. While the "4G" label has been used to describe many of the services provided by cellular networks today, insiders know that true 4G LTE, as originally defined by the International Telecommunications Union, begins with LTE-Advanced.

The intended goal of 4G technology is to provide higher data throughput rates and better coverage. In order to meet the ITU's original 4G requirements, the technology must deliver a peak (low-mobility) downlink throughput of 1 Gbps and peak uplink throughput of 500 Mbps. LTE-Advanced also intends to deliver greater peak spectral efficiency of 30 b/s/Hz in the downlink and 15 b/s/Hz in the uplink, approximately double the efficiency of today's commercial-deployed "4G" technologies.

Toward that end, the industry has focused on three critical areas of improvement in LTE-Advanced: relay nodes, improved radio antenna techniques and carrier aggregation. The latter two directly affect the design and implementation of mobile devices (UE) and are further discussed in this article.

MIMO AND BEAMFORMING

Neither Multiple-Input-Multiple-Output (MIMO) nor beamforming antenna techniques are new with LTE-Advanced. Both techniques have been used in other radio communications technologies, besides cellular communications, for some years. In one of the industry's more interesting challenges, the two techniques are being combined into "MIMO beamforming" and will be a highly significant factor in the TD-LTE rollouts being readied in major markets in Asia.

Technically, MIMO beamforming transmission modes have been defined since the 3GPP's Release 8. However, the stated performance goals of Release 10 (specifically the data throughput rates in both downlink and uplink) were created based on the assumption that MIMO would be fully implemented. Release 10 introduces a new downlink transmission mode (Transmission Mode 9) that implements beamforming in an 8 × 8 MIMO scheme. It also officially introduces the use of MIMO in the uplink.

In MIMO beamforming, multiple antennas are used to create a polarized "beam" of

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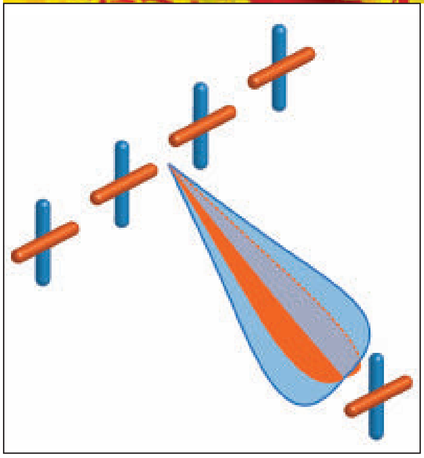

Fig. 1 *MIMO beamforming – two cross polarized beams.*

focused energy (shown as orange in ***Figure 1***). A second set of antennas (shown as blue in the diagram) creates a second beam that is cross-polarized in relation to the first. All of this happens in the same frequency band at the same time. The result is that the system can deliver multiple data streams (due to MIMO's ability to differentiate between the polarized beams) and can target those data streams in specific directions (due to the beams formed).

Both of these techniques are extremely complex, but at a high level, MIMO uses multiple antennas at both the transmitter and receiver to exploit space as a domain in which to increase data rates, or share time/frequency resources between users. At an equally high level, beamforming uses multiple antennas at the transmitter or receiver (or both) to increase coverage by focusing energy in specific spatial directions.

While it is important to note that TD-LTE technology is not characteristic of LTE-Advanced (it has been a part of the LTE family since Release 8), the combination of MIMO and beamforming is extremely important in TD-LTE. The timing of their availability coincides with large-scale TD-LTE deployments being planned in China, India, Japan and elsewhere. More significantly, MIMO and beamforming both require that a transmitter has some knowledge about the radio channel on which it is transmitting; in FDD-based LTE systems, this knowledge is acquired through feedback systems.

TD-LTE has a distinct advantage when it comes to deploying MIMO and beamforming. Since the uplink and downlink frequencies are the same, the eNodeB (base station) transceiver can analyze a received signal and use the collected information to form a reasonable estimate of the transmission channel. This eliminates the need for a feedback loop from the mobile device, which both expedites and eases the implementation of MIMO, beamforming and MIMO beamforming.

While this goal is well worth the effort, this added value comes at the cost of complexity in testing. Today's specifications include 8 × 8 MIMO beamforming mode, meaning that in the not-too-distant future, eight antennas will be transmitting and eight will be receiving, all at the same frequency and at the same time. The UE will have to process all received data in order to differentiate between all these data streams. In addition, certain radio characteristics (such as signal phase) take on new importance in MIMO beamforming, bringing complexity and the requirement for a new level of accuracy in the emulated channels used in lab-based testing. A new generation of channel emulation solutions, such as the Spirent VR5, has been developed to address this evolving need.

CARRIER AGGREGATION

Based on the throughput and spectral efficiency requirements of LTE-Advanced, a quick calculation shows that both the uplink and downlink require more than 20 MHz of bandwidth to achieve these targets. Due to the reality of the fragmented spectrum allocated to cellular technologies, finding sufficient contiguous spectrum is not an option in most cases. For this reason carrier aggregation, a distinct feature of Release 10, which addresses this spectrum fragmentation issue, is the most likely LTE-Advanced feature to be deployed on a large scale in the near future.

Carrier aggregation enables high data rates by combining multiple Release 8 carriers to support transmission bandwidths of up to 100 MHz. This approach provides several advantages:

- Backward compatibility with Release 8 and Release 9 channels
- Flexible dynamic scheduling to mitigate varying channel conditions
- Increased throughput rates

The spectral "building blocks" of an aggregated carrier are called "component carriers," each of which is the equivalent of a Release 8 carrier delivered by a separate serving cell. A UE using carrier aggregation will establish a link with one Primary Cell (PCell) and one or more Secondary Cells (SCells). Three types of carrier aggregation are defined: inter-band, contiguous intra-band and non-contiguous intra-band. ***Figure 2*** offers a graphical explanation of these terms. Because of global spectrum fragmentation, most deployments will implement inter-band carrier aggregation.

Carrier aggregation relies on new elements of the Radio Resource Control (RRC), Medium Access Control (MAC) and Physical (PHY) layers:

- RRC layer modifications deal with cell connection and handover processes and are outlined in the 3GPP RRC protocol specification (TS 36.331) and UE radio access specification (TS 36.306)
- MAC sub-layer changes accommodate the use of multiple cells and are described in detail in 3GPP TS 36.321
- PHY layer changes allow such options as cross-carrier scheduling, which enacts all scheduling on a single carrier (thereby reserving SCells for user data)

Other protocol layers such as the Packet Data Convergence Protocol (PDCP) and Radio Link Control (RLC) are not impacted by carrier aggregation. In fact, from the perspective of the user plane the aggregated carrier is a single bearer just like any other.

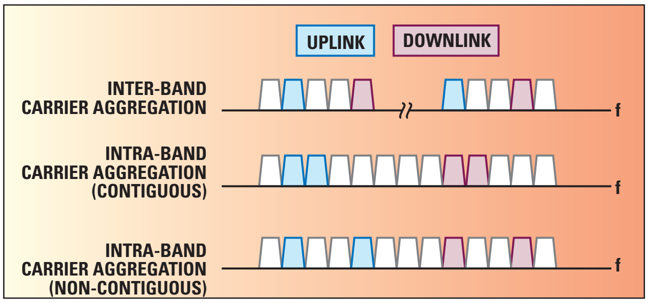

Fig. 2 *Three types of carrier aggregation.*

TABLE I

CARRIER AGGREGATION BANDWIDTH CLASSES

Carrier Aggregation Bandwidth Class	*Aggregated Transmission Bandwidth Configuration*	*Maximum Number of Component Carriers (CC)*
A	$N_{RB,agg} \leq 100$	1
B	$N_{RB,agg} \leq 100$	2
C	$100 \leq N_{RB,agg} \leq 200$	2
D	$200 \leq N_{RB,agg} \leq [300]$	Under Study
E	$[300] \leq N_{RB,agg} \leq [400]$	Under Study
F	$[400] \leq N_{RB,agg} \leq [500]$	Under Study

OTHER CONSIDERATIONS

UEs that support carrier aggregation are classified by aggregate bandwidths as a function of frequency, with each resource block occupying up to 200 kHz.

Release 10 includes provisions for six classes, but has only fully defined class A, B and C (as of the time this article was written). ***Table 1*** lists the definition of each class by the number of component carriers (CC) supported, as well as the aggregated resource blocks ($N_{RB,agg}$). Note that the aggregate bandwidth (BW_{agg}) is a function of frequency, with each resource block occupying up to 200 kHz.

As of Release 10, a UE must be able to report which bands are supported and the carrier aggregation capability for each band. Since some of the operators most interested in deploying carrier aggregation do not own spectrum in the bands defined in Release 10, they will likely deploy the technology in the bands they have available. A more widely-applicable set of configuration scenarios is likely to be defined in Release 11.

Meaningful testing of carrier aggregation techniques needs much more than just a radio-channel emulation solution. It requires the ability to readily create the protocol interactions that can exercise the UE's ability to manage all the possible combinations of carrier-aggregation scenarios.

CONCLUSION

LTE-Advanced introduces new device and network capabilities that will have a profound influence on the success or failure of next-generation cellular technology. Two of the more critical features are carrier aggregation and enhanced MIMO beamforming, technologies that add significant complexity to device development and bring us much closer to "True 4G." Due to the combination of feature importance and complexity in LTE-Advanced, UE testing takes on a new level of consequence. Realization of LTE-Advanced will not only require updates to existing testing tools, but also the creation of new and innovative tools designed specifically to help drive the success of this next generation of global wireless technology. ■

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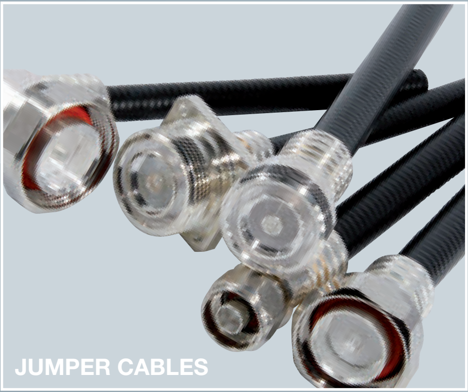
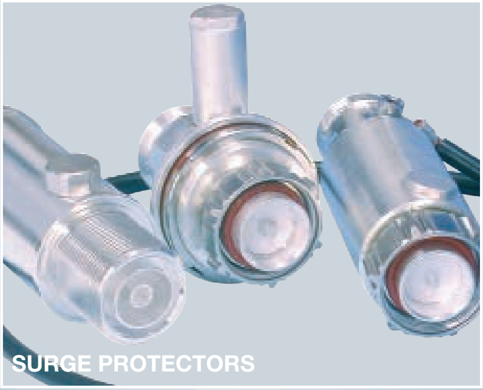
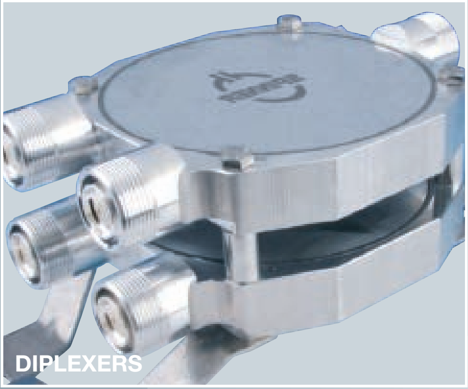


JUMPER CABLES



SURGE PROTECTORS



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Three years ago, the concepts of "small cells" and "heterogeneous networks" were just beginning to be discussed and their importance as possible solutions to the growing consumer demand for data services was just starting to be understood. Today nearly the entire wireless infrastructure ecosystem including operators, original equipment manufacturers (OEM) and component vendors recognize that small cells deployed within a 3G/4G heterogeneous network will soon be necessary to maintain or establish highly competitive broadband service offerings. Based on the ever increasing demand for data services brought on by the popularity of smartphones and tablets, some dense urban environments have already run out of capacity causing dropped or limited data connections. Operators and equipment vendors will put forth different solutions to optimize cell size and coverage based on specific environments and consumer behaviors. In many cases, operators will support areas of high demand with small cells in order to offload the macro base-stations, thus creating an efficient voice overlay and data underlay.

The timing of broad small cell deployments will vary by region and operator, but it will tip in favor of subscribers when operators recognize that capital expenditures are necessary to maintain and grow revenues. This shift will likely be driven by dissatisfied subscribers who will switch carriers in an attempt to gain access to higher data bandwidth (BW) and more reliable and consistent coverage. By some estimates, the small cell market will experience this tipping point and see widespread adoption by mid-2014. However, between today and mid-2014, the cellular industry will need to solve some challenges including frequency planning, network deployment, management and maintenance, back-

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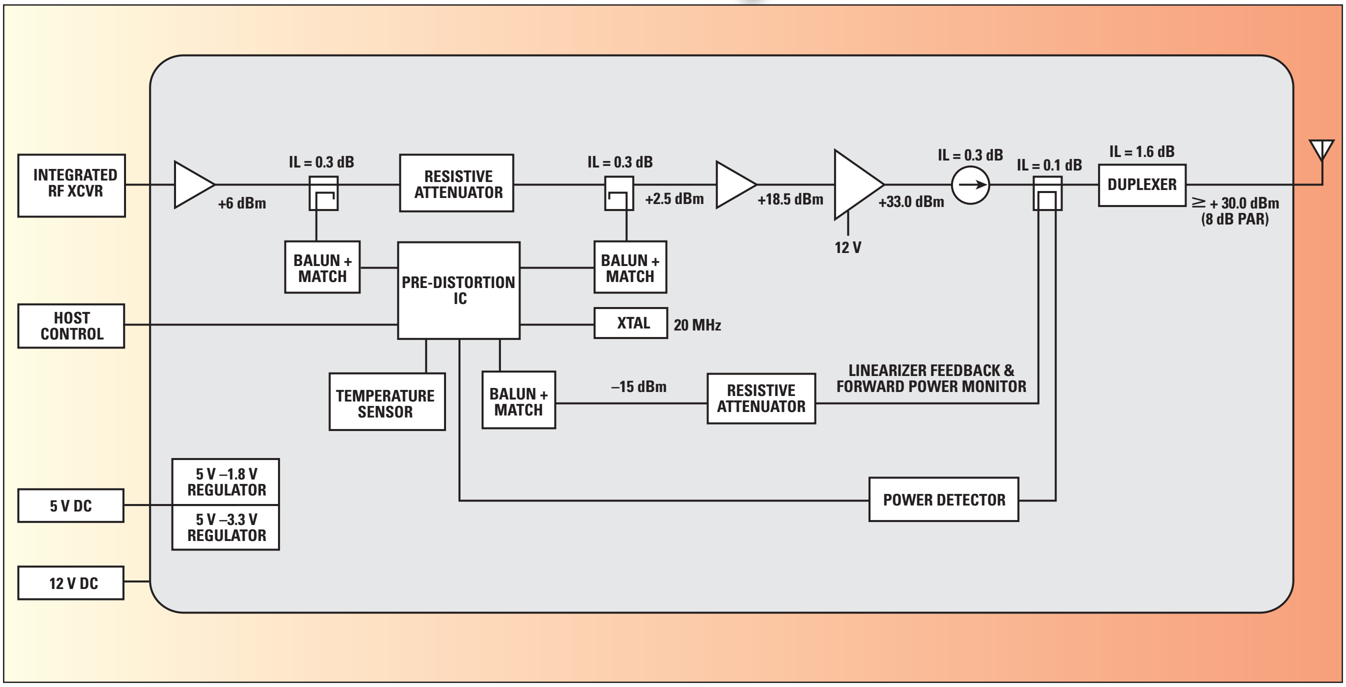


▲ *Fig. 1 Compact and efficient linearized 1 W (rms at antenna) transmitter design for small cells.*

haul and siting. Furthermore, working backwards from mid-2014, one quickly reaches the conclusion that component solutions are required now in order to develop, test and deploy small cells in a timely manner. These high-level challenges can, to an appreciable degree, be translated as requirements down to the component level including control of output spectrum (RF power and ACLR), low power consumption (enabling low cost enclosures and power over Ethernet as possible backhaul and low cost indoor deployments) and long-term reliability (minimize in-field failures).

There is no widely accepted definition for small cells, but in order to offer a context for the solutions provided, the following definition will be used. Largely speaking, there are two types of small cells: unmanaged and operator-managed. Unmanaged small cells are those typically bought commercially and deployed by individuals or enterprises. These small cells like residential femtocells transmit at very low power, typically less than 0.25 W (rms) at the antenna, have limited coverage area and are not required to meet stringent performance specifications. For the most part, these unmanaged small cells are outside the scope of this article. As would be expected, operator-managed small cells have more stringent requirements than non-managed cells. First, these cells have higher output levels depending on the type of small cell. Average output power at the antenna ranges from 0.25 to 0.5 W for an indoor carrier small cell, 1 to 5 W for an outdoor picocell and 10 to 30 W for a microcell. Increased power provides increased coverage area thus reducing the number of units that need to be deployed, but also presents challenges for designers of these units.

Many vendors of small cells have started designs and face the decision of scaling down a macrocell design, scaling up residential femtocells or initiating a brand new design. Scaling down a macrocell design has proven to be expensive, power inefficient and suffers from long design cycles. These designs must carry forward a complex digital pre-distortion (DPD) and digital signal processing (DSP) architecture requiring an expensive field programmable array (FPGA) and a broadband transmit path accommodating both the desired signal and the correction signal – typically 5× of desired signal BW – thus forcing the use of a high-performance wide bandwidth discrete transceiver. Furthermore, the design cycle for such architectures can be quite long, even exceeding 18 months simply to optimize the DPD portion of the design. Therefore, many vendors have chosen the latter two paths in order to achieve low cost, low power consumption and a small footprint while still meeting the stringent performance requirements. This article will focus on design of a 1 W (rms at the antenna) outdoor picocell though the design can easily be migrated up in power by simply changing the PA and the pre-distortion solution within the RFPAL family.

Scintera and TriQuint working together with integrated transceiver vendors have developed a solution allowing rapid design of an outdoor 3G/4G picocell supporting LTE and WCDMA while also lowering the overall bill of material and system power consumption. This design (see ***Figure 1***) supports all major global cellular bands including 700, 900, 2100 and 2600 MHz and, based on the performance of the integrated transceiver, support up to 20 MHz of signal BW making it ideal for the large majority of designs that require support of a 10 or 20 MHz LTE (TDD or FDD) carrier, or of one to four WCDMA carriers.

The pre-distortion solution is a fully-adaptive, RF_{in}/RF_{out} predistortion linearization solution that precisely compensates PA nonlinearities including AM/AM and AM/PM distortion, spectral regrowth, memory effects and other system level impairments (see ***Figure 2***). It is optimized for Class A/AB and

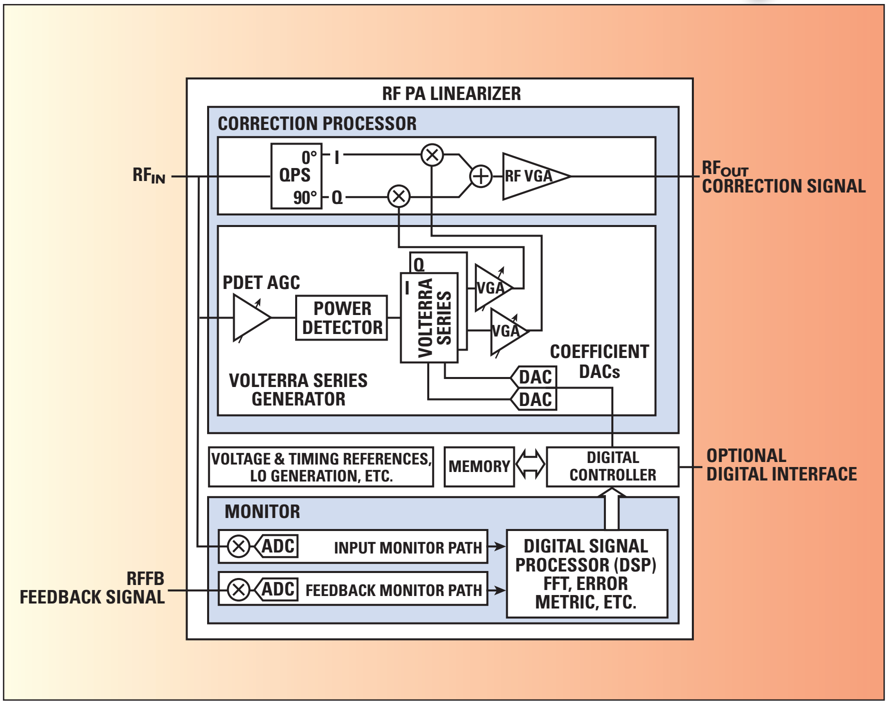


Fig. 2 Pre-distortion integrated circuit block diagram.

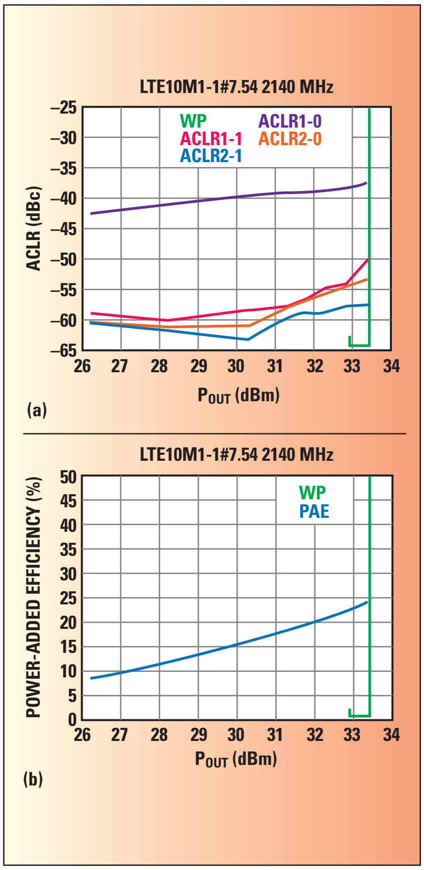


Fig. 3 ACLR performance (a) and PAE performance (b) vs. power.

Doherty RF power amplifiers operating at an average power level of 500 mW to 10 W (rms). The module measures the feedback signal from the power amplifier output, and optimizes the correction function by minimizing distortion. The correction function is based on a Volterra series with memory terms but uses a unique linearization architecture that shifts complex signal processing from the digital domain into the more computationally efficient analog RF domain thus allowing it to operate with very low power consumption.

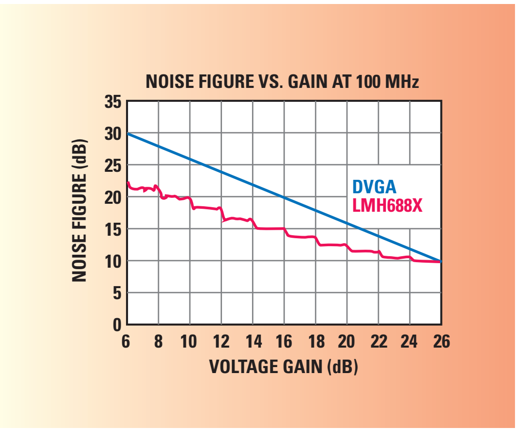
By compensating for these system level impairments, the integrated circuit allows a PA to transmit higher power at higher efficiency while still maintaining or exceeding the required system ACLR or distortion requirements. It can typically enable an existing Class A/B PA to transmit at least 3 dB more than the same PA operating in backoff. Now assuming that two different Class A/B PAs are transmitting the same power, the PA linearized will benefit from a 30 to 50 percent reduction in power consumption compared to the PA operating in backoff depending on the PAR and BW of the signal. The power consumption improvement even includes the integrated circuit power consumption which can be configured to be as low as 400 mW. It is important to note that some PAs may never reach desired linearity regardless of the amount of backoff with which they are operated. This situation may be experienced more often with wide BW and/or high PAR waveforms.

Using an example PA (TriQuint AP561) operating in linear mode and transmitting a 7.54 dB PAR waveform typical of what can be experienced with an LTE signal, the PA would in theory have an maximum rms operating point of 31.46 dBm – still more than 1.5 dB less than the required 33 dBm needed at the output of the PA in order to achieve 30 dBm at the antenna. However, when the PA is optimized for peak power in conjunction with the pre-distortion integrated circuit, the performance of the entire transmit path is significantly improved. As can be seen in ***Figure 3***, the pre-distortion provides 16 dB of correction easily enabling the PA to meet the –50 dBc linearity requirement at an operating point at nearly 33.5 dBm. Additionally, since the PA is able to operate at a much higher operating point, it is now able to achieve efficiency of greater than 24 percent.

This combination provides designers an innovative platform solution that may be brought to market very quickly using components available and in production today. With minor changes to the bill of material and no changes to the printed circuit board design, this solution can support all global cellular bands, 3G and 4G protocols including WCDMA, LTE. The solution can also support other protocols as well as varying numbers of carriers adding up to a total signal BW of up to 20 MHz or less. ■

A New Class of Amplifier, Programmable Differential Amplifiers

Texas Instruments recently introduced a new class of amplifier, the programmable differential amplifier (PDA), combining the best of fully differential amplifiers (FDA) and digital variable gain amplifiers (DVGA).



▲ *Fig. 1 The LMH688x PDAs offers better and more consistent noise and distortion performance over the entire gain range.*

Designing with high speed operational amplifiers (op amps) is often challenging. Simultaneously achieving high levels of performance across multiple specification requirements such as bandwidth, noise, distortion and impedance can be tricky. Anyone who has had an "op-amp afterthought" design experience will vouch for how tedious it can be to redesign and optimize the signal chain for a different gain value. The 2.4 GHz LMH6881 single-channel PDA and 2.4 GHz LMH6882 dual-channel PDA enable flexible and effortless signal chain design, allowing engineers to use one chip and one design for a broad range of applications.

In order to change the gain with a traditional FDA, an engineer would have to change the value of the external resistors, and then re-optimize the entire design. Additionally, the performance of a balanced signal path system

Texas Instruments
Dallas, TX

TABLE I

COMPARISON OF PDA VERSUS FDA AND DVGA

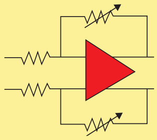
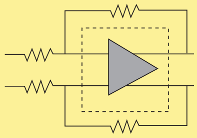
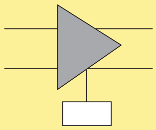
Feature	LMH688x PDA	FDA	DVGA
			
Gain Control	• Superior flexibility and accuracy • SPI control or dedicated pins	• Need to change external resistors for each gain setting	• Programmable gain control
Noise/ Distortion Performance	• Maintains noise and distortion performance over entire gain range	• Noise figure dependent on external resistors and changes with gain	• Noise figure increases dB-for-dB as gain is decreased from maximum gain
External Resistors	• No need for external resistors	• Four precision external resistors required per amplifier	• No need for external resistors
Bandwidth	• Nearly constant across gain range	• Bandwidth goes down as gain goes up	• Nearly constant across gain

TABLE II

KEY SPECIFICATIONS OF THE SINGLE-CHANNEL LMH6881 AND DUAL-CHANNEL LMH6882

Specification	LMH6881	LMH6882
Small Signal Bandwidth (GHz)	2.4	2.4
Gain Range, Gain Step Size	6 to 26 dB, 0.25 dB step size	6 to 26 dB, 0.25 dB step size
Noise Figure (dB)	9.7	9.7
OIP3@100MHz (dBm)	44	42
HD3@100MHz	-100	-100
Channel-to-Channel Matching: Gain/Phase	Not Applicable	0.2 dB/1.5 deg
Package	24-pin, 2.6 × 2.6 mm QFN	36-pin, 4.6 × 4.6 mm QFN

depends on precise matching of the external resistors. Unlike an FDA, the gain control in a PDA is programmable and does not require external resistors, thereby reducing both BOM cost and board space. Furthermore, gain is tightly controlled and performance is improved since well-matched external components are no longer required.

Next, consider signal chain design using DVGAs. While the DVGA does allow the same flexible programmable gain control as the PDA, its noise performance is not as good. A typical DVGA does not maintain its noise performance across the entire gain range. As attenuation is reduced, the DVGA's noise figure increases dB for dB. In contrast, the PDA's noise figure remains relatively flat across the gain range. Hence, PDAs offer better dynamic range performance across a wider range of gain settings versus traditional DVGAs (see ***Figure 1*** and ***Table 1***).

Both the LMH6881 and LMH6882 offer a gain range from 6 to 26 dB, with a 0.25 dB gain step size. The wide gain range and fine step size enables flexible gain scaling. The gain for these devices can be controlled in either of two modes: a serial mode control through the SPI bus, or a parallel mode control through dedicated pins. The parallel pin control mode provides a simple and quick design approach for engineers who do not want to write code to program their PDAs via the SPI bus. Both PDAs also exhibit high linearity: the single-channel LMH6881 provides an OIP3 of 44 dBm at 100 MHz input frequency, and the dual-channel LMH6882 delivers OIP3 of 42 dBm at 100 MHz. This excellent linearity helps address the demand for ever increasing bandwidth in communications channels.

With an input impedance of 100 ohms, both PDAs can be easily driven from a variety of sources including mixers and filters. Both PDAs support either DC- or AC-coupling, and single-ended (50 ohm) or differential inputs while driving differential output, eliminating expensive and space consuming external baluns. Additionally, the output impedance remains low, allowing the PDAs to drive a wide range of loads with excellent performance.

The versatility and excellent performance of the LMH6881 and LMH6882 over the entire gain range make them a universal design choice for any flexible or scalable platform that would typically use an FDA or DVGA (see ***Table 2***). They address many applications including wireless communications, microwave backhaul, industrial and medical, test and measurement, as well as military and defense equipment. In addition, the LMH6882 offers exceptional channel-to-channel gain matching of 0.2 dB and phase matching of 1.5 degrees, giving it superior image rejection capability for I/Q- or zero-IF sampling applications.

In order to speed up development with the LMH6881 and LMH6882, TI provides a comprehensive support ecosystem. Evaluation modules, reference designs and TINA-TI SPICE models are available, in addition to the E2E support forums for answering high speed amplifier questions. Both the single LMH6881 and dual LMH6882 are available and ready to simplify the way engineers design with differential amplifiers.

Texas Instruments Inc.,
Dallas, TX,
www.ti.com/lmh688x,
www.ti.com.

High-Performance 13 GHz PLL Synthesizer

The ADF4159 from Analog Devices is a 13 GHz PLL synthesizer that achieves a phase detector operating frequency of 110 MHz while simultaneously consuming less than 100 mW of power. The device contains a 25-bit fixed modulus as well as on-chip functionality to generate highly linear ramp profiles, making it an ideal solution for frequency-modulated continuous-wave (FMCW) radar applications, including automotive radar systems. The ADF4159 is also ideal for microwave point-to-point (PtP) systems, communications infrastructure, instrumentation and test equipment.

ADI's ADF4159 fractional-N PLL synthesizer consists of a low-noise digital phase frequency detector (PFD), precision charge pump and a programmable reference divider. It can be used to implement frequency shift keying (FSK) and phase shift keying (PSK) modulation. There are also a number of frequency sweep modes available that generate various waveforms, such as sawtooth and triangular waveforms. The functional block diagram of the ADF4159 is shown in ***Figure 1***.

APPLICATIONS

ADI's high-performance ADF4159 PLL features industry-leading phase noise performance of –223 dBc/Hz and 1/f noise performance of –120 dBc/Hz. The very high maximum PFD frequency allows for very good in-band phase noise while it also allows for very wide loop bandwidths if extremely fast settling time is required.

The ADF4159 supports a 25-bit fixed modulus which allows for very fine resolution. The minimum channel spacing is calculated by dividing the PFD frequency by 2^{25}, so for a 100 MHz PFD frequency, the minimum channel spacing is 2.98 Hz. Lower minimum channel spacing can be achieved by reducing the PFD frequency using the internal reference divider. The overall N divider value is calculated from the programmed INT and FRAC values.

$$N = INT + \left(\frac{FRAC}{2^{25}}\right) \tag{1}$$

The ADF4159 is powered by a 2.7 to 3.3 V analog power supply and a 1.8 V digital power supply. The typical current drawn by the part is 33 mA.

RAMP GENERATION

ADI's ADF4159 PLL can generate a variety of frequency sweeps or ramps. The ADF4159 is initially programmed once and will contin-

ANALOG DEVICES
Norwood, MA

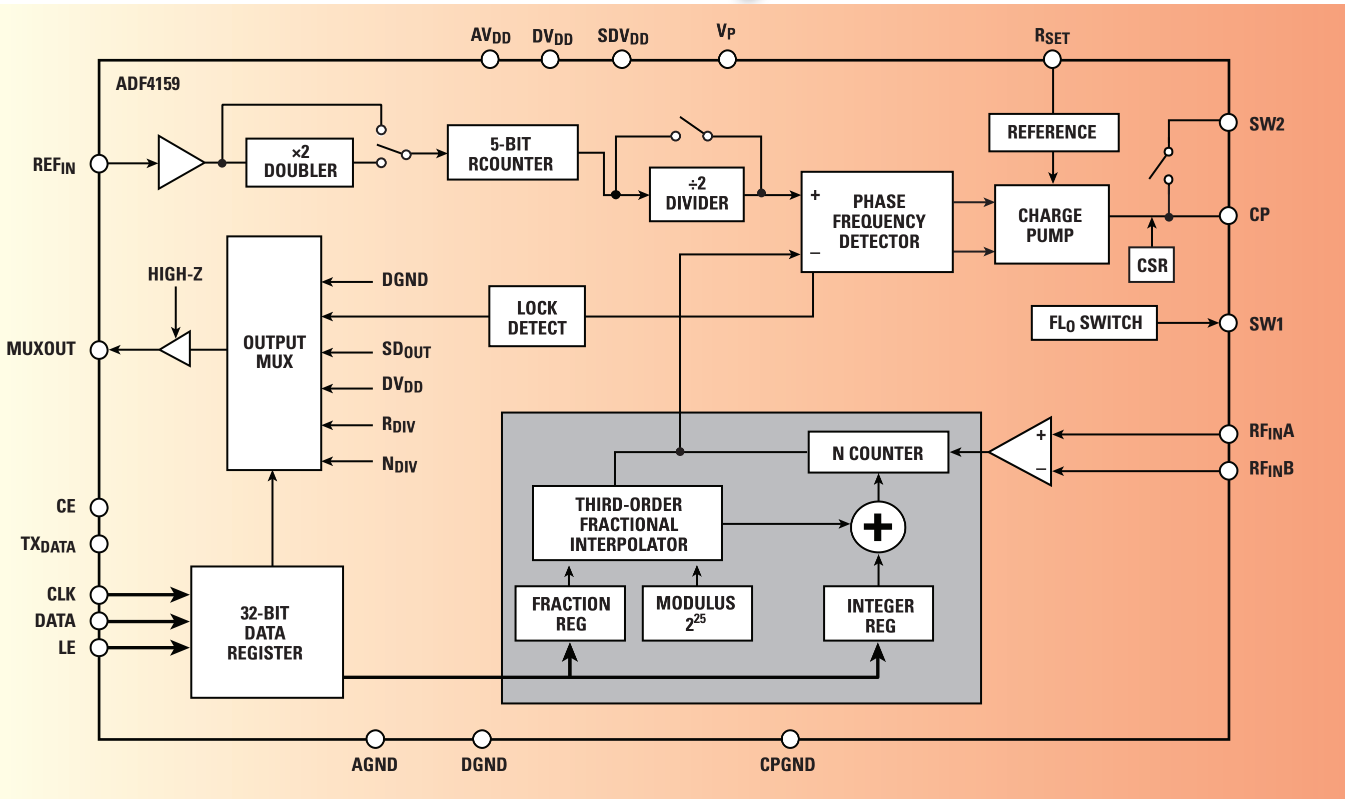


Fig. 1 ADF4159 functional block diagram.

ue to output the changing frequency without the need to re-program the part for each frequency. The frequency deviation of each step, the number of steps and the time each step takes can be individually controlled to optimize system performance. The ramp can be clocked by the internal clock or by an external pin for synchronous control.

Ramps can range anywhere from hundreds of megahertz in tens of microseconds, to tens of hertz in minutes. Some of the frequency ramps that the ADF4159 generates can be found in ***Figure 2***. Time delays can be added to any of the ramps, either at the start of the ramp or between ramp cycles. FSK, PSK and sawtooth waveforms with FSK superimposed onto the signal can be implemented on the ADF4159 by toggling the logic level on an external pin.

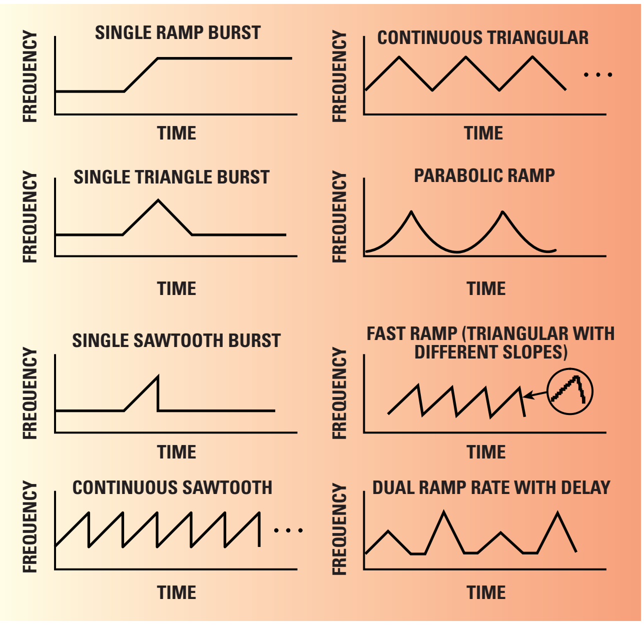


Fig. 2 Some of the frequency ramps that the ADF4159 can generate.

In addition, the ADF4159 is supported by Analog Devices' ADIsimPLL™ design tool, which simulates and optimizes ramping profiles. This software is a free download available at www.analog.com/adisimpll.

ADF4159 IN FMCW RADAR

A block diagram of an FMCW radar is shown in ***Figure 3***. The sweeping frequency is transmitted from the Tx antenna, bounces off the target (for example, a vehicle in the next lane) and is received by the Rx antennas. The received signal can then be compared to the transmitted signal to establish the distance to the target. The distance to the target is calculated as follows:

$$R = \frac{f_B c}{2A}, \text{ where} \qquad (2)$$

- R = Distance to target (m)
- f_B = Beat frequency (Hz)
- c = Speed of light (3×10^8 m/s)
- A = Sweep rate of modulating waveform (Hz/s)

For example, a FMCW radar is operating by sweeping frequency from 24 to 24.1 GHz in 5 ms. It is modulated by a sawtooth signal. That gives A = 20 GHz/s. The measured difference between the transmitted and received signal is f_B = 1.3 kHz. This means that the target is 9.75 m away.

For a 24 GHz radar system, the ADF4159 can be locked to the divide-by-2 output of a 24 GHz VCO. Alternatively, the VCO can operate around 12 GHz and its output frequency multiplied by 2 to generate the Tx signal.

(Continued on page 31)

Innovative RF Front End

Just look at any recent smartphone or tablet, and it is a safe bet that it will be noticeably thinner than models of just a year ago. It is a trend that will continue. On the one hand, devices are getting thinner, and on the other hand, batteries, displays and functionalities are growing. The amount of space left for antennas, the device's connection to the network, decreases by 25 percent each year.

In the past, mobile phones handled voice calls across two bands, and in some cases had Bluetooth®, GPS and Wi-Fi functionalities too. Today's devices have to cover 2G, 3G, 4G, Bluetooth, GPS and Wi-Fi plus large amounts of data while still supporting voice calls. LTE makes that situation even more challenging:

- There are more than 40 potential LTE bands. To enable global roaming, a device would need to support at least 13 LTE bands.
- Some countries, including the U.S., use the low frequency 700 MHz band.
- The number of LTE cellular antennas is double their 3G counterparts because LTE requires two antennas (MIMO) for receive diversity.

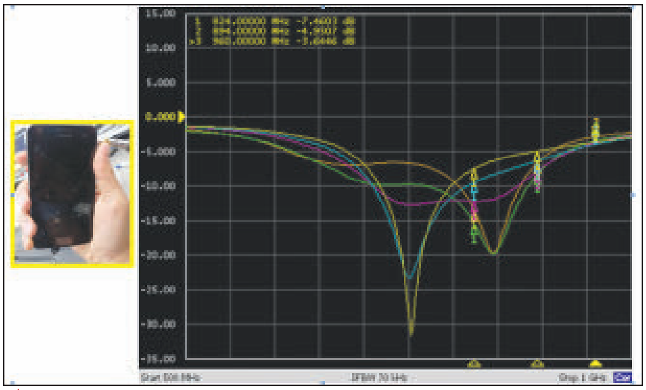


Fig. 1 *Hand and head effect correction.*

Traditional passive antennas will struggle to support LTE because they require more volume to cover the additional bands and/or the low frequency 700 MHz band. The good news is that innovations in antenna system technology can help to solve these challenges. Active antenna systems, advanced antenna structure combined with active components such as tunable capacitors and/or switches, can be used to provide advanced capabilities not possible with traditional passive antennas.

CHANGING THE RF LANDSCAPE

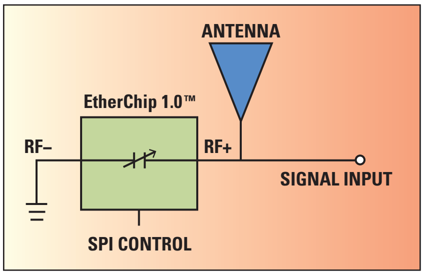
Ethertronics developed EtherChip 1.0™ to address the challenges facing today's product designers. EtherChip 1.0 uses Ethertronics' Air InteRFace Digital Conditioning (AIRFDC™) technology to provide a tuning function through tunable capacitance for the antenna system; seamlessly adjusting the cellular antenna's characteristics to its dynamic requirements for optimal connectivity:

- Reducing the antenna's physical volume by up to 50 percent without performance tradeoffs
- Making a wideband antenna by correcting the impedance mismatch
- Retuning the antenna for frequency shifts
- Offsetting hand and head effects

So even when the user's head or hand covers the antenna, causing the antenna to detune or a frequency shift, EtherChip 1.0 adjusts the antenna to maintain the call, file download or video stream (see ***Figure 1***).

Thin form factors will not come at the expense of voice, video and data performance with this product. All that the user notices is consistently great performance, giving the OEM's smartphone, tablet or notebook a market differentiator. This consistency and reliabil-

ETHERTRONICS INC.
San Diego, CA

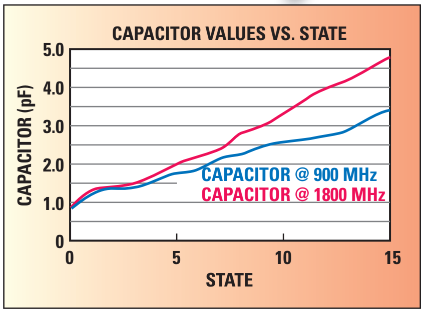


▲ *Fig. 2 Tunable antenna block diagram.*

ity also benefits the mobile operator because those customers are far less likely to report problems. That translates into lower contact center costs, potentially making for a more positive relationship between the operator and the device OEM.

EtherChip 1.0 is designed specifically for tunability on the matching of the antenna in a shunt configuration (see ***Figure 2***). All of the controls are linked to an SPI bus.

The capacitance versus the hexadecimal input shows a variation from 0.85 to 3.4 pF at 900 MHz and from 0.85 to 4.6 pF at 1800 MHz with 16 states (see ***Figure 3***). Operational frequency is from 100 to 3000 MHz.



▲ *Fig. 3 Capacitance value at 900 and 1800 MHz.*

Mechanical specifications include dimensions of 2.0 × 2.0 × 0.45 mm in an 8 pin QFN package. The chips are designed for surface mounting and are packaged in tape and reel. EtherChip 1.0, through a joint design with the antenna, supports all major bands and air interfaces, including 3G, LTE, LTE-Advanced and Wi-Fi, so it is a solution that OEMs can leverage across multiple product lines.

THE FUTURE IS A VERSATILE ANTENNA FRONT END MODULE

EtherChip 1.0 is the first in a series of chips that will enable the integration of the antenna front-end module (AFEM) in the space that the antenna once occupied. Leveraging the antenna's characteristics, the AFEM architecture will be changed progressively to enable a more cost-effective, higher performance approach.

The ultimate goal for the OEMs will be to significantly reduce cost and lead-time for developing new smartphones, tablets and other mobile devices. Those savings give OEMs a competitive advantage, such as getting a hot new design to market ahead of a rival's big launch, or reducing overhead costs so a new product can be priced profitably yet affordable enough for the mass market.

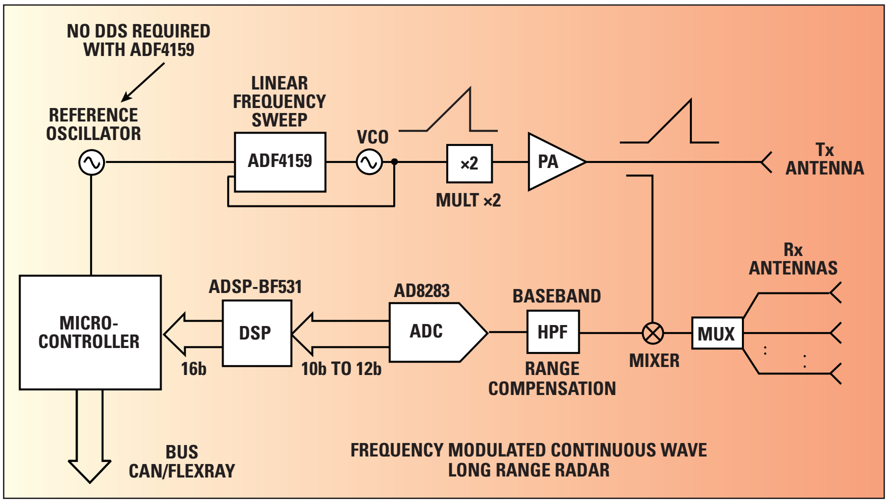
The EtherChip™ family of chips pioneers a much-needed new approach to RF front end design, one that gives device OEMs a way to turn shrinking form factors from a challenge into an opportunity. It is an idea whose time could not come soon enough.

Ethertronics Inc.,
San Diego, CA (858) 550-3820,
www.ethertronics.com.

(Continued from page 29)

Signals for 77 to 79 GHz radar systems can be generated in a similar manner.

To generate a system where the output sawtooth ramps from 24 to 24.1 GHz in 128 µs, the ADF4159 needs to be programmed to output a ramp from 12 to 12.05 GHz in 128 µs. If the system requires 256 frequency steps per ramp, the frequency deviation of each step is determined by dividing the total ramp frequency, 50 MHz, by the number of steps, 256. This results in a frequency deviation of 195.3125 kHz per step. Alternatively, if the frequency deviation per step is fixed, then the calculation can be reversed to find the number of steps, for example, 50 MHz divided by 200 kHz is 250 steps. The ADF4159 can be programmed to output any amount from 1 step to over 1,000,000 steps.



▲ *Fig. 3 FMCW radar block diagram.*

To generate the ramp in 128 µs, with 256 steps, each step will take 0.5 µs. The 0.5 µs is generated by programming two timers on the ADF4159. To achieve 0.5 µs per step, the loop filter bandwidth (LBW) must be wide enough to allow the loop to lock quickly enough. On the ADF4159, with its high maximum PFD frequency, this is easily achievable.

The maximum PFD frequency of the ADF4159 is 110 MHz. In order to maintain loop stability, the LBW cannot be greater than 1/10 of the PFD frequency. The ADF4159 is a fractional-N PLL, so care should be taken to attenuate sigma delta modulator (SDM) noise. Ideally, to suppress the SDM noise to acceptable levels, the LBW cannot be greater than 1/100 of the PFD frequency. Using ADIsimPLL, the optimum loop filter can be designed and simulated to ensure sufficient lock time and noise attenuation.

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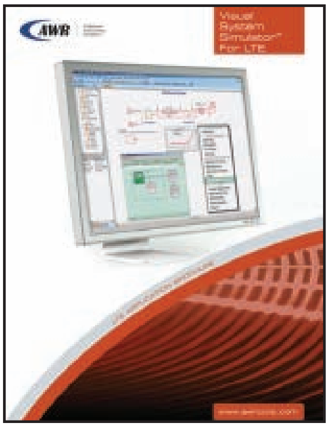

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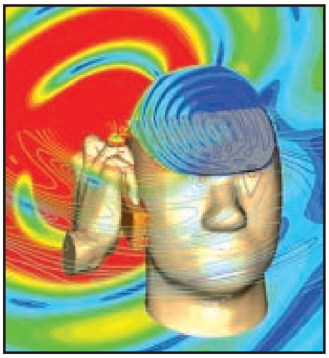

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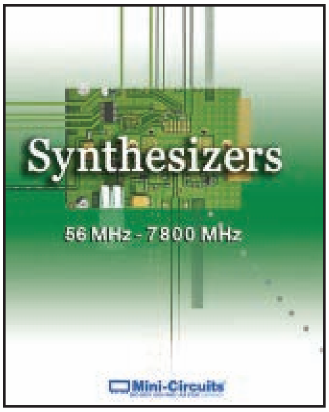

Synthesizers Brochure

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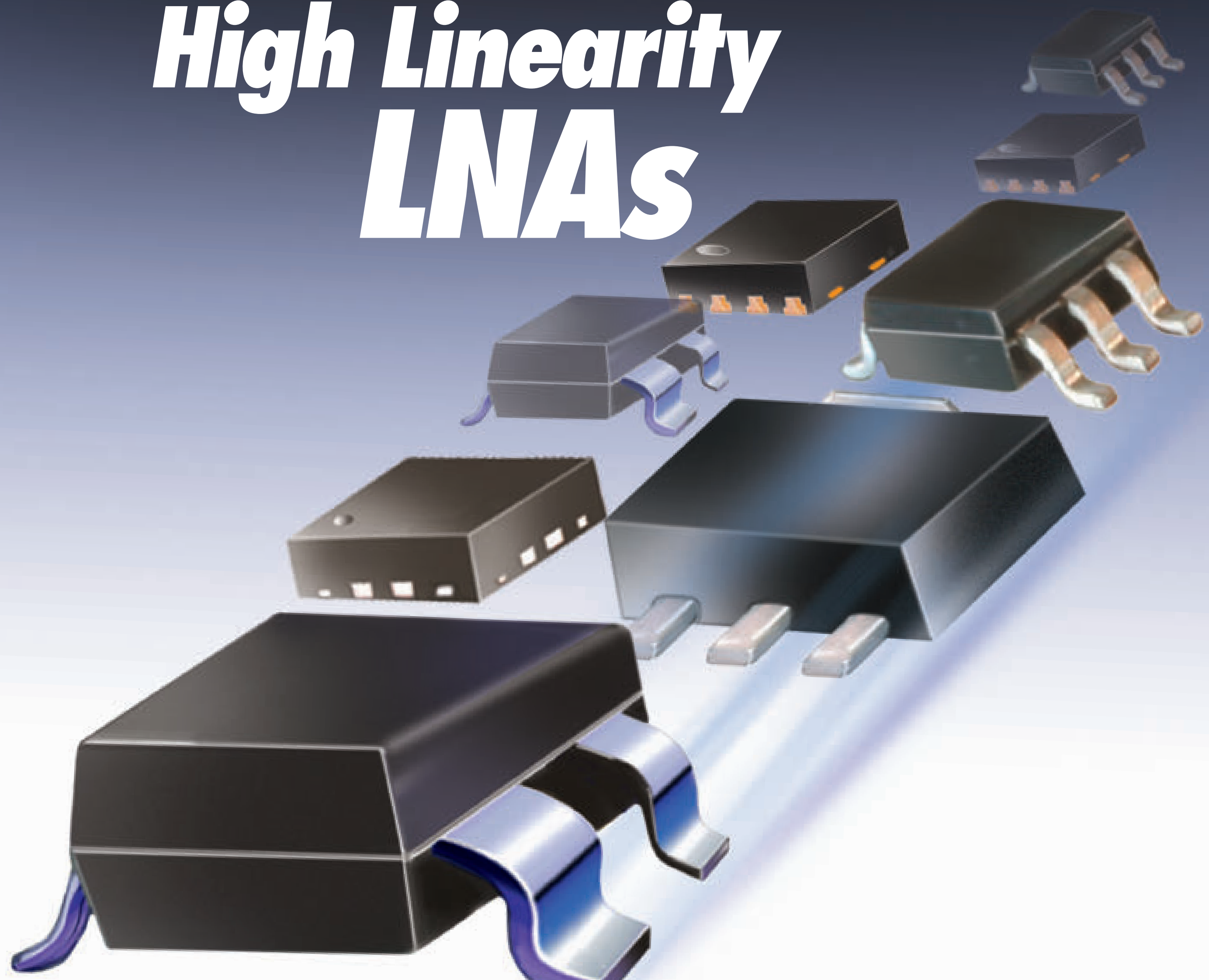

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Model	Freq. (MHz)	Gain (dB)	NF (dB)	IP3 (dBm)	P_{out} (dBm)	Current (mA)	Price $ (qty. 20)
PMA2-162LN+	700-1600	22.7	**0.5**	**30**	20	55	2.87
PMA-5452+	50-6000	14.0	**0.7**	**34**	18	40	1.49
PSA4-5043+	50-4000	18.4	**0.75**	**34**	19	33 (3V) 58 (5V)	2.50
PMA-5455+	50-6000	14.0	**0.8**	**33**	19	40	1.49
PMA-5451+	50-6000	13.7	**0.8**	**31**	17	30	1.49
PMA2-252LN+	1500-2500	15-19	**0.8**	**30**	18	25-55 (3V) 37-80 (4V)	2.87
PMA-545G3+	700-1000	31.3	**0.9**	**33**	22	158	4.95
PMA-5454+	50-6000	13.5	**0.9**	**28**	15	20	1.49

Model	Freq. (MHz)	Gain (dB)	NF (dB)	IP3 (dBm)	P_{out} (dBm)	Current (mA)	Price $ (qty. 20)
PGA-103+	50-4000	11.0	**0.9**	**43**	22	60 (3V) 97 (5V)	1.99
PMA-5453+	50-6000	14.3	**0.7**	**37**	20	60	1.49
PSA-5453+	50-4000	14.7	**1.0**	**37**	19	60	1.49
PMA-5456+	50-6000	14.4	**0.8**	**36**	22	60	1.49
PMA-545+	50-6000	14.2	**0.8**	**36**	20	80	1.49
PSA-545+	50-4000	14.9	**1.0**	**36**	20	80	1.49
PMA-545G1+	400-2200	31.3	**1.0**	**34**	22	158	4.95
PMA-545G2+	1100-1600	30.4	**1.0**	**34**	22	158	4.95
PSA-5455+	50-4000	14.4	**1.0**	**32**	19	40	1.49

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Company Showcase

3G/4G LTE PAs

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RFMD introduced its revolutionary ultra-high efficiency 3G/4G LTE PAs at Mobile World Congress 2012. For MWC 2013, the company will introduce next-generation RF platforms that cover FD-LTE, TD-LTE, HSPA, CDMA EV-DO, and EDGE modulations, with support for all world-wide frequency bands. RFMD's solutions enable increased battery life in smartphones while reducing the thermal impact of advanced data-based applications, including web surfing, video calling, and social media. RFMD experts will be on-site at MWC in Hall 2, Suite 2B91.

RF Micro Devices,
www.rfmd.com.

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From femtocells to picocells and microcells, Richardson RFPD offers a wide range of products that are ideal for small cell applications, including RF amplifiers, switches, mixers, transceivers, bandpass filters, duplexers and data converters. Leverage the company's decades of experience and rely on its localized global design support — from prototype to production — for the latest new products from the world's leading suppliers of components and solutions for small cell applications. For more on Richardson RFPD's small cell products, visit www.richardsonrfpd.com/small-cell.

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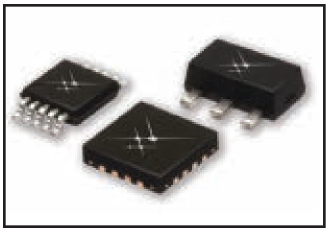

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