Vol. 57 • No. 6

June 2014

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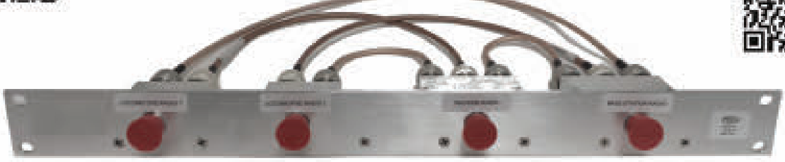

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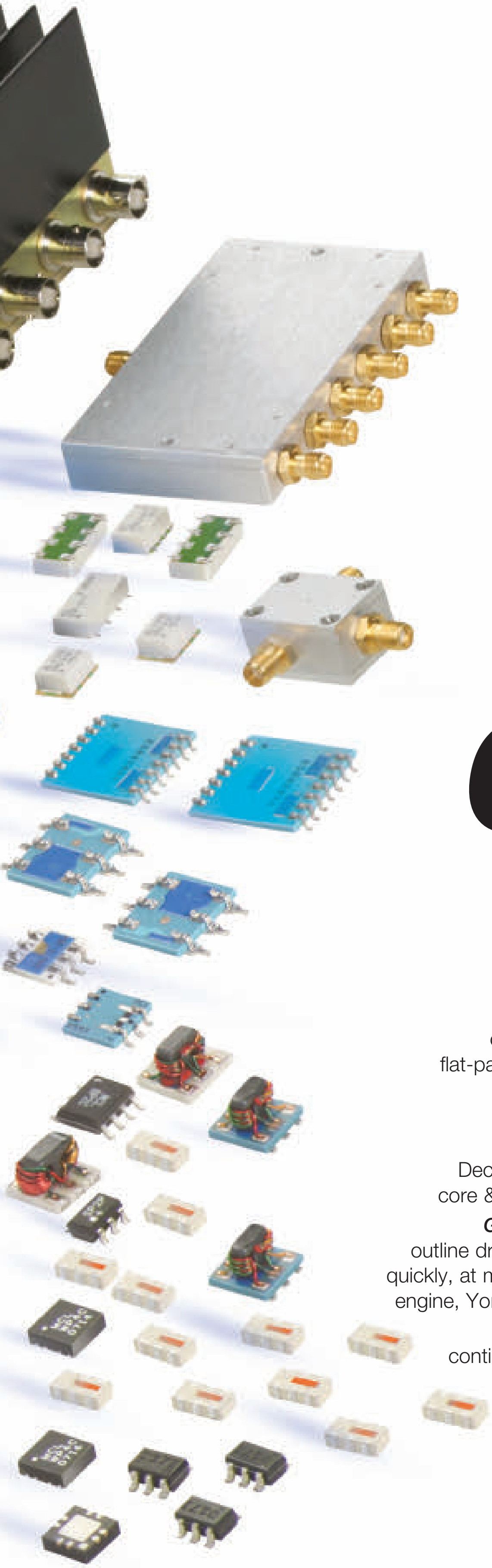

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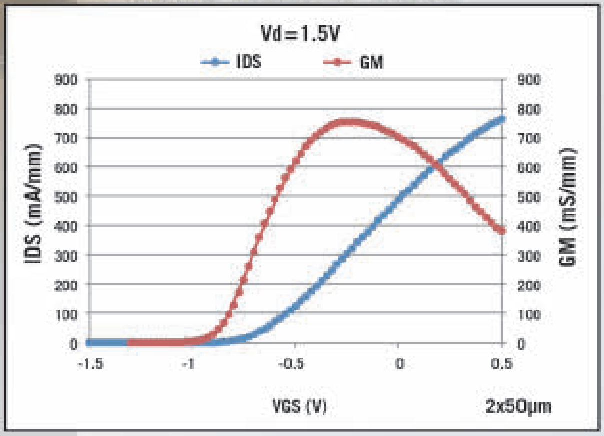

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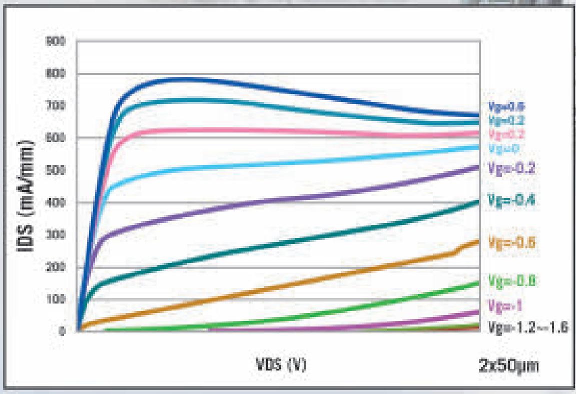

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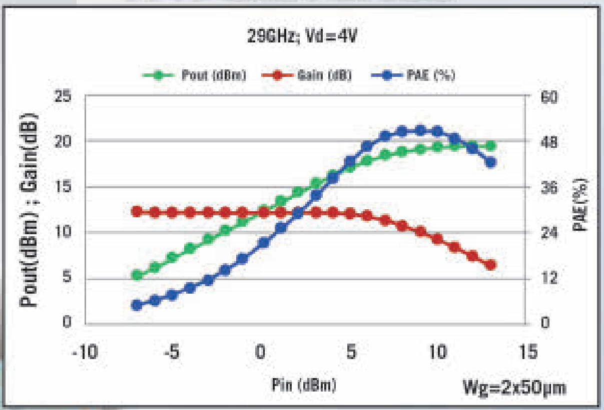

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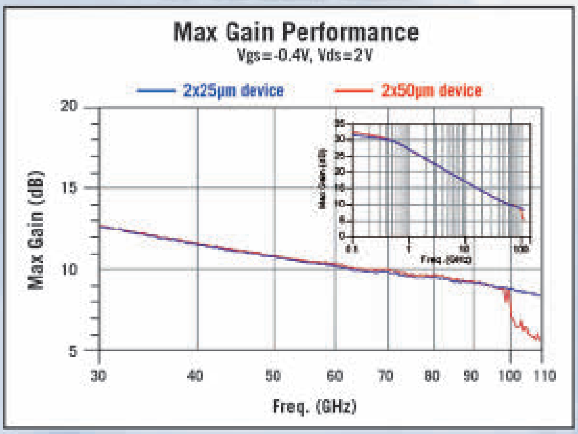

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Solid State Power Amplifiers

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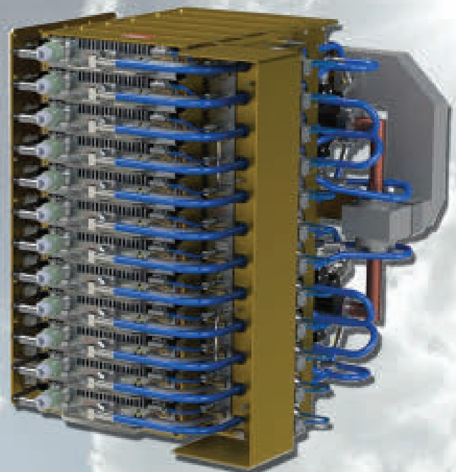

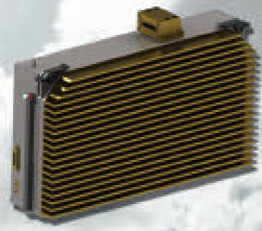

X-Band

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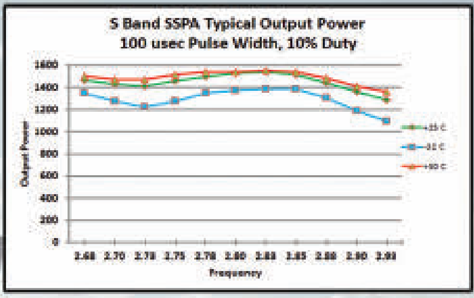

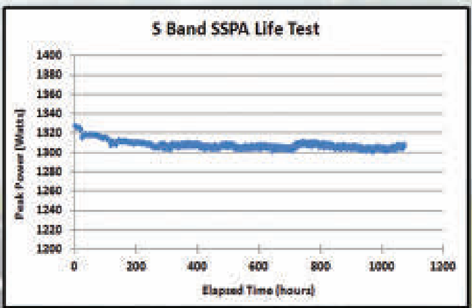

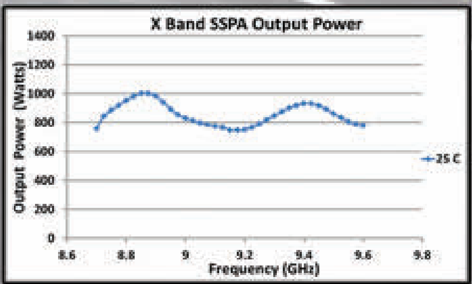

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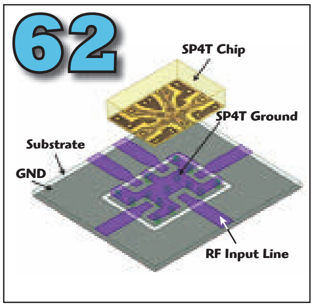

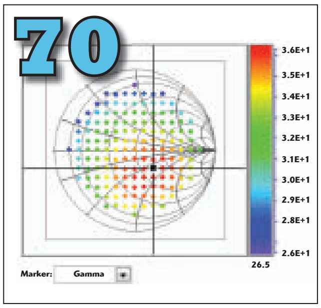

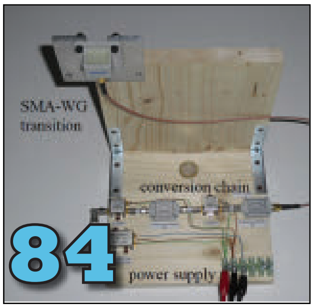

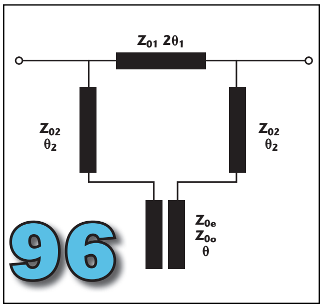

Cover Feature

Technical Features

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Refer to page 128 for this month's participants

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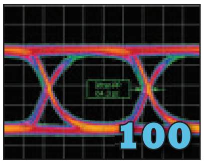

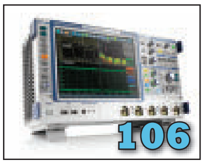

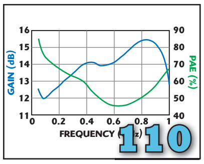

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Microwave Journal (USPS 396-250) (ISSN 0192-6225) is published monthly by Horizon House Publications Inc., 685 Canton St., Norwood, MA 02062. Periodicals postage paid at Norwood, MA 02062 and additional mailing offices.

POSTMASTER: Send address corrections to *Microwave Journal*, PO Box 3256, Northbrook, IL 60065-3256 or e-mail mwj@omeda.com. Subscription information: (847) 291-5216. This journal is issued without charge upon written request to qualified persons working in the RF & microwave industry. Other subscriptions are: domestic, $120.00 per year, two-year subscriptions, $185.00; foreign, $200.00 per year, two-year subscriptions, $370.00; back issues (if available) and single copies, $10.00 domestic and $20.00 foreign. Claims for missing issues must be filed within 90 days of date of issue for complimentary replacement.

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Simulating Dynamic Load Modulated Amplifiers – An Alternative Solution to Maintaining Efficiency Over a Power Range
By: AWR Corp. 6/18

Designing Custom Filters using Direct Synthesis and Network Transforms
By: Agilent Technologies 6/26

Web Survey

What technology most threatens GaAs market share?

Look for our multiple choice survey online at mwjournal.com

April Survey

Which design technology will have the biggest impact on improving amplifier efficiency for 4G designs?

- Envelope Tracking [33 votes] (35%)
- Doherty [24 votes] (25%)
- Asymmetric Multilevel Outphasing [8 votes] (8%)
- Chireix Outphasing [3 votes] (3%)
- Some hybrid of the above [27 votes] (28%)

John Croteau, president and CEO of **MACOM**, discusses the company's strategy to mainstream GaN products and future plans for other product areas.

Executive Interview

www.microwavejournal.com/JohnCroteau

VIEW VIDEO

WHITE PAPERS

- Agilent Technologies: Techniques for Precise Cable and Antenna Measurements in the Field Using Agilent FieldFox Handheld Analyzers
- ARROW: An IQ Demodulator-Based IF-to-Baseband Receiver with IF and Baseband Variable Gain and Programmable Baseband Filtering
- ROHDE & SCHWARZ: Radar Waveforms for A&D and Automotive Radar
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29	30	1	2	3	4	5
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www.ispsd.org

DAS & Small Cells Congress
June 16–18, 2014 • Las Vegas, NV
www.dascongress.com

MRW 2014
6th International Conference Microwave and Radar Week
June 16–18, 2014 • Gdansk, Poland
www.mrw2014.lp.edu.ua

JULY

First Responder Communication Interoperability
July 14–16, 2014 • Washington, DC
www.firstrespondersforum.com

AUGUST

EMC 2014
IEEE International Symposium on Electromagnetic Compatibility
August 3–8, 2014 • Raleigh, NC
www.emc2014.org

NIWeek 2014
August 4–7, 2014 • Austin, TX
www.ni.com/niweek

METAMATERIALS 2014
8th International Congress on Advanced Electromagnetic Materials in Microwaves and Optics
August 25–30, 2014 • Copenhagen, Denmark
http://congress2014.metamorphose-vi.org

RFIT 2014
IEEE International Symposium on Radio-Frequency Integration Technology
August 27–30, 2014 • Hefei, China
www.rfit2014.org

SEPTEMBER

ICUWB 2014
IEEE International Conference on Ultra-Wideband
September 1–3, 2014 • Paris, France
www.icuwb2014.org

ION GNSS+ 2014
September 8–12, 2014 • Tampa, FL
www.ion.org

Super Mobility Week 2014
September 9–11, 2014 • Las Vegas, NV
www.supermobilityweek.com

4G World 2014
September 9–11, 2014 • Las Vegas, NV
www.4gworld.com

IRMMW-THz 2014
39th International Conference on Infrared, Millimeter and Terahertz Waves
September 14–19, 2014 • Tucson, AZ
www.irmmw-thz2014.org

AUTOTEST 2014
September 15–18, 2014 • St. Louis, MO
www.ieee-autotest.com

OCTOBER

EuMW 2014
European Microwave Week
October 5–10, 2014
Rome, Italy
www.eumweek.com

MILCOM 2014
October 6–8, 2014
Baltimore, MD
www.milcom.org

AMTA 2014
36th Antenna Measurement Techniques Association Meeting & Symposium
October 12–17, 2014
Tucson, AZ
www.amta2014.org

ITC/USA 2014
October 20–23, 2014 • San Diego, CA
www.telemetry.org

MWP/APMP 2014
International Topical Meeting on Microwave Photonics (MWP)
9th Asia-Pacific Microwave Photonics Conference (APMP)
October 20–23, 2014 • Sapporo, Japan
www.mwp2014.com

IME/China 2014
9th International Conference & Exhibition on Microwave and Antenna
October 29–31, 2014 • Shanghai, China
www.imwexpo.com

NOVEMBER

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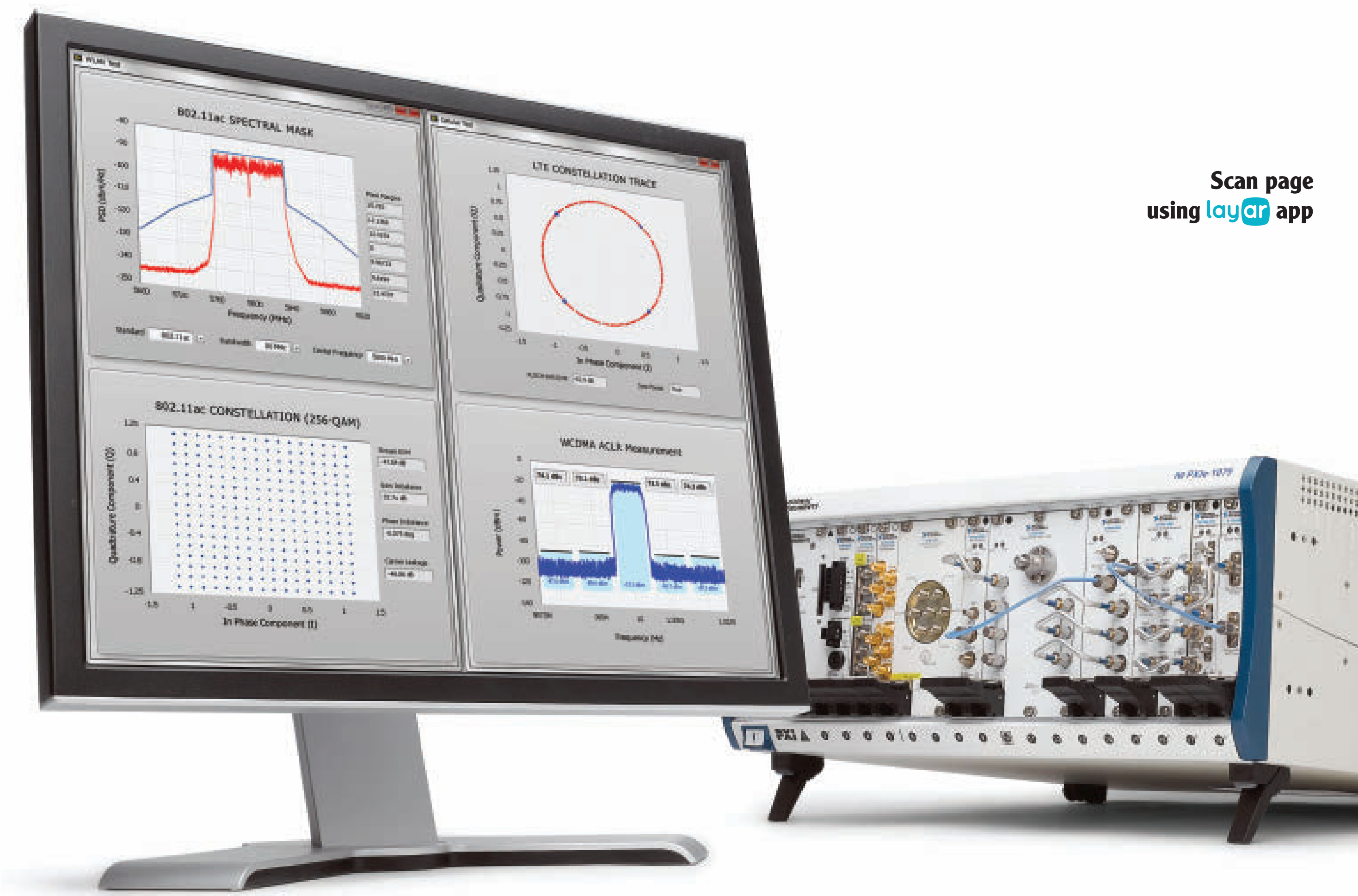

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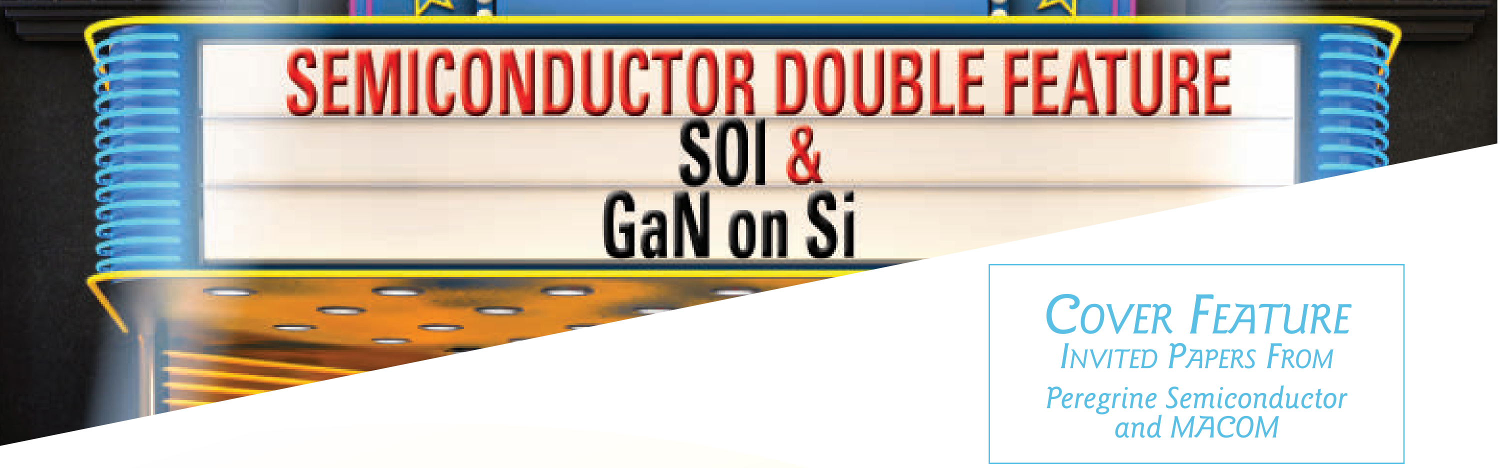


Cover Feature
Invited Papers From
Peregrine Semiconductor and MACOM

Challenging the Status Quo

Reconfigurable CMOS RF Front End

Duncan Pilgrim, *Peregrine Semiconductor, San Diego, CA*

Commercialization of GaN

Doug Carlson, *MACOM, Lowell, MA*

Editor's Note: We are at an exciting time in our industry where several technologies seem poised to start replacing incumbent technologies that have performed well for many years causing a large shift in the marketplace. These new technologies provide the same or better performance at a significantly lower cost and smaller footprint.

CMOS PAs have traditionally not been able to match the performance of GaAs PAs but now have accomplished that in the form of handset front end PA modules even in 4G/LTE applications. With a much lower cost structure and higher level of integration, CMOS is now positioned to penetrate the high volume handset front end market.

GaN has been able to outperform GaAs PAs and challenge LDMOS PAs but because it has been more expensive it has had only limited success in some high performance markets. This is changing as GaN on Si is ready to scale to 8 inch wafers and use low cost plastic packaging techniques that will significantly reduce the cost of GaN on Si and allow it to become a mainstream solution in the RF industry. *Microwave Journal* solicited the following two pieces from companies well positioned to challenge the status quo with CMOS and GaN technologies.

RECONFIGURABLE CMOS RF FRONT END

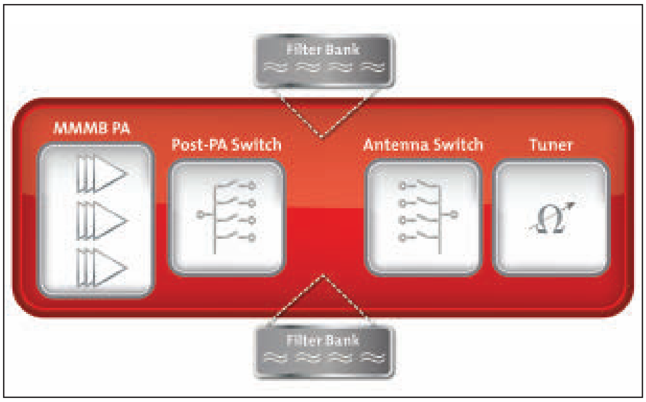
Duncan Pilgrim
Peregrine Semiconductor, San Diego, CA

CMOS technology rapidly dominates any market where it meets the required performance. The reason is clear – the incredible amount of investment in CMOS technology has led to massive manufacturing scale and continuous process technology improvements. When CMOS reaches the equivalent performance, it represents an inflection point for rapid transition from an incumbent technology to CMOS. This principle is well understood in the RF industry – advancements in CMOS always yield a disruption in the marketplace.

Changing the Status Quo in the RFFE

In 2004, Peregrine Semiconductor introduced its first CMOS-based cellular antenna switch, which earned market share in size-critical products due to the high level of integration and the small footprint. However, it did not meet all of the RF performance metrics, primarily insertion loss of the incumbent GaAs switches. But the release of UltraCMOS® 5

technology offered the market all of the benefits of integration, size and quality and also superior performance to GaAs switches. A key figure of merit used to compare the performance of switch devices is $R_{ON}C_{OFF}$. In a perfect switch the R_{ON} would be zero, resulting in zero insertion loss, and the C_{OFF} would be zero, resulting in infinite bandwidth. With UltraCMOS 5 technology, the $R_{ON}C_{OFF}$ was 253 fs, which was for the first time below that of GaAs processes. The impact of this combination of high-level CMOS integration with GaAs-level performance can be best illustrated by the resulting volume of shipped products. It took 10 years to ship the first billion chips into the market; following the UltraCMOS 5 technology introduction, it took less than two years to ship the 2nd billion. Currently, GaAs antenna switch suppliers are transitioning to CMOS to remain competitive in the market. With the introduction of the UltraCMOS 10 technology in 2013 and the UltraCMOS Global 1 RF front end (RFFE) in 2014, another performance milestone in CMOS performance has been achieved, this time with the potential to allow CMOS-based power amplifiers (PA) to overtake GaAs-based power amplifiers–even in the high-end LTE smartphone market.



▲ *Fig. 1 Peregrine's UltraCMOS® Global 1 is the first reconfigurable RFFE system.*

The Next Inflection Point

The UltraCMOS Global 1 system introduces the first reconfigurable RFFE, accommodating all 40-and-growing LTE bands, which allows OEMs to develop a single-SKU product for all global mobile device markets and provides engineers with tunability to simplify the design and testing of more than 5,000 times increase in possible RFFE states. The reconfigurable RFFE is based on an RF silicon on insulator (SOI) CMOS technology that has a foundation of more than 170 filed and pending patents along with proven manufacturing capability that has resulted in more than 2 billion units shipped.

Architecture Overview

This integrated RFFE solution based on the UltraCMOS 10 technology platform offers an architecture that is 100 percent CMOS-based, which enables all components to be integrated including (see ***Figure 1***):

- 3-path, multimode, multiband PA
- Post-PA switch
- Antenna switch
- Antenna tuner
- Common RFFE MIPI interface

A key factor in Global 1's design is the UltraCMOS 10 technology platform, a 130 nm RF SOI technology manufactured in partnership with GLOBALFOUNDRIES. This recent process delivers a 50 percent performance improvement as measured using the $R_{ON}C_{OFF}$ figure of merit over comparable RF SOI processes.

Each component supports the demanding linearity, isolation and low loss requirements for LTE devices and is tightly integrated in the system. This combination of performance and integration simplifies the design process and reduces the total RFFE footprint as much as 50 percent. All of the functions are controlled through a common MIPI RFFE 1.0 interface, allowing easy integration onto platform vendors' reference designs.

Supporting Technologies

The RFFE meets – and, in certain bands, exceeds – the raw power added efficiency (PAE) of current alternatives, that are based on a hybrid of SOI, bulk CMOS and GaAs technologies. When supporting technologies, such as envelope tracking and digital pre-distortion (DPD), are added, they further enhance the technology's performance advantage. Global 1 is designed to seamlessly integrate

Make the Connection

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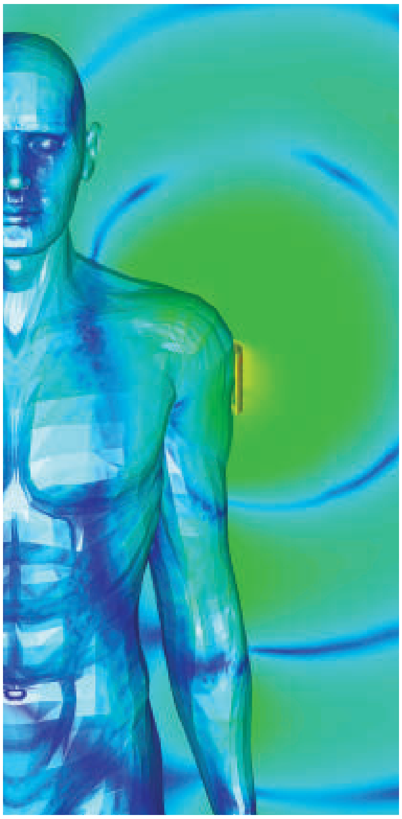

Components don't exist in electromagnetic isolation. They influence their neighbors' performance. They are affected by the enclosure or structure around them. They are susceptible to outside influences. With System Assembly and Modeling, CST STUDIO SUITE helps optimize component and system performance.

Involved in antenna development? You can read about how CST technology is used to simulate antenna performance at **www.cst.com/antenna**.

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Get the big picture of what's really going on. Ensure your product and components perform in the toughest of environments.

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CST SUCCESS STORY

PULSE ELECTRONICS IMPROVES ANTENNA EVALUATION AND REDUCES PRODUCT DESIGN LEAD TIME WITH CST MICROWAVE STUDIO

Heikki Korva, Team Manager, RF, Pulse Electronics Wireless Division

Figure 1 LTE antenna audio-module, from simulation to mass production.

Pulse Electronics Mobile Division produces compact antennas for mobile communications and networking. Mobile antennas need to function in complex and mechanically limited environments, and so most antennas used today are specially designed and customer-specific.

About Pulse Electronics Wireless Division

Pulse Electronics boosts appealing mobile devices by providing intelligent antenna design and manufacturing solutions for handsets, tablets, laptops, small cell base stations and PMR.

Our aim is to optimize antenna designs for complex multi-radio environments under all circumstances. The carefully developed Pulse solutions truly delight end users.

Pulse has delivered close to 2 billion antennas to the leading manufacturers of mobile devices. Pulse Wireless Division is headquartered in San Diego, USA, and has sites in Finland, China, South Korea, and Taiwan.

www.pulseelectronics.com

The antenna is one of the first electromechanical components considered in a new product concept design. In the past, most of the R&D work was done in the laboratory, with the engineers constructing and testing different antenna designs for customers' products. While this is still a good approach for single antenna systems, the introduction of LTE diversity schemes and other radio systems such as Wi-Fi and GPS to current smartphones make reliable prototype evaluation very challenging.

Antenna prototypes typically include the device ground, PCBs, batteries, covers and any other large parts. Obviously, early prototypes seldom include any active transceivers, and so each antenna must be driven from an external coaxial cable. A typical LTE smartphone, with its main and diversity antennas, GPS and GLONASS systems and 2.4 GHz and 5 GHz WLAN capabilities, can need 7 or 8 cables to measure all the components at once. These cables would occupy too much of the volume of the prototypes, and severely distort the evaluation results. With electromagnetic simulation, the performance of a complex device can be calculated without worrying about these cable effects.

An example of an antenna product designed using only CST MICROWAVE STUDIO® (CST MWS) is shown in **Figure 1**.

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Find out how Pulse Electronics improves antenna evaluation and reduces product design lead time with CST MICROWAVE STUDIO.

CST

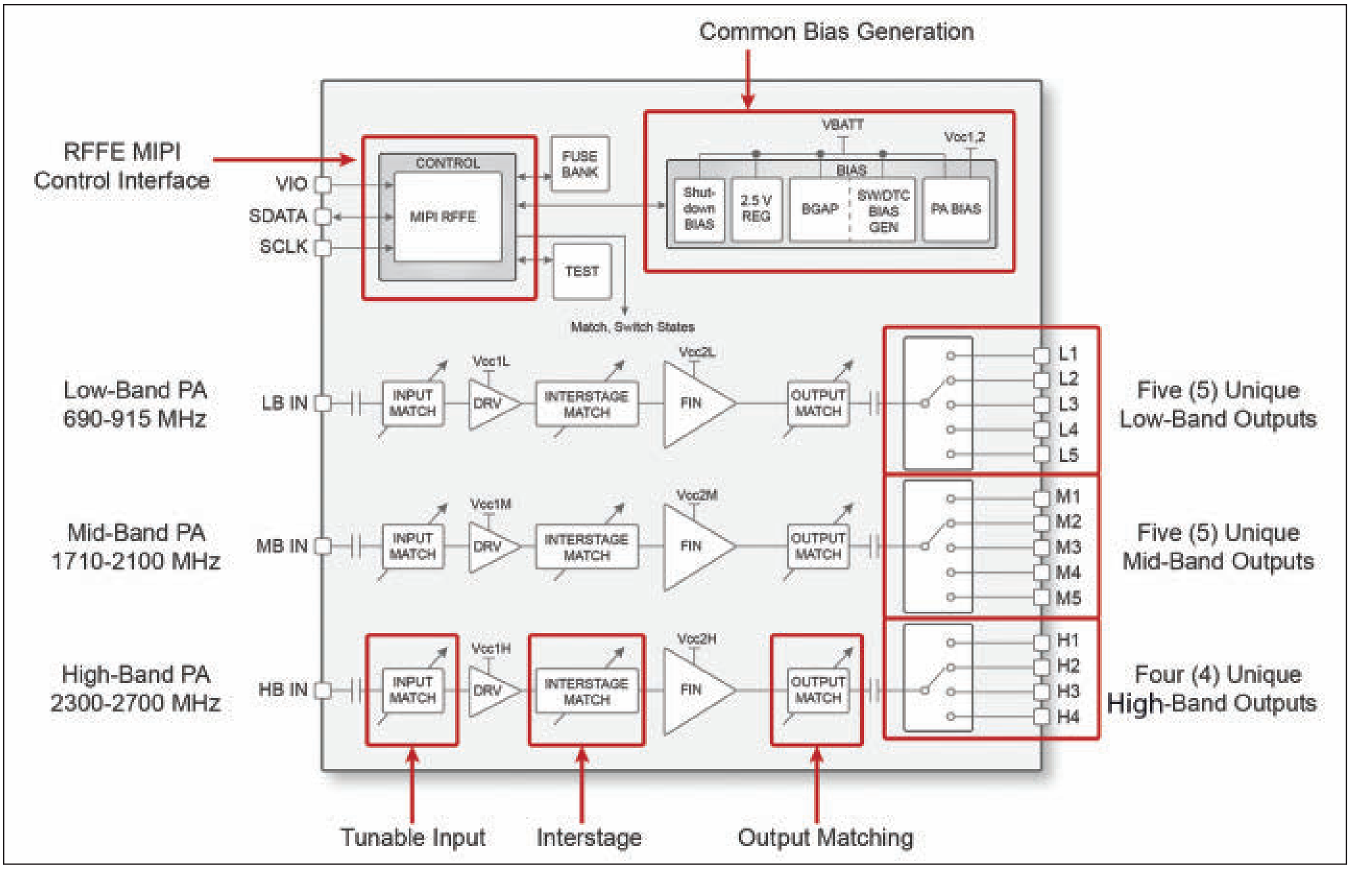


Fig. 2 Peregrine's UltraCMOS Global 1 PA can exceed the performance of GaAs-based LTE PAs and offers substantially more integration benefits.

onto any reference-design platform and can use any third-party filters and envelope-tracking modulator, allowing the flexibility to select the components that optimize performance and/or cost based on the unique criteria of the reference design.

Power Amplifier

Before now, GaAs was the only technology capable of delivering power amplifiers with the high performance LTE devices require. After eight years of research and development, this technology represents one of the first CMOS SOI power amplifiers to meet the performance of GaAs-based products. The UltraCMOS Global 1 PA (see ***Figure 2***) is a multimode, multiband PA that monolithically integrates the three amplifier paths – bias generation and control – via a MIPI interface.

The post-PA switches are integrated onto the same die as the PA, so it can support five unique bands for low band, five unique bands for mid band and four unique bands for high band. The PA supports a range of frequencies: 690 to 915 MHz in the low band, 1710 to 2100 MHz in the mid band and 2300 to 2700 MHz in the high band. In recent years a single, high-band path was all that was required, and this was cost-effectively supported via the use of a satellite PA. Today's devices must support as many as four different high-frequency bands, and the integration of the high band is critical in order to support the roll out of bands – 38 and 40 for the TD-LTE network in China, B7 in Europe and Hong Kong, B41 in the United States and other bands in various geographic locations.

PA Performance

A standard industry benchmark for PA performance is PAE using a W-CDMA (voice) waveform at an adjacent channel leakage ratio (ACLR) of -38 dBc. Under these conditions, the performance of the low band, multimode, single-band (MMSB) PA is more than 50 percent PAE (see ***Figure 3***). This surpasses the leading GaAs PAs and exceeds the performance of other CMOS PAs by 13.5 percentage points. Initial Global 1 figures released in February displayed the Global 1 PA matching the performance of GaAs PAs and exceeding CMOS PAs by at least 10 percentage points. However, after continued product development, Peregrine is reporting a higher level of performance – a level that exceeds GaAs PAs in certain bands.

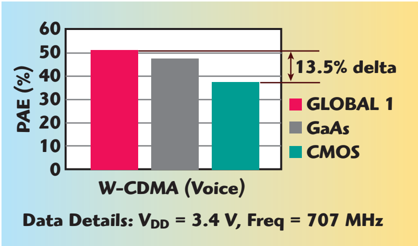


Fig. 3 The Global 1 PA has better performance than GaAs and exceeds the performance of existing CMOS PAs by 13.5 percentage points.

The PA is not limited to W-CDMA – using e-UTRA test conditions, ***Figure 4*** shows a typical LTE drive-up curve with a 25 resource block (RB) QPSK signal at 782 MHz. The ACLR1 is very well behaved, and the PA has been designed to work over the entire output power range. At -35 dB ACLR, the PA achieves approximately 43 percent efficiency for a MMSB PA using a 25 resource block (RB) QPSK signal at 782 MHz. These curves are very similar to the performance of a state-of-the-art GaAs PA.

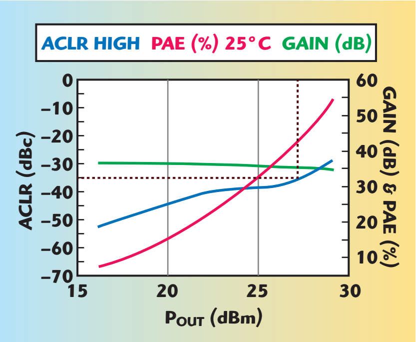


Fig. 4 This real-time performance test shows a drive-up curve in which the red line indicates the PAE and the blue line indicates the ACLR.

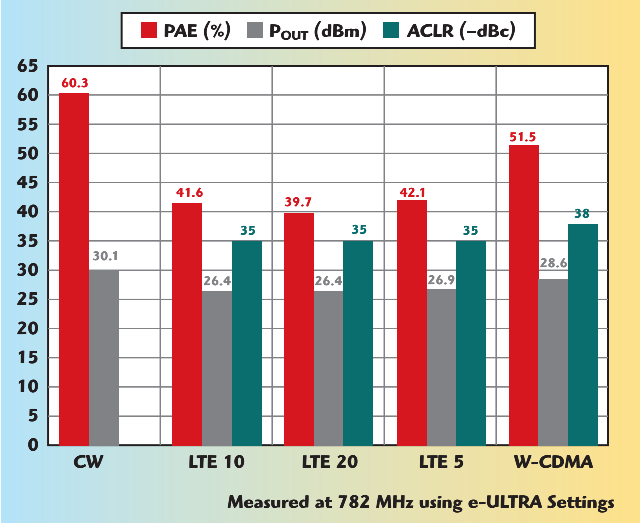


Fig. 5 Across the low band, the UltraCMOS Global 1 PA shows little performance roll-off with W-CDMA, LTE5, LTE10 and LTE20 waveforms.

The data in ***Figure 5*** shows that GaAs-equivalent performance is maintained for LTE waveforms (RB) allocations up to 100 RB. The level of performance achieved is in line with current high-end GaAs PAs. Similar competitive results have been achieved in mid and high bands of operation. The CW measurements show performance when the PA runs into saturation and is a good indication of the approximate performance that can be achieved when envelope tracking is added.

Adding Envelope Tracking

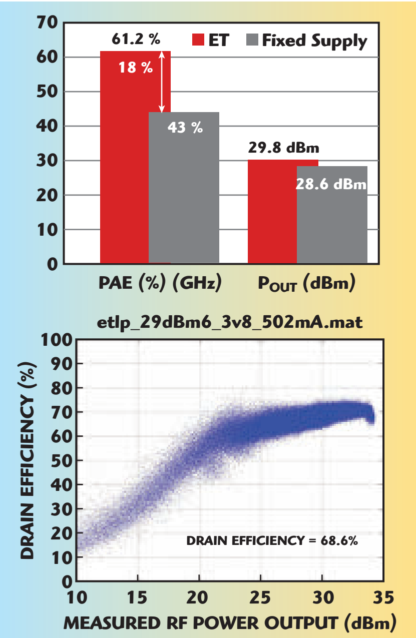
Achieving the efficiency benefits of envelope tracking while still meeting linearity and noise requirements has proven challenging. Now a number of envelope-tracking modulators meet all of the requirements. Most modulators have unique architectures that impose slightly different requirements on the PA, but certain commonalities in the requirements exist, including minimizing the AM-AM / AM-PM distortion characteristics of the PA and maintaining a consistent gain response down to low-drain voltages. Careful design of the biasing structures and PA architecture are critical in achieving these requirements. Integrating the bias circuits and the PA together enables tight control across process, voltage and temperature (PVT) and reduces the variation of these effects.

As with traditional GaAs-based PAs, the UltraCMOS Global 1 PA gains performance improvement with envelope tracking (ET). Peregrine's PA configurability enables the match and the biasing to be optimized based on the selected ET solution. As such, the design can support a broad range of ET modulators, giving engineers a full range of choice for optimizing their reference designs.

As an example, Peregrine has completed testing using Nujira's NCT-L1300 envelope tracker in conjunction with an UltraCMOS MMSB PA. This combination yields a more than an 18 percent point PAE performance improvement (see ***Figure 6***) and results in a system efficiency of more than 50 percent. The data is taken at 780 MHz using a 25 RB QPSK LTE signal with a PAPR of 7.3 dB. The results are measured at a 29.8 dBm with an ACLR -38 dBc. These results are taken using a linear output match and modulating only the final-stage supply. It is possible to gain more performance improvement if the supply of the driver is also modulated and if the match is optimized for saturated operation.

PA Configurability

The combination of tunable matching and extensive bias control allows the device to be configured based on



▲ *Fig. 6 When Nujira's envelope tracking is added, the Global 1 PA's PAE performance increases by 18 percentage points; output power increases by more than 4%; and the drain efficiency exceeds 68%.*

the mode, power and frequency of operation. Configurability has become a necessity in the RFFE as the number of frequency bands and modes that devices need to support grows. China Mobile, for example, is targeting phones that support ten bands and five modes, and this trend is expected to continue. With all of these modes, band combinations, power levels and other factors, the number of possible states grows exponentially. Peregrine estimates that there will be more than a 5,000 fold increase in the number of possible states of the RFFE. Consider that there are more than 150 different switch elements integrated on the Global 1 die, and all of these must be controlled and routed. This level of control and configurability can only be economically implemented with a fine-geometry CMOS process.

Support for Multiple Frequency Bands

Global 1's CMOS-based process enables monolithic integration of low-loss switches, digitally tunable capacitors, high-Q on-chip passives and control circuitry, and it includes tunable matching networks enabling load-line optimization. This results in an RFFE that is frequency agile and can be tuned and optimized for the band of operation.

Each path of the power amplifier covers a wide frequency range, and, within this range, there are multiple 3GPP frequency bands – 11 are in the low band alone. Currently, engineers have two choices for supporting multiple frequency bands in a single device. One option is to have a PA and a duplexer per supported band, which offers the highest performance but can be expensive and prohibitive due to the amount of real estate this consumes. The second option is to use a multimode, multiband (MMMB) PA, which is capable of supporting broadband operation; in low band this would require support from 699 to 915 MHz. With the MMMB PA option, engineers must accept lower performance across the entire band. GaAs PAs minimize output-power degradation across the band well, but the PAE curves show significant roll-off. For example, the PAE could be very high at 900 MHz but could drop by as much as 10 to 12 percent at 700 MHz. With Peregrine's fully tunable PA, engineers can optimize ACLR, output power and PAE for each desired band of operation.

Interfacing Into the Duplexers

In a traditional MMMB PA – where the output match (Z_O) is fixed – it is not possible to provide an optimal match into all of the different duplexers as shown in ***Figure 7***. The match can either be optimized for one of the paths which results in degraded performance for all other paths, or the match can compromise performance in all bands but to a lesser extent.

Mismatches between PAs and duplexers can lead to increases in insertion loss of tenths of dB's equating to percentage points of reduction in PAE. This has been a major factor in the success of the single-band PA with integrated duplexer (PAiD) modules, which have been used extensively by OEMs that are focused on the highest performance possible.

The alternative is a MMMB PA that includes a tunable output match (see ***Figure 8***) that can be tuned based on the band of operation. This PA offers band specific optimization of the interface impedance that has traditionally only been possible with PAiD modules.

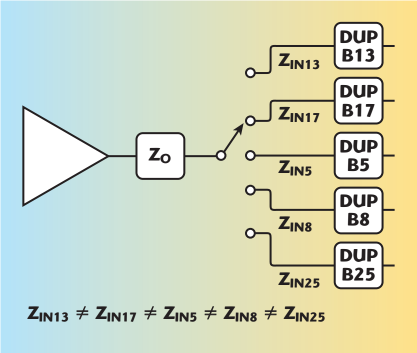


Fig. 7 In this block diagram of a traditional MMMB PA and duplexer, there is no way to provide an optimal match from the PA to all duplexers.

With impedance tuning, ZOX is effectively re-tuned so that the output of the MMMB PA is matched to the input impedance of the duplexer on a per-band basis.

$Z_{013} = Z_{IN13}$; $Z_{017} = Z_{IN17}$; $Z_{05} = Z_{IN5}$; $Z_{08} = Z_{IN8}$ & $Z_{025} = Z_{IN25}$

This tunability enables the device to easily work with any filter products on the market, and it reduces the benefit of co-packaging the filter elements with the rest of the solution. In addition, Global 1 supports external filters and can be easily configured to support different frequency bands and combinations.

Configurability

The tunable PA helps engineers achieve multiband operation with minimal performance degradation and a host of additional benefits, including:

- Removal of production make tolerances
- Temperature compensation to minimize variation across the temperature range
- Optimization for the different modes and power levels
- Match re-tuning for envelope tracking or for average power tracking
- Compensation for mismatches between the PA and duplexer, antenna or even variations in PCB layout

RF design engineers will benefit most from the UltraCMOS Global 1 system because it can dramatically reduce the engineering and validation time required. Platform providers can develop a single reference platform, reducing reference design development costs and validation time. The ability to electronically tune the frequencies of operation means that the traditional hand tuning required to get the "optimal" performance can now be completed by running an optimization program overnight. OEMs can quickly optimize the reference design based on the feature set and form factor of the product. This cuts research and development costs, accelerates time to market, streamlines supply chains and improves inventory management. Consumers can enjoy longer battery life, better reception, faster data rates and a wider roaming range.

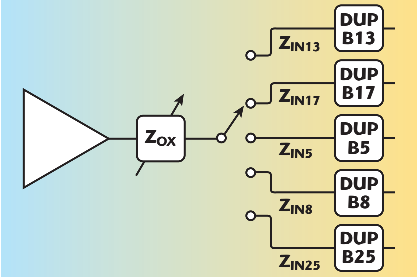


Fig. 8 Global 1 integrates a tunable output match, enabling optimized performance for all paths.

Conclusion

Why now? Just look at what is going on in the LTE market as noted in the ABI Research report "The Connected World of Tomorrow: Predictions for 2014 and 2015." According to that report, there are 375.2 million LTE subscriptions in 2014, and that number will increase by more than 60 percent, to 588.9 million, in 2015. In addition, 4G-mobile-network data traffic will more than double in 2014, reaching 12.4 exabytes. These demands require an unprecedented RFFE performance. What is needed is a true disruption in the marketplace.

History has shown that true innovation and forward progress is the result of challenging the normal way. To meet this challenge, Peregrine has developed a fully reconfigurable RFFE designed on an advanced CMOS platform based on 25 years of RF expertise. The final piece of the complete system – introduced in February 2014 – is an LTE-class, CMOS PA that exceeds the performance levels of GaAs-based alternatives, delivering reconfigurability and performance that make possible a single, global SKU accommodating all 40+ LTE bands and more than 5,000 RF states. The resulting system provides greater flexibility and choice to help RF engineers meet the next wave of global, mobile-device innovation.

COMMERCIALIZATION OF GaN

Doug Carlson
MACOM, Lowell, MA

The performance advantages that are achievable with GaN technology are well known to all involved with the RF and microwave industry today. GaN delivers as much as eight times the raw power density of incumbent GaAs and LDMOS technologies at high efficiency, with the ability to scale the device technology to high frequency. GaN technology has allowed device designers to achieve broad bandwidths while maintaining high efficiency. It has also shown to perform well in high power switching and LNA applications.

GaN technology development has been driven primarily by government funding and R&D. GaN on Silicon Carbide (SiC) is being successfully applied in the military domain today for applications including broadband electronic warfare jammers and radar systems, while GaN on Silicon (Si) has been successfully deployed in military communications. This activity has opened the door for GaN's penetration into commercial markets including CATV, cellular infrastructure and other applications, and we are seeing the initial penetration of GaN into these markets now.

In order to accommodate the unique price/performance requirements of these diverse commercial applications, GaN will remain segmented into two distinct varieties: GaN on SiC for specialized high performance applications, and GaN on Si for cost-sensitive volume applications. MACOM is positioned to evaluate these two varieties of GaN as they market a broad portfolio of pulsed and CW products based on both SiC and Si substrates. At the device level, the performance of GaN/Si and GaN/SiC are essentially identical (see ***Table 1***).

GaN technology is reaching its potential – solving both the technical and cost challenges is critical to its mainstream commercial adoption. On the technical front, MACOM has recently demonstrated device performance, targeting significant commercial applications (see ***Figure 9*** as an example), that demonstrate that GaN on Si is a leading candidate as the next generation RF power technology to counter today's incumbent silicon based solutions. GaN on Si has achieved the output power, efficiency, gain, bandwidth and operating voltages that, when coupled with a silicon based manufacturing roadmap and associated cost structure, demonstrate why GaN is revolutionizing the RF industry.

In addition to offering compelling performance, GaN on Si has proven device reliability. At both 28 and 48 V bias, MACOM's GaN on Si HEMT processes demonstrate excellent reliability as demonstrated with three tempera-

TABLE I

COMPARISON OF GaN/SI VERSUS GaN/SiC PERFORMANCE

0.5 µm gate length at 2 GHz	GaN on Si	GaN on SiC
Power Density (W/mm)	7	7
Gain (dB)	17.5	15
Efficiency (%)	> 70	> 65

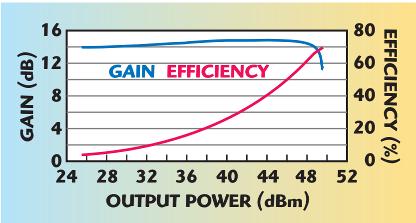


Fig. 9 GaN on Si performance example, 100 W device at 2.7 GHz, 48 V V_{ds}.

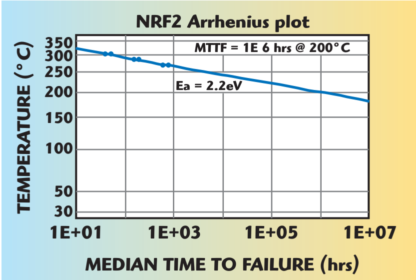


Fig. 10 Results of GaN on Silicon Three Temperature Operating Life Test.

ture accelerated life testing. The life test results, using a 20 percent change in IDSS as the criteria of failure, result in an MTTF of 1×10^6 hours at 200°C junction temperature with an activation energy of 2.2 eV (see ***Figure 10***).

Scratching The Surface

Today, we are only at the very beginning of GaN market penetration and adoption. GaN revenue for 2013 was $188.6 M according to ABI Research (Gallium Nitride RF Power Devices (MD-GAN-106), Sept. 24, 2013), suggesting that GaN technology today has penetrated less than 2 percent of the approximate $9.5 B overall analog semiconductor market. Given the hype around GaN, this narrow market penetration may come as a surprise, especially when one measures GaN's potential impact beyond the RF and microwave market. It has been said that there is not a single analog function that will not be made better with GaN. If GaN's cost structure comes into alignment with incumbent technologies, its disruptive effect on the analog domain could be massive.

There are several critical requirements that must be met in order to propel GaN to mainstream market adoption, many of which are driven by cost, and others that pertain to how vendors approach customers/system designers with this nascent technology. Among the practical considerations to be mindful of is that any new technology must solve a technical problem that current technologies cannot. In this sense, new technologies like GaN do not replace older technologies, but rather augment capabilities and expand performance to allow the next wave of innovation. System designers and GaN vendors alike need to understand where GaN fits in the toolbox.

Another important consideration is applications support. System designers, in general, are not experts in semiconductor technologies and capabilities, nor are they expected to be. This means that vendors need to come to the table with more than just product specs, but also the appropriate system and application-level knowledge needed to help the designer build a better product which fully captures the advantages of GaN.

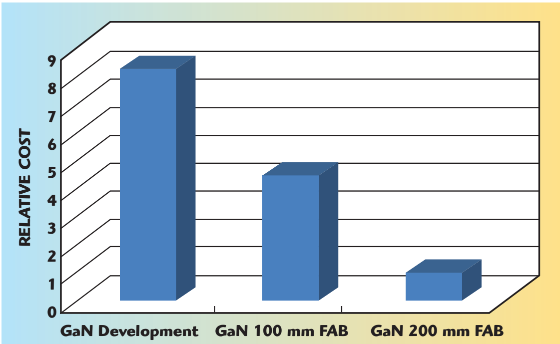
These challenges can be readily overcome with the right combination of designer and vendor savvy. The really major hurdle standing in the way of mainstream GaN adoption and commercialization today is the supply chain.

Efficiencies Throughout The Chain

The supply chain for GaN will be defined along separate paths for GaN on SiC and GaN on Si, which cater to distinctly different target applications with different price/performance requirements. Not surprisingly, their respective supply chains look very different as well. As the RF and microwave industry's only provider of both GaN on SiC and GaN on Si devices, MACOM has good perspective on each.

GaN on SiC offers superior thermal properties compared to GaN on Si and is therefore ideally suited for applications with high power density (W/mm^2) requirements. Vendors of GaN on SiC-based devices have demonstrated considerable success in their early efforts – particularly in the electronic warfare domain – and GaN on SiC will remain the specialized GaN flavor of choice for power density driven applications. But the high attendant costs of producing SiC ensure that this market will be serviced by a select group of high mix, low volume fabs.

By comparison, the silicon industry today does 2000 times the volume of the SiC industry, which is driving enormous industrial manufacturing scale. Because Si grows at 200 times (or more) faster rate than SiC, the energy required for manufacturing is much lower and the capital equipment utilization is much higher. This ultimately yields a fundamentally lower cost structure than what's possible with GaN on SiC. And whereas carbide is a relatively new material with a correspondingly short history of use in industrial scale applications, silicon has benefited from



▲ *Fig. 11 Cost comparison to produce GaN devices.*

more than 60 years of industrialization and development and is arguably the most technically engineered material on the face of the earth. So the supply chain for GaN on Si has a host of natural cost efficiencies aligned in its favor.

With regard to the GaN epitaxy, cost is directly proportional to the thickness of the epi put on the substrate. For both Si-based and SiC-based devices, the epi thickness is essentially the same so the associated epi cost is approximately equal.

Process Discipline

GaN on SiC has been produced mainly by relatively low volume 3" and 100 mm compound semiconductor fabs. The main volume application to date for compound semiconductors has been cellular handsets, which today is under attack from CMOS due to the attendant cost efficiencies previously discussed. SiC-based GaN has no clear viable roadmap to large diameter, high volume production facilities that can drive cost for consumer markets.

The use of silicon on the other hand allows vendors to move to larger diameter fabs with typical volumes greater than 5,000 8-inch wafer starts per week. Here CMOS process control typically enables line yields that are above 98 percent. Because of the extreme high volume of the end markets that CMOS is addressing, balancing yield and cost dynamics is critical, and this drives a level of operational discipline that is not available in the III-V industry.

At full maturity, the GaN on Si cost structure in mainstream silicon fabs could be reduced significantly from today's GaN on SiC structure. As shown in ***Figure 11***, scaling GaN from small diameter GaN development fabs to 200 mm silicon fabs achieves an almost 10 times reduction in cost. This cost advantage is further multiplied by the very high volume of a CMOS facility and could reach a 100 times reduction in total cost in the future.

To achieve significant GaN volumes at 8 inch, RF demand will be augmented with GaN on Si production that will be driven by the DC power market. This market may be as much as 10 times larger than the RF and microwave market. With upwards of 95 percent of GaN unit volume going forward tied to GaN on Si, both the DC power and RF domains will likely be serviced by the same 8 inch silicon fabs.

To fully realize the commercial promise of GaN, there must also be surety of supply to promote stability and resiliency – to say nothing of economic efficiency – across the GaN supply chain. Dual-source support is a key requirement for high volume, risk adverse applications.

Advanced Packaging

GaN supply chain optimization will be driven in parallel by process efficiencies and customer demand, the alignment of which will ultimately yield significant cost reductions for all involved. Manufacturing efficiency gains drive reduced production and product costs, which drive volume demand, and so on. But system designers in the RF and microwave domain are of course no strangers to these dynamics, having already seen this evolution in previous technology deployments.

A plurality of packaging options, that support end market applications, is the next critical performance and cost factor which must be considered

for a complete product solution. Developments have led to the adoption of organic packaging technologies into RF, microwave and millimeter wave applications, extending the functionality and frequency of performance of plastic packaged parts. Recently, MACOM has focused on the introduction of surface mount plastic packaging for high power devices. Plastic packaged high power GaN enables designers to adopt conventional surface mount manufacturing approaches that lead to system size and weight reductions. In this way, the adoption of GaN in plastic facilitates system manufacturing cost reduction together with test efficiencies associated with high volume plastic packaging. The arrival of GaN in plastic devices has given system designers newfound flexibility to reach power levels up to 90 W without the size or weight penalties typically associated with packaged transistors (see ***Figure 12***).

GaN on Ceramic remains the packaging option of choice for devices that must be hermetically sealed in order to ensure reliable operation in environmentally challenging conditions. Ceramic-packaged GaN devices are also capable of managing much greater power output levels than plastic-packaged alternatives available today.

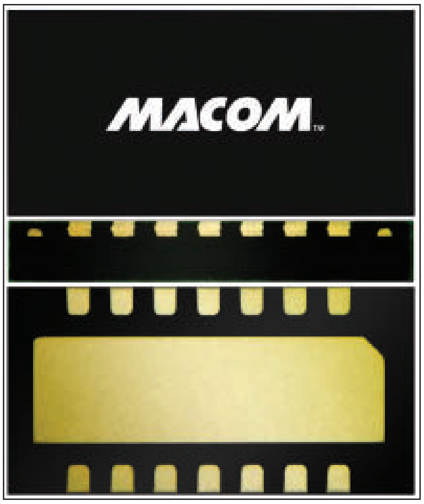


Fig. 12 Typical plastic DFN package (3 × 6 mm) used for GaN devices.

When measuring the value/useful applicability of ceramic- versus plastic-packaged GaN transistors, the target lifecycle for the end system is often the deciding factor. Military radar system designers have higher expectations for environmental ruggedness than designers of many consumer products. Ceramic-based GaN devices are ideally suited for systems that are expected to deliver extremely high reliability for long periods of time with minimal maintenance, and are often less sensitive to cost pressures than commercial-caliber systems.

Conclusion

GaN on SiC is well suited for high performance RF applications but GaN on Si is well suited to most commercial and some military applications that are cost sensitive and where the performance of GaN on Si meets its needs. As GaN on Si scales up and uses larger diameter Si fabs, it will have a cost structure low enough to broadly replace many incumbent technologies in a wide range of applications. Just as one can leverage high volume silicon fabs to achieve low cost structures for compound semiconductors, one can leverage packaging and production efficiencies – also enabled by silicon – to help achieve the mainstream commercialization of GaN technology. ■

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DefenseNews
Cliff Drubin, Associate Technical Editor

Distributed Targeting System will Significantly Enhance Flight Crew Situational Awareness

Harris Corp. has received a two-year, $19 million full-rate production contract to provide key avionics components that will enhance flight crews' targeting capabilities on the U.S. Navy's F/A-18 E/F Super Hornet fighter aircraft.

The Distributed Targeting System will significantly improve the aircraft's networking capabilities, enhance targeting precision and shorten the time period from target sensing to shooting.

"Start of full-rate production is a key milestone in the F/A-18 E/F Network Centric Warfare Upgrades program," said Ed Zoiss, vice president and general manager, Defense Programs, Harris Government Communications Systems. "Upgrading the mission- and image-processing prowess of the Super Hornet will help ensure that it continues to be the primary fighter aircraft for the U.S. Navy."

"Upgrading the mission- and image-processing prowess of the Super Hornet will help ensure that it continues to be the primary fighter aircraft for the U.S. Navy."

"The Super Hornet brings critical capability to naval aviation and our national security, and is vital to the U.S. economy," said Mike Gibbons, F/A-18 program vice president, Boeing. "Harris is a key supplier of advanced avionics for these aircraft."

The combat-proven Super Hornet provides unequaled air dominance and precision strike capability. The EA-18G Growler, derived from the Super Hornet, is the United States' newest and most advanced airborne electronic attack platform. The Super Hornet and Growler programs support 60,000 jobs in the U.S., with 800 suppliers in 44 states and account for $3 billion in annual economic impact.

Source: U.S. Navy.

Anti-IED Jammers-in-a-Backpack

VIEW VIDEO

The U.S. Marine Corps has selected Northrop Grumman Corp. to provide electronic jamming backpack systems to counter the threat of roadside improvised explosive devices (IED).

Under the Counter Radio-controlled IED Electronic Warfare Marine Expeditionary Unit Special Operation Capable, or CREW MEU (SOC), contract, Northrop Grumman will deliver and support five initial production systems for testing.

The maximum ceiling for the firm-fixed-price, indefinite delivery, indefinite quantity (IDIQ), multiple award contract is $90 million over five years. The initial contract awarded to Northrop Grumman by Program Manager, Ships (PMS) – 408 via the Marine Corps Systems Command, Quantico, Va., was $4.1 million for five initial CREW MEU (SOC) systems. The Navy will purchase an indefinite number of systems in accordance with an IDIQ award.

Northrop Grumman is offering its Freedom 240 for CREW MEU (SOC) that provides precision electronic jamming of a wide range of IEDs and is designed to create a protective barrier around a Marine ground combat team and their equipment while minimizing disruption to friendly communications systems.

"The Freedom 240 is designed to defeat complex clusters of current, emerging and future IED threats..."

The Freedom 240 dismounted system is part of the Joint CREW Increment 1 Build 1 (I1B1) family of precision multifunctional electronic warfare systems that protect warfighters, vehicles, watercraft and permanent structures from IEDs. The CREW MEU (SOC) and JCREW I1B1 programs are managed by the U.S. Naval Sea Systems Command (NAVSEA).

"Our troops face the IED threat around the world, and these Marine Expeditionary Units are the ones that go to the most dangerous places at a moment's notice. Northrop Grumman's Freedom 240 dismounted system is lightweight, powerful and designed to keep up with these hard-fighting Marines," said Mike Twyman, sector vice president and general manager, Defense Systems division, Northrop Grumman Information Systems.

"The Freedom 240 is designed to defeat complex clusters of current, emerging and future IED threats. It's also capable of worldwide deployment with only software changes. Because the system features a fully open architecture common across all the JCREW I1B1 variants, the Marine Corps can take advantage of technologies developed by third parties and benefit from the system's flexibility, extensibility, ease of upgrades and reduced lifecycle cost," said Jeannie Hilger, vice president, Network Communication Systems business, Northrop Grumman Information Systems. "This award perpetuates the Northrop Grumman Freedom product line, providing the Marine Corps with a software-defined system that supports CREW and enabling future multifunction radio frequency capabilities."

For More Information — Go to mwjournal.com for more defense news items

Flexible, Reconfigurable, Multi-Mission Aperture to Revolutionize Radars

The Office of Naval Research (ONR) has awarded Raytheon Co. an $8.5 million base contract to design the Flexible Distributed Array Radar (FlexDAR), enabling dynamic multi-mission radars capable of executing a variety of functions including surveillance, communications and electronic warfare.

"Raytheon is a pioneer in radar development, pushing the limits of technology to achieve the best possible solutions for our customers," said Paul Ferraro, vice president of Raytheon Integrated Defense Systems Advanced Technology Programs. "Migrating digital technologies closer to the front end of radars will allow for more re-configurability and ultimately more flexible radars resulting in game-changing improvements."

The FlexDAR effort is being developed under the ONR Integrated Topside (InTop) Program as an innovation effort to demonstrate new capabilities provided by the implementation of every-radar-element-level digital beamforming, combined with network coordination and precise time synchronization.

FlexDAR will develop technology that will lead to enhanced capability for future radar sensors including software-defined digital re-configurability at the foundational level. The program demonstrates both radar and radar-to-radar communications functions so as to implement bi-static exchange and control. This provides increased detection and firm-track range, and improved electronic protection relative to existing standalone mono-static radars.

Source: U.S. Navy.

This first phase of the InTop FlexDAR program will design the radar front end and will demonstrate all critical components and subassemblies. In the subsequent phase, Raytheon will build two identical multi-function array antennas that will be installed at ONR's Chesapeake Bay Detachment to demonstrate several important advantages of network-linked, distributed sensors and serve as foundations to test and explore next-generation radar capabilities.

Operators to Deploy LTE Networks in 150 Countries

Firm commitments to deploy LTE networks have been made in 150 countries by 497 network operators, according to findings from research by the Global mobile Suppliers Association (GSA) and published in its latest Evolution to LTE Report.

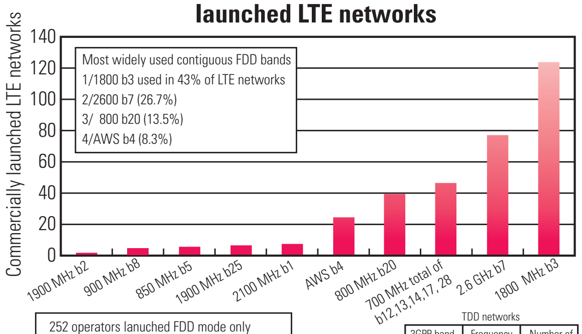
288 LTE networks have now commercially launched in 104 countries. The majority of LTE operators have deployed the FDD mode of the standard. The most widely used spectrum in network deployments continues to be 1800 MHz (3GPP band 3) which is used in 43 percent of deployments. 124 LTE operators have commercially launched with 1800 MHz spectrum in 64 countries, either as a single band system, or as part of a multi-band deployment.

The next most popular contiguous bands are 2.6 GHz (band 7) used in 26.7 percent of networks in commercial service today, followed by 800 MHz (band 20) used in 13.5 percent of networks, and AWS (band 4) used in 8.3 percent of networks. GSA estimates there were 240 million LTE subscribers worldwide at the end of Q1 2014.

Alan Hadden, president of GSA, said: "108 LTE networks have been launched in the past year, coverage is rapidly expanding, and LTE subscriptions growth is impressive. More operators are preparing to introduce voice service for their LTE customers with VoLTE, and investments in LTE-Advanced carrier aggregation technology is now the main trend."

36 LTE TDD networks are commercially launched in 24 countries, including three networks in China. 23 operators launched LTE service using only the TDD mode, while 13 operators deployed both TDD and FDD modes in their networks. 252 operators have commercially launched using FDD mode only.

Spectrum used currently in commercially launched LTE networks



252 operators lanuched FDD mode only
23 operators launched TDD mode only
13 operators launched FDD & TDD modes
—
288 commercially launched LTE neworks

TDD networks

3GPP band	Frequency	Number of networks
40	2.3 GHz	16
38	2.6 GHz	10
41	2.6 GHz	7
42	3.5 GHz	4
39	1.9 GHz	1

Note: Some LTE TDD network deployments use more than one band

Source: GSA, www.gsacom.com

Thales Alenia Space Creates New British Subsidiary

Thales Alenia Space is further expanding its presence in Europe with the creation of a new British subsidiary, Thales Alenia Space UK. Based at the Harwell Science and Innovation Campus (HISC) in Oxfordshire, Thales Alenia Space UK is an integral part of the company's strategy to bolster its presence in key countries that invest heavily in the space sector.

It follows the opening of Thales Alenia Space subsidiary in Germany in 2011 and the extension of the presence of Thales Alenia Space in Belgium by the creation of an office in Leuven.

The decision to locate a new subsidiary in the UK was spurred by the UK Government's commitment to fund space activities and create new initiatives to foster growth in the space industry – including the formation of the UK Space Agency, an increased contribution to the European Space Agency (ESA), the investment in the UK Space Gateway at Harwell, and more recently securing a significant share of the Neosat program for the UK.

> **"...the space industry is moving very fast ..."**

Martin Gee, CEO of Thales Alenia Space UK said "Globally, the space industry is moving very fast, and there is exponential growth in demand for space-based communications, navigation and observation. Thales Alenia Space's decision to come to the UK is a direct result of the UK Government's work to create a space-friendly R&T environment, new access to funding and an effective business support network."

Thales Alenia Space President and CEO Jean Loïc Galle emphasized that, "Through this new subsidiary, Thales Alenia Space UK will support the UK Space Agency in meeting their ambitious goals, and play a key role in the development of new skilled jobs in the most advanced space technologies. This approach is a natural fit with the company's strategic plan of enhanced growth for the coming years."

ITU Releases 2014 ICT Figures

New figures released by the International Telecommunication Union (ITU) indicate that, by end 2014, there will be almost 3 billion Internet users, two-thirds of them coming from the developing world, and that the number of mobile-broadband subscriptions will reach 2.3 billion globally. 55 percent of these subscriptions are expected to be in the developing world.

"The newly released ICT figures confirm once again that information and communication technologies continue to

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"...information and communication technologies continue to be the key drivers ..."

be the key drivers of the information society," said ITU Secretary-General Hamadoun I. Touré.

Mobile-cellular subscriptions will reach almost 7 billion by end 2014, and 3.6 billion of these will be in the Asia-Pacific region. The increase is mostly due to growth in the developing world where mobile-cellular subscriptions will account for 78 percent of the world's total.

Africa and Asia and the Pacific, where penetration will reach 69 percent and 89 percent, respectively by end 2014, are the regions with the strongest mobile-cellular growth (and the lowest penetration rates). Penetration rates in the Commonwealth of Independent States (CIS), Arab States, the Americas and Europe have reached levels above 100 percent and are expected to grow at less than two percent in 2014. The region with the highest mobile-cellular penetration rate is the CIS.

DOCOMO to Conduct 5G Experimental Trials

VIEW VIDEO

NTT DOCOMO Inc. will conduct experimental trials of emerging 5G mobile communications technologies with six world-leading mobile technology vendors: Alcatel-Lucent, Ericsson, Fujitsu, NEC, Nokia and Samsung.

"5G studies are starting to gain real momentum..."

The parallel collaborations between DOCOMO and each of the six vendors will involve experimental trials to confirm the potential of 5G mobile technologies to exploit frequency bands above 6 GHz and realize very high system capacity per unit area, and new radio technologies to support diverse types of applications including machine-to-machine (M2M) services. DOCOMO also expects to collaborate with other companies in its effort to test a wide range of 5G mobile technologies.

"5G studies are starting to gain real momentum as we point toward 2020," said Seizo Onoe, executive vice president and chief technical officer at DOCOMO. "I am delighted that we will collaborate on 5G experimental trials with multiple global vendors from this early stage."

DOCOMO will begin indoor trials at the DOCOMO R&D Centre in Yokosuka, Kanagawa Prefecture this year, to be followed by outdoor field trials planned for next year. Key findings and achievements will be shared with research institutes and at international conferences to contribute to 5G standardization, which is expected to start from 2016. Key findings also will be utilized for research aimed at incubating future advanced technologies.

Emerging Markets, Indoor Location and Advertising to Boost Mobile Location-based Services Market

VIEW VIDEO

Falling barriers to the adoption of location-based services (LBS) in emerging markets, combined with momentum behind indoor LBS and mobile advertising, are set to fuel future growth in mobile LBS according to Strategy Analytics' Wireless Media Strategies (WMS) report "Emerging Markets, Indoor Location & Mobile Advertising to Drive Future Mobile LBS Market Growth."

Falling price points for GPS enabled handsets coupled with rising mobile data adoption will boost LBS adoption and use. Furthermore, increasing activity around indoor maps and accurate indoor positioning technology via low-energy Bluetooth beacon technology and WiFi will enable the rise of indoor LBS, including proximity marketing on mobile devices.

The adoption of mobile location based services such as maps and in-car navigation has been widespread in countries with both high smartphone and data plan adoption, and will spread to countries like India and China, where smartphone ownership and data plan adoption is rising fast. Nitesh Patel, director of wireless media strategies at Strategy Analytics, noted "In addition to the continued adoption of mobile LBS in rising mobile data markets, venue owners and brands are increasingly testing the capabilities of mobile devices to deliver enhanced customer experiences and engagement. We see the increasing activity around indoor location and mobile marketing by brands, retailers and owners of complex venues as a clear signal that indoor LBS and location-enhanced marketing will drive the next wave of growth in the mobile LBS sector."

> "...increasing activity around indoor location and mobile marketing are a clear signal that indoor LBS and location-enhanced marketing will drive the next wave of growth in the mobile LBS sector."

David MacQueen, director of media and apps at Strategy Analytics, says "HERE is the overall leader in terms of its mapping and location capabilities, followed by Google, TomTom and then Apple. HERE's opportunity for growth have improved significantly with its horizontal strategy, following the sale of Nokia's devices and service unit to Microsoft. However, Google is the leader in business – to-consumer (B2C) LBS applications, as it benefits from preloading on most Android handsets, and is the most widely used map, navigation and local search app. Apple remains in catch-up mode, although its high smartphone market share and acquisitions to enhance its LBS capabilities, such as Locationary, WiFiSlam, Embark and BroadMap, keep it a major player."

Wi-Fi Chipset Shipments will Near 18 Billion During the Next Five Years

With over 2.6 billion chipsets expected to ship during 2014, Wi-Fi is currently the most ubiquitous wireless connectivity technology for Internet access. As the technology continues to adapt and expand with new protocols such as 802.11ac, 802.11ax, 802.11ad (WiGig) and Wi-Fi Direct, nearly 18 billion more chips will ship cumulatively from 2015 to 2019. "There will be a roughly even split in 2019 for Wi-Fi chipsets of different integration levels," said research director Philip Solis of ABI Research. "Standalone, or discrete, Wi-Fi chipsets – increasingly targeting the Internet of Things – will be the largest group, followed by integrated platforms with Wi-Fi targeting mobile devices, followed by Wi-Fi combo chipsets."

Wi-Fi protocols will continue evolving as well. By the end of the forecast period, dual-band 802.11n/802.11ac will comprise the vast majority of chipsets shipped among all the protocols. Dual-band 802.11n/802.11ac had a strong start in 2013 by surpassing 100 million shipments in the smartphone space alone, which accounted for a sizable fraction of the total shipped that year. There will be a strong ramp of tri-band 802.11n/802.11ac/802.11ad during the next five years as well.

Wi-Fi Direct-enabled products will surpass three billion shipped in 2019 with the highest attach rates in ultraportable PCs media tablets, and traditional laptops. However, the largest category of Wi-Fi Direct-enabled products in terms of units shipped in 2019 will be smartphones.

"Even as the industry starts to move this year from 802.11ac Wave 1 to Wave 2 chipsets that can support larger channels and MU-MIMO, Wi-Fi's evolution will not stop there. Aside from this shift and pairing Wi-Fi with WiGig (802.11ad), 802.11ax will start replacing 802.11ac towards the end of the forecast period," added Solis. "802.11ax will further maximize efficient use of 5 GHz spectrum by utilizing unused chunks of spectrum, even coordinating this with other nearby access points. Essentially, 802.11ax will be a better version of 802.11ac Wave 2 that will allow for even greater data rates. The proliferation of Wi-Fi in the home will be supported by the technology's continued evolution."

> "Standalone, or discrete, Wi-Fi chipsets – increasingly targeting the Internet of Things – will be the largest group followed by integrated platforms with Wi-Fi targeting mobile devices..."

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The Microwave Tube Market is Still Strong at Over $1B for 2014, but Changes are on the Horizon

While microwave and millimeter wave high power vacuum electron devices (VED) remain "below the radar" of many industry observers, the total available market (TAM) for this segment is over $1 billion.

Despite its size, and although these tubes remain essential elements in specialized military, scientific/medical and space communications applications, this market is generally under-reported and poorly understood by those not directly involved in it.

Essentially, this is now a stable industry after several rounds of consolidation in recent years. ABI Research Director Lance Wilson says, "There is potential for some further consolidation, but there are no signs of that happening yet. However one new RF semiconductor technology – gallium nitride – will change the landscape but has not yet done so to any large scale. While it is not yet near monopolizing the RF/microwave power industry, GaN is advancing steadily and is a technology that should be closely watched, as it will be a threat to some aspects of the microwave and millimeter wave VED marketplace."

Wilson continues, "The size of this historic market continues to surprise everyone and its longevity and firm resistance to RF power semiconductor encroachment is as surprising; however, that will be changing as GaN devices move up in frequency and power."

"These specialized vacuum electron devices may at first seem anachronistic, but in some cases there is no other way to generate such high levels of RF power within an acceptably small space..."

"These specialized vacuum electron devices may at first seem anachronistic," he adds. "But in some cases there is no other way to generate such high levels of RF power within an acceptably small space. Certain microwave and millimeter wave VEDs can generate megawatts, and it would take tens of thousands of transistors to do that."

Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Agilent Technologies Inc. announced its acquisition of electrothermal analysis technology from **Gradient Design Automation**, the maker of HeatWave electrothermal analysis software. Agilent EEsof EDA now has sole ownership of Gradient's core technology and will serve customers of both the integrated Advanced Design System software solution and Gradient's HeatWave solution.

COLLABORATIONS

Skyworks Solutions Inc. announced the creation of a joint venture with **Panasonic Corp.**, electronic product manufacturer, to design, develop and deliver high performance filters including surface acoustic wave (SAW) and temperature compensated (TC) SAW devices. At the core of the joint venture is Panasonic Filter Division's engineering and process talent, expertise in filter design and leading edge products as well as 412 fundamental filter patents and patent applications.

Nokia Solutions and Networks and the **NYU WIRELESS Research Center** at the New York University Polytechnic School of Engineering jointly organized the first Brooklyn 5G Summit, held April 23-25 in Brooklyn, New York. The invitation-only event brought together wireless and mobile industry research and development leaders in academia, business and government to explore the future of 5G wireless technology, with special focus on antennas, propagation and channel modeling. This inaugural event is slated to be an annual forum to discuss trends and the next steps toward understanding and framing the world's 5G wireless technology.

Thales has appointed **Global Komited Sdn Bhd**, a wholly owned subsidiary of the Weststar Group of Companies, to develop, promote, market and distribute a wide range of Ground-Based Air Defence systems to the Malaysian Armed Forces. A signature ceremony, attended by The Malaysian Defence Minister, YB Datuk Seri Hishamuddin Tun Hussein, held during the first day of the Defence Services Asia Exhibition and Conference in Kuala Lumpur marked the appointment of Global Komited Sdn Bhd as a key industrial partner agent for Thales in the region.

Spectracom, a business of the Orolia Group, announced it has extended its global service capability through a partnership with **EZU Technologies**. Joining Spectracom service centers in North America and Europe, EZU Technologies will support Spectracom users throughout the Asia-Pacific region from their facility in Hong Kong. Initially services will include equipment calibration and repair services. Over time, more capability will be added to deliver Spectracom's full range of services in the region.

Two of Australia's pre-eminent information and communication technology research institutions – **CSIRO** and **NICTA** – have joined forces with the ng Connect Program, the multi-industry open innovation ecosystem founded by **Alcatel-Lucent** to create new ultra-broadband end user experiences. CSIRO, Australia's national science agency through its Digital Productivity and Services Flagship and NICTA, Australia's ICT Research Centre of Excellence, have announced their participation in ng Connect, the multi-industry open innovation ecosystem created to foster collaborative development of new service and business models.

NEW STARTS

Fujitsu Ltd., **Panasonic Corp.**, and Development Bank of Japan Inc. (DBJ) have signed a memorandum of understanding in which DBJ will make an investment and provide a line of credit for a new fabless company specializing in Large Scale Integration (LSI) design and development, which Fujitsu and Panasonic will jointly establish.

ACHIEVEMENTS

Raytheon Co. successfully completed a passive seeker test designed for a Toma-hawk Block IV cruise missile using company-funded independent research and development investment. The captive flight test, using a modified Tomahawk Block IV missile nose cone, demonstrated that Raytheon's advanced, next-generation; multi-function processor can enable the cruise missile to navigate to and track moving targets emitting radio frequency signals.

Micro Lambda Wireless Inc. has received ISO 9001:2008 certification for its Quality Management System. Achieving ISO 9001:2008 confirms that superior quality management practices are adhered to and a systematic approach to quality processes and testing is taken to ensure that products meet or exceed customer requirements through continuous process improvement.

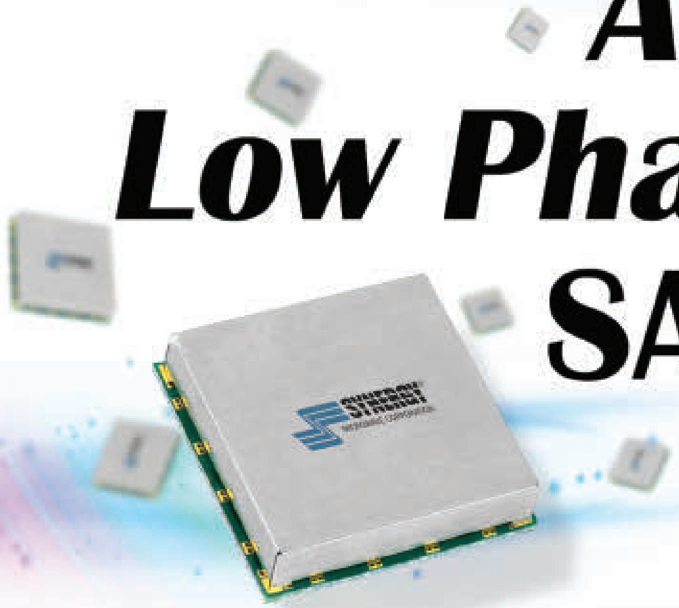
Norden Millimeter's Quality Management System has been certified to be in conformance with ISO 9001:2008 and AS9100:2009 Rev C. This confirms Norden's commitment to customer satisfaction by providing quality products that meet our customer's needs.

Passive electronic components built for RF and microwave applications - it is a narrow niche that's increasingly active in commercial, military and space applications. Television's Manufacturing Marvels has shed some light on this business sector, and on **Res-net Microwave**, one of the very successful microwave component manufacturers in this sector. The two-minute profile aired on the Fox Business Network on May 8^{th} between 9:30 and 9:45 PM Eastern Time.

For More Information

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

Amazingly Low Phase Noise SAW VCO's



Model	Frequency (MHz)	Tuning Voltage (VDC)	DC Bias VDC @ I [Max.]	Phase Noise @ 10 kHz (dBc/Hz) [Typ.]
HFSO640-5	640	0.5 - 12	+5 @ 35 mA	-151
HFSO745R84-5	745.84	0.5 - 12	+5 @ 35 mA	-147
HFSO776R82-5	776.82	0.5 - 12	+5 @ 35 mA	-146
HFSO800-5	800	0.5 - 12	+5 @ 30 mA	-146
HFSO914R8-5	914.8	0.5 - 12	+5 @ 35 mA	-139
HFSO1000-5	1000	0.5 - 12	+5 @ 35 mA	-141
HFSO1600-5	1600	0.5 - 12	+5 @ 100 mA	-137
HFSO2000-5	2000	0.5 - 12	+5 @ 100 mA	-137

SAW VCO Features

- Small Size 0.5" x 0.5"
- Very Low Post Thermal Drift

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Phone: (973) 881-8800 | Fax: (973) 881-8361
E-mail: sales@synergymwave.com
Web: WWW.SYNERGYMWAVE.COM
Mail: 201 McLean Boulevard, Paterson, NJ 07504

Around the **Circuit**

CONTRACTS

An international customer signed an agreement with the U.S. Government for a foreign military sale (FMS) of tube-launched, optically tracked, wireless-guided (TOW) missiles to be supplied by **Raytheon Co.** in a deal valued at approximately $750 million. Raytheon plans to deliver nearly 14,000 TOW missiles to the customer over a three-year period beginning in 2015.

Lockheed Martin received a $611 million contract from the ***U.S. Army Aviation and Missile Command*** for the first production order of the PAC-3 Missile Segment Enhancement (MSE) following the Army's successful Milestone C decision earlier this year. The contract includes the production of both PAC-3 MSE missiles and Launcher Modifications Kits (LMK).

The U.S. Navy has awarded **Harris Corp.** an eight-year contract valued at up to $133 million to provide shipboard terminals that give crews access to high-bandwidth voice and data communications. Under the agreement, Harris will provide up to 120 terminals in addition to the 70 terminals already delivered since 2008 under the indefinite delivery/indefinite quantity Commercial Broadband Satellite Program (CBSP) Unit Level Variant (ULV) contract.

Exelis has received a contract valued at more than $91 million from the U.S. Navy to begin full rate production on Lot 11 of the ALQ-214 electronic self-protection system for F/A-18C/D Hornet and F/A-18E/F Super Hornet fighter aircraft. The Exelis ALQ-214(V)4/5 is a cutting-edge jamming subsystem at the heart of the Integrated Defensive Electronic Countermeasures (IDECM) suite. IDECM is used by the U.S. Navy to protect carrier-based F/A-18s and their aircrews from sophisticated radio frequency threats, such as hostile radar and air defense systems. The jamming technology enables operations in contested environments to address anti-access/area denial challenges.

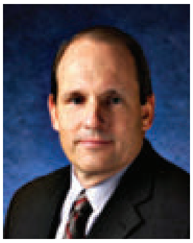
A top four U.S. wireless carrier customer has placed a $4 million dollar follow-on order with **Ceragon Networks Ltd.** to continue its network modernization rollout. The planned deployments will include hundreds of wireless backhaul links throughout the U.S. Ceragon has been a supplier to this tier 1 U.S. carrier since 2010 and the follow-on order will bring the company's installed base within the carrier to over 2,000 high-capacity microwave links.

Mercury Systems Inc. announced it received a $3.2 million follow-on order from a leading defense prime contractor for high-performance digital signal processing modules for an unmanned airborne synthetic aperture radar (SAR) application. In related news, Mercury Systems Inc. celebrated the grand opening of its new Advanced Microelectronics Center (AMC) in Hudson, New Hampshire. New Hampshire Governor Maggie Hassan and representatives from the offices of United States Senators Kelly Ayotte (R) and Jeanne Shaheen (D) attended the ribbon cutting ceremony hosted by Mercury President and CEO Mark Aslett, along with other senior Mercury executives.

API Technologies Corp., a leading provider of high performance RF/microwave, power and security solutions for critical and high-reliability applications, announced the receipt of a new $1.6 million award to provide microwave filters and switched filters to a leading global defense company. These high reliability filters will be used in a major airborne electronic warfare (EW) platform.

Chemring Technology Solutions' Gioconda industry consortium has been awarded an extension to an existing contract to support the UK Ministry of Defence's (MoD) Defence Science and Technology Laboratory's (Dstl) nano-satellites research project. The work under the extension follows on from the consortium's initial contract, which delivered a major element of Dstl's CubeSat research project.

PEOPLE



▲ *Pete Alexander*

Anritsu announced the appointment of **Pete Alexander**, PhD as vice president and general manager of Anritsu Co., the United States subsidiary of Anritsu Corp. Alexander, who has 25 years of experience in the test and measurement industry, will be responsible for all sales, marketing and field support operations for Anritsu's wireless, optical, RF/microwave, and digital test solutions in North America and Latin America.

▲ *Duncan Pilgrim*

Peregrine Semiconductor Corp., founder of RF silicon on insulator (SOI) and pioneer of advanced RF solutions, announced **Duncan Pilgrim** has been promoted to vice president of marketing. Pilgrim will drive all the product marketing and marketing communication initiatives.

Aeris Communications announced the addition of **Michelle Avary** as the vice president, business development-automotive. Avary brings more than 15 years of experience to the role, serving most recently as the director, technology strategy for Harman International. Previously, she worked for Toyota for more than a decade where she led and developed strategies for its telematics products and services.

Intel Corporations' Intel Labs vice president and director of integrated computing research (ICR) **Vida Ilderem** served as plenary session speaker on Monday, June 2, 2014 at the **IEEE MTT-S 2014 International Microwave Symposium (IMS)**, marking the first female plenary speaker in the history of IMS.

Around the **Circuit**

▲ *Linda Katehi*

UC, Davis Chancellor, **Linda Katehi** gave the Keynote address to the WAMICON 2014 audience on June 6, 2014 in Tampa, FL. **WAMICON 2014** is co-located with IEEE MTT-S IMS and ARFTG at the Marriott Waterside Hotel and Marina.

Indium Corp. technology experts served as session chair and gave a poster presentation at **IMAPS New England** May 6 in Boxborough, Mass. Derrick Herron, technical support engineer, gave a poster presentation called Methods of Choosing a Solder Paste and Overcoming Common Challenges. His presentation discussed what to consider when choosing a solder paste and how to prevent some of the common defects that may arise during manufacturing, such as head-in-pillow, graping and QFN voiding.

REP APPOINTMENTS

RFMW Ltd. and **Aviacomm Inc.** announced a distribution agreement effective April 1, 2014. The agreement initially covers customers in North America, Europe and South East Asia with the possibility of future expansion. Aviacomm is a leader in wideband RF CMOS ICs.

ECM announced a new authorized distribution agreement with **MECA Electronics Inc.** to supply the manufacturer's line of USA made rugged & reliable RF/microwave passive DC – 20 GHz microwave components and solutions globally.

PLACES

Rohde & Schwarz has inaugurated its new "Das Spektrum" building in the Changi Business Park in Singapore. The SGD 58 million investment (around EUR 33 million) underscores the location's strategic significance for the German electronics company. This Rohde & Schwarz global hub is a platform for research, development, production, global sourcing and supply chain management in areas of test and measurement, broadcasting, secure communications, and radiomonitoring and radiolocation, while helping to skill up Singapore as a talent pipeline for high technology engineering careers.

NEC Corp. announced that its subsidiary **NEC Saudi Arabia** has opened a new office in Dubai in response to increased demand for reliable ICT social infrastructure. The new regional branch has begun operation and will strengthen NEC's presence in Gulf Cooperation Council (GCC) countries. Dubai plays an important role as a commercial hub for GCC member countries, which include Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and United Arab Emirates, and is attracting the attention of businesses around the world.

Anokiwave Inc. announced the opening of its newest design center, located in Billerica, MA to support the company's increasing demand for highly integrated SiGe core chips and GaAs/GaN front end solutions. The 12,000 square foot site will support integrated designs and layouts, RF-laboratory work, and customer support through early manufacturing.

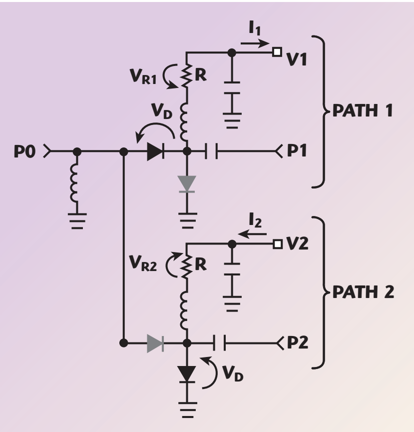
MWJ REVIEW BOARD APPROVED

PIN-Diode SPMT Switch with Single-Supply, TTL-Compatible Driver

Giovanni Bianchi, *Advantest Europe GmbH, Boeblingen, Germany*
Fabrizio Gentili and Roberto Sorrentino, *University of Perugia, Perugia, Italy*
Laura Urbani and Luca Pelliccia, *RF Microtech SRL, Perugia, Italy*

A PIN-diode-based single-pole multi-throw (SPMT) switch with a low power driver for applications where only a single source is available eliminates the need for DC-DC converters and the current required to power them. Further current savings are obtained by powering the enabled branch of an SPMT switch with the currents flowing on the disabled ones. In the example reported, CMOS ports are used to bias an SP4T switch and simultaneously realize a decoding network for the input commands, which are TTL compatible. RF measurements show good performance compared with those obtained with a bipolar supply voltage.

SPMT RF switches are widely employed in switching systems, multiband selectors and filter banks.[1-3] For a PIN-diode-based SPST switch, the typical configuration of the RF port is a series diode where signal flows in the low attenuation state and a shunt diode that directs the signal to ground in the high attenuation state. Compared to an SPST switch, the SPMT switch must also present a high impedance to the input RF port in order to minimize disturbances on the output caused by the non-activated branches. The currents required to enable one branch while simultaneously disabling the other ones always have opposite signs. This requires a bipolar voltage to properly drive an SPMT switch.



▲ *Fig. 1 Biasing network of an SP2T switch controlled with bipolar voltages.*

For applications where only a single supply voltage is available, a bipolar voltage can be achieved through the use of a DC-DC converter. This device requires current for its operation in addition to that required to drive the switch. To eliminate the need for a DC-DC converter, an alternative means has been developed to drive an SPMT switch with a single voltage. Since an external user is normally interested in changing an SPMT switch state by using a digital signal without concern for the required internal voltages, a TTL-compatible decoding network based on CMOS components is incorporated as well. The approach is applied to a commercial SP4T switch. RF measurements are compared with those of the same device driven by bipolar voltages, demonstrating comparable performance.

CONCEPT

The typical configuration of an SP2T switch is shown in ***Figure 1***. V_1 and V_2 are the voltages that are applied to each on and off path, respectively. Along with the value of the resistance R, they determine the current that flows through a branch. For example, a current of I_{ON} = 20 mA may be selected for the branch in the low attenuation state and I_{OFF} = 20 mA

may also be selected for the branch in the high attenuation state.

If a commercially available resistance of R = 270 Ω is fixed, the required driving voltages V_{ON} and V_{OFF} can then be found. With reference to Figure 1, suppose that one path is operative ($V_1 = V_{ON}$ and $I_1 = I_{ON}$) and the second one is off ($V_2 = V_{OFF}$ and $I_2 = I_{OFF}$). Then:

$$V_{ON} = -\left(RI_{ON} + V_D\right) = \quad (1)$$

$$-\left(270 \times 20 \times 10^{-3} + 0.7\right) = -6.1 \text{ Volts}$$

$$V_{OFF} = RI_{OFF} + V_D = \quad (2)$$

$$270 \times 20 \times 10^{-3} + 0.7 = 6.1 \text{ Volts}$$

where the voltage across the diode (V_D) is considered to be equal to 0.7 V. This result shows that the control of the switch can be realized by two voltages of opposite sign with a total current of 40 mA.

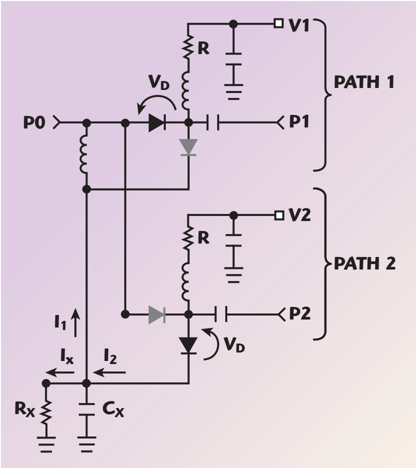
A way to obtain the same working conditions (I_{ON} = 20 mA and I_{OFF} = 20 mA) with a single voltage is by modifying the circuit as shown in ***Figure 2***. In this circuit a resistor (R_X) is inserted between all diodes and the reference ground. To maintain proper device operation, however, the reference voltage for RF signals must be preserved. This is done by placing a capacitor (C_X) in parallel with the voltage source. With this configuration, a positive voltage applied to the second path is sufficient for generating the required currents I_1 and I_2. In this example, I_1 and I_2 are the same and the remaining current I_X ($I_X = I_2 - I_1$) is zero, but in general this may not be the case. For I_X to always be zero, the value of R_X must be infinite, i.e. an open circuit.

The voltage applied to disable the second path is $V_2 = V_{OFF}$ = 5 V, so the original current values I_{ON} and I_{OFF} are maintained if R = 90 Ω, as found from Equations 3 and 4. Since only a single supply voltage is available, the value of $V_1 = V_{ON}$, to enable the first path, is zero.

$$RI_1 + RI_2 + 2V_D = V_{OFF} \quad (3)$$

$$R = \frac{V_{OFF} - 2V_D}{I_1 + I_2} = \frac{5 - 1.4}{40 \times 10^{-3}} = 90\ \Omega \quad (4)$$

Besides providing the ability to drive a switch with a single voltage,



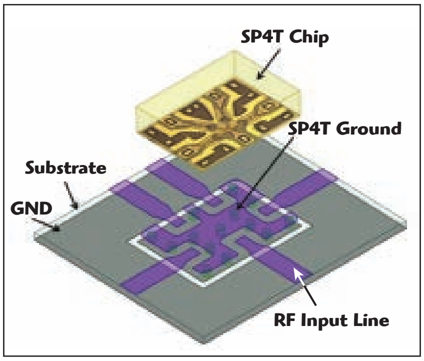
▲ *Fig. 2 Modified biasing network to drive an SP2T switch with a single voltage.*

this circuit provides additional current savings. The total current flowing in the circuit is $I_1 = I_2$ = 20 mA, which is half the current required for the bipolar circuit (see Figure 1). ***Table 1*** compares SPDT, SP4T and SP8T switches having $I_{ON} = I_{OFF}$ = 20 mA, where the total currents required by the two driving methods are shown.

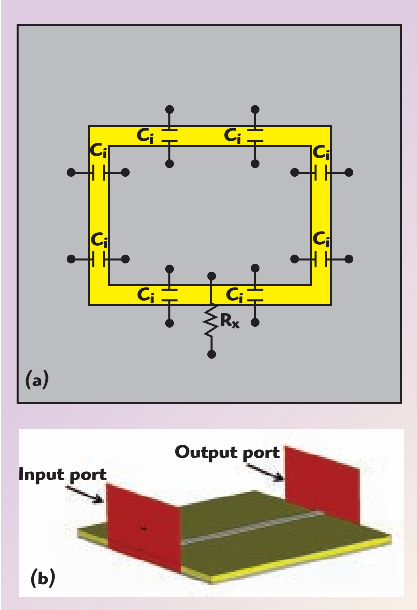
APPLICATION

A commercial SP4T switch is used to test the performance of this design.[5] The surface-mountable SP4T chip is assembled in a microstrip circuit (see ***Figure 3***). Via holes are used to connect its ground to the bottom layer. The bottom layer has a gap that divides the ground plane into two portions. The outer portion is the DC reference which is separated from the inner part by a gap of 150 µm. To maintain an RF short circuit, a capacitance (C_X) is placed across these two portions of the ground plane. For best RF performance, this capacitance should not be concentrated at only one point but should be distributed as uniformly as possible along the perimeter of the gap, as illustrated in ***Figure 4a***.

In practice this is achieved with N evenly spaced lumped components of value Ci connected in parallel. In this case, N = 8 and C_X = 8Ci. Each is modeled by an equivalent circuit including a series inductance along with its nominal capacitance. This data was obtained from the datasheets of commercially available SMD capacitors for RF applications.



▲ *Fig. 3 Surface mountable on-chip SP4T switch assembled on a microstrip circuit with split ground plane.*



▲ *Fig. 4 Split ground plane with a distributed capacitance over the two ports (a) and microstrip transmission line (b).*

To determine the proper C_X value, a transmission line that models a path of the SP4T switch is simulated as shown in ***Figure 4b***. EM simulations, shown in ***Figure 5*** for different values of Ci, are used to optimize the transmission coefficient in the frequency range 3 to 6 GHz. Good transmission performance ($S_{21} \approx$ 0 dB) and good return loss (S_{11} > 20 dB) are achieved

TABLE I

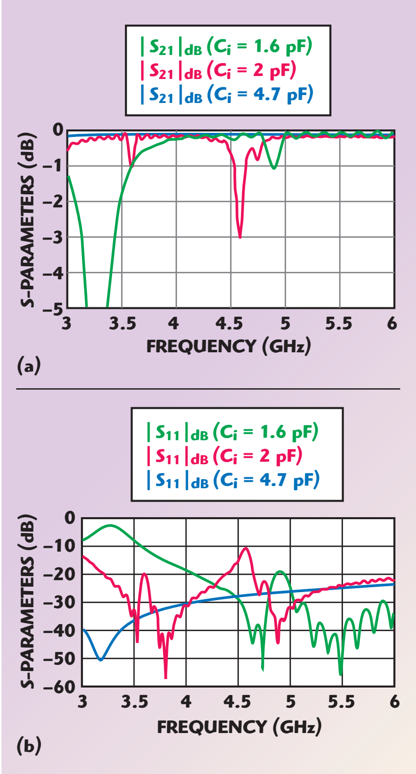
BIAS CURRENTS FOR BIPOLAR VERSUS SINGLE VOLTAGE SWITCH CIRCUIT ARCHITECTURES

Switch Type	Bipolar Voltage	Single Voltage
SPDT	ION+IOFF = 40 mA	IOFF = 20 mA
SP4T	ION+3IOFF = 80 mA	3IOFF = 60 mA
SP8T	ION+7IOFF = 160 mA	7IOFF = 140 mA

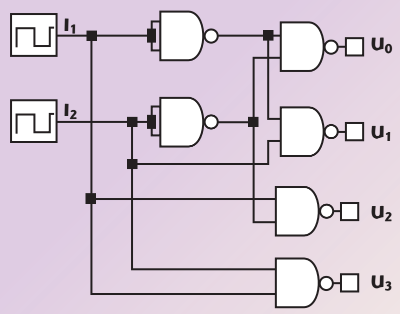
over the entire band for Ci = 4.7 pF (C_X = 37.6 pF).

The actuation voltages are V_{ON} = 0 V and V_{OFF} = 5 V, and the currents are I_{ON} = I_{OFF} = 20 mA (as in the previous case). These voltages can be supplied by a CMOS device, and therefore NAND logic ports are used to build this function together with a decoding network for the SP4T's external commands (see ***Figure 6***). In order to use all identical components in this network, two of the NAND ports act as inverters. CMOS technology has several advantages: its high (low) output is close to 5 V (0 V), its static power consumption is virtually zero and its input is compatible with a TTL driver.

Measurements of the SP4T switch are shown in ***Figure 7*** with a bipolar voltage driving (red dashed line) and with the proposed architecture (solid blue line). They show the aver-

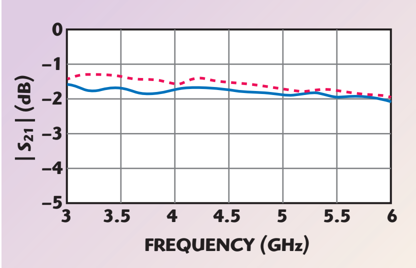


▲ *Fig. 5 S-parameters of the microstrip line in Fig. 4b for different values of C_i; $|S_{21}|$ dB (a) and $|S_{11}|$ dB (b).*



V_1	V_2	U_0	U_1	U_2	U_3
0	0	0	1	1	1
0	1	1	0	1	1
1	0	1	1	0	1
1	1	1	1	1	0

▲ *Fig. 6 NAND port-based logic circuit employed for driving the SP4T switch.*



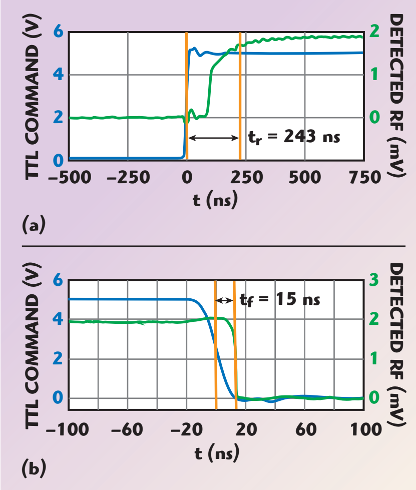
▲ *Fig. 7 Average transmission coefficient of the SP4T switch driven using the described single supply architecture (solid blue line) and with bipolar voltages (dashed red line).*

age transmission coefficient of the four channels in both cases, which includes the biasing network, microstrip lines of the test board and connectors used to carry out the measurements. The isolation between the four channels is comparable with that listed in the datasheet of the SP4T switch, i.e. between 55 and 60 dB in the band considered.

Settling time is shown in ***Figure 8***. The rise time (t_r) = 243 ns, between 50 percent of the TTL input command and the 90 percent of the maximum detected RF output. The fall-time (t_f) = 15 ns, between 50 percent of the TTL input command and the 10 percent of the maximum detected RF output. These values are compatible with the typical applications where SPMTs switches are employed.

CONCLUSION

A PIN diode SPMT switch with a low-power driver uses a single bias



▲ *Fig. 8 Settling time measurement showing rise time t_r = 243 ns (a) and fall time t_f = 15 ns (b).*

voltage. This eliminates the need for a DC-DC converter to convert a single supply into a bipolar supply, as well as the current required to power it. Moreover, with this architecture, the enabled branch is powered by the currents flowing through the deactivated ones, providing further energy savings. A decoding network in CMOS technology is used to provide the required switch voltages, making the driver compatible with TTL input commands. RF measurements show that switch insertion loss is comparable to what is achieved using a bipolar voltage supply. ■

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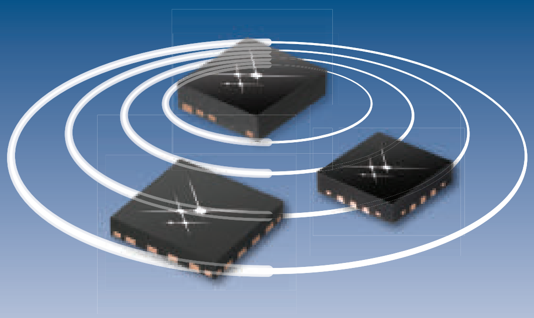

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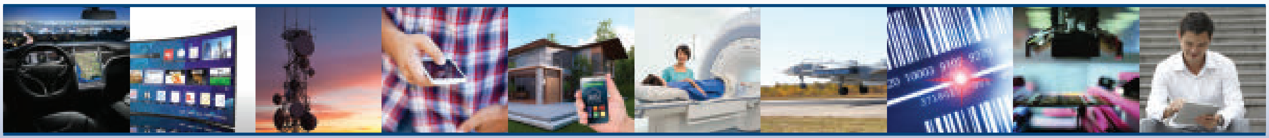

Key Test Requirements of Modern Handset Power Amplifiers

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National Instruments (NI), Austin, TX

The need to continually improve power amplifier (PA) efficiency and linearity has resulted in a broad range of evolving technologies that are driving PA test requirements. To address these requirements, this article covers developments in modern cellular handset PA test and evaluation techniques including: digital pre-distortion (DPD) testing, envelope tracking (ET) characterization, and load pull as key parameters to characterize the device.

In order to understand the context of new test requirements, one must first consider that a PA will generally operate with highest efficiency as it nears its saturation region – a region often characterized by highly nonlinear behavior. In addition, high peak-to-average power ratio (PAPR) characteristics of modern communications signals such as LTE or 802.11ac exacerbate this condition by requiring greater back-off to avoid distortion.

Increasingly popular technologies such as DPD, ET and load pull are each designed to improve either the linearity or efficiency of the PA to address these challenges. DPD effectively linearizes a PA at higher output powers and improves the likelihood that the device will meet standard-specific transmission requirements for modulation quality and spectral purity. Envelope tracking is aimed at improving efficiency for high-PAPR waveforms by dynamically changing the efficiency profile of the device. Finally, load pull enables engineers to improve the overall efficiency of the device by finding the optimal input and output impedance of the power transistor.

TESTING DPD-ENABLED PAS

The combination of increasing signal processing capabilities combined with the use of more challenging signals such as LTE has increased the use of DPD technology in mobile devices. DPD algorithms improve modulation quality and reduce spectral re-growth in the frequency domain – especially at higher output power levels.

In the past, PA characterization required only a vector signal generator (VSG) to produce the modulated signal and a vector signal analyzer (VSA) to measure the output. While powering the PA with a power supply or source measure unit (SMU), one would measure characteristics such as error vector magnitude (EVM) and adjacent channel leakage ratio (ACLR).

Although PA testing has historically required fairly simple instrumentation and measurement practices, testing of today's DPD-

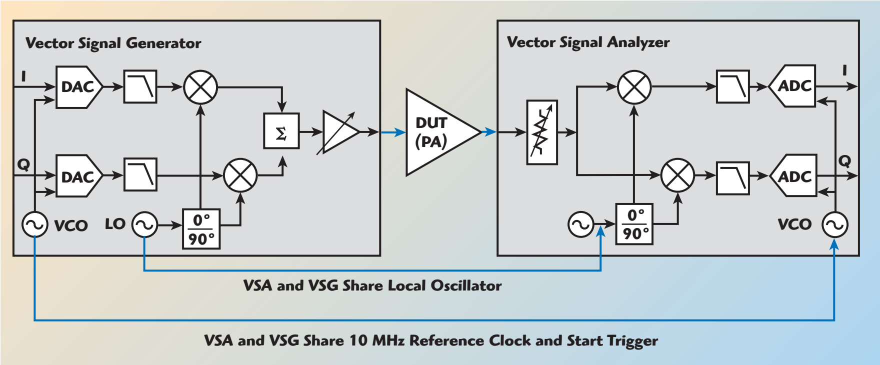


Fig. 1 Block diagram of a VST-based PA measurement system.

enabled PAs is more complex. Given the increased likelihood that a PA will transmit pre-distorted waveforms in its end use, engineers are less interested in its raw performance and are more interested in its ability to be pre-distorted with one of several common DPD algorithms. As a result, modern PA testing requires engineers to mimic the functionality of the DPD algorithm with advanced test equipment.

Approaches to DPD

Two DPD implementations that are gaining increasing interest are the simple memoryless look-up table (LUT) and more complex algorithmic techniques based on the Volterra series. In both implementations, the DPD model is derived from stimulus-response measurements that require one to compare input signals introduced to the PA with the acquired output signals. Although engineers traditionally performed common stimulus-response measurements like AM-AM and AM-PM with a vector network analyzer (VNA), these instruments are traditionally unable to provide modulated signals.

An increasingly popular method to measure AM-AM and AM-PM is with a modulated stimulus that is generated with a VSG and acquired with a VSA. By comparing both the input and output power and phase on a sample-by-sample basis, one can measure AM-AM and AM-PM. Not only does the VSG-VSA approach capture the memory effects of the PA, but it also enables the use of more sophisticated DPD models.[1]

Measuring AM-AM and AM-PM

When measuring AM-AM and AM-PM using a VSG and VSA, it is extremely important to share any and all clock signals to avoid measurement error. Note that although VNAs inherently share timing signals between stimulus and response, VSAs and VSGs historically do not. As shown in ***Figure 1***, important timing signals including the local oscillator (LO) and the 10 MHz reference clocks can be easily shared on an NI vector signal transceiver (VST). Note that LO sharing is generally only possible in direct conversion VSAs and VSGs. In more traditional IF-based VSAs, the LO frequency will inherently offset the center frequency of the signal being acquired. Thus, when using an IF-based VSA, LO synchronization is not possible and sharing a 10 MHz reference clock is the best alternative.

The memoryless LUT approach to DPD uses measured AM-AM and AM-PM data to construct a simple LUT. Based on the measured data, the LUT predicts the needed power and phase of each input sample in order to achieve a linear output response. As observed in ***Figure 2***, the AM-AM response of a memoryless LUT-corrected PA achieves almost constant gain versus output power. The resulting signal is characterized by reduced spectral re-growth in the frequency domain.

One can also see the relationship between the "measured" response and the "curve fit." Especially with wideband signals, PA memory effects create a scenario where the phase and magnitude of the output signal cannot be completely predicted by the phase and magnitude of the input signal. Thus, even though measuring AM-AM and AM-PM with a VSG and VSA captures memory effects, the memoryless LUT model does not compensate for memory effects directly.

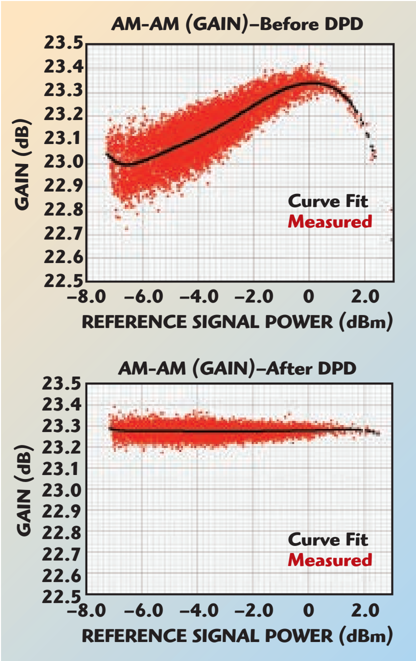
Volterra Series and Memory Polynomial Model

A more comprehensive model for nonlinear systems with memory is a Volterra series[2] (see Equation 1). The Volterra series can be computationally intensive, and the complexity of this model increases drastically with increasing nonlinearity order (K) and memory depth (M).

$$X_{out}[n] = \sum_{k=1}^{K} \sum_{l_1}^{M} \cdots \sum_{l_p}^{M} h_p\left(l_1, \cdots, l_p\right) \cdot \prod_{m=1}^{k} x_{in}\left[n - l_m\right] \qquad (1)$$

In practice, nonlinear systems with memory can be adequately modeled with only a subset of the terms in a full Volterra series. Common models based on this approach include the memory polynomial, the Weiner, and the Hammerstein models.[3] Because these models are considerably simpler to implement, they are more practical for modern mobile devices.

Similarly to the memoryless LUT, testing of DPD-enabled PAs that use models based on a Volterra series requires a modulated stimulus and response. In general, it is desired that the instrumentation supports signal bandwidths three to five times the bandwidth of the waveform. In addition, many test equipment vendors provide software to control both the VSG and VSA and implement the model within the instrumentation itself. These software utilities enable the engineer to characterize the ability of the PA to be pre-distorted (based on the predictability of its distortion) without requiring an intimate knowledge of the model.



▲ *Fig. 2 DPD algorithms correct the AM-AM response of the PA.*

ENVELOPE TRACKING

A second increasingly important test requirement for wireless PAs is the ability to test under envelope tracking conditions. Envelope tracking technology is based on two fundamental premises:

1. Modulated signals have an inherently non-zero PAPR
2. PA efficiency increases as the device approaches saturation

Given these premises, one can improve overall PA efficiency by operating the device close to its saturation point as often as possible.

Because modern communications signals tend to have relatively high PAPRs (LTE uplink is 6 to 8 dB), one straightforward method to improve overall PA efficiency is to modulate the Vcc signal such that it tracks the envelope of the RF signal.[4,5] By effectively modulating the Vcc signal in real-time, it is possible to better optimize instantaneous output power over a range of output power levels. As shown in ***Figure 3***, power-added efficiency (PAE) is actually a function of output power and Vcc. Thus, one can optimize PAE by instantaneously choosing the lowest Vcc necessary to achieve the desired output power.

It is worth noting that the process of modulating Vcc as a function of desired output power creates two specific requirements on the system. First, because PA gain is also a function of Vcc, merely modulating the Vcc signal introduces AM-AM distortion that must be corrected with DPD algorithms. Second, modulating the Vcc signal introduces additional synchronization requirements between instruments sourcing the RF input and the modulated Vcc signal.

Synchronization in ET Testing

A typical envelope tracking test system includes an RF signal generator to provide RF input to the PA and an arbitrary waveform generator (AWG) to provide the shaped Vcc signal. In this test system, both instruments must be tightly synchronized. The synchronization requirements of an ET PA test bench are fairly significant. In practice, the method by which an ET PA achieves higher PAE is to associate each input power level with a corresponding Vcc control voltage. Moreover, because PA gain is a function of Vcc, skew or jitter between the Vcc and RF input signals can introduce significant additional AM-AM and AM-PM distortion.

If, for example, the Vcc waveform lags the RF signal, the power modulator will not supply ample power to the device at the peak output power of the input waveform. A similar situation occurs if Vcc leads the RF. For wideband signals, even a small amount of skew (more than 10 ns) can significantly affect the performance of the PA.

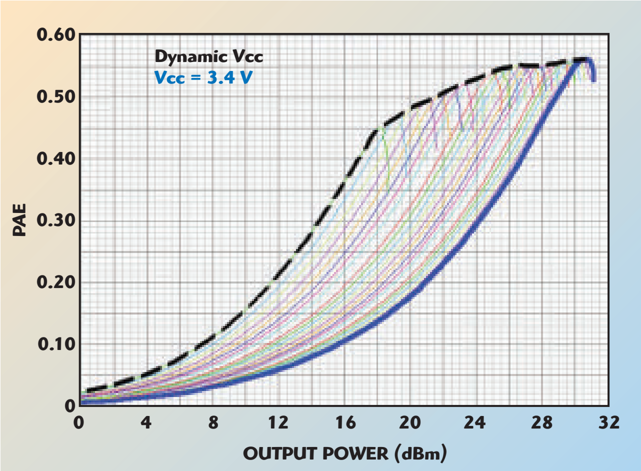


Fig. 3 PAE vs. power out across Vcc.

Sharing Reference Clocks and Start Triggers

One of the most common methods to synchronize the VSG and AWG is through shared reference clocks and start triggers. With both instruments synchronized, one must typically apply a small delay between the VSG and the AWG to compensate for differences in signal path.

Although both skew and timing jitter (variable skew) between the AWG and VSG can impair test results – jitter is the least predictable and is by far the most problematic. Generally, the effects of static skew can be measured either directly as a time domain signal or indirectly through the AM-AM distortion or spectral re-growth it produces. Jitter, however, is much more difficult to compensate for as it is frequently the result of the instrumentation architecture. Note that PXI instruments are generally subject to less AWG-to-VSG jitter due to PXI's use of an internal 10 MHz system clock that provides all modules with a timing reference that offers < 1 ns channel-to-channel skew.[6]

The effect of AWG-to-VSG skew on AM-AM and AM-PM distortion can be observed in ***Figure 4***. With < 1 ns of skew, curve fitting the gain versus output power is relatively straightforward – as there is very little deviation. However, with 20 ns of skew between the AWG and VSG, there is significant

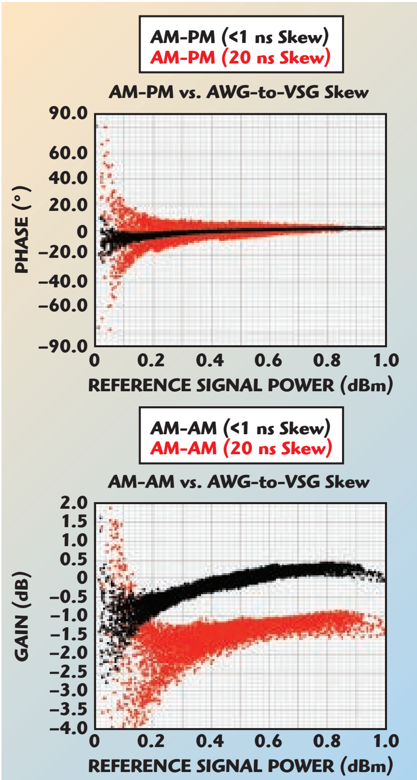


Fig. 4 AM-PM and AM-AM distortion with < 1 ns and 20 ns of skew.

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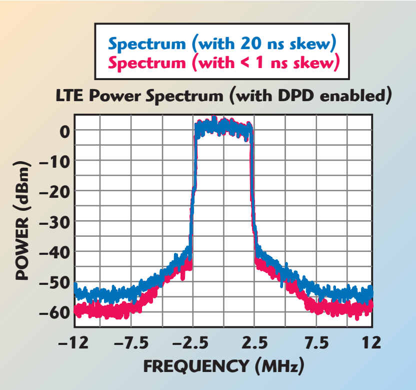
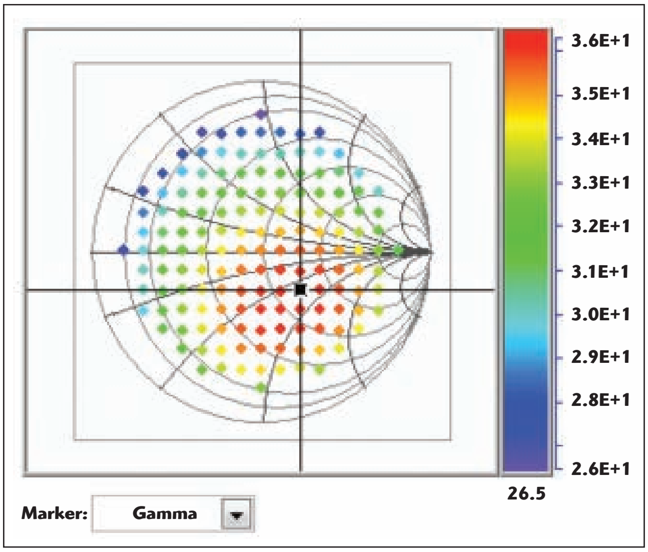


▲ *Fig. 5 Spectral regrowth with < 1 ns and 20 ns of skew.*

AM-AM distortion and lower gain. Not only does this distortion create spectral re-growth, but the wider “spread” of the AM-AM and AM-PM makes pre-distortion more difficult.

In the frequency domain, one can easily observe the effects of AM-AM distortion introduced by poor synchronization between the AWG and VSG. ***Figure 5*** shows the resulting signal in the frequency domain with a memory polynomial DPD algorithm applied. The configuration with 20 ns



▲ *Fig. 6 Load pull plots on Smith Chart.*

of skew provides worse ACLR performance. Given this result, one common technique to identify VSG-to-AWG misalignment is to measure ACLR as a function of skew. Because skew ultimately results in worse ACLR, the optimal AWG-to-VSG delay can be identified by choosing the best-case ACLR as a function of programmatic delay.

LOAD PULL

The third PA optimization technique is load pull. Although engineers have been using load pull test systems for many years to test extremely high power PAs for wireless infrastructure equipment – increasing efficiency demands of handset PAs has made load pull measurements more pervasive over a wider range of modern PAs.

The basic approach is to experimentally identify the ideal source and load impedance of a PA to achieve the highest possible PA efficiency. By identifying these ideal impedances, a PA designer can then develop corresponding impedance matching networks.[7]

A traditional source and load pull setup presents a wide range of source and load impedances to the PA under varying RF input power and DC bias conditions.[8,9] By measuring PA output power as function of source and load impedance, one can identify the impedances that will produce the highest output power. Moreover, by measuring DC bias voltages and currents as well, one can also measure output efficiency and power added efficiency (PAE) as a function of impedance. The results are typically visualized as contour plots on a Smith Chart (see ***Figure 6***), or imported into EDA tools such as the AWR design environment.

Source and Load Pull Challenges

Traditional source and load pull measurement systems use power meters to measure input and output powers under CW conditions. Unfortunately, due to their measurement principle and wideband nature, power meters are typically slow and cannot resolve power between the fundamental frequency and harmonics.

Modern load pull measurement systems[10] typically use vector instrumentation such as a VNA, a large signal network analyzer (LSNA), a VSG used in conjunction with a VSA, or a broadband oscilloscope (see ***Figure***

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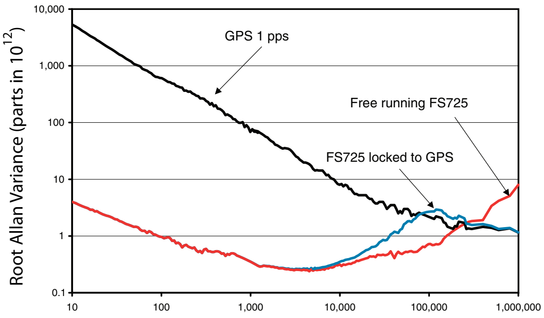
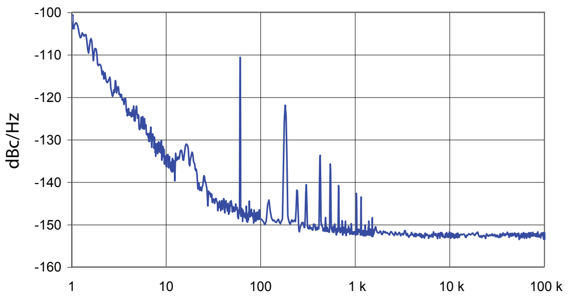


Observation Interval (seconds)

FS725 Single Sideband Phase Noise



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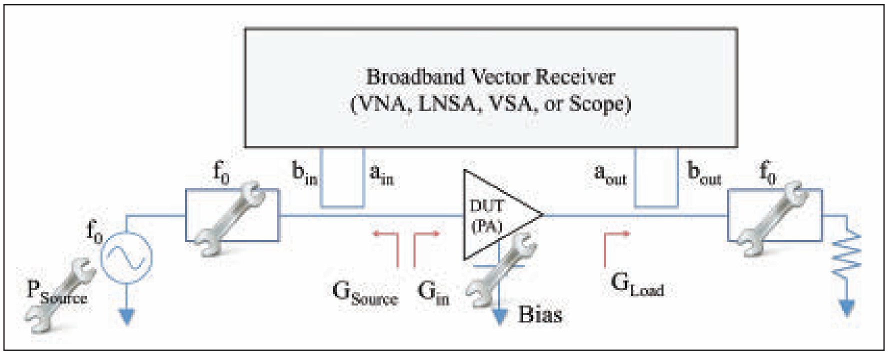

▲ *Fig. 7 Modern source and load pull setup.*

7). These types of instruments offer inherently faster, frequency-selective, measurements – although only systems using a VSG offer a modulated stimulus. For example, a PXI-based load pull system[11] with an NI vector signal transceiver and Maury impedance tuners includes both a VSG and a VSA to support both CW and modulated stimulus of the DUT.

Note that the impedance presented to the PA can be formalized as a complex value (real and imaginary part or amplitude and phase) in different formats: impedance (Z), voltage standing wave ratio (VSWR), or reflection coefficient (Γ), i.e. the ratio between incident and reflected travelling waves, with respect to the observed impedance. In fact, source and load pull systems can introduce various impedances to a PA either by adjusting the impedance directly (passive tuning), or by emulating a particular impedance by actively injecting a signal (active tuning).

Passive Tuning

Traditional source and load pull measurement systems use passive mechanical tuners to affect the impedance conditions of a circuit. In this scenario, the tuner presents various impedances to the PA by perturbing the electric field of an airline using a metallic probe (called a "tuning slug"). By selecting the appropriate vertical and horizontal positions of the probe with respect to the airline, a mechanical tuner can be configured to provide a wide range of impedance conditions. Generally, passive mechanical tuners change impedance relatively slowly compared to other tuning systems because they require moving mechanical parts.

Recently, new approaches to passive tuning include passive electronic impedance tuners based on PIN diodes or MEMS technology. Such tuners overcome the speed issue of traditional passive mechanical tuners by electronically changing the length of stubs along a transmission line. However, these tuners can typically present only a limited set of impedances on the Smith Chart compared to passive mechanical tuners.

Unfortunately, passive tuning systems have significant drawbacks when testing PAs designed for wideband communications signals such as LTE. Because the impedance of a device can vary over the modulation bandwidth, performing load pull measurements with a modulated stimulus provides a more accurate representation of how the PA will perform under particular impedance conditions.

Active Tuning

Active tuning systems can be further grouped into two sub-categories: open-loop and closed-loop architectures. Unlike passive tuning, which involves the manual creation of a specific impedance, the principle of active tuning is to create the desired impedance condition by injecting additional signals into the PA.

Closed-loop active tuning systems use a part of the incident wave, through a coupler or a circulator, to emulate the desired impedance condition. In this setup, a combination of variable amplifiers and phase shifters modify the incident wave, both in amplitude and phase, before sending it back to the DUT as the reflected wave. Because the synthesized reflection is electronically controlled, the tuning process can be

quite fast. Although the synthesized reflection is fully synchronous with the incident wave even when the incident power changes, closed-loop active tuning systems are subject to oscillation depending on their architectures.

Recently, NI demonstrated a PXI-based pseudo closed-loop active tuning system developed in cooperation with Mesuro.[12] This system samples the incident signal with the help of a downconverter and passes it to an onboard FPGA. Inside the FPGA, the phase and amplitude of the sampled incident signal are digitally controlled before generating the reflection with an RF signal generator.

In addition to closed-loop active tuning systems, one can adjust the effective output impedance of a DUT using an open-loop approach. Open-loop active tuning systems use external RF sources to generate and control the amplitude and phase of the reflected wave. Although these systems avoid the oscillation issues present in closed-loop systems they require tight synchronization between each of the signal generators.

In this context, a new mixed-signal open-loop active load pull system has been patented by Anteverta Microwave and developed in cooperation with NI. Using external frequency upconverters and downconverters, the Anteverta system benefits from tightly synchronized PXI arbitrary waveform generators and analog-to-digital converters (ADC) to generate and capture wideband modulated signals at baseband.[13]

CONCLUSION

With the emergence of more sophisticated PA technologies, testing today's handset PAs is becoming more complex. As a result, engineers must understand how to characterize PAs designed to operate under DPD and ET conditions and even construct more sophisticated load pull test systems. Fortunately, each of these measurement conditions is reasonably straightforward and can be addressed through modern test instrumentation. ■

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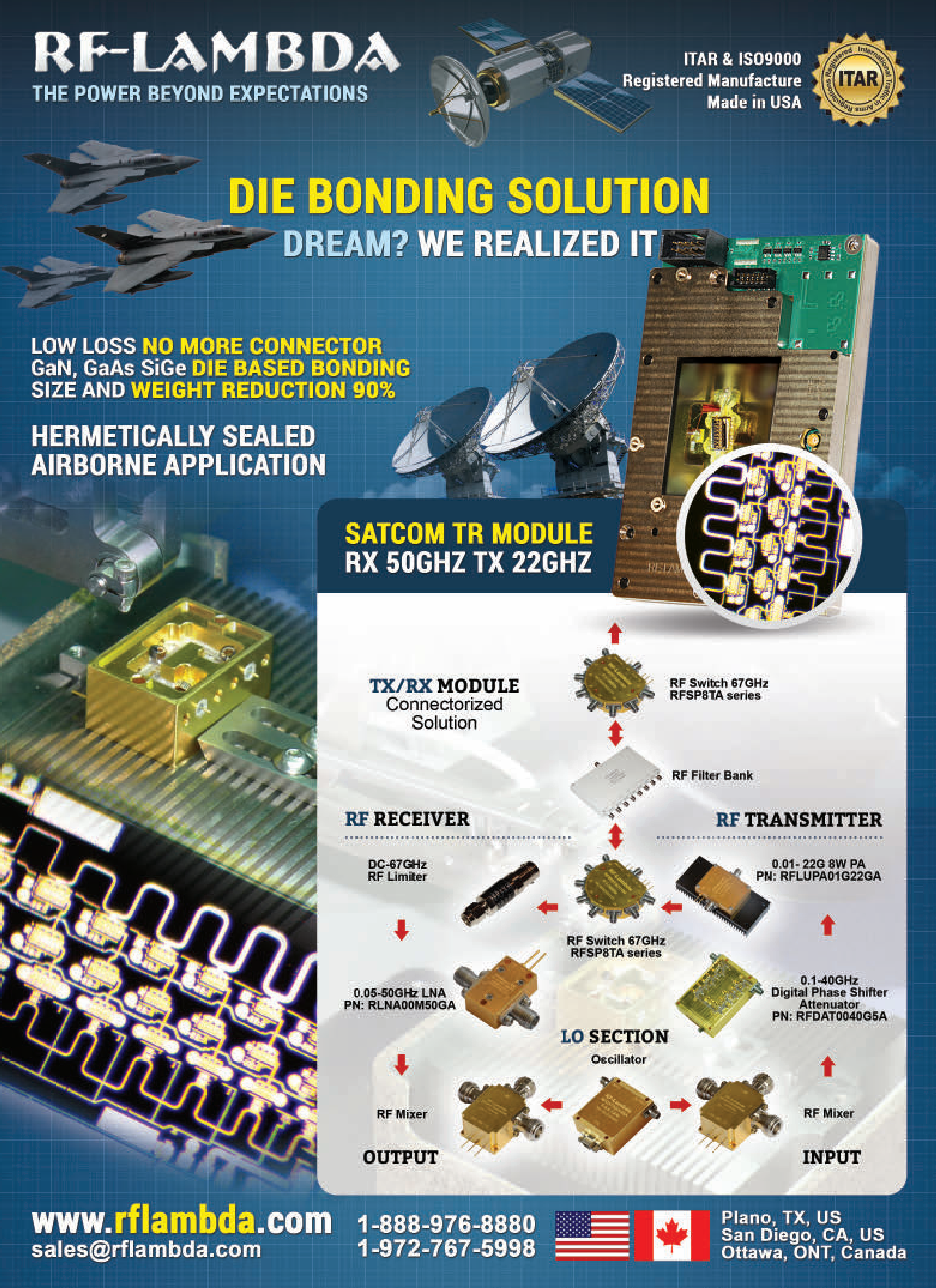

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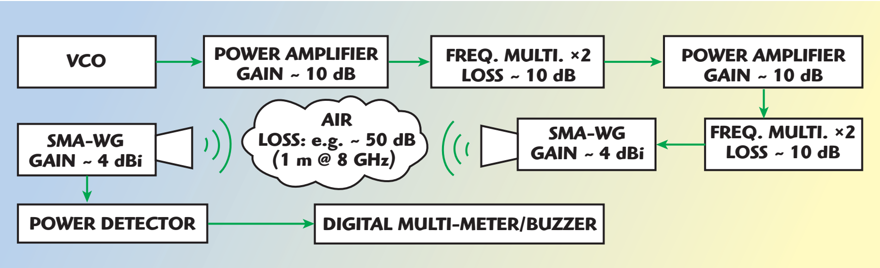
A new experimental approach to teaching antenna and microwave topics is realized with general-purpose, off-the-shelf devices and is suitable for different educational levels and scenarios, from children to high-school students, from science shows to under-graduate and graduate courses. Its flexibility enables efficient budgeting for educational activities that can be easily tailored to meet learning needs at all education levels and encourage young people to pursue science, technology, engineering and mathematics (STEM) careers.

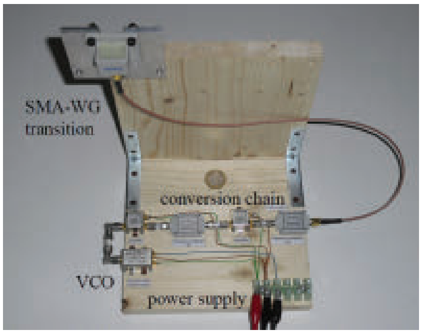
Microwaves, electromagnetic theory, antennas and propagation are standard topics for undergraduate and graduate courses in electronics and telecommunications,[1] while the growing use of microwave devices and services, such as mobile phones, car navigators and satellite broadcasting is having an increasing impact on people's lives.[2] There continues to be, however, a lack of understanding of basic microwave and electromagnetic (EM) field principles.[3] There are two main reasons; first, the equations describing EM phenomena (e.g., Maxwell equations and the wave equation) are often considered complex by most students and second, the effects associated with microwaves are not directly visible by the human eye. The consequences are a general misconception about microwaves and a limitation in the number of students deciding to follow an educational track in microwaves and EM fields.[4]

This problem has been addressed in recent years with courses to engage and motivate students through the use of alternative lectures[5,6] and by re-addressing the most critical points of classical lectures.[3,7-9] Systems have been proposed to support microwave and EM theory comprehension based on software-aided approaches[10-12] or through experimental activities.[12,13] These usually target specific types of students. Software-aided approaches (usually best suited for high-level education) and experimental approaches (suitable to different levels according to the experimental setup) address only a limited range of educational scenarios.

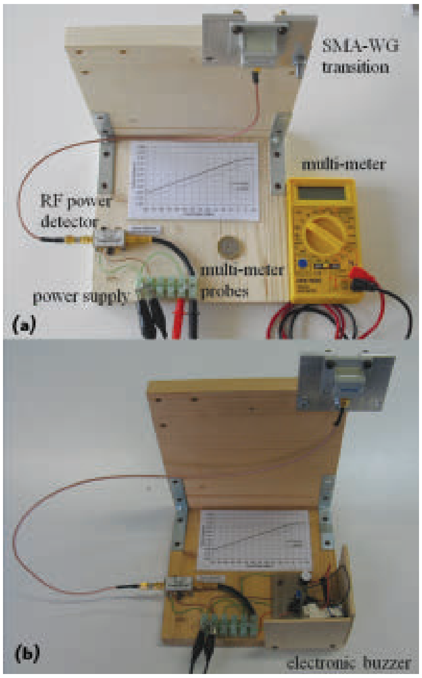
This article describes a new experimental approach, preferred over software-aided lectures because it is believed to be the most convenient and easiest way to explain EM phenomena.[14-16] Two main aspects distinguish it from other experimental approaches recently proposed.[17-21] First, the experiments are based on off-the-shelf devices, easily purchased and prepared by most high-school and university laboratories, even with limited budgets. Second, since it is expected to be used at several different educational levels – from children to high-school students, from science shows to



▲ *Fig. 1 System schematic.*



▲ *Fig. 2 Transmit section.*



▲ *Fig. 3 Receive section with multimeter (a) or with buzzer (b).*

under-graduate and graduate students – it is designed to be very general, covering several different topics. In this way, it is possible to select the most suitable experiments. In addition, each experiment is explained using both quantitative and qualitative feedback, the former best suited for high-school, under-graduate and graduate students and the latter best suited for children and for science shows.

This flexible, inexpensive and experimental system is easily adapted to different scenarios.[22] It has been used since 2010 for dissemination and educational purposes, obtaining great interest from general public (science shows, children, high-school students) and from undergraduate students.

DESCRIPTION

Figure 1 is the system schematic, while ***Figures 2*** and ***3*** are photographs of the system itself. A voltage-controlled oscillator (VCO) generates a low-band signal (tunable from 1.5 to 2.5 GHz). For these frequencies, inexpensive devices are readily obtainable. The signal is brought to the high-band (6 to 10 GHz, more convenient for the intended experiments) by means of two passive frequency doublers and two power amplifiers and then routed to an SMA-waveguide (SMA-WG) transition that also acts as the transmitting antenna (see Figure 2). By using the proper SMA-WG transition (WR112) it is possible to have the entire high band within the fundamental-mode bandwidth of transition. After propagating through air, the signal is received by a twin SMA-WG transition and rectified by a power detector (see Figure 3). The output voltage of the power detector is read by a digital multi-meter and translated into a power level according to its response curve. Alternatively, the detector signal is read with an in-house designed front end that drives an electronic buzzer. If used for undergraduate and graduate courses, the digital multi-meter is best suited because it allows for quantitative study of the EM phenomena, whereas the electronic buzzer is better for children and for science shows. Each device is selected for compatibility with all other devices in terms of input/output connectors, power supply voltages, input/output powers and operating frequencies.

The system is designed to be inexpensive. In particular, all active devices are powered with a +5 V DC power supply. Only the VCO may require an additional DC voltage to tune the frequency of the generated signal, if required. With no tuning voltage (i.e, zero volts), the VCO signal is around 1.5 GHz and, therefore, the output signal after the multipliers is around 6 GHz.

All the devices in the transmit and the receive sections are mounted on L-shaped wooden supports where the horizontal plane is used for the electronic devices while the vertical plane is used to hang the SMA-WG transition, that can also rotate around the hanging bolt in order to change linear polarization. The entire setup is inexpensive and easy to assemble with normal DIY skills. All devices are readily available. The only (not mandatory) device requiring in-house development is the front end for the buzzer; however, it is simple as it requires basic skills taught in electronic and telecommunication courses and some high-school programs. Thus, it provides a great opportunity to further stimulate interest in scientific topics.[23]

ANTENNA AND PROPAGATION

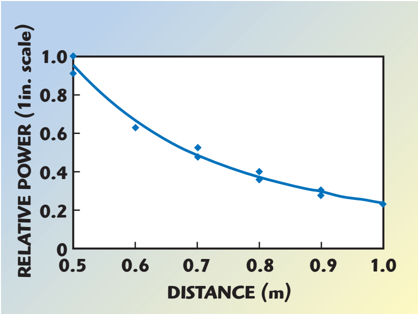
This system can be used to demonstrate several different concepts related to antennas and propagation such as 1) the Friis formula, 2) polarization, 3) propagation through materials, 4) radiation patterns and 5) radar.

Friis Formula

The Friis formula is used to determine the loss due to free-space attenuation experienced by a microwave link.[24] With the digital multi-meter it is possible to derive the Friis formula, and this is particularly useful for high-school, undergraduate and graduate students. Otherwise, the electronic buzzer returns a qualitative feedback given by the volume of the sound generated by the buzzer. This is attractive for children and science shows.

As an example, the transmitting and receiving sections are placed in front of each other at a distance of around 0.5 m (see ***Figure 4***) and the VCO is tuned to around 8 GHz. The voltage read by the digital multimeter is recorded and translated into a power level. The antennas are then moved away from each other and each time

▲ *Fig. 4 Basic setup.*



▲ *Fig. 5 Measured power (diamonds) and fitting quadratic curve (solid line).*

the multimeter voltage is recorded. The data (see ***Figure 5***) is used to demonstrate the quadratic relationship between received power and the distance.

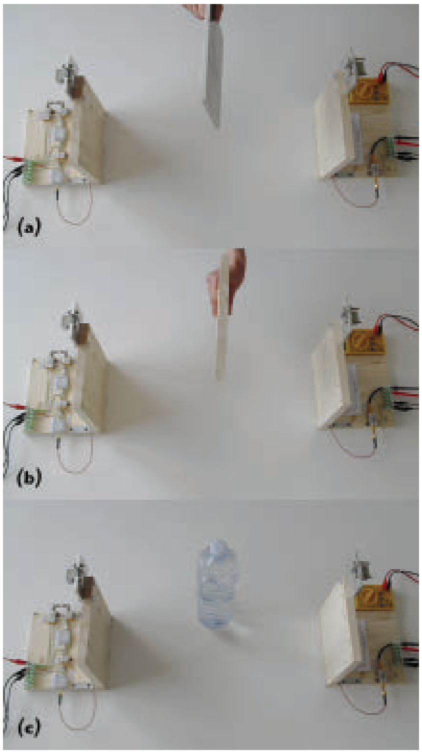
Another relevant aspect of the Friis formula is antenna gain. To show its importance, the transmit and receive antennas are placed at a fixed distance (e.g., 1 m) and the received power is recorded with and without a standard horn antenna (see ***Figure 6***) mounted on one of the two SMA-WG transitions. The result is a +7 dB gain with the horn antenna versus the SMA-WG transition. Using the electronic buzzer, the higher gain may not be easily detectable.

To better show how the antenna gain affects power collected by the receiving antenna, it is helpful to explain that antenna gain is a way of measuring the antenna's capability to concentrate the power in certain directions. The familiar world of visible light can be used to support this understanding. If a standard light bulb is turned on, a certain amount of light is generated all around it. If the same light bulb is then placed in front of a suitable reflecting surface (such as that used for car lights) a higher illumination is obtained in certain directions. This analogy between microwaves and visible light is effective at any education level and can be exploited in the other experiments, as well.

Polarization

As with antenna gain, the analogy

▲ *Fig. 6 Horn antenna.*



▲ *Fig. 7 Propagation through materials; metal plate(a), wooden plate (b), water bottle (c).*

with visible light is quite useful. In fact, polarized sunglasses and polarized camera filters are well known examples. The setup is similar to the one shown in Figure 4, but in this case one of the antennas is rotated of an arbitrary angle, up 90 degrees. With the antennas cross-polarized, the signal received is very low and the buzzer does not work. With the antennas co-polarized, the signal received is high and the buzzer sounds. Data collected with the multimeter shows a 30 dB difference in power between the two configurations.

Propagation Through Materials

One of the most spectacular aspects related to microwave propagation is its interaction with obstacles. To better illustrate this, the analogy with the visible light is fully exploited. The setup shown in ***Figure 7*** is similar to that of Figure 4, but with an

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Simplified Functional Block Diagram

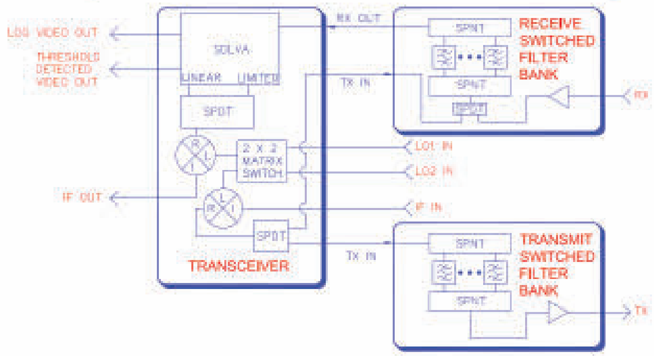

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TABLE I
PROPAGATION THROUGH MATERIALS

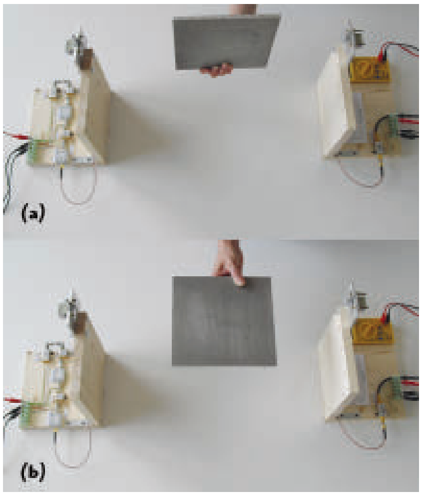
Antenna Configuration	Relative Power (dB)
No Obstacles	0
Front Metal Plate	-30
Front Wooden Plate	-3
Water	-30
Vertical Metal Plate	-30
Horizontal Metal Plate	-1

obstacle placed between the transmit and receive antennas. A thin metal plate, Figure 7(a), stops both visible light and microwaves; therefore, power recorded by the digital multimeter is strongly reduced (with the buzzer, no sound is audible). A thin wooden plate, Figure 7(b), stops visible light but does not materially affect microwaves; therefore, the power recorded by the digital multimeter is only slightly reduced (the same for the buzzer sound). Finally, a bottle of water is used in Figure 7(c). Of course, it is possible to see through a small amount of water while it completely stops microwaves; therefore, the power recorded by the digital multi-meter is strongly reduced (with the buzzer no sound is audible).

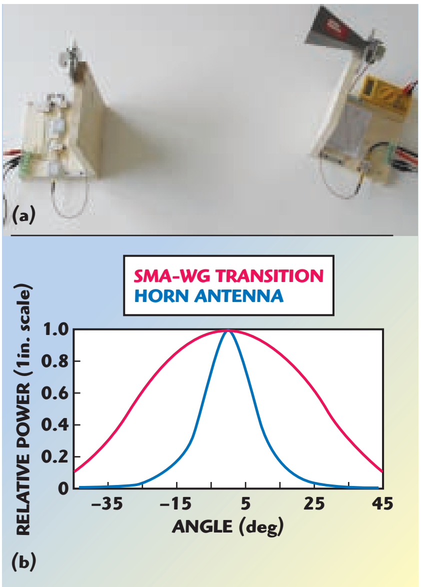
The experiment takes into account not only the nature of obstacles but also their shapes. Moreover, the concept of polarization is recalled. The thin metal plate is placed along the thin side vertically and horizontally in front of the transmitting antenna in ***Figure 8***. When placed vertically the power recorded by the digital multimeter is strongly reduced, whereas it is almost unchanged (compared to no obstacle at all) when placed horizontally, even though the blocking area is the same in both cases. Results from these experiments are summarized in the ***Table 1***.

Radiation Patterns

This is useful for illustrating that different applications call for different antennas. For example, to illuminate an entire room, a stand-alone bulb is used because it generates light in all directions. Conversely, if only a portion of the room requires light, a reflecting surface may be used in conjunction with the light bulb to concentrate its light in a desired direction. This is illustrated with radiation patterns.



▲ *Fig. 8 Polarization experiment; vertical plate (a), horizontal plate (b).*



▲ *Fig. 9 Radiation patterns; setup (a), measured patterns (b).*

Using the setup shown in ***Figure 9a***, the receive section is rotated by using tick marks on a sheet of paper placed beneath the base (not shown in figure). Using the digital multi-meter, this experiment may be repeated twice, first with the SMA-WG transitions and then with one transition replaced by a standard horn antenna. In this way, different radiation patterns are generated with different gain antennas, as shown in ***Figure 9b***. Using the buzzer, it is convenient to consider only one case (e.g., SMA-WG transition) and to limit the explanation to the importance of antenna reciprocal orientation. Data

▲ *Fig. 10 Radar experiment.*

recorded with the digital multi-meter is plotted in ***Figure 10***.

Radar

In order to avoid the use of costly transmit/receive devices (e.g. circulators), a bi-static radar is used (see Figure 10). The transmitting and receiving sections are set at an angle with respect to each other and power level detected by the digital multimeter is recorded. A target (e.g., a metal or wooden plate) is moved between the two antennas while varying its orientation. Sample data shows up to a 5 dB increase in received power in the presence of the metal plate. This demonstrates that material, shape and orientation are key parameters for target recognition using a radar system.

DISSEMINATION AND EDUCATIONAL IMPACT

This system has been used in a number of different events since its development in 2010. In particular, they can be grouped into two categories: dissemination activities, mainly intended for children, science show and academic open days, and educational activities, mainly intended for under-graduate students in the framework of academic courses.

For dissemination activities, the interest from the public has been enthusiastic, with many questions on the use of microwaves in everyday life. The system provides an easy-to-understand approach to difficult topics and has been clarifying misconceptions about microwaves and EM fields. The success of these events is demonstrated by the number of people attending them. In October 2011 and in October 2012, the system was presented at BergamoScienza (Bergamo, Italy),[25] an Italian national science show with around 100,000 attendees over a period of two weeks, in the framework of experiments on EM and mechanical waves prepared by the University of Pavia. The presentation of the system was followed by more than 3,000 people each year. In addition, during 2011 and 2012 the system was presented to around 2,000 children with dedicated events at schools, and to the faculty of engineering of the University of Pavia. Finally, the system has been presented since 2010 to tens of thousands of high-school students in the framework of open days organised by the University of Pavia in order to attract new students.[26] The system was part of a set of events promoted by the Department of Electronics to stimulate high-school students toward engineering encouraging STEM careers.

In the framework of educational activities, during the academic year 2011/12 and in the academic year 2012/13 the system has utilized as extra activity for the under-graduate students of the class on Electromagnetic Fields students of the course on Electronics and Computer Engineering. The principal aim has been to aid student comprehension and provide experimental evidence of the equations studied during standard lectures. Student feedback has been enthusiastically positive.

CONCLUSION

A new approach based on hands-on experiments teaches microwaves and EM theory and stimulates interest in these topics. The goal is to efficiently and effectively provide educational and dissemination activities. The intended audience spans from children to high-school students, from science shows to under-graduate and graduate students.

The system is designed to explain different microwave phenomena both qualitatively and quantitatively, according to the educational level of the audience. The experimental setup is not designed to demonstrate a specific phenomenon but, instead, can be used to demonstrate several different concepts, tailored to the educational level of the audience. The equipment uses inexpensive, commercially available, general-purpose devices that limit system cost and enhance reproducibility. This is particularly attractive for most high-school and university laboratories, furthering the dissemination of a microwave education to students and society, and providing a means to attract students toward scientific educational paths. It has been used since 2010, receiving great interest from the general public (science

shows, children, high-school students) and from under-graduate and graduate students.

ACKNOWLEDGMENT

The author wishes to thank Prof. Marco Bressan, Prof. Maurizio Bozzi and Prof. Carla Vacchi for providing the data related to attendance during dissemination and educational activities, Prof. Luca Perregrini for useful discussions and the IEEE Antennas and Propagation Society for its contribution to system development in the framework of the AP-S 2010 Student Design Contest. ■

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A Wide Stopband Lowpass Filter with Three Transmission Zeros

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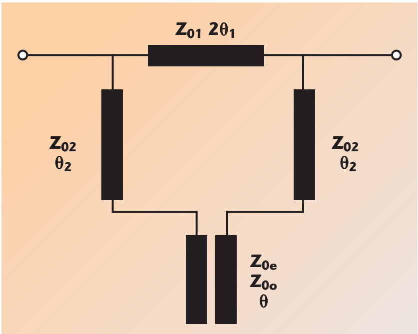
A compact, wide stopband lowpass filter using a tri-section impedance hairpin resonator with three transmission zeros is described. Measured results demonstrate a sharp transition rate from transmission to cutoff of 61.8 dB/GHz and a wide stopband of 1.06 to 5.3 GHz with out-of-band rejection higher than 20 dB.

Compact sized microwave lowpass filters (LPF) with wide stopbands and sharp cutoff frequencies are needed in various wireless communication systems to suppress harmonics and spurious signals; however, conventional LPFs, using open-circuited stubs and stepped impedances, are large and have narrow stopbands with a gradual cutoff.[1] To improve performance, the usual approach is to raise the order of the stepped impedance, making the circuit larger without significantly improving the cutoff skirt. LPFs using defected ground structures (DGS)[2-6] and coupled-line structures[7-11] have been recently proposed. The LPF with DGS proposed by Ahn et al[2] and the coupled line LPF with three attenuation poles described by Lee et al[7] both have very gradual cutoff skirts. The filter described by Hsieh and Chang[12] also suffers from this problem because the only transmission zero in the stopband is far from the cutoff frequency. For the DGS resonator described by Chen and Xu,[5] two transmission zeros are applied to the LPF, which has a sharp rejection slope and a very wide stopband; however, this design is complex and has fabrication difficulties. In Veledi et al[9] and Wei et al,[10] both LPFs using coupled-line hairpin units have wide stopbands, but rejection is very poor at some frequencies.



▲ *Fig. 1 Lowpass filter structure.*

To address these deficiencies, we describe a structure with three transmission zeros in the stopband using a tri-section impedance hairpin resonator. This structure is compact and has a wide stopband and a sharp cut-off frequency response.

THEORETICAL ANALYSIS

Figure 1 shows the structure of the proposed lowpass filter. The feed lines are linked to the joining ends of transmission lines whose characteristic impedances and electrical lengths are Z_{01}, Z_{02} and θ_1, θ_2, respectively. The coupled line, which has even- and odd-mode impedances Z_{0e} and Z_{0o} and electrical length θ, is connected to the remaining ends of the two symmetrical transmission lines with characteristic impedance Z_{02}. Because the structure is symmetrical, it can be analyzed by using odd- and even-mode networks.

When the structure is excited by the even mode, the equivalent circuit is depicted in ***Figure 2a***. The even-mode admittance of the circuit is

$$Y_{even} = j\tan\theta_1 / Z_{01} + j\frac{Z_{02}\tan\theta + Z_{0e}\tan\theta_2}{Z_{02}\left(Z_{0e} - Z_{02}\tan\theta_2\tan\theta\right)} \quad (1)$$

When the structure is excited by the odd-mode, the corresponding equivalent circuit is shown in ***Figure 2b***. The odd-mode admittance of the circuit is

$$Y_{odd} = -j\cot\theta_1 / Z_{01} + j\frac{Z_{02}\tan\theta + Z_{0o}\tan\theta_2}{Z_{02}\left(Z_{0o} - Z_{02}\tan\theta_2\tan\theta\right)} \quad (2)$$

The transmission coefficient of the total network is obtained by

$$S_{21} = \frac{Y_0\left(Y_{odd} - Y_{even}\right)}{\left(Y_0 + Y_{even}\right)\left(Y_0 + Y_{odd}\right)} \quad (3)$$

where Y_0 is the characteristic admittance of the input and output transmission lines.
When $|S_{21}|=0$, the transmission zeros meet the following requirement:

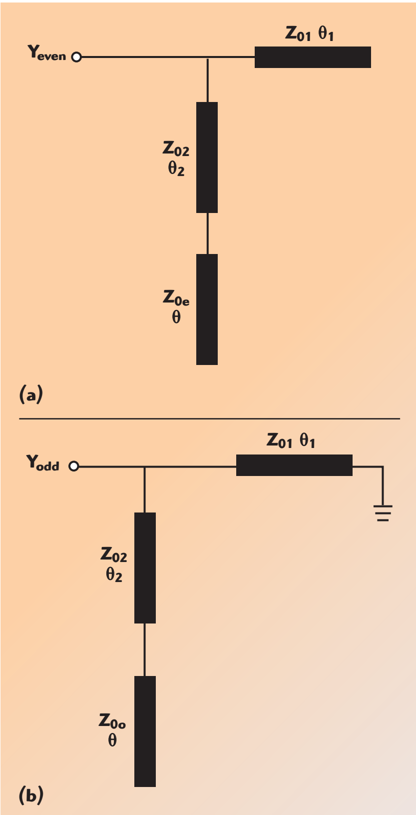
$$Y_{even} = jB_1 = Y_{odd} = jB_2 \quad (4)$$

where

$$B_1 = \tan\theta_1 / Z_{01} + \frac{Z_{02}\tan\theta + Z_{0e}\tan\theta_2}{Z_{02}\left(Z_{0e} - Z_{02}\tan\theta_2\tan\theta\right)} \quad (5a)$$

$$B_2 = -\cot\theta_1 / Z_{01} + \frac{Z_{02}\tan\theta + Z_{0o}\tan\theta_2}{Z_{02}\left(Z_{0o} - Z_{02}\tan\theta_2\tan\theta\right)} \quad (5b)$$

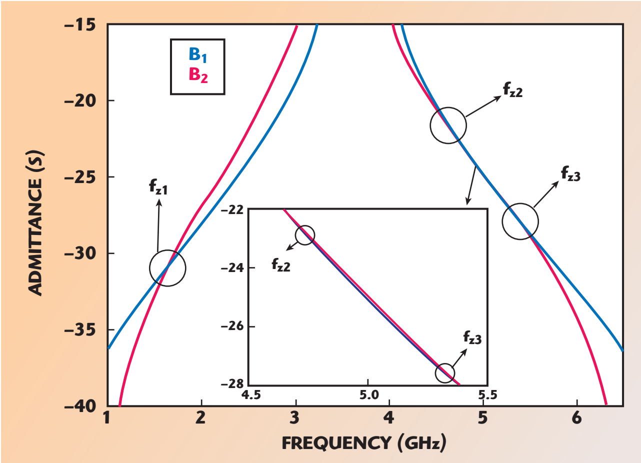
As shown in ***Figure 3***, the curves of reactance B_1 and B_2 have three common points, which means that Equation 4 has three answers. The locations of the three points in ***Figure 4*** (Z_{01}=160 ohms) are nearly the same as these three transmission zeros. When increasing the characteristic impedance Z_{01}, the position of the first zero (f_{z1}) is almost the same, while the distance between f_{z2} and f_{z3} becomes longer. In fact, the locations of f_{z2} and f_{z3} both change slightly and, the rejection between these two frequencies decreases with increasing Z_{01}. Z_{01} should be chosen to achieve the desired stopband rejection based on the analysis and observations.



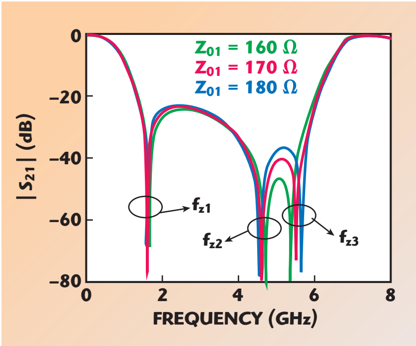
▲ *Fig. 2 Equivalent circuit. Even-mode (a). Odd-mode (b).*

Frequency response is also affected by the coupled line. The coupling factor is defined as K = (Z_{0e}- Z_{0o}) / (Z_{0e}+ Z_{0o}). As shown in ***Figure 5***, the first transmission zero (f_{z1}) moves to the lower side with an increase in K, resulting in a sharper cutoff frequency and a smaller circuit size. The second zero (f_{z2}) moves to the lower side while the third zero (f_{z3}) moves to the higher side, increasing the distance between f_{z1} and f_{z2} and between f_{z2} and f_{z3}. This provides a broader stopband, but with decreased rejection between the transmission zeros, especially between f_{z2} and f_{z3}.

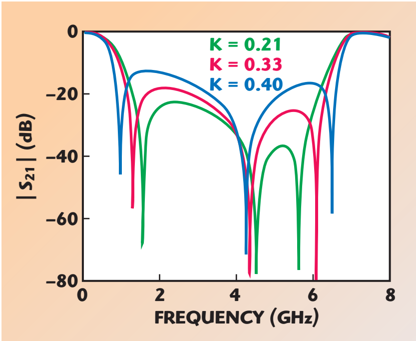
Analysis of the final design predicts very good performance (see ***Figure 6***). The 20 dB stopband width is very broad, ranging from almost 1 to 6 GHz and rejection is high. In addition, the cutoff skirt is sharp, improving the lowpass response.



▲ *Fig. 3 The curves of B_1 and B_2 (Z_{01} = 160 Ω, Z_{02} = 40 Ω, Z_{0e} = 35 Ω, Z_{0o} = 23 Ω, θ = 22.2° at 1 GHz, $θ_1$ = 24.5° at 1 GHz, $θ_2$ = 2° at 1 GHz).*



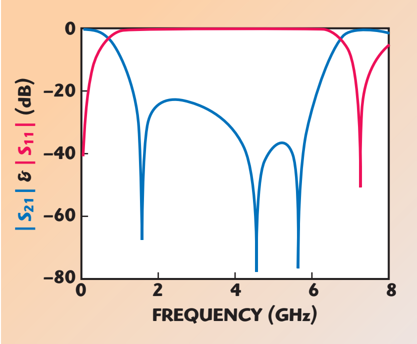
▲ *Fig. 4 $|S_{21}|$ of the structure with different characteristic impedances (Z_{01}). (Z_{02} = 40 Ω, Z_{0e} = 35 Ω, Z_{0o} = 23 Ω, θ = 22.2° at 1 GHz, $θ_1$ = 24.5° at 1 GHz, $θ_2$ = 2° at 1 GHz).*



▲ *Fig. 5 $|S_{21}|$ of the structure with different coupling factors (K). (Z_1 = 180 Ω, Z_2 = 40 Ω, θ = 22.2° at 1 GHz, $θ_1$ = 24.5° at 1 GHz, $θ_2$ = 2° at 1 GHz).*

FABRICATION AND MEASUREMENT

An LPF was fabricated on a substrate with a thickness of 1.5 mm and relative dielectric constant of 2.65 (see ***Figure 7***). The circuit dimensions are: w_1 = 0.15 mm, l_{11}= 15.6 mm, l_{12} = 5.56 mm, w_2 = 5.5 mm, l_2 = 1.5 mm, w_3 = 8 mm, l_3 = 16.5 mm and s = 0.16 mm. The overall circuit size is 34 × 16 mm (0.08λg × 0.04λg, where λg is the guide wavelength at f_c). The filter's size is much smaller than the sizes in references 13-15, which is very compact so as to meet the requirement of miniaturization.

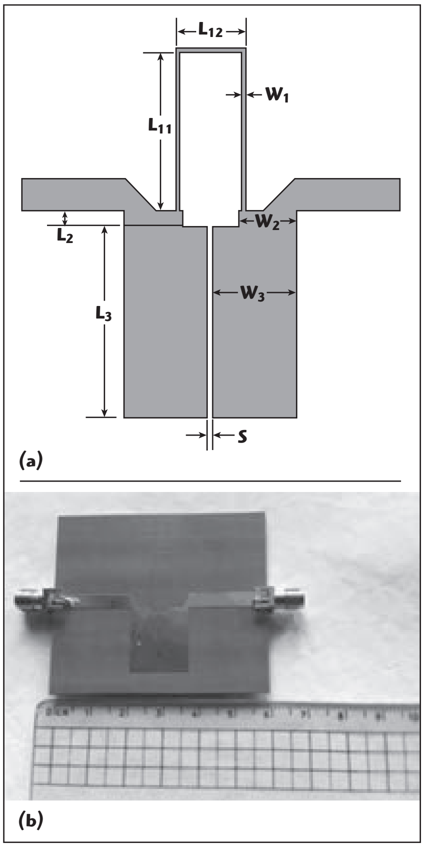


▲ *Fig. 6 $|S_{11}|$ and $|S_{21}|$ of the structure. (Z_1 = 180 Ω, Z_2 = 40 Ω, Z_{0e} = 35 Ω, Z_{0o} = 23 Ω, θ =22.2° at 1 GHz, $θ_1$ = 24.5° at 1 GHz, $θ_2$ = 2° at 1 GHz).*

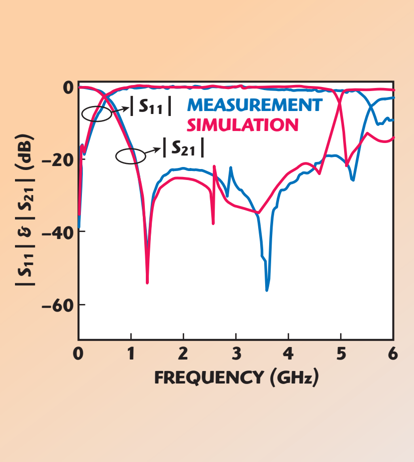
Simulations with Agilent Technologies' Advanced Design System (ADS) agree closely with measurements using an Agilent 8510C vector network analyzer (see ***Figure 8***). The measured 3 dB passband extends from DC to 0.54 GHz. Three transmission zeros are located at 1.3 GHz with S_{21} = -50 dB, at 3.57 GHz with S_{21} = -56.6 dB and at 5.22 GHz with S_{21} = -26 dB. Rejection is greater than 20 dB from 1.06 to 5.3 GHz (a fractional bandwidth of 133 percent). The roll-off rate is 61.8 dB/GHz (attenuation: 3 dB at 0.54 GHz and 50 dB at 1.3 GHz).

CONCLUSION

A compact lowpass filter with three transmission zeros using a tri-section impedance hairpin resonator is described. By tuning the transmission line parameters, three zeros are used to expand the stopband, sharpen the cutoff frequency and deepen the rejection. The measured results agree with the simulations and show that this filter has very attractive features: sharp transition, a very compact circuit size and a wide stopband. ■



▲ *Fig. 7 Layout (a) and photograph (b) of the test circuit.*



▲ *Fig. 8 Measurement versus simulation.*

ACKNOWLEDGMENTS

This work has been supported by the National Natural Science Foundation of China under grants (61101052, 60873020, and 61070063), Zhejiang Provincial Natural Science Foundation under grants (Y1110297, Z1080702) and the Foundation of Zhejiang Sci-Tech University under grants (1004811-Y).

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Noise on Vcc for Serial Data Communications

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The supply voltage (Vcc) specification is a key parameter for almost all integrated circuits' (IC) datasheets. Unless its requirements are met there is no way to know if the remaining IC specifications will be valid. Therefore before specifying the operational supply voltage range of a device, designers, verification and quality engineers use the results of extensive testing to make sure the IC meets all the specification requirements within the tested Vcc voltage range. With the exception of the power supply rejection ratio (PSRR) specification of some analog and RF ICs, what is often not specified or ignored is the immunity of the IC to noise and spurs riding on its supply voltage.

IC design verification testing is typically done using clean lab power supplies and well shielded power supply cables to baseline performance under ideal conditions. Yet those conditions are almost never the operating conditions and environment of the IC in real life circuits and applications. As a result, almost all IC manufacturers provide reference designs and board layout practices to minimize noise on Vcc. In the end, the responsibility of providing clean Vcc to the IC is placed on the board designer whose specific application and operating environment may require taking additional precautions beyond datasheet reference design and application circuit recommendations. Unless specific information is provided by the IC manufacturer about the noise immunity of the device, the board designer may be forced to overdesign the support circuitry which, given space and cost constraints, is not always possible. The designer may have to make educated guesses or be forced to plan for an additional board spin to verify there are no immunity issues. The additional work inevitably can delay product release and increase development cost.

Although the concept of noise on Vcc is nothing new, advancements in IC die technology over the past decade have introduced new challenges. Mainly through die shrinking, higher levels of integration and lower supply voltages have been achieved resulting in reliability, cost and performance benefits such as reduced parts count, improved power efficiency and thermal performance. In the meantime, the IC board level designer has new design challenges introduced by the lower supply and I/O voltage. What was once an insignificant amount of noise on the Vcc of a 3.3 or 5 V circuit can no longer be ignored on a 1.2 V IC due to lower noise margins. Furthermore, the integration of digital, analog and RF functionalities on a single IC operating at ever higher data rates can generate higher internal noise, making the low voltage and high speed device more susceptible to added external noise and ripple on Vcc.

Noise on Vcc impacts a wide range of applications and circuits. In transceivers, receiver sensitivity and transmitter spurious emission performance may degrade due to noise on the

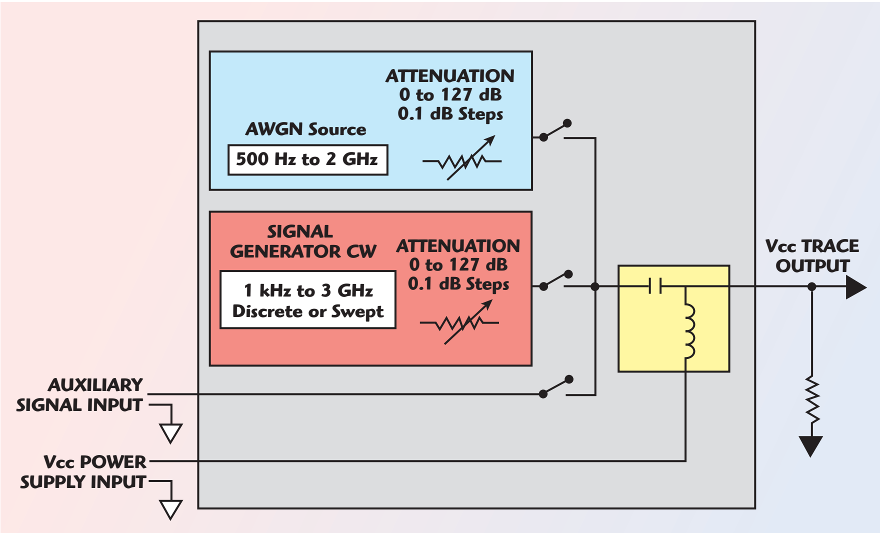
Vcc of an analog-to-digital converter (ADC) and a digital-to-analog converter (DAC). Similarly, for clocking and local oscillator (LO) circuits with PLL/VCOs and PLL/VCXO/XOs used in transceiver designs, noise on Vcc can generate clock jitter and LO phase noise impacting spurious emissions and receiver sensitivity. In high speed serial data communication circuits the clock jitter caused by noise and spurs on the Vcc of the PLL/XO circuitry can cause data jitter potentially degrading BER performance.

In this application note, we look at a high speed data/clock buffer IC, DUT, and the effect noise on its Vcc has on overall system performance. In characterizing system performance, BER testing is used to measure the system performance and is supplemented by eye diagrams as a visual tool. The injection of additive white Gaussian noise (AWGN) and CW tones into the Vcc path of the DUT is accomplished using Noisecom's JV9000 unit. The unit intakes a clean power supply voltage and injects CW tones and/or AWGN signal in a controlled manner with 0.1 dB precision (see ***Figure 1***).

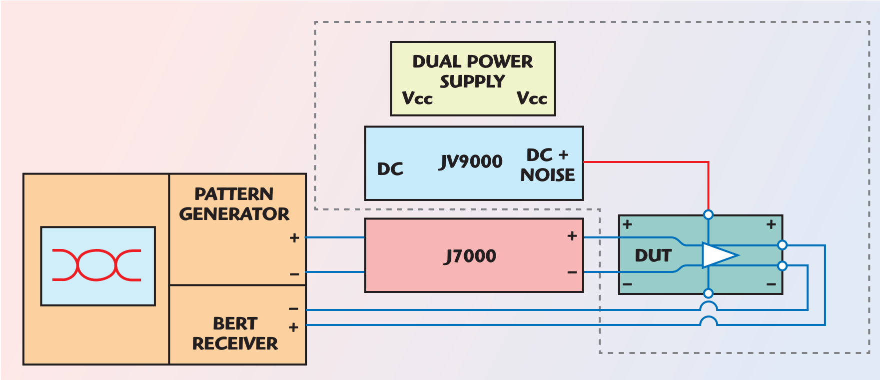
We also use the jitter generator to degrade the BER performance of the channel. The unit injects AWGN noise on serial data which in turn causes random jitter, Rj. The jitter is created during the transitions from a 0 to a 1 or from a 1 to a 0 when the noise added to the signal during this transitional period causes the receiver to interpret the timing of the transition incorrectly. The resulting timing uncertainty is called jitter, and in case of AWGN it is random. The unit's high crest factor output allows the generation of realistic peaks that makes it ideal for BERT testing and can be used as a random jitter source for various serial data bus applications, including PCI Express Gen I & II, Serial ATA, Fiber Channel, 10, 40, and 100 GB Ethernet (802.3).

In the test set up, BERT's pattern generator is used as a high speed differential serial data source and the BERT output is connected to the J7000. Note that the J7000 is operating in bypass mode (no noise added) for the initial part of the test. It is turned on for the second phase of our test to degrade the serial link performance by introducing random jitter. The output of the J7000 feeds the DUT, the output of the DUT then drives the BERT detector input, looping the signal back into the BERT receiver. The Vcc of the DUT comes from the JV9000, also initially configured with all its noise and spur signals turned off, providing a clean supply voltage to the eval board for baseline testing. A block diagram of the set up is shown in ***Figure 2***.

In order to mimic how an IC designer or verification engineer would test for immunity of the IC to noise and spurs on its Vcc, bypass capacitors of the DUT eval board were removed; enabling the tester to see which frequencies riding on the Vcc have the greatest impact on system performance. Before presenting the test procedure and results it is important to note that for actual IC performance verification testing, the designer or test engineer would likely use a special fixture, free of parasitic effects of an evaluation board, in order to measure the raw performance of the IC. In this test set up, it is very likely that parasitic effects of the eval board play a role in the outcome. In fact the test set up may be closer to how a circuit board designer would test the noise immunity of a circuit given a particular board layout and its parasitics.



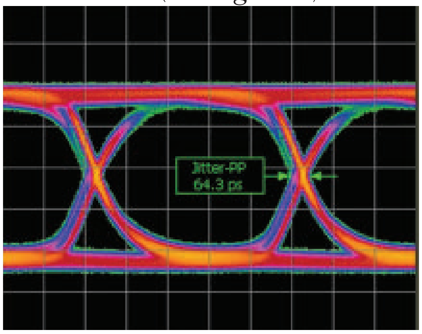
▲ *Fig. 1 JV9000 block diagram.*



▲ *Fig. 2 The test set-up diagram.*

TEST PROCEDURE

1) Both JV9000 and J7000 noise and spur sources are turned off to establish baseline performance with BER = 0 (see ***Figure 3***).



▲ *Fig. 3 "Clean" error free channel BER = 0 (J7000 & JV9000 both off, not injecting noise).*

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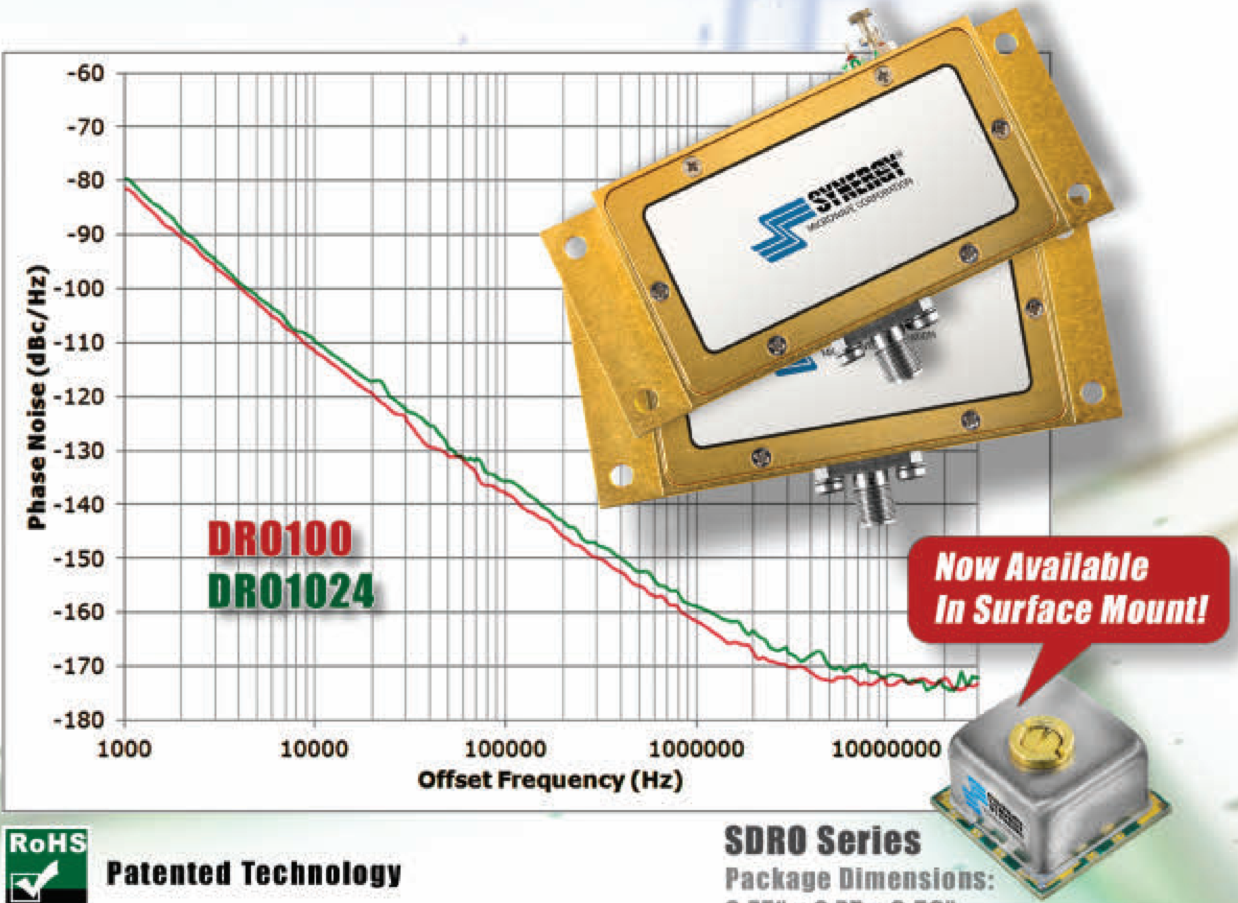

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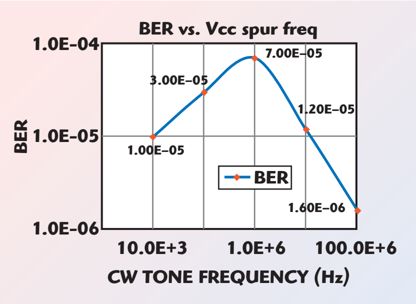
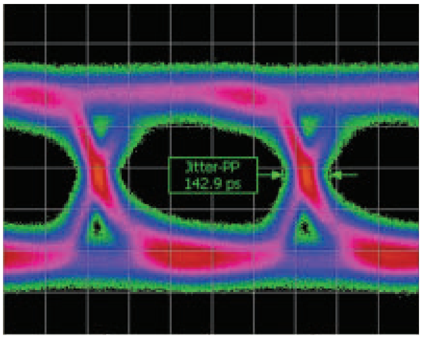


▲ *Fig. 4 BER vs. CW (spur) frequency.*

2) JV9000 AWGN path is turned on and the injected noise level is increased slowly as the BER is monitored.
3) JV9000 AWGN noise source is turned off and CW tones of 10 kHz, 100 kHz, 1 MHz, 10 MHz and 100 MHz are injected one at a time to see how the BER changes at each frequency. Note that CW coupling from the Vcc to the data outputs will cause deterministic jitter, Dj.
4) And finally, step 3 is repeated with the AWGN noise turned on to see the combined effect AWGN and CW spurs have on BER performance.
5) We then turn off all broadband noise and CW signals on the JV9000 and degrade the channel BER to 1E-07 by injecting AWGN on to the data lines using the J7000 jitter generator and creating random jitter, Rj. The same tests that are performed at steps 2, 3 and 4 are repeated on the 1 E-7 BER channel to see the combined impact of AWGN noise and spurs on Vcc have on the already degraded channel.

The results of the tests can be summarized by noting that when the initial channel BER is 0 and the AWGN noise and CW tones injected onto the Vcc are at the maximum standard levels (0 dBm tones at the mentioned frequencies and 0 dBm total AWGN power from 500 Hz to 2 GHz) we could not introduce any significant bit errors even though the added noise could easily be seen on the eye diagram. So there is evidence of the existence of noise leaking from the Vcc pin to the data output pins but there is no effect on BER performance. However, when the BER is degraded to 1 E-07 by injecting AWGN noise onto the data lines, creating random jitter, the added noise and spurs do



▲ *Fig. 5 BER = 1 E-07 (J7000 injecting AWGN noise –10 dBm, JV9000 off).*

TABLE I

SUMMARY OF THE DATA TAKEN WHEN THE BASELINE CHANNEL PERFORMANCE IS 1 E-07

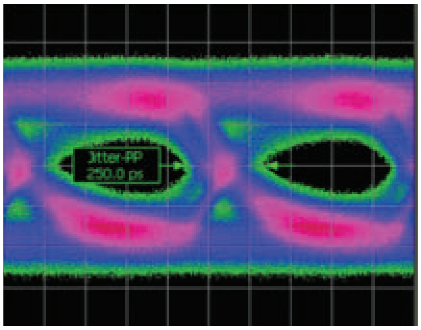
Noise Source	BER
AWGN	2.5 E-07
CW – 10 kHz	1.0 E-05
CW – 100 kHz	3.0 E-05
CW – 1 MHz	7.0 E-05
CW – 10 MHz	1.2 E-05
CW – 100 MHz	1.6 E-06
AWGN + 1 MHz	9.0 E-05

play a very significant role where the BER is now degraded from 1 E-07 up to 7 E-05 when a 1 MHz CW tone is injected. It is also worth noting that switching power supplies generally switch at anywhere from 100 kHz to a few MHz, so an IC's Vcc noise immunity at these low frequencies is important in most designs.

The test results are presented in a tabular format in ***Table 1*** where the channel BER is baselined at 1 E-07. For a graphical view of how the DUT responded to various injected frequencies on its Vcc see ***Figure 4***.

Injecting broadband noise (AWGN) from 500 Hz to 2 GHz into the Vcc of the IC (DUT) increases the system BER to just over twofold. However, when the injected power is concentrated at one frequency (CW) then impact is much greater. As the frequency of the injected constant power tone into the Vcc pin of the IC changes so does the impact on the receiver. We see a BER resonance at around 1 MHz, where the BER degrades the most, when a CW tone at 1 MHz is injected.

Figures 3, 5 and 6 are eye diagrams for various test conditions. Figure 3 shows the eye diagram when BER=0 and all noise sources are turned off. ***Figure 5*** shows the eye diagram BER=



▲ *Fig. 6 BER = 9 E-05 (J7000 injecting AWGN noise, JV9000 injecting AWGN and 1 MHz CW).*

1 E-07 when only J7000 is injecting noise (JV9000 noise sources are off). ***Figure 6*** shows the eye diagram for the received signal under worst case spur and noise conditions (1 MHz CW + AWGN) when the baseline channel performance is BER is 1E-07.

CONCLUSION

As the Vcc levels and IC logic levels drop and the integration of multiple functions in a mixed signal environment generates more noise within the IC, the need to test for impact of noise and spurs on Vcc on the IC operation becomes increasingly important. The goal of this application note is to show how IC performance verification engineers and circuit designers can characterize the operation of an IC or circuit in the presence of noise and spurs on Vcc. The test results show that an IC can be more sensitive to noise and spurs riding on its Vcc at certain frequencies. Additionally, the combination of data jitter and Vcc noise may impact the receiver performance very differently than what one may surmise from individual independent tests. Taking it a step further, the testing performed in accordance with this application note is also necessary when an IC designer, an application engineer or a circuit designer needs to decide what filtering is required on Vcc for optimum IC performance.

There are many home-made solutions adopted to perform these tests. When multiple test stations need to be built or design teams in different geographic regions need to work together, an integrated test set up allows test and verification engineers to perform their testing in a repeatable and controlled manner. There are also the savings associated in programming, bench space, set-up and system verification, as well. ■

Procedure for how to use the N, TNC and 7/16 Push-On male. Push-On Connectors mate with any standard female connector of the same connector style.

1. Convert your standard Assembly into a Push-On Assembly using the Nf to Nm Push-On Adapter.

2. Put your fingers firmly onto the knurls of the “Lock Nut”.

3. Push “Lock Nut” forward and engage the Push-On end of the Adapter with the mating female. Back nut must be released.

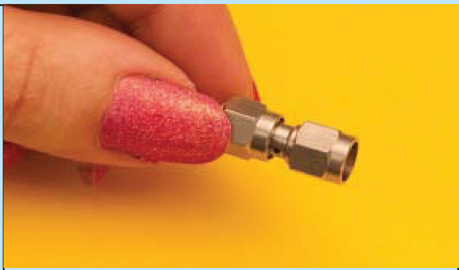
4. The Connection has been completed, easy and fast. The connector has been locked on safely.

5 . To unlock (when “Back Nut” is in unlocked mode) push the “Lock Nut” forward and stop reverse movement by setting your fingers onto the “Back Nut”.

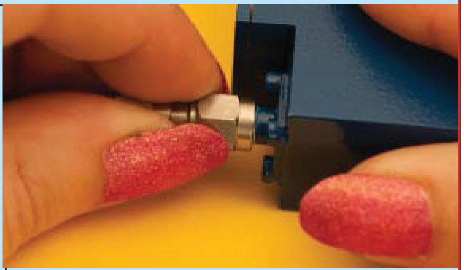
6. Keep fingers on “Back Nut” to ensure that “Lock Nut” cannot slide back and pull the connector off.

Procedure for how to use the SMA male and SMA female Push-On connectors. SMA Push-On Connectors mate with any standard connector of the same but opposite connector style.

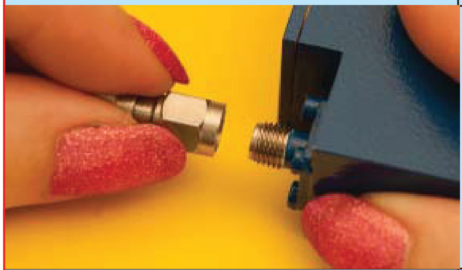
1. Convert your standard cable assembly into a Push-On Assembly by threadening the standard female side of the adapter onto the male connector of the assembly.



2. Your standard SMA male cable assembly is converted into an SMA male Push-On Assembly.



3. Just slide the Push-On SMA male Connector onto any standard SMA female. The connection is securely completed in seconds.



4. To disconnect, just pull the connector off.

Spectrum Elektrotechnik GmbH

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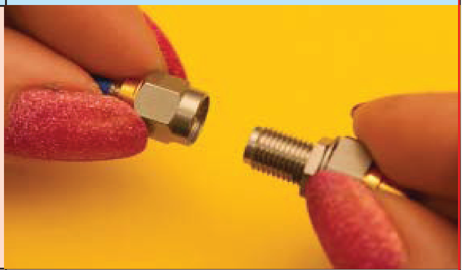
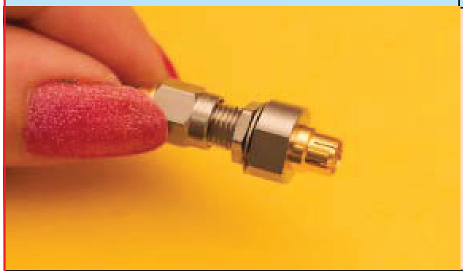
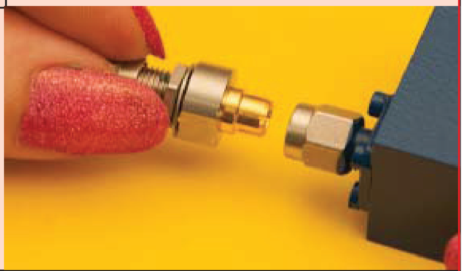


1. Convert your standard cable assembly into a Push-On Assembly by threadening the standard female side of the adapter onto the male connector of the assembly.



2. Your standard SMA male cable assembly is converted to a Push-On SMA female Cable Assembly.

3. Just slide the Push-On SMA female Connector onto any standard SMA male. The connection is securely done in seconds.

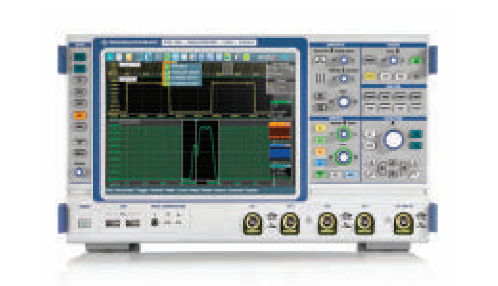


4. To disconnect, just pull the connector off.

Easy and Powerful Oscilloscopes

Rohde & Schwarz
Munich, Germany

R&S®RTE digital oscilloscopes offer fast and reliable solutions for everyday test and measurement tasks such as embedded design development, power electronics analysis and general debugging. Users benefit from features such as a high sampling rate of 5 Gsample/s, a high acquisition rate of one million waveforms per second and good signal fidelity. A comprehensive set of measurement and analysis tools delivers fast results, and the high resolution touchscreen makes the oscilloscope very easy to use.



▲ *Fig. 1 The R&S RTE is available with two or four channels and a bandwidth of 200 MHz, 350 MHz, 500 MHz or 1 GHz.*

Shown in ***Figure 1***, the R&S RTE is available with two or four channels and a bandwidth of 200 MHz, 350 MHz, 500 MHz or 1 GHz. It handles everyday test and measurement challenges quickly, accurately and easily, providing time domain, logic, protocol and frequency analysis in a single box.

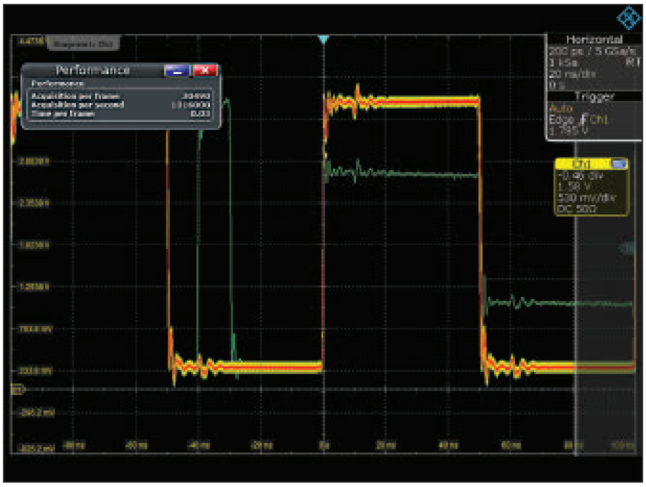
CONFIDENT MEASUREMENT

The main purpose of a digital oscilloscope is to measure electrical signals. This can be simple measurement of signal characteristics such as frequency and rise and fall times or complex analysis such as determining the switching loss of a switched-mode power supply. The most important factor for users is that they can rely on the quality of measurement results.

The more details an oscilloscope can show, the higher the probability that the user will be able to analyze signal faults or important events. As a prerequisite, the oscilloscope must have a high time resolution that is based on the sampling rate. In addition, many applications also require long record lengths, for instance for analyzing the data content of serial protocols.

In order to maintain a high sampling rate even for long signal sequences, the oscilloscope requires a deep memory. The R&S RTE offers a combination of a sampling rate of 5 Gsample/s at a memory depth of 10 Msample per channel. This can be optionally expanded to 50 Msample per channel.

The less often signal faults occur, the longer it can take to detect them. This makes a high acquisition rate critical. The core of the new oscilloscope is an ASIC that was especially designed for parallel processing. As a result, the R&S RTE can acquire, analyze and display more than one million waveforms per second without a special acquisition mode. The high acquisition rate makes it possible to find signal faults faster and more reliably, effectively shortening debugging time (see ***Figure 2***).



▲ *Fig. 2 The R&S®RTE finds rare signal faults very quickly thanks to its high acquisition rate of one million waveforms per second.*

Also, the highly accurate Rohde & Schwarz digital trigger system provides precise results. This system determines when a trigger condition is met by directly analyzing the digitized signal with 500 fs resolution independently of the current sampling rate. The result is very low trigger jitter (< 1 ps RMS) and high measurement accuracy. Thanks to the digital trigger system, the trigger hysteresis can be adjusted to the signal quality. This ensures, for example, stable triggering even on extremely noisy signals.

The single-core A/D converter with more than seven effective bits (ENOB) almost completely eliminates signal distortion. The input sensitivity of 1 mV/div without any bandwidth limitations ensures that low-amplitude signals can also be measured with a high degree of accuracy. The main features of the new oscilloscope are listed in ***Table 1***.

MORE FUNCTIONS, FASTER RESULTS

The R&S RTE includes many integrated measurement tools for detailed signal analysis. They range from simple cursor functions to mask tests to complex mathematical operations. Many measurement functions such as histograms, spectrum display and mask tests are hardware-implemented. This ensures a very responsive scope and a high acquisition rate. Furthermore, statistically conclusive measurement results are available fast.

In addition to the automatic measurements that are customary for digital oscilloscopes, the R&S RTE offers the QuickMeas function. QuickMeas simultaneously displays the results of several measurement functions, which users select according to their needs. A toolbar at the upper edge of the screen provides fast access to this function.

Mask tests reveal whether a specific signal lies within defined tolerance limits and use statistical pass/fail evaluation to assess the quality and stability of a device under test. Mask creation in the R&S RTE is simply a matter of pressing a few buttons. The high acquisition rate ensures that mask violations are detected rapidly and reliably. Signal anomalies and unexpected results are easy to identify by stopping the measurement if the mask is violated.

▲ *Fig. 3 Together with the R&S HZ-15 near-field probe set, the R&S RTE oscilloscope is ideal for EMI debugging during development.*

Where does the interference pulse in the signal come from? What caused the loss of a data bit? The real cause of a problem can often only be found by looking at the history of a signal sequence. The R&S RTE history function always provides access to previously acquired waveforms. This enables users to later analyze in detail the measurement data stored in the memory.

The FFT function of the new oscilloscope makes spectral analysis easy. The high acquisition and postprocessing rate conveys the impression of a live spectrum, and operation is as simple as entering the center frequency, span and resolution bandwidth. Using the persistence mode, rapid signal changes, sporadic signal interference and weak superimposed signals can easily be made visible.

The ability to overlap FFT frames enables the R&S RTE to detect intermittent signals such as pulsed interferers. This powerful FFT function plus the high dynamic range and input sensitivity of 1 mV/div make the oscilloscope ideal for tasks such as EMI debugging of electronic circuits during product development (see ***Figure 3***).

TABLE I

R&S®RTE AT A GLANCE

Bandwidth	Analog Channels	Sample Rate	Memory Depth	Acquisition Rate	ENOB (ADC)	MSO (R&S®RTE-B1 Option)	Display
200 MHz, 350 MHz, 500 MHz, 1 GHz (upgradable)	2/4 channels	5 Gsample/s per channel	10 Msample per channel (optional 50 Msample)	> 1 000 000 waveforms/s	>7	16 digital channels 5 Gsample/s and 100 Msample per channel	10.4", color, touch, 1024 × 768 pixel, multiple grids

EASY TO USE

Thanks to the high resolution 10.4" XGA touchscreen, users can intuitively perform their daily test and measurement tasks. For example, users can simply 'drag & drop' waveforms to arrange them on the screen. The screen can flexibly be divided into several diagrams according to the user's requirements. Real-time miniature views of the signals on the edge of the screen allow users to always see what is happening.

The R&S RTE controls are color-coded and indicate which channel is currently active. The color coding corresponds to the signal display on the screen. Dialog boxes are opened as semi-transparent overlays over the active waveforms, which maintain their full size. Users can adjust the transparency of dialog boxes as required. Signal flow diagrams and forward and back buttons in the dialog boxes simplify navigation, while the configurable toolbar provides fast access to frequently used functions.

Users simply select a tool and apply it to their waveform. Tools that have a similar function are grouped together. In addition to the standard tool suite, the R&S RTE features many highlights such as fingertip zoom, which allows users to quickly view signal details by moving their finger or mouse along the signal. Another example is the SaveSet tool which enables users to quickly load different configurations. To select the right configuration, the user simply swipes a screenshot.

DEDICATED APPLICATIONS

In addition to the standard functionality, the R&S RTE offers various optional application solutions, including trigger and decoding options for serial buses (such as I2C, SPI and CAN) and a power analysis option. The logic analysis capability is essential for analyzing digital components of embedded designs. The R&S RTE-B1 mixed signal option can be added to any base unit and offers 16 additional digital channels with a sampling rate of 5 Gsample/s and a memory depth of 100 Msample per channel. It is possible to decode up to four serial or parallel buses simultaneously.

A comprehensive portfolio of high-quality active and passive probes is available for the R&S RTE to perform measurements in common voltage and current ranges. One of the highlights of the active probes is a micro button on the probe tip. This button can be used to perform a variety of functions such as run/stop, autoset and adjust offset on the oscilloscope. The highly precise R&S ProbeMeter DC voltmeter (measurement error: ±0.1 percent) is integrated into the active probe and provides a convenient means of answering questions such as: "Is the supply voltage correct?" and "Is DC voltage superimposed?"

VENDORVIEW

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Handheld Mobile Radio PA Solution

MACOM
Lowell, MA

Despite radio standard evolution, interoperability with older or other modulation formats/services remains a requirement, and the incorporation of these bands and standards into a single radio system poses a difficult design challenge. The simplest solution is to integrate multiple single band radios, but this can be impractical. A better solution is a single broadband radio, one capable of multiple bands and waveforms; but this places difficult restrictions on the radio designer requiring multi-band, multi-mode operation without compromising cost, size, or efficiency – a significant challenge.

Because the RF power amplifier dominates overall radio power consumption, the amplifier is often the key to achieving the design goals. The advent of Gallium Nitride (GaN) technology opens a practical path to next generation, flexible, future-proof, and frequency agile architectures for handheld radios. Radios based on these design platforms are both cost effective and configurable for land mobile radio standards deployed worldwide today, while being adaptable for the standards of tomorrow.

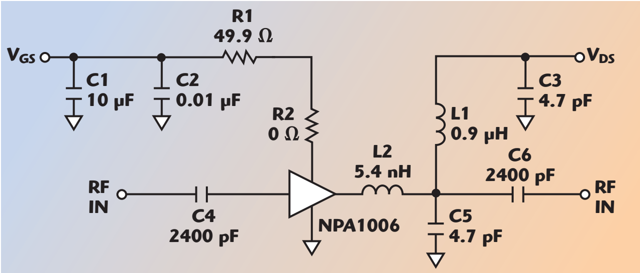
Typical handheld radio PA design requirements include:

- Battery packs of 4.5 to 12 V, usually around 2 amp-hours
- Moderate output power, 1 to 10 W at the PA, 1 to 8 W at the antenna
- RF power control for battery conservation, -6 to -10 dB reduction typical
- ALC to maintain constant output power
- High PA efficiency to extend operating time, reduce battery size and weight
- 50 Ω load impedance but must tolerate moderate VSWR from broadband antennas
- Small area and volume, low cost

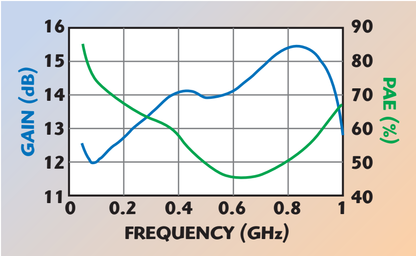
THE NPA1006 HANDHELD SOLUTION

The NPA1006 is an integrated GaN power amplifier that offers 10 W minimum output power from a 28 V supply continuously from 20 MHz to 1 GHz. The package is a low profile overmolded plastic 6×5×1 mm surface mount (SMT) package well suited to the space limitations of a handheld product. External support circuitry is minimal, requiring only a few passive lumped elements on the output to improve the high frequency performance and provide proper depletion-mode GaN transistor biasing.

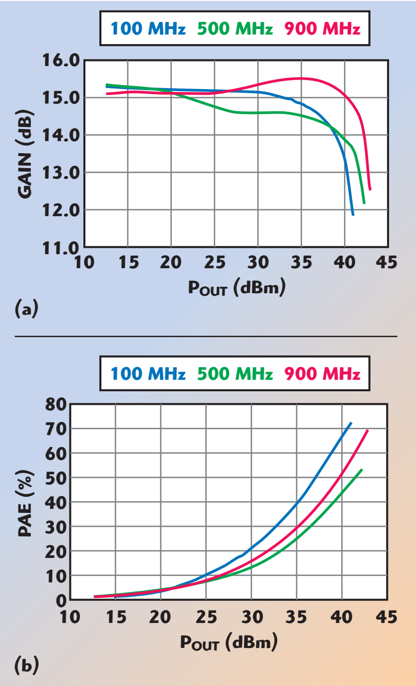
The NPA1006 includes internal input-matching providing a near 50 Ω input impedance. The output of the PA is unmatched, but a simple matching network provides a broadband match to 50 Ω, as seen in ***Figure 1***. Combining high operating voltage and low intrinsic capacitance, the transistor works well natively from low to mid band for both large and small signal conditions. At high frequencies the simple external match of the applications circuit maintains good power and efficiency through 1 GHz. The external output match can also be optimized for narrower band performance if desired (such as VHF/UHF or UHF/800 MHz only).



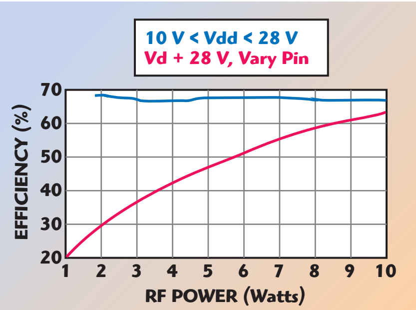
▲ *Fig. 1 Matching network for the NPA1006 provides a broadband match to 50 Ω.*



▲ *Fig. 2 Gain and PAE vs. frequency for NPA1006.*



▲ *Fig. 3 Gain (a) and PAE (b) vs. output power for NPA1006.*



▲ *Fig. 4 Efficiency using power control by adjusting input drive only (red) and adjusting both the input drive and the supply voltage (blue).*

Figure 2 shows broadband performance of the NPA1006 at 41 dBm (12.5 W) output power with power added efficiency (PAE) ranging from 50 to 85 percent. ***Figure 3*** shows both gain and PAE versus output power.

Targeting peak efficiency will provide the longest battery life for a portable radio. Using a battery plus DC-DC converter configuration for the power supply of the radio allows real-time adjustment of the amplifier supply voltage up or down as needed. For every combination of frequency, desired output power, and load VSWR there is an optimum supply voltage for best efficiency. The efficiency difference between using power control by adjusting input drive only, and the proposed configuration, which adjusts both the input drive and the supply voltage, can be significant. ***Figure 4*** contrasts these two approaches with the NPA1006 operating at 100 MHz.

By reducing both the drive and the supply voltage the efficiency remains well above 60 percent from under 2 W to more than 10 W as seen in the upper curve. Using drive reduction alone the lower red curve shows that the efficiency falls rapidly at low power levels. A variable supply voltage, intelligently controlled, can reduce or counter the effect of these factors while maintaining maximum performance. Thermally, the NPA1006 is an optimized device with a low 4.6° C/W thermal resistance.

The next generation of LMR radios must support both legacy and LTE modulation and frequency bands. While it is possible to continue to expand capability through stacked system blocks, the more efficient method takes advantage of software defined radio advances combined with broadband GaN based power amplifiers. These new systems provide ultimate flexibility supported by simple transceiver architectures.

VENDORVIEW

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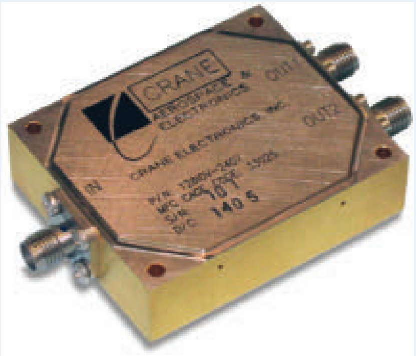

Ku-Band Iso-Divider

Crane Aerospace & Electronics Microwave Solutions Ku-Band Iso-Divider product line is designed for use in satellite applications. The Iso-Divider represents a marriage of the company's heritage space passive and space ferrite products. This unit combines the functions of high performance power dividers with ferrite isolators to provide a high isolation power divider solution, making the external isolators redundant, for satellite receiver applications, without introducing complex switch-based solutions. Integration of the two functions into a single package provides enhanced product reliability due to fewer external components, interconnects and transitions. Additionally, marrying the power divider and isolators in the same package allows the performance of the integrated unit to be carefully matched for better overall performance. The integration saves weight, and reduces external assembly and additional screening cost.

Crane has been able to achieve the full range of 10.7 to 14.8 GHz isolator performance while simultaneously maintaining excellent insertion loss. In the past, for optimum loss performance, this band has typically been broken into two segments. With over 20 years of experience designing and manufacturing both space qualified passive components and isolators, Crane successfully brings this product to the market.

Due to the integrated unit design being optimized, performance for insertion loss is held at 1.8 dB maximum. If separate components were utilized for the function, this performance would be over 2 dB. This provides a great improvement in receiver sensitivity for the overall system. Because of the unit integration, phase balance of ±5° maximum is maintained as well.

Future plans are for this product line to offer Iso-Dividers and Iso-Combiners in various configurations (4, 6, 8 ports). These versions will be developed and released as market demand is validated.

VENDORVIEW

Crane Aerospace & Electronics Microwave Solutions, Chandler, AZ (480) 940-1655, www.craneae.com/mw.

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EuRAD	€ 300	€ 100	€ 390	€ 130
2 Conferences				
EuMC + EuMIC	€ 630	€ 230	€ 830	€ 310
EuMC + EuRAD	€ 600	€ 220	€ 780	€ 290
EuMIC + EuRAD	€ 520	€ 210	€ 680	€ 280
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EuMC + EuMIC + EuRAD	€ 760	€ 330	€ 1000	€ 440

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EuMIC	€ 450	€ 150	€ 590	€ 200
EuRAD	€ 390	€ 130	€ 510	€ 170
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EuMC + EuMIC	€ 830	€ 310	€ 1080	€ 410
EuMC + EuRAD	€ 780	€ 290	€ 1020	€ 380
EuMIC + EuRAD	€ 680	€ 280	€ 880	€ 370
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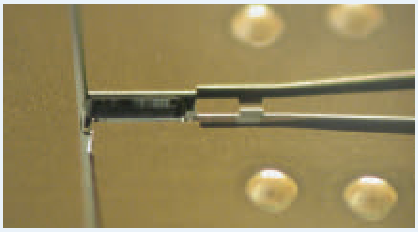
Date	**Time**	**Title**	**Location**	**No. of Days**	**Cost**	
Wednesday 8th October	09:00h - 18:20h	Defence, Security & Space Forum	Flavia	1	€ 10 for delegates (those registered for EuMC, EuMIC or EuRAD)	€ 50 for all others (those not registered for a conference)



Two-Thermistor Bolometer

There are many techniques for measuring microwave power, with different methods most suited to different applications. Some have advantageous features for portability, speed of response, or cost, and these are seen in many production power sensor systems. As a manufacturer of calibration systems, TEGAM chooses to research measurement methods that result in the lowest total uncertainty and clearest traceability to the SI units.

For many years, the two thermistor coaxial bolometer has been the arrangement providing lowest uncertainty with straightforward traceability. As TEGAM worked toward a 50 GHz, 2.4 mm calibration system, TEGAM engineers developed a new system that provides the uncertainty and traceability benefits of the thermistor bolometer, while using modern electronic manufacturing techniques to control reflections.

The key to a two-thermistor bolometer is splitting the RF power such that it divides between the two thermistors. The historic arrangement involves bifurcating the center conductor of an air line and then hanging thermistor beads in interruptions on the two sides of the center conductor. In the new design, an innovative launcher structure splits the incoming RF from a 1.85 mm air line to a pair of coplanar waveguides that mirror each other on opposite sides of a thin Quartz substrate. The launch design minimizes reflection caused by the split of RF power, and results in the use of a narrow planar conductor that is much more suitable for matching with a thermistor.

The new design is at the heart of the TEGAM 1510A and 2510A calibration standards. The units are temperature controlled coaxial RF feedthrough and terminating power transfer standards that enable the precise measurement of microwave power in the 10 MHz to 50 GHz frequency range.

VENDORVIEW

TEGAM,
Geneva, OH
(800) 666-1010,
www.tegam.com.

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International Symposium on Electromagnetic Compatibility

EMC 2014 SIPI 2014

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- Understanding the Importance of Bore Sight Antenna Measurements
- Smart Grid EMC Update
- EMC Issues for Unmanned Aircraft Systems
- Nanotechnology Applied to EMC
- Application of Reverberation Chambers
- Introduction to Medical EMC
- Recent Developments in EMC for Emerging Wireless Technologies
- Using CEM Modeling to Understand the Underlying Physics in EMC Problems
- Basic EMC Measurements
- EMC for Space Applications
- EMC Consultant's Toolkit
- Time Domain Site VSWR (sVSWR) Method above 1 GHz and Correlations to CISPR sVSWR
- Introduction to Spectrum Engineering
- Electromagnetic Time Reversal with Emphasis on Lightning and Fault Detection
- Details of the First Practical Method for Risk-Managing EMC (or Achieving EMC for Functional Safety)
- Understanding Recent EMC Standards from the IEEE
- System Level Approaches to Design and Test for EMI Control
- Introduction to Spectrum Engineering

There is much to be learned in the NEW embedded SI/PI 2014 Conference!

- Introduction to SI/PI Modeling and Design
- Advanced Topics in Signal and Power Integrity - Achieving 25 Gb/s to 100 Gb/s
- Essential Principles of Jitter

Read the details about these programs and the excellent symposium planned for you in the Advance Program posted on

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IEEE

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Silicon mmW Core IC Solutions

Visit Anokiwave's new website to learn about how its silicon mmW Core IC Solutions enable next generation Radio, Radar and AESA applications. Discover Anokiwave's AESA expertise, SATCOM design successes, and pioneering automotive radar solutions. Explore the company's growing standard product lineup as well. Visit www.anokiwave.com today to see how its mmW solutions are enabling a new world!

Anokiwave
www.anokiwave.com

CST Optimization Tools

VENDORVIEW

CST STUDIO SUITE® has parameterization and optimization tools that allow engineers to get the most out of their devices. The new optimization page on the CST website describes the optimization process, detailing the use of local and global optimizers and its integration into the electromagnetic design workflow. Using optimization tools, users can find the parameters which fulfill their desired goal. To find out more, visit the CST website: www.cst.com/Optimization

CST
www.cst.com/Optimization

RF Academy

VENDORVIEW

National Instruments announced that it has launched the RF Academy at ni.com/rf-academy. It contains tutorial videos and application notes for anyone working in RF and wireless – from students to veterans. The RF Academy is where you can watch whiteboard-style tutorials and "how-to" videos as well as read in-depth application notes. Whether you're a seasoned engineer looking to solve new RF challenges or a new engineer hoping to understand the fundamentals, NI can help you.

National Instruments
www.ni.com/rf-academy

Millimeter-wave Store

VENDORVIEW

SAGE Millimeter Inc. announced the launch of its industry-first online store for millimeter-wave components up to 170 GHz. This new tool offers millimeter-wave engineers a convenient method to check product datasheets and stock quantities. Currently, the online store carries a selection of standard products including waveguide to coax adapters, directional couplers, detectors, Faraday isolators, waveguide taper and mode transitions, bulkhead adapters, passive multipliers and a variety of antenna. More products will be added soon.

SAGE Millimeter Inc.
www.sagemillimeter.com

New Website

VENDORVIEW

AR has made numerous changes to enhance both its corporate and RF/Microwave Instrumentation website by giving it a more modern look and feel, while offering easier navigation and more comprehensive information. AR's menu system and flash spotlights have been redesigned to work with various touch screen tablets and mobile devices and enhanced streamlining of code makes its menus much more search engine friendly, and easier to read. Please check out the newly redesigned corporate website at: www.arworld.us or the AR RF/Microwave Instrumentation one at: www.arww-rfmicro.com/html/00000.asp.

AR
www.arworld.us

Microwave and RF Switches

Logus Microwave, a supplier for switches in Unmanned Aerial Vehicles, recently revamped its website. The company's UAV ultra-light, high reliability switches are the cutting edge in design for our nation's Defense, Homeland Security, Real Time Weather Data and Surveillance Programs. Logus offers complete custom designed switches as well as the Logus standards of SPDT, DPDT, SP3T and DP4T including stacked and ganged Waveguide Switches.

Logus Microwave
www.logus.com

Redesigned Website

VENDORVIEW

Pasternack launched its new website which boasts best-in-class site search functionality, one-page checkout and an updated user-friendly interface. The new site is the first major redesign since the company's 2012 website overhaul. Most noticeable to the user is the simplified, stripped down look and feel of the new homepage. Pasternack's main objective was to provide engineers and buyers the easiest, most intuitive process for searching and finding any of the company's 40,000+ RF components and cable assemblies with as few clicks as possible.

Pasternack Enterprises
www.pasternack.com

Crystal Oscillator Products Site

Visit Wenzel's new website and learn why world-class performance and innovative design characterize them as the leader in low phase noise crystal oscillators, synthesizers and frequency related modules. Since 1978, the company has defined the state-of-the-art in ultra-low phase noise while providing system manufacturers with the highest quality, cost effective frequency components and instruments.

Wenzel Associates
www.wenzel.com

eLEARNING center

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June Short Course Webinars

Technical Education Training
Unleashing 5G mm-waves – A Test & Measurement Perspective
Presented by: Rohde & Schwarz
Live webcast: 6/11/14

Technical Education Training
Simulating Dynamic Load Modulated Amplifiers – An Alternative Solution to Maintaining Efficiency over a Power Range
Sponsored by: AWR Corp.
Live webcast: 6/18/14

Innovations in EDA
Designing Custom Filters using Direct Synthesis and Network Transforms
Presented by: Agilent Technologies
Live webcast: 6/26/14

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Past Webinars On Demand

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

Technical Education Training Series
- Overview of FEKO Suite 7.0
- Practical Antenna Design for Advanced Wireless Products
- Antenna Measurements in Under 1 Second Using Very-Near-Field Technology
- Advanced Safety Systems in Automotive Designs
- The Design of a 100 W, X-Band GaN PA Module
- Learn How to Select the Right RF Product Solution to Improve Overall Radar Performance
- Current Induced in Si RFIC Substrates by Spiral Inductors and Patterned Ground Shields
- Overcome LTE-A and 802.11ac Manufacturing Test Challenges with Agilent's New EXM
- Analysis of FMCW Radar Signals in Automotive Applications
- Learn to Make Power Amplifier Tests Faster!
- Overcome LTE-A UE Design Test Challenges with Agilent's New UXM
- Design and Simulation of Modern Radar Systems
- PCB Material Selection for High Speed Digital Design
- Improve Overall System Performance with New TriQuint GaN Products
- Freescale and Scintera: The Small Cell Transmitter Solution Provider

CST Webinar Series
- New Features for MW, RF and Optical Simulation in CST STUDIO SUITE 2014

Innovations in EDA/Signal Generation & Analysis Series
Presented by: Agilent EEsof EDA/Agilent Technologies
- ADS 2014: New Technologies, New Capabilities & Impressive Productivity Improvements
- Non-Standard Connection Characterization with ATE Systems
- How to Improve PA Performance and Reliability Using Electro-Thermal Analysis

Agilent in Aerospace/Defense Series
- Effectively Maintain Mission Critical Communication Systems
- Understanding Low Phase Noise Signals

Agilent in LTE/Wireless Communications Series
- IEEE 802.11ad (WiGig) PHY and Measurement Challenges
- E-Band Wireless Backhaul: System Design and Test Challenges
- Carrier Aggregation: Fundamentals and Type of Deployments

FieldFox Handheld Analyzers Series
Presented by: Agilent Technologies
- Techniques for Precise Cable and Antenna Measurements in the Field
- Precision Validation of Radar System Performance in the Field

RF and Microwave Education Series
Presented by: Agilent Technologies
- EMC Back to Basics

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New Waves: Semiconductors/MMICs/RFICs

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FEATURING VENDORVIEW STOREFRONTS

Broadband High Power Amplifier

Agile MwT introduced its high linearity broadband power amplifier series which includes model AMT-A0117. It operates in a frequency range from 100 to 1500 MHz, offers P1dB of +34 dBm, OIP3 of +52 dBm, 36 dB of gain, and excellent VSWR. The operating voltage is +15 V DC with current of 1.2A. Its compact size and low cost makes it ideal for commercial or military applications.

Agile MwT,
www.agilemwt.com.

Power Amplifier Module

COMTECH PST introduced a new high power density solid state RF module quickly becoming available in today's marketplace. Comtech's latest development continues to expand on its proven innovative integrated RF GaN power amplifier designs by further increasing the RF power density. Consistent with its planned technology development roadmap, Comtech introduced the latest in GaN-based 6 to 18 GHz RF amplifier. This highly integrated design is ideal for use in communication, electronic warfare, and radar transmitter systems where space, cooling and power are limited.

Comtech PST,
www.comtechpst.com.

Broadband Drop-In Amps

Introducing Microwave Solutions broadband drop-in amplifier family. They are perfect when you need a boost of power with low noise on a test, ground or aerospace MTBF that are over 8,000,000 hrs. These amplifiers are designed to meet MIL-STD-883 and manufactured in compliance with AS9100. The frequency range covered is 1.5 to 16 GHz with typical noise figure range of 1.4 to 3 dB. The output power is 18 dBm, 1 dB GCP typ. Size is approximately 0.76 × 0.65 × 0.22 without SMA connectors.

Microwave Solutions Inc.,
www.microwavesolutions.com.

Monolithic Amplifier

VENDORVIEW

Mini-Circuits PMA2-33LN+ is an E-PHEMT based, ultra-low noise MMIC amplifier with a unique combination of low noise and high IP3, making this amplifier ideal for sensitive, high-dynamic range receiver applications. This design operates on a single 3 V supply, is well matched for 50 Ω systems, and comes in a tiny, low-profile package accommodating dense circuit board layouts.

Mini-Circuits,
www.minicircuits.com.

Millimeter-wave High Power Amplifier

QuinStar Technology introduced a new line (Model QBP) of high power solid-state power amplifiers (SSPA) covering 25 to 110 GHz. Power levels of standard products range from 200 W at Ka-Band to 50 W at 94 GHz. Both pulsed and CW models are offered to suit virtually any application. In addition to their compact size and high efficiency, these amplifiers also incorporate many useful features, such as power monitoring, remote control and thermal management.

QuinStar Technology Inc.,
www.quinstar.com.

Components

Hybrid Power Module

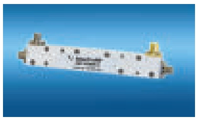
VENDORVIEW

AR's Hybrid Power Module (HPM), 37HM6G18-40, is a broadband power amplifier, which operates from a single DC voltage and covers 6 to 18 GHz. It delivers a minimum of 5 W output power and 42 dB small signal gain with excellent gain flatness and harmonics. The HPM has a built-in over voltage protection and is a Class A design. It is extremely load tolerant and can be used as a microwave power amplifier for both the military and commercial industries.

AR RF/Microwave Instrumentation,
www.arww-rfmicro.com

Directional Couplers

VENDORVIEW



AtlanTecRF introduces directional couplers with frequency capability up to 40 GHz in a number of bands including 18 to 40, 6 to 40, 2 to 40 GHz and the ultra-wide band version 1 to 40 GHz. Each frequency range in the new AKC series is available in a choice of either 10, 20 or 30 dB coupling and the lightweight units feature aluminium housings and 2.92 mm stainless steel female connectors. Coupling accuracy and flatness are ±1.0 dB max across the individual bands, while typical VSWR is 1.5:1 and power handling capability is 30 W.

Atlantic Microwave Ltd.,
www.atlantecrf.com.

Microwave Space Qualified Products (MSQP)

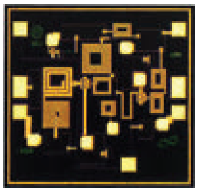
VENDORVIEW

Crane Aerospace & Electronics Microwave Solutions announced the recently relaunched Microwave Space Qualified Products (MSQP) product line. This line offers a range of standard passive products including power dividers, hybrids, couplers and mixers. These products have been previously qualified to internally generated standards derived from industry standards. They can be deployed to space-flight applications in a more rapid fashion and with lower cost as complex and time-consuming qualifications would not be required.

Crane Aerospace & Electronics,
www.craneco.com.

Double-Balanced Fundamental Mixer

VENDORVIEW



The Custom MMIC CMD179 is a general purpose, double-balanced GaAs mixer that can be used for up- and down-converting applications between 16 and 26 GHz. The mixer, which offers conversion loss of 7 dB, an LO to RF isolation of greater than 40 dB, an IF bandwidth of 8 GHz, and an input IP3 of +18 dBm, is ideally suited for hybrid assemblies given its small die size of 0.9 mm^2.

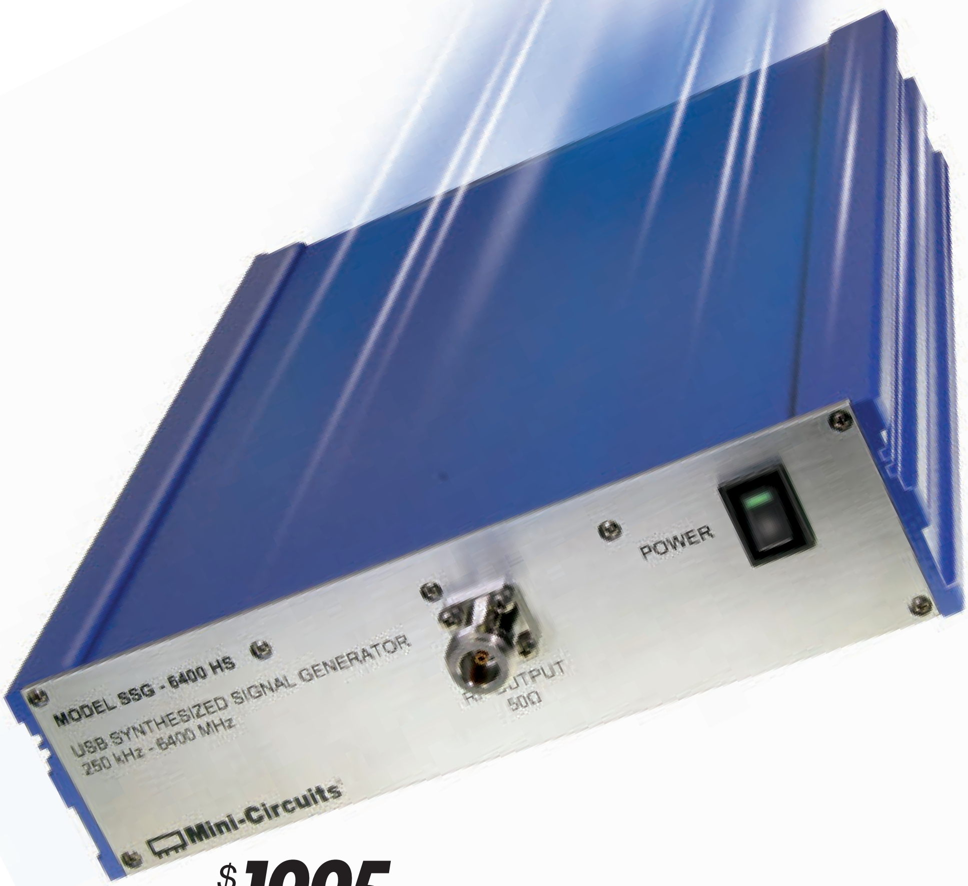
Custom MMIC,
www.custommmic.com.

Economic Sensor

Model SRF-77120910-01 is a low cost 77 GHz sensor designed for Doppler speed measurement. It is constructed with a high performance circular horn antenna, a linear to circular polarizer and T/R diplexer. It also incorporates a balanced mixer and a high performance Gunn oscillator. The sensor fea-

USB & Ethernet SIGNAL GENERATORS

To fit your budget.



from $1995 ea.

0.25 to 6400 MHz

Control your test setup via Ethernet or USB with a synthesized signal generator to meet your needs and fit your budget! The SSG-6400HS and the new SSG-6000RC feature both USB and Ethernet connections supporting HTTP and Telnet protocols, giving you more choices and more freedom.

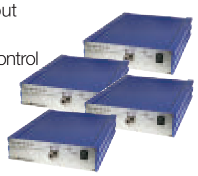
Small enough to fit in your laptop case, all models provide sweep and hopping capabilities over frequencies and power levels and are designed for easy integration with other test equipment using trigger and reference ports. They even feature built-in automatic calibration scheduling based on actual usage!

Our user-friendly GUI software, DLLs, and programming instructions are all included so you can control your SSG through our software or yours! Visit minicircuits.com today to find the right model for your application!

Models Available from Stock at Low Prices!

SSG-6400HS *$4,995*
- 0.25 to 6400 MHz
- -75 to +10 dBm output P_{out}
- AM, PM, FM, and pulse modulation
- USB and Ethernet control

New ***SSG-6000RC*** *$2,795*
- 25 to 6000 MHz
- -60 to +10 dBm P_{out}
- Pulse modulation
- USB and Ethernet control



SSG-4000LH *$2,395*
- 250 to 4000 MHz
- -60 to +10 dBm P_{out}
- Pulse modulation
- Low harmonics (-66 dBc typ.)
- USB control

SSG-4000HP *$1,995*
- 250 to 4000 MHz
- High power, -50 to +20 dBm P_{out}
- Pulse modulation
- USB control

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New**Products**

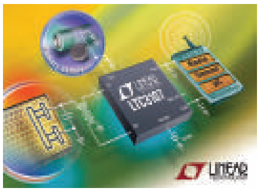
tures a 12 degree 3 dB beamwidth, 10 dBm output power and 9 dB conversion loss. The sensor can readily be modified to offer different beam widths, dual channel (I-Q) output or FMCW versions.
Ducommun Inc.,
www.ducommun.com.

Directional Couplers

KRYTAR Inc. announced the continued expansion of its line of directional couplers with the addition of two new models offering 30 dB of coupling over the frequency range of 4 to 12.4 GHz and 7 to 12.4 GHz, each in a single, compact and lightweight package. KRYTAR's new directional couplers expand the family of superior performance products offering 4 to 12.4 GHz coverage in compact packages.
KRYTAR Inc.,
www.krytar.com.

DC/DC Converter

VENDORVIEW



Linear Technology announced the LTC3107, an integrated DC/DC converter designed to extend the life of a battery in low power wireless system networks. It combines energy harvesting and power management capability with a primary battery cell to extend the battery's usable lifetime. The LTC3107 harvests energy from thermoelectric generators and thermopiles when these sources are available, storing excess power in a storage capacitor and seamlessly transitioning to the primary cell to power a wireless sensor node when harvested power is unavailable.
Linear Technology,
www.linear.com.

Tunable Bandpass and Band Reject Filter

VENDORVIEW

Pasternack Enterprises' new tunable bandpass filters and band reject filters are bench top units

designed for lab use. Six bandpass configurations are available with octave-band tuning from 125 MHz to 3 GHz and a 5% passband. These bandpass filters use a tunable 5-section design and have a mechanical direct dial that is accurate within 1%. Five band reject configurations are available with octave-band tuning ranges from 100 MHz to 2 GHz.
Pasternack Enterprises Inc.,
www.pasternack.com.

Two Throw Switch

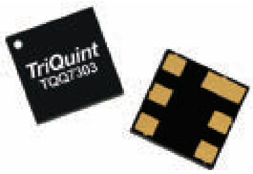
VENDORVIEW

PMI's model no. P2T-500M18G-50-T-SFF-I is a terminated, single pole, two throw switch

that operates over the frequency range of 0.5 to 18 GHz. This model handles +23 dBm CW input power with port to port isolation of 50 dB min. It has a low insertion loss of 2.8 dB max while still offering a fast switching speed of 50 nsec max. The unit is supplied with SMA female connectors in a housing measuring 1.0" × 1.0" × 0.5".
Planar Monolithics Industries Inc.,
www.pmi-rf.com.

BAW Filters for Wireless Infrastructure

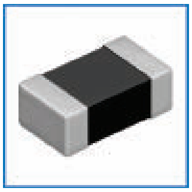
VENDORVIEW



RFMW Ltd. announced design and sales support for three new TriQuint Bulk Acoustic Wave (BAW) filters. These filters offer low in-band insertion loss and high out-of-band attenuation coupled with the improved performance and power handling capability of BAW. The TQQ7303 has a usable bandwidth of 75 MHz with minimum attenuation of 45 dB at 1805 MHz. TriQuint's TQQ7307 offers 70 MHz bandwidth with 32 dB of attenuation and the TriQuint 885069 has 100 MHz of usable passband with 45 dB min attenuation.
RFMW Ltd.,
www.rfmw.com.

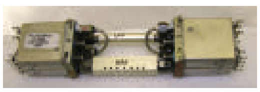
Chip Power Inductors

VENDORVIEW



Richardson RFPD Inc. announced immediate availability and full design support capabilities for the MDT Series of multilayer ferrite chip power inductors from TOKO. TOKO's architecture creates robust, magnetically-shielded, multilayer ferrite power inductors offering low resistance and high current handling in miniature footprint, low profile sizes ranging from 2.5 × 2.0 × 1.0 mm to 2.5 × 2.0 × 1.2 mm. With high efficiency through 10 MHz switching frequency coupled with the small size and low flux leakage.
Richardson RFPD,
www.richardsonrfpd.com.

Switched Filter Bank



RLC provides switched filter bank assemblies designed and built to customers' exact specifications. RLC is able to help the design engineer minimize mass and overall circuit footprint while optimizing the transitions between circuit elements. By optimizing internal interfaces, RLC is able to provide improved loss and VSWR performance in a small package. RLC's designs for switched filter banks can cover the frequency range of DC to 65 GHz. Typical applications are for military and commercial use, including calibration services and ATE.
RLC Electronics Inc.,
www.rlcelectronics.com.

V-Band Eight Way Power Combiner

VENDORVIEW

Model SWP-50366308-15-C1 is a V-Band waveguide eight-way power combiner that

operates from 50 to 66 GHz. The power combiner exhibits 2 dB insertion loss and 18 dB port to port isolations between non-adjacent ports and 13 dB between adjacent ports in the operational bandwidth. The power combiner possesses excellent phase and amplitude balance. The power combiner is equipped with WR-15 waveguides and UG385/U flanges.
SAGE Millimeter Inc.,
www.sagemillimeter.com.

Coaxial Switch

The Series CCR-40K is a broadband SPDT, electromechanical, coaxial switch designed to switch a microwave signal from a common input to either of two outputs. It incorporates 2.92 mm high performance connectors and a characteristic impedance of 50 V. The new CCR-40K series measures 1.50" × 0.52" × 2.02", has a maximum weight of 1.65 oz (46.78 g) and expands the company's switching line card to frequencies as high as 40 GHz.
Teledyne Coax Switches,
www.teledynecoax.com.

Combiner/Divider

VENDORVIEW

Power, efficiency, and bandwidth. Werlatone provides all three qualities in its growing line of high power 2-way combiners/dividers. Model D9392 is no exception. Covering the full 500 to 2500 MHz, the D9392 is conservatively rated at 500 W CW, and operates with less than 0.3 dB of insertion loss.
Werlatone Inc.,
www.werlatone.com.

Cables and Connectors

Low Loss Cable Assemblies

Fairview Microwave Inc. introduced a new line of low loss test cables using LL335i and LL142 coax. These new low loss cable assemblies are ideal for test environments where a rugged, phase stable cable assembly is required. Fairview Microwave's new LL335i and LL142 cables allow for higher power transmission because

Director
Advanced Radar Research Center

The University of Oklahoma seeks an exceptional, dynamic leader to serve as Director of its Advanced Radar Research Center (ARRC).

The ARRC builds upon a university, government and industry alliance that leads the world in the development, testing, operational deployment, and support of advanced weather radar systems. Through a recent strategic initiative, the ARRC has expanded capabilities in radar and other electromagnetic technologies, with applications in surface, airborne and space-based defense, security and intelligence. Principal capabilities of the ARRC include design/prototyping of both large and small, fixed and mobile radar systems; phased array technology; digital signal/array processing; automated algorithms; decision support tools; data assimilation; and end-user training. Multi-functional, dynamically adaptive radars are now being evaluated in the field and more than two-dozen radars are located across Oklahoma, including both operational and research systems for weather, air surveillance, and security applications. The ARRC currently consists of 16 faculty members, 16 post-doctoral scientists, 7 staff members, and over 60 graduate students, across the disciplines of engineering and meteorology.

In support of our highly regarded programs in radar remote sensing and related fields, the University of Oklahoma opened its state-of-the-art Radar Innovations Laboratory (RIL) in March 2014. Located adjacent to the National Weather Center on the OU Research Campus, the RIL will be the new hub of ARRC operations. The 36,000-square-foot, $15 million RIL will provide world-class facilities to move ideas for next-generation radar, microwave electronics and related technologies from conception through research, development and full prototyping. The facility features a full suite of microwave measurement equipment and two anechoic chambers enabling far-field, near-field, and radar cross-section measurements, down to 300 MHz. The lab will serve both the research and educational missions of the University by providing a hands-on, active learning environment for OU students.

The Association of University Research Parks named OU's Research Campus the 2013 Outstanding Research Park **http://vpr-norman.ou.edu/**). The Research Campus hosts the National Weather Center (NWC), one of the largest facilities of its kind in the world, housing twelve University of Oklahoma, state, and federal organizations with more than 650 faculty, researchers, support staff, and students. The NWC includes NOAA's National Weather Service Forecast Office, Storm Prediction Center, National Severe Storms Laboratory, Radar Operations Center, OU-NOAA Cooperative Institute for Mesoscale Meteorological Studies, and School of Meteorology. The School of Electrical and Computer Engineering is housed nearby in the new Devon Energy Hall.

The ARRC Director provides intellectual leadership in a multidisciplinary environment. The Director works in collaboration with private industry and federal agencies and carries out a vigorous program of teaching, research, and service that attracts exceptional students and prepares them to become future leaders in the development and application of advanced radar technologies. The ARRC Director reports to the Executive Board, consisting of the Dean of the College of Engineering, the Dean of the College of Atmospheric and Geographic Sciences, and the Vice President for Research. The successful applicant must be an internationally recognized scholar with a science or engineering doctoral degree and an outstanding record of professional achievement, commensurate with appointment to a tenured position at the Associate or Full Professor level within the School of Meteorology (College of Atmospheric and Geographic Sciences) or the School of Electrical and Computer Engineering (College of Engineering). Demonstrated ability of working collaboratively with private industry and eligibility to obtain a security clearance are highly desired.

To apply, please submit a letter of interest including a statement of research goals and teaching vision, current curriculum vitae, and the names of four or more people who can serve as references (with full mailing and e-mail addresses, telephone, and FAX numbers). Screening of applications will begin on 15 Sept. 2014 and will continue until the position has been filled.

Please address all correspondence to the two Co-Chairs of the Search Committee:

Dean Thomas Landers
AT&T Chair
College of Engineering
University of Oklahoma
202 W. Boyd Street CEC 107
Norman, OK 73019
PH: 405-325-2621 FAX: 325-7508
E-mail: landers@ou.edu

Dean Berrien Moore
Vice President for Weather and Climate
College of Atmospheric and Geographic Sciences
University of Oklahoma
120 David L. Boren Blvd.
Norman, OK 73072
PH: 405-325-3095 FAX: 405-325-1180
E-mail: berrien@ou.edu

The University of Oklahoma is an Affirmative Action, Equal Opportunity Employer.
Women and minorities are encouraged to apply.
Protected veterans and individuals with disabilities are encouraged to apply.

the resulting higher temperatures do not have a negative effect on the cable due to the thermal stability of the PTFE tape dielectric.
Fairview Microwave Inc.,
www.fairviewmicrowave.com.

Floating SMPM Coaxial Contacts

Looking for an RF (DC to 26.5 GHz) addition to the VPX Platform? Check out SV Microwave's latest high density, high performance VITA 67 product offering. SV's floating SMPM coaxial contacts ensure excellent RF performance in any mating condition. These parts are also designed for side-by-side implementation with VITA 46 hardware and can be cabled to 0.086 and smaller coaxial cable types. COTS options for VITA 67.1 & 67.2 and custom configurations for VITA 67.3 are available.
SV Microwave,
www.svmicrowave.com.

Surge Protection Products

The LP-HBX-N high performance lightning protector series provides exceptional protection over the 100 to 700 MHz frequency band addressing high power (up to 750 W) single or multi channel applications. The DC blocked design provides superior surge protection while maintaining outstanding return loss and insertion loss performance. The white bronze plated construction of the LP-HBX-N series eliminates potential galvanic corrosion issues and provides long life in hostile environments and the fully weatherized housing is sealed to IP65 standards allowing for outdoor installation.
Times Microwave Systems,
www.timesmicrowave.com.

Sources

WhisperSyn Synthesizer

VENDORVIEW

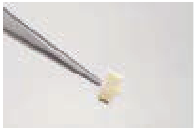
American Microwave Corp. (AMC) announced the first member of the new WhisperSyn synthesizer product line, the model PSYN-06510-100. Whispersyn technology offers superior low phase noise and fast switching synthesizer technology. This compact package offers wide bandwidth coverage of 0.65 to 10 GHz, fast switching time of <100 μsec, excellent resolution of 0.001 Hz and super low phase noise.
American Microwave Corp.,
www.americanmic.com.

3200 MHz VCO

Crystek's CVCO55CC-3200-3200 VCO operates at 3200 MHz with a control voltage range of 0.5 to 4.5 V. This VCO features a typical phase noise of -112 dBc/Hz of 10 KHz offset and has excellent linearity. Output power is typically +5 dBm. The model CVCO55CC-3200-3200 is packaged in the industry-standard 0.5" × 0.5" SMD package. Input voltage is 8 V, with a max. current consumption of 30 mA. Pulling and pushing are minimized to 3 MHz and 0.1 MHz/V, respectively. Second harmonic suppression is -12 dBc typical.

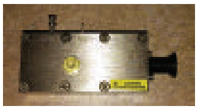
Crystek Corp.,
www.crystek.com.

Microlithic Doubler



The MLD-1640 is the first multiplier available using Microlithic technology. It offers an input range of 8 to 20 GHz and an output range of 16 to 40 GHz. The Microlithic design technique allowed us to increase the fundamental suppression by over 10 dB to a typical 33 dB suppression across the band. Designers will be able to significantly relax the filtering requirements on their high frequency LO generation chains. It comes in a standard 0.152" × 0.090" Microlithic chip or connectorized S package.
Marki Microwave Inc.,
www.markimicrowave.com.

Free Running DRO



Mesa Microwave introduced a free running dielectric resonator oscillator (DRO). This DRO operates at a frequency of 4.3 GHz, +15 dBm, -55° to +85°C. Frequencies up to 40 GHz are available.
Mesa Microwave Corp.,
www.mesamicrowave.com.

High Performance Synthesizer

Synergy's low phase noise synthesizer model LFSW170225-1M offers wideband coverage from +5 V supplies. The close-in phase noise is -102 dBc at 1 kHz through 10 kHz offset and –123 dBc at 100 kHz offset. It also provides buffered output power of +5 dBm (min), spurious suppression of 75 dB (typ.), and harmonics of 25 dB (typ). The frequency is varied in 10 MHz steps. This great performance is packaged in a small 1.25" × 1.00" × 0.230" housing (RoHS compliant).
Synergy Microwave Corp.,
www.synergymwave.com.

Fixed Frequency Synthesizer

Z-Communications Inc. announced a fixed frequency synthesizer in the X-Band. The SFS11800C-LF is a single frequency synthesizer that operates at 11.8 GHz with a 10 MHz reference and features a typical phase noise of -90 dBc/Hz and -120 dBc/Hz at the 10 kHz and 100 kHz offsets, respectively. It is designed to deliver a typical output power of 3 dBm with a VCO voltage supply of 5 VDC while drawing 90 mA (typical) and a phase locked loop voltage of 3 VDC while drawing 11 mA (typical).
Z-Communications Inc.,
www.zcomm.com.

Software

CST STUDIO SUITE® 2014

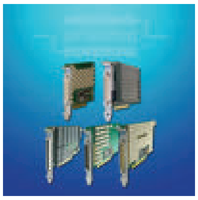
VENDORVIEW

Computer Simulation Technology announced the release of the 2014 version of the electromagnetic simulation tool, CST STUDIO SUITE®. The latest edition has been developed to improve the performance of the solvers and increase the capabilities for hybrid simulation without compromising on usability. CST STUDIO SUITE comprises a range of electromagnetic simulation tools for high frequency, low frequency, charged particle and multiphysics applications, which are all available within a single graphical user interface.
Computer Simulation Technology,
www.cst.com.

Test Equipment

PCI Switching Solutions

VENDORVIEW



Pickering Interfaces is expanding its range of PCI switching solutions by introducing seven new PCI cards and expansion of an eighth card. Expansion includes programmable

MICRO-ADS

and precision resistors, general purpose relays, high-density matrices and multiplexers. Pickering Interfaces stands behind all of its manufactured products with a standard three-year warranty and guaranteed long-term product support. Pricing and availability information is available on the company's website.
Pickering Interfaces Ltd., www.pickeringtest.com.

Network Analyzer

VENDORVIEW

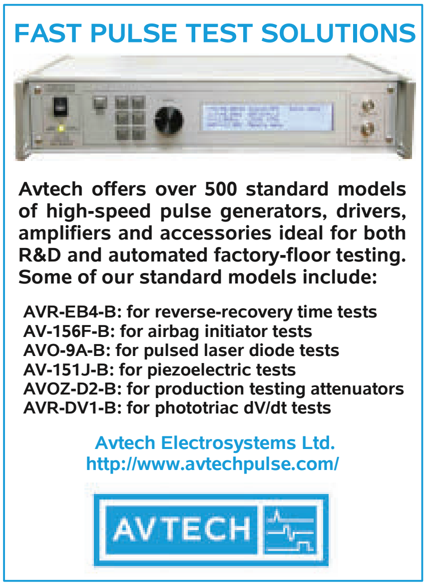
The R&S ZNBT is claimed to be the first network analyzer with 24 integrated test ports: The instrument covers the frequency range from 9 kHz to 8.5 GHz, and the base model is equipped with four test ports, but can be enhanced to include 24 ports. When fitted with its maximum number of test ports it is capable of determining all 576 S-parameters of a 24-port DUT. It requires no switching, and can also measure multiple DUTs in parallel.
Rohde & Schwarz, www.rohde-schwarz.com.

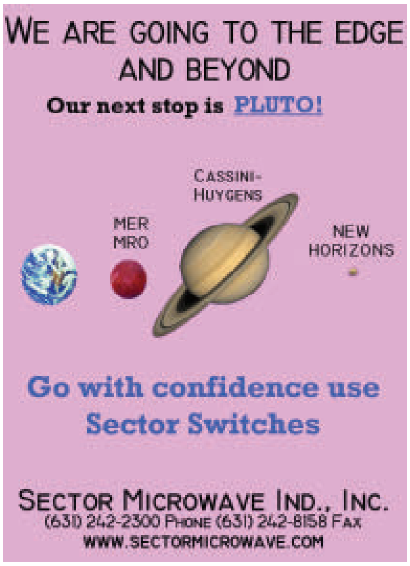
Packaging

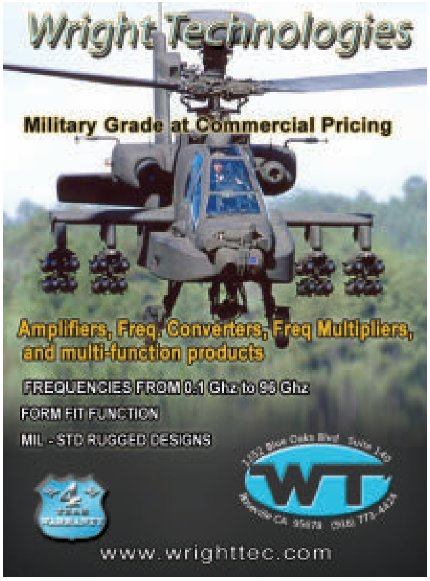
Connectivity Solutions

VENDORVIEW

Skyworks Solutions unveiled several wireless networking products incorporating flip-chip packaging. These newest devices leverage innovative and proprietary manufacturing techniques that allow smartphone and tablet OEMs to incorporate smaller, thinner solutions for 802.11ac system-in-package modules. As high-end mobile devices deliver ever-increasing functionality and ubiquitous connectivity, reducing the front end circuit board footprint is critical as system providers seek high performance, highly flexible solutions for next-generation platforms.
Skyworks Solutions Inc., www.skyworksinc.com.







Radio Receiver Technology: Principles, Architectures and Applications

Ralf Rudersdorfer

Written by an expert in the field, this book covers the principles, architectures, applications, specifications and characterizations of radio receivers. The author introduces the basic principles and theories of present-day communications receiver technology. The first section of the book presents realization concepts at the system level, taking into consideration the various types of users. Details of the circuitry are described providing the reader with an understanding of fully digitized radio receivers, offering an insight into the state-of-the-art.

Key Features:

- Introduces the basic principles and theories of present-day technology
- Discusses concepts at system level (aligned to the various types of users)
- Addresses (fully) digitized radio receivers focusing on the state-of-the-art
- Close contacts to the industry were utilized to show background information
- Enables the reader to comprehend and evaluate the characteristic features and the performance of such systems
- Examines the wide range of parameters that are characteristic of the technology including the physical effect and measuring techniques
- Includes results of experiences gained in extended laboratory work and practical testing with examples
- Provides a uniform and systematic approach for ease of understanding e.g. many didactic figures for the visual illustration have been newly created as well as real-world examples
- Alphabetical index with over 1,200 entries, the appropriate explanations can be found quickly in the text

This book is an good resource to understand the principles of work, for professionals developing and testing radio receivers, for receiver users (e.g. at regulatory agencies, surveillance centers, secret services, classical radio communications services), technicians, engineers and technicians who work with RF-measurement instruments, postgraduate students studying in the field and university lecturers. Handlers/operators will also find this book useful. Due to high level of detail, it also serves as a reference to the subject.

To order this book, contact:

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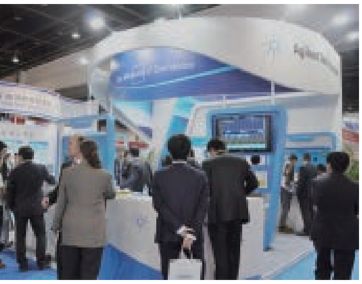
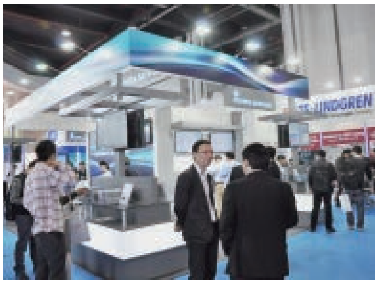
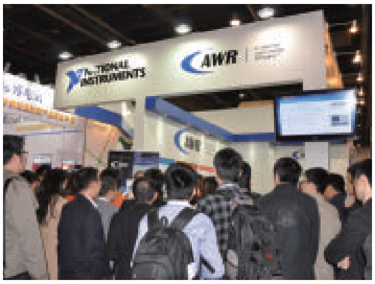

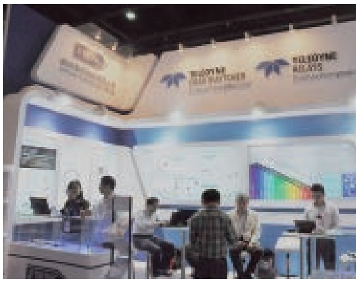

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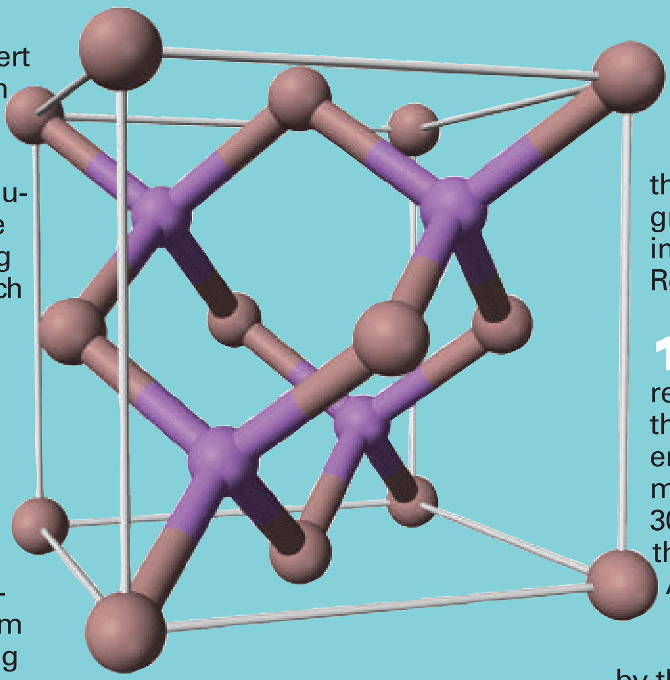
STEM Works

Gallium Arsenide [ga-lē-əm] [är-sə-nīd]

Gallium arsenide (GaAs) is a compound of the elements gallium and arsenic. It is a III/V semiconductor, and is used in the manufacture of devices such as microwave frequency integrated circuits, monolithic microwave integrated circuits, infrared light-emitting diodes, laser diodes, solar cells and optical windows. GaAs is often used as a substrate material for the epitaxial growth of other III-V semiconductors including: InGaAs and GaInNAs.



1250 Alchemist, Albert the Great was the first to form almost pure Arsenic.

1874 Lecoq de Boisbaudran discovers Gallium while studying Zinc. After searching for it for years, he had a hunch that it would be the next element to zinc based on Dmitri Mendeleev's periodic trends.

1907 British radio researcher and assistant to Guglielmo Marconi, Henry Joseph Round discovered infrared emission called electroluminescence from Gallium Arsenide while experimenting with the material and a cat's whisker.

1962 IBM physicist J.B. Gunn's research on gallium arsenide (GaAs) led to the discovery of high frequency oscillation of the electrical current flowing through certain semiconducting solids—now known as the 'Gunn Effect'. This breakthrough paved the way for early military detectors to be constructed using Gunn diodes.

1978 Tektronix engineers begin experimenting with gallium arsenide as the base material for integrated circuits, seven years later TriQuint Semiconductor is formed as a subsidiary of Tektronix.

1985 GaAs microprocessors developed by RCA are considered for the Star Wars program of the U.S. DoD initiated by President Reagan.

1998 RFMD reported that 87% of the company's revenue for the three months ending June 30th were derived from the sale of Gallium Arsenide heterojunction bipolar transistors (manufactured by the company's largest shareholder, TRW).

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D8969	2-Way	1.5-30	12,500	0.2	20	17 x 17 x 8
D6139	4-Way	1.5-32	5,000	0.25	20	13 x 11 x 5
D6774	4-Way	1.5-32	20,000	0.3	20	21 x 17.25 x 11
D6846	6-Way	1.5-30	4,000	0.35	20	3U, 19" Rack
D8421	8-Way	1.5-30	12,000	0.3	20	22.5 x 19.5 x 8.75
D7685	4-Way	2-100	2,500	0.5	20	14.75 x 13 x 7
D2786	4-Way	20-150	4,000	0.5	20	18 x 17 x 5
D6078	2-Way	100-500	2,000	0.25	20	13 x 7 x 2.25
H7521	2-Way (180°)	200-400	2,500	0.3	20	15 x 10 x 2
D7502	2-Way	400-1000	2,500	0.25	NI*	9.38 x 3.12 x 1.25

*NI = No Isolating Terminations

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