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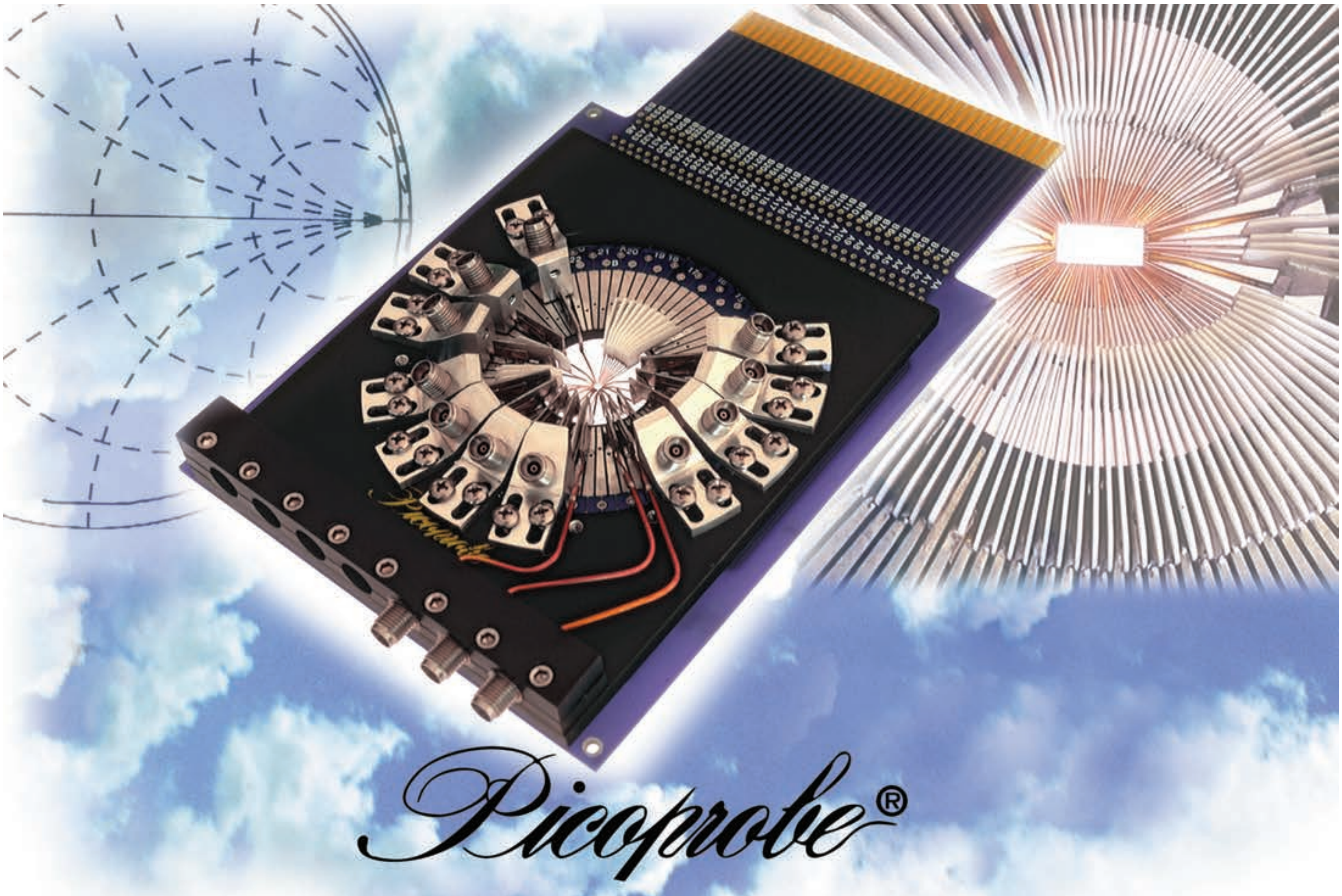

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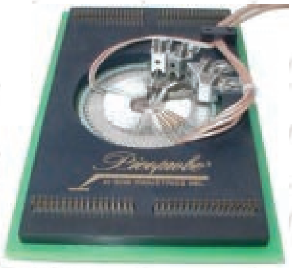

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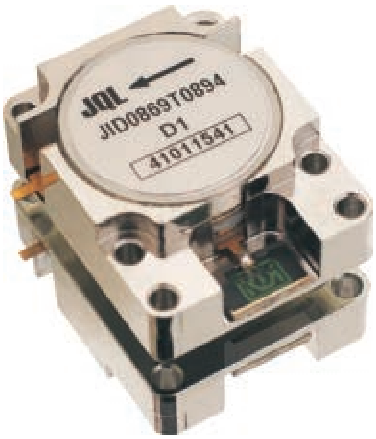

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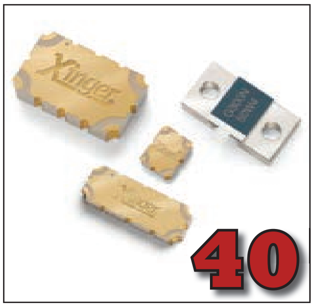

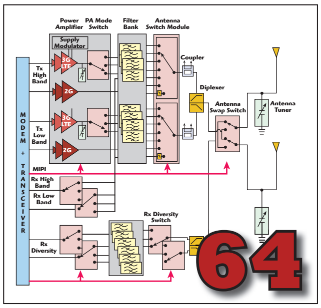

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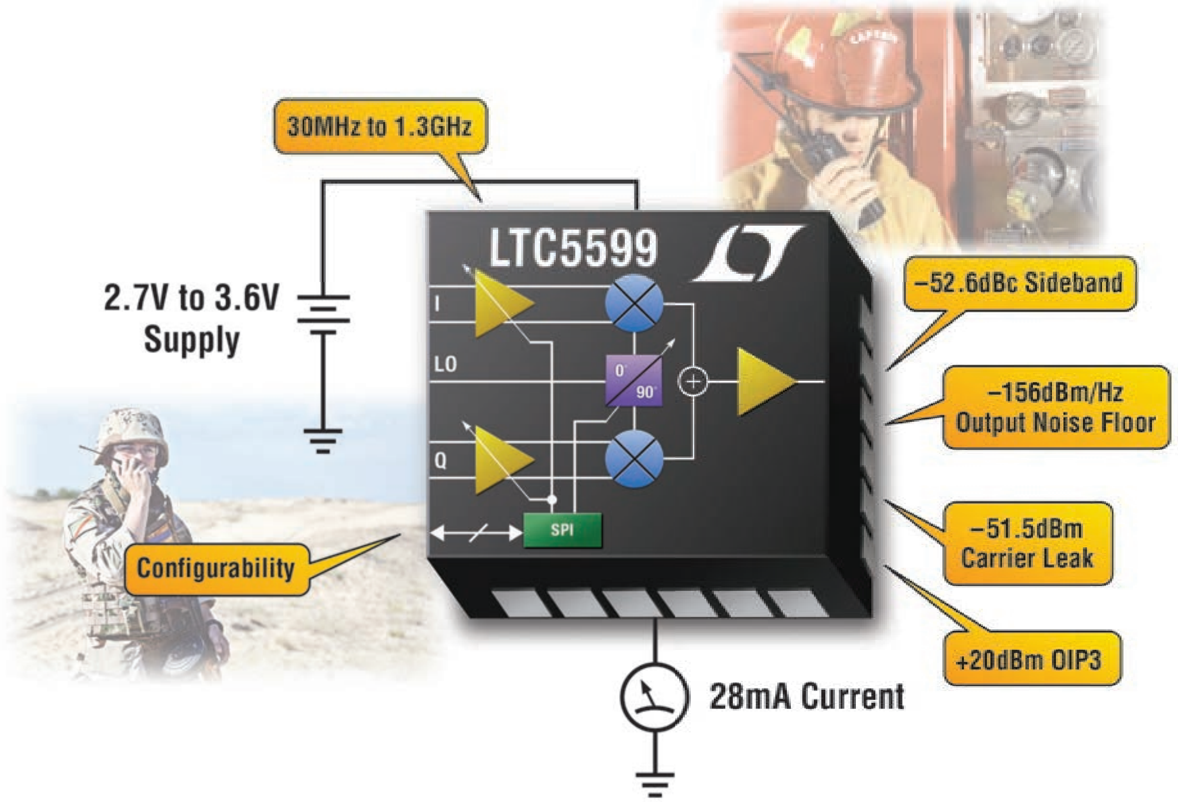

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Built-in Configurability Features:

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- Improves Sideband Suppression from –52.6dBc to –60dBc
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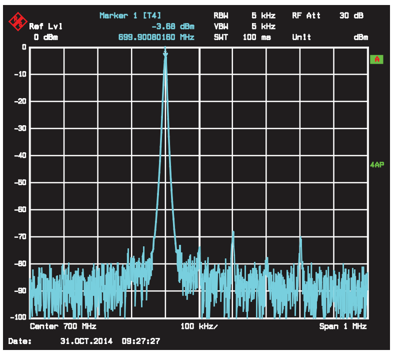
Output Spectra (Optimized)



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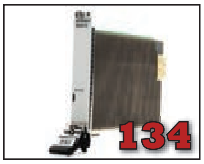

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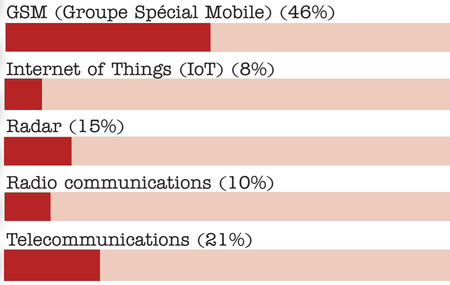

Ed Liang, co-founder and CTO of **MCV Microwave**, discusses the company's expertise in ceramic materials and filter/antenna technology as they launch a new antenna product for the base station market.

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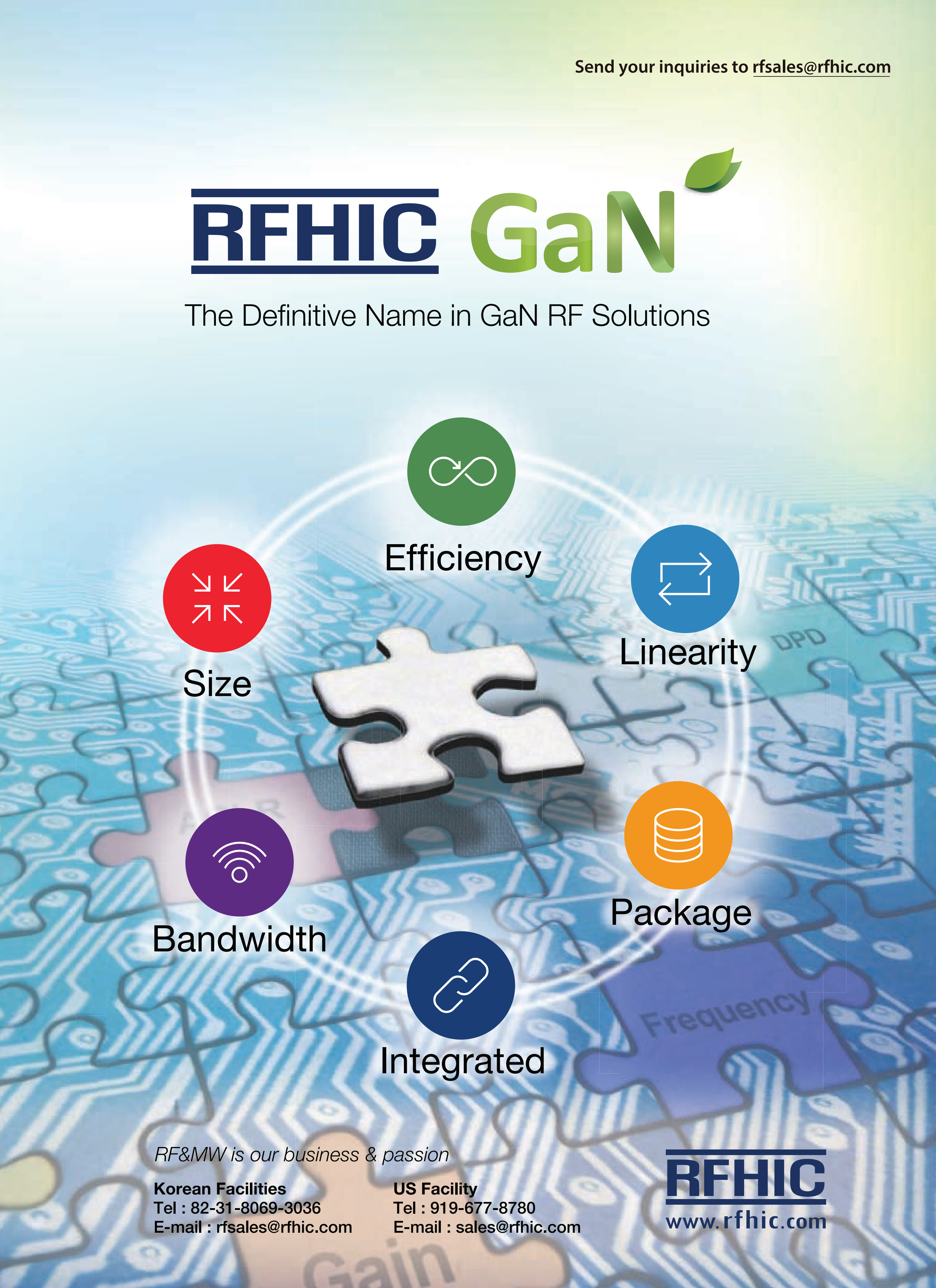
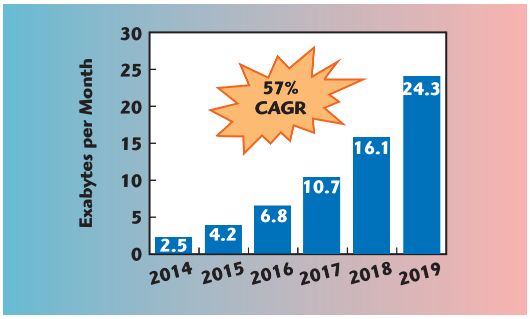


COVER FEATURE
INVITED PAPER

RF SOI: Revolutionizing RF System Design

Peter A. Rabbeni, Alvin Joseph, Theodore Letavic and Anirban Bandyopadhyay
GlobalFoundries, Santa Clara, Calif.

RF SOI has taken the mobile RF world by storm recently in helping to solve the challenges that go along with ensuring users seamless, always available connectivity and access to the power of the Internet from virtually anywhere. The introduction of cloud computing is driving user expectations even higher. RF SOI is well positioned to become the innovation platform for delivering improved performance, lowering overall system costs needed to accommodate these rising expectations and staying ahead of the ever evolving network requirements. This article examines the industry trends that got us here, what's next and how RF SOI can improve the performance of RF systems.

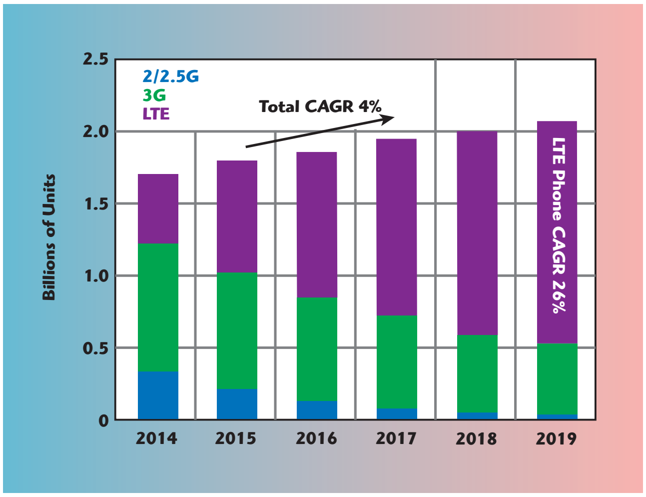


▲ *Fig. 1 Global mobile data traffic forecast.*[2]

THE WIRELESS LANDSCAPE

Rich content delivery to users has grown exponentially over the last five years. In developed countries, compressed high-definition video streaming over the Internet through services such as Netflix and Hulu is already nearly ubiquitous. The need for greater bandwidth will only increase as demands for higher quality content gives way to true uncompressed 1080p and 4K video delivery in the future. Cisco forecasts that by 2019, global Internet traffic will triple over 2014 levels, rising to 168 exabytes (EB) per month, a cumulative annual increase of over 23 percent.[1]

The rise of cloud computing now allows this data rich content to be accessed anywhere and, more importantly, to be accessed anywhere while mobile. For an enhanced user experience, delivery of this content can be achieved only through higher data rates — within the confines of the available spectrum — with as low latency as possible. Demand for higher data rates is one of the main drivers for the evolution of current wireless communication standards. Over the last five years, both cellular and Wi-Fi have advanced at unprecedented rates. Cellular standards have transitioned from 2G/2.5G to 3G/4G, and now 4G/



▲ *Fig. 2 Global wireless handset forecast.*[3]

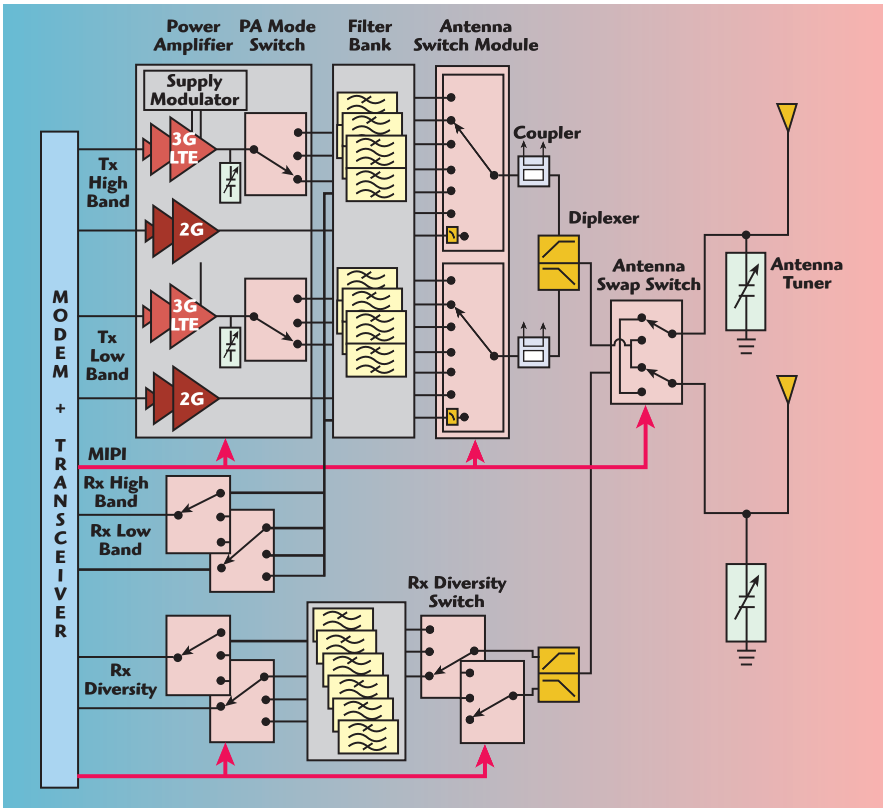
traffic combined. To put this in perspective, this amount of data is equivalent to transmitting the entire text and media content of the Library of Congress over 70,000 times every month.

Achieving these predictions is not hard to understand given the rapid global adoption of LTE in cellphones (2014-19 CAGR = 26 percent). Although the overall mobile handset market growth has begun to plateau (CAGR = 4 percent), it is actually demand for LTE-capable handsets that is sustaining the growth of the overall mobile handset market. This clearly demonstrates the transition from devices supporting older legacy standards to devices that can provide a richer user experience, as shown in ***Figure 2***.

Enabling increased data rates in mobile devices does not come easily. Challenges in working within the allocated cellular spectrum across various regions have surfaced, creating a hodge-podge of fractured bands that carriers must deal with as part of network deployment. The emergence of LTE as a cellular standard has made this evident; LTE now has defined more than 40 bands, many of which are non-contiguous, currently covering 700 MHz to 2.6 GHz, with proposals to add more spectrum both above and below this range. The provisions within the standard enable high data rate capability (>300 Mbps downlink and up to 75 Mbps uplink) through the use of various techniques, including higher order orthogonal frequency division modulation (OFDMA) and carrier aggregation. These provisions are enabled to achieve as much spectral efficiency as possible to reach the target data throughput and serve as many users as possible within a given regional frequency plan.

LTE. The same holds true for Wi-Fi standards, which have evolved from their humble 802.11a/b/g beginnings as a replacement for 56 Kbps wired modems to today's 802.11ac, rivaling CAT6 wired Ethernet connections and promising wireless Gbps speeds.

Trends in mobile data consumption parallel this transition. Cisco also predicts that total global mobile data traffic will grow 10-fold between 2014 and 2019, to more than 24 EB per month (see ***Figure 1***) — a growth rate nearly double that of global data



▲ *Fig. 3 4G/LTE RF FEM architecture.*[6]

Similar provisions for data rate expansion in Wi-Fi networks not only provide a better user experience for data-rich content but also offer a potential means to augment cellular network capacity through offloads to carrier grade Wi-Fi access points. For example, the IEEE 802.11ac Wi-Fi standard has seen significant adoption (projected 13 percent CAGR over 2014-20) since its introduction and, with the Wave 2 specifications, promises data rates up to 3.5 Gbps through the use of multiple-input-multiple-output (MIMO) and channel bonding techniques.[4]

CAN'T WE ALL JUST BE FRIENDS?

Enabling the high data rate supported by LTE is driving the complexity we see today in all segments of the RF interface – the front-end module (FEM), in particular, but also the RF transceiver and baseband processor. The complexity in the FEM originates primarily from four sources:

1. Increasing number of bands supported per handset (ranging from 2 to 18 LTE bands in addition to legacy 2G/3G bands)
2. Introduction of high frequency bands (6 bands at 2.5 GHz and above)
3. High peak to average power ratio (PAPR) from OFDM (also used in other UMTS technologies and in Wi-Fi), where the PAPR can be up to 11.5 dB[5]
4. Carrier aggregation (CA) which

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further enhances the complexity due to the low efficiency of handset antennas of limited size and the demand of long battery life.

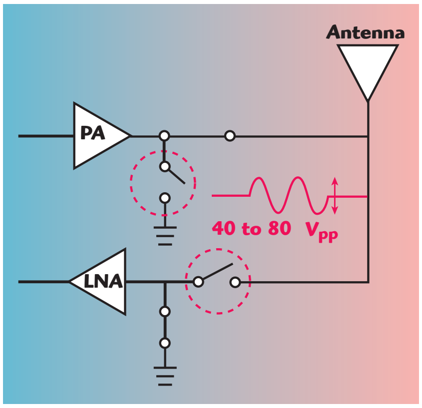
The architecture of one of today's advanced LTE capable smartphones demonstrates this complexity, as shown in the example block diagram of ***Figure 3***. Support for multiple bands in a mobile device requires a complex array of filters and switches with high throw counts to route signals to and from the antenna to the main RF transceiver/baseband for Tx/Rx processing. Within this array of filters and switches, careful consideration must be given to path loss, isolation, stopband rejection and linearity to ensure the fidelity of the signal being processed.

The RF switch plays an important role in this architecture by providing high electrical isolation between the "on" channel and other "off" channels, while protecting the highly sensitive receiver channels from the high power transmitter signal. The high peak power of the LTE transmitter (which can reach one watt or more) also generates harmonic frequency components and non-harmonic, intermodulation frequency components, due to the nonlinear behavior of any of the FEM components in the signal path. These include the RF switches and other active and passive components such as tuners, low noise amplifiers (LNA), power amplifiers (PA) and filters. These undesired frequency components drain power from the desired fundamental signal and may also cause saturation in the receiver LNA, depending on power level.

The high peak-to-average ratio of the modulated LTE signal requires that all FEM components have highly linear characteristics. Reduced linearity anywhere in the signal chain requires that the signal be "backed-off" in terms of the average power incident to the device to remain within the linear operating region of the entire signal path. Reduced linearity inherently translates to lower power delivered by the mobile device to the base station on transmit and lower power than can be processed by the receiver baseband processor. Both scenarios can cause dropped calls.

Although not immediately intuitive, signal back-off also affects battery life. Power amplifiers tend to be most efficient when operated at saturated power levels; however, these conditions are worst for linearity. Therefore, for linear transmission, one needs to back off power levels, causing amplifiers to be less efficient. Special techniques such as average power tracking (APT) and envelope tracking (ET) have been employed to adjust the PA bias on a real-time basis according to the envelope of the modulated output waveform, so that the PA always operates near optimum efficiency. These techniques have been implemented with some success. It requires additional computing cycles from the baseband/applications processor to deliver the necessary control to the PA bias controller to accurately track the modulation signal envelope. For improving PA linearity, digital predistortion (DPD) techniques have also been employed in cellular applications. These DPD and ET techniques are emerging in Wi-Fi power amplifier applications as well, significant challenges that need to be addressed.

The physical limitation of today's mobile device form factors have also contributed to the ever changing demands of today's wireless standards. The Wheeler limit relates the physical dimensions of an antenna structure to its resultant gain and bandwidth. Achieving flat broadband gain and directivity from an antenna, not much larger than a stick of gum, over all 40+ LTE frequency bands is very



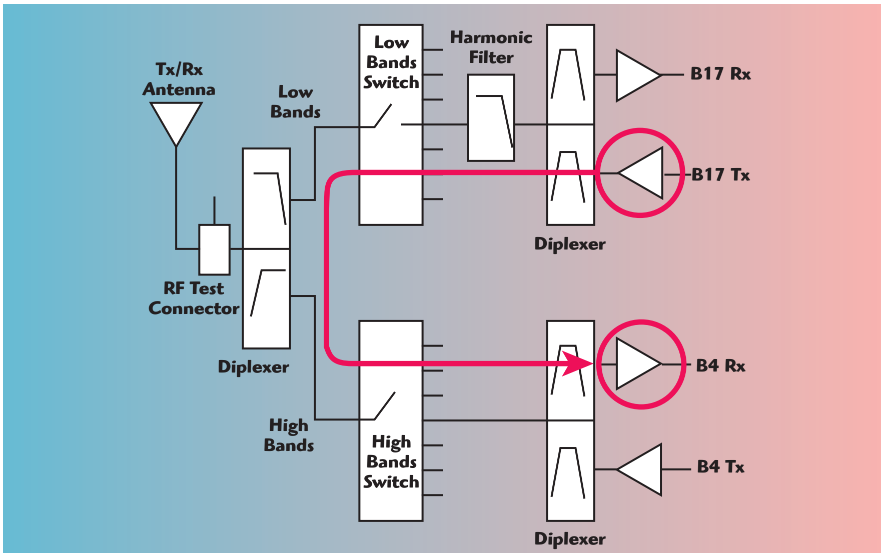
▲ *Fig. 4 Peak-to-peak voltage with high antenna VSWR.*[7]

difficult. In addition, the impedance the antenna presents to the front end components (switch or filter/diplexer) over this frequency range is not constant and can vary greatly, resulting in very high VSWR, up to 20:1. This can result in reflected signals from the antenna appearing at the main antenna RF switch as high as 80 Vpp (see ***Figure 4***). High reverse breakdown is essential in handling these conditions reliably. Techniques such as antenna impedance tuning and aperture tuning have been introduced in some radio architectures to address these issues.

Impedance tuners are typically placed at the antenna port of the main antenna RF switch module and are used to adjust the impedance presented to the PA, measuring the reflected voltage from the antenna by coupling some of the energy into a detector. The impedance is adjusted using fixed tuner settings across the band (open loop) or in real time (closed loop) using active reflected power measurement techniques performed at baseband. Aperture tuners are typically placed at the antenna input port and are used to actively adjust the radiation pattern of the antenna to achieve maximum EIRP in a given direction. Both methods are used to enhance the sensitivity of the mobile device and deliver the best possible signal between the base station and the user.

All the complexities discussed in the cellular FEM (insertion loss, isolation, nonlinearity, antenna bandwidth and mismatch) are compounded by the introduction of carrier aggregation. Carrier aggregation (CA) binds two or more channels simultaneously to enhance the effective bandwidth of the signal and boosting the combined data rate. A similar technique is used in today's fiber optic networks, where multiple high speed channels are combined to create a single ultra-high speed data stream. Handsets are already being introduced in the market which can support downlink carrier aggregation. In the future, the LTE standard provides for handsets to support uplink carrier aggregation. Handsets supporting either of these requirements must operate efficiently and with good reception characteristics. This can only be achieved by improving these key figures of merit (loss, isolation, linearity) even further.

The complexity associated with CA is evident from a specific example of aggregation between Band 4 and Band 17, a problem raised several years ago, when it was found that the third harmonic of B17 Tx (700 MHz) fell within the B4 Rx (2.1 GHz), prompting tougher constraints on RF switch isolation, out of band interferer rejection and path linearity to mitigate the problem (see ***Figure***



▲ *Fig. 5 Isolation and interferers challenge the implementation of carrier aggregation with the current LTE band plan.*[8]

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5). Even if the Rx frequency is not a multiple (second, third harmonic, etc.) of the Tx frequency aggregation bands, there can be interference for carrier aggregation frequency pair combinations where the Rx frequency coincides with one of the inter-modulation frequencies of the Tx band. There are a number of carrier aggregation band pairs which fall into this category.

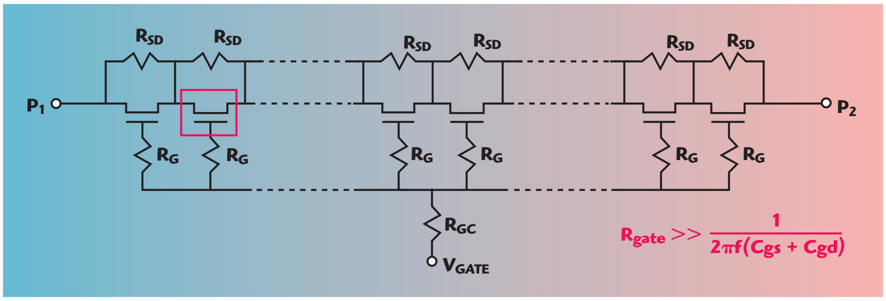

Fig. 6 RF SOI device stacking.[9]

WHAT ABOUT WI-FI?

A similar complexity in FEM architectures is seen in 802.11ac Wi-Fi. MIMO channel binding and beamforming techniques are leveraged to maximize signal fidelity, and each of these techniques has its own challenges in implementation. Compared to cellular, Wi-Fi operates at reduced signal power levels (20 dBm maximum user equipment transmitted power compared to 23 dBm for LTE), since coverage is over a shorter distance. However, these systems use complex modulation to support the high data rate (up to 256 QAM in 802.11ac) and a high carrier frequency (5.8 GHz), which require careful system design. The linearity requirement for Wi-Fi 802.11ac power amplifiers is very stringent because of high PAPR and EVM requirements (< 1.8 percent Tx for 256 QAM constellation density). The LNA noise figure and linearity requirements (for RF switches as well) are also stringent due to high levels of interference of overlapping channels, particularly in the 2.5 GHz Band. Together these requirements put significant pressure on overall front-end performance to minimize power consumption and achieve good reception.

In an access point, 802.11ac promises a peak data rate of 6.7 Gbps with 160 MHz bandwidth and an 8 × 8 MIMO configuration, while compatible terminal devices will push 1 Gbps with a 2 × 2 MIMO configuration. These requirements put a significant burden on the PA efficiency and total solution size, which favors silicon integration. In the future, to drive >10 Gbps data rates, the standards being discussed today will either push improved spectral efficiency of 802.11ac transmission (as is being proposed in 802.11ax) or a move to a higher frequency band (802.11ad). For the foreseeable future, the Wi-Fi data rate requirements will place significant pressure on overall front-end efficiency to minimize power consumption and module size.

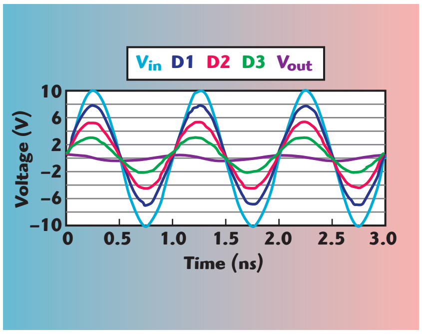

Fig. 7 10 V peak-to-peak input across a 4-stack SOI FET, with almost equal voltage drop across the drain nodes of each FET (D1, D2 and D3).[7]

WHY RF SOI AND WHY NOW?

It is well known that RF SOI has established itself as the technology of choice for cellular and Wi-Fi RF switches in many applications. In the early days of 3G/4G adoption, a new technology was needed that could achieve the same or similar performance in terms of Ft, mobility and breakdown voltage with sufficient manufacturing capacity to meet the

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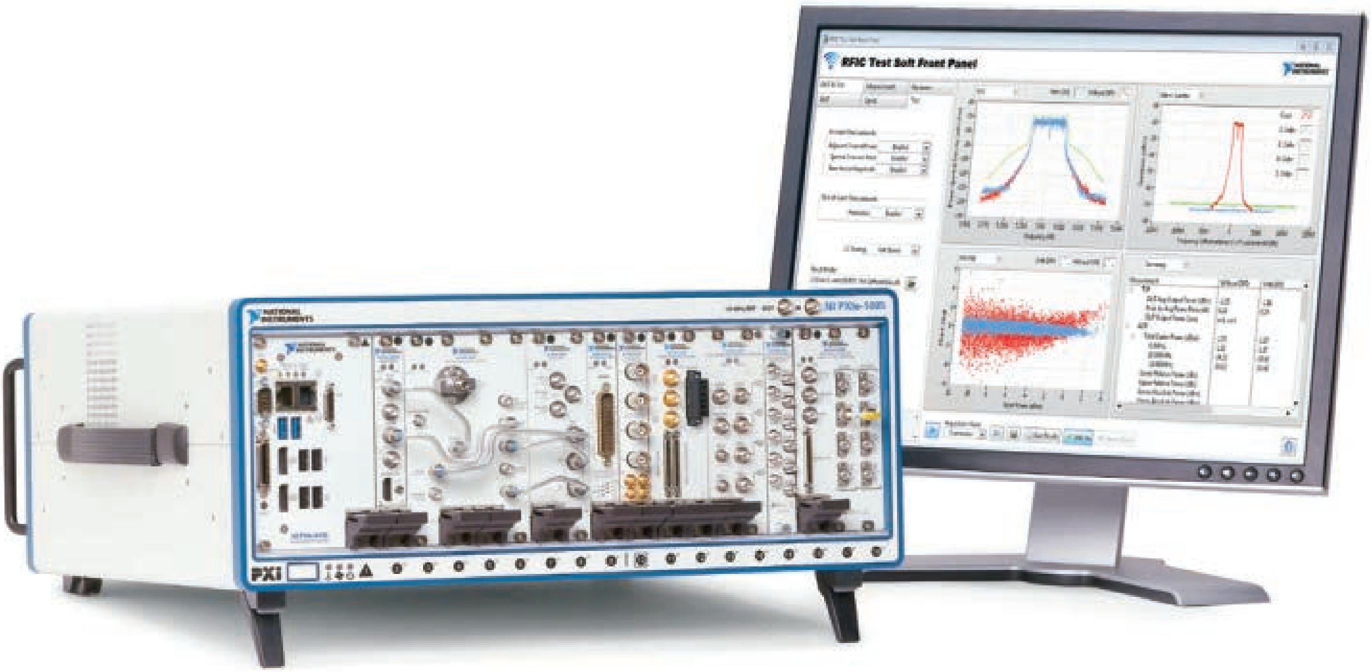

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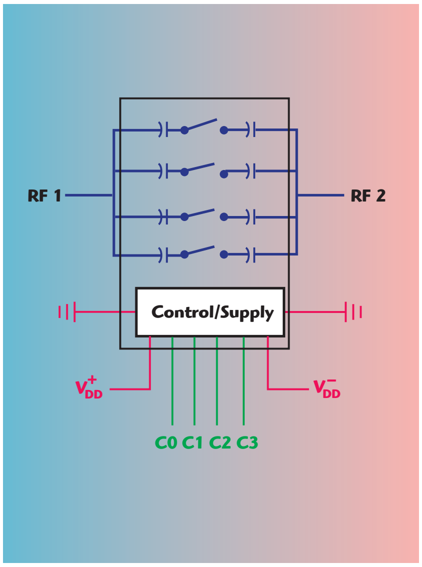
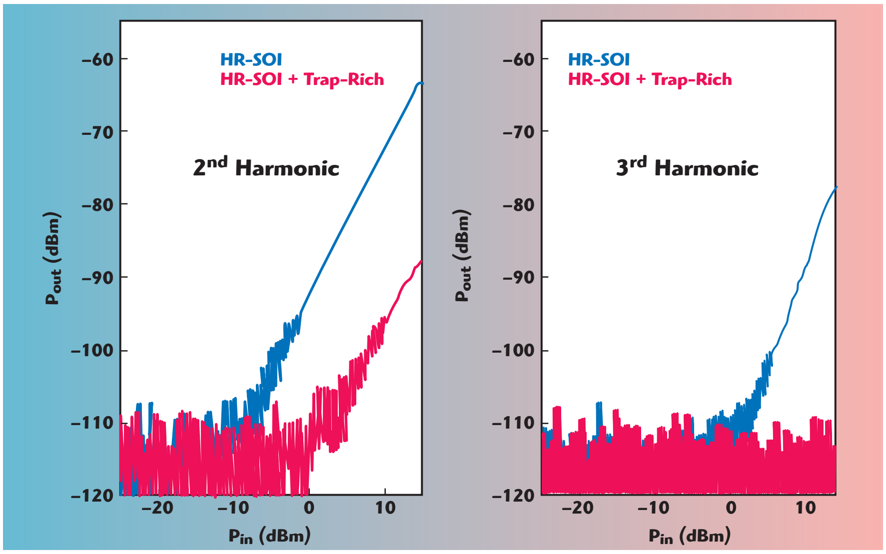


▲ *Fig. 8 16-state variable capacitor array.*[7]



▲ *Fig. 9 Harmonic distortion of a coplanar transmission line, comparing HR-SOI to HR-SOI with a trap-rich layer.*[10]

expected market demand at a lower cost. Until that point, GaAs PHEMT and PIN diode technologies were used for the RF switch function. The key characteristics that have solidified RF SOI's role in mobile FEMs are:

1. Device stacking ability for higher voltage handling
2. Low on-resistance (Ron) for reduced insertion loss
3. Low off-capacitance (Coff) and substrate parasitics for high isolation and high Q
4. Logic and control integration
5. Low cost and improved economics over III-V technologies
6. Mainstream silicon manufacturing

It has been covered in the literature[9] that RF SOI on a high resistivity substrate with sufficiently high gate resistors allow the FET body terminals to float and allow multiple FET devices to be stacked in order to handle high voltage, high power conditions (see ***Figure 6***).

By combining these inherent properties of RF SOI along with the use of proper bias network design, one can achieve the correct voltage division across the stack in the off state and very low resistance in the on state (Ron) for low insertion loss (see ***Figure 7***). Intrinsic device Ron reduction is achieved fundamentally by lowering channel length, but this must be carefully balanced with the corresponding reduction in BVdss. Reduction in BVdss requires a larger device stack height and chip area in order to maintain the high voltage handling capability. The off state capacitance (Coff) is another key metric in switch design and determines the off state isolation the device can achieve. Reduction in Coff to achieve greater isolation can be challenging and must employ a variety of techniques including junction engineering, device layout and metal stack optimization. Continual reduction in the Ron Coff product while maintaining a reasonable BVdss has allowed complex switch products to be designed.

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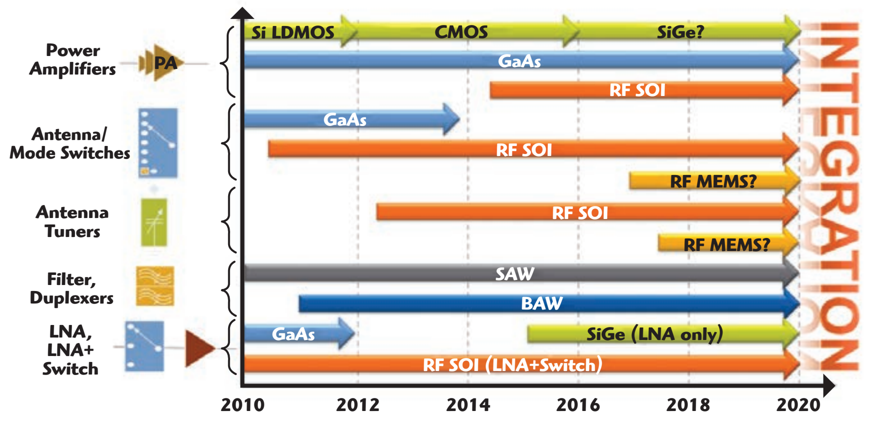
Cost	−	−	+	+

▲ *Fig. 10 Comparison of key FEM technologies.*



▲ *Fig. 11 RF FEM technology trends.*

can handle high power levels and achieve low insertion loss with high isolation, one can begin to imagine other applications where this device can be used. By combining RF switches and capacitors in series or in shunt into an array, a selectable or tunable high Q capacitor bank can be created, as shown in ***Figure 8***, that can be used as a dynamic or variable tuning element. Many of today's RF SOI technologies have high quality metal-insulator-metal (MIM) and metal-oxide-metal (MOM) capacitors with reasonably high density (>2 fF/μm^2) and high breakdown voltages to support large standing wave signals. The combination of MIM/MOM capacitors and RF switches makes tuners possible, leading to the adoption of RF SOI for applications such as antenna impedance matching or antenna aperture tuning to address the antenna bandwidth and impedance variability problems.

Both of the applications described require an element of digital control to select a given switch configuration or tuner state. In GaAs or other III-V technologies, this typically requires a separate CMOS controller chip to be paired with the GaAs device to dynamically adjust the device state based on commands from the baseband processor. RF SOI allows the complete monolithic integration of the controller element and the RF function into a single chip, thus reducing cost, space and overall system complexity.

Due to the power levels involved, each of the applications described requires very high linearity and low harmonic response in order to minimize the creation of distortion products in high power, multi-carrier conditions. Today's LTE system specifications require any harmonics generated by the RF switch to be >70 dB below the main carrier signal. Increased FET breakdown voltage allows reducing stack height and improving insertion loss and related harmonic generation. However, another component of non-linearity is associated with surface charge recombination in the substrate, where high power RF signals can induce the creation of a parasitic conduction layer in the SOI substrate silicon/buried oxide (BOX) interface. RF signals may couple to this parasitic layer and modulate its conduction characteristics. This dynamic has been

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addressed through various substrate treatments, such as charge trap-injection, which minimize the creation of this parasitic layer at the interface. This has resulted in better than 15 dB improvement in device linearity performance over standard high resistivity substrates without these treatments (see ***Figure 9***).

RF SOI has enabled the integration of two other critical components of the FEM: LNAs and PAs. The noise figure and gain performance of an LNA is driven by the ft, fmax and gate resistance of the FET. SOI provides a very low capacitance device thereby helping both ft and fmax. Since the early introduction of RF SOI, the Wi-Fi FEM has widely deployed the use of both switches and LNAs integrated on a single IC. With the advent of carrier aggregation in LTE cellular applications, improved LNA performance for both main Tx/Rx and diversity Rx antenna paths is desired. This presents an opportunity for RF SOI to allow the integration of optimized switches and LNAs in the cellular FEM as well. Power amplifiers, on the other hand, need high ft and high breakdown voltages. FET stacking concepts have been demonstrated on high resistivity (HR) substrate RF SOI devices in the literature to provide acceptable cellular PA performance.[11] HR SOI also allows improved passives to support on-chip matching. Many challenges related to PA integration on SOI, such as thermal and substrate coupling, have been addressed over time and products have been demonstrated. RF SOI circuit design and architecture innovation are important components of driving these solutions into the mainstream. Of all of the technologies addressing FEM applications today, RF SOI provides a unique balance in meeting key technical and economic requirements (see ***Figure 10***).

THE FUTURE FOR RF SOI

The rapid growth in smartphones and tablet PCs and other mobile consumer applications has created an opportunity and demand for chips based on RF SOI technology, particularly for antenna interface and RF front-end components such as RF switches and antenna tuners. As a low cost and more flexible alternative to GaAs, RF SOI is recognized as the technology of choice for the majority of RF switches and antenna tuners manufactured today for mobile devices.

As wireless standards continue to evolve, there will be tougher challenges ahead across the entire RF SOI value chain including handset providers, RF component makers, SOI foundries and substrate suppliers. The next release of the 3GPP LTE standard (Rel. 13) will pave the way for uplink carrier aggregation. This requirement will push linearity requirements for all FEM components, particularly RF switches, even further than today's levels (estimates vary between 85 to 90 dBm IIP3).

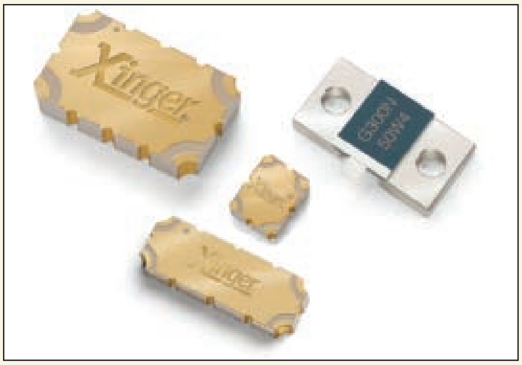
There will also be specifications defined for LTE operation in the unlicensed bands and require coexistence with Wi-Fi. In parallel, there is a plan in the next phase of Wi-Fi evolution to adopt 1024 QAM modulation which will further raise the bar for linearity and phase noise in Wi-Fi FEM components. All of these standard dynamics will present an interesting challenge for both cellular and Wi-Fi FEM manufacturers in mitigating the coexistence requirements for linearity and receiver sensitivity.

To address these highly complex, multi-band and multi-standard designs, RF front-end modules will require further integration of multiple RF functions like power amplifiers, antenna switches and transceivers, as well as digital processing and power management, to simplify the architecture and lower the cost. Today these functions are addressed by different technologies, but the trends seem to favor a silicon approach to achieve true integration (see ***Figure 11***).

Mobile devices that exploit RF SOI for RF front-end module functions benefit from higher levels of integration that combine with improved linearity and insertion loss and translate to better transmitter efficiency and longer battery life, enabling longer talk times (lower power) and a better user experience. Higher levels of integration also lead to RF circuit and architecture innovation as these technology benefits are combined with digital signal processing to create a dynamically adaptable solution to suit a given set of conditions. These are the clear benefits of a silicon-based technology. The exploration of the capabilities of RF SOI is just beginning. ■

References

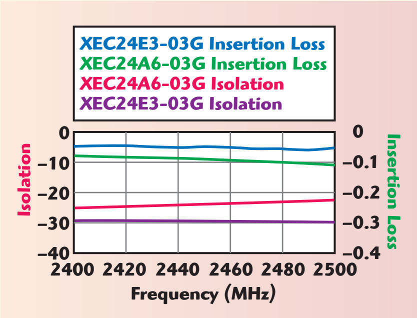
1. Cisco White Paper: *Cisco Visual Networking Index: Forecast and Methodology*, 2014-2019, May 2015.
2. Cisco White Paper: *Cisco Visual Networking Index: Global Mobile Data Traffic*, 2014-2019, February 2015.
3. iHS smartphone-electronics-design-intelligence-database, Q2 2015.
4. "Cisco Will Ride the 802.11ac Wave," http://blogs.cisco.com/wireless/cisco-will-ride-the-802-11ac-wave2.
5. Sassan Ahmadi, "LTE-Advanced: A Practical Systems Approach to Understanding 3GPP LTE releases 10 and 11 Radio Access Technologies," Chapter 13, Academic Press, 2014.
6. SOITEC White Paper, February 2013.
7. Ali Tombak, "Silicon on Insulator (SOI) Switches for Cellular and WLAN Front End Applications," *IMS 2012 Workshop*.
8. "Recent Advances in RF Front End for D/L Carrier Aggregation," muRata, *IWPC, Lund*, Sweden, June, 2013.
9. M.B. Shifrin, P.J. Katzin and Y. Ayasli, "Monolithic FET Structures for High Power Control Component Applications," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 37, Issue 12.
10. J. P. Raskin et al., "RF SOI CMOS Technology on Commercial Trap-Rich High Resistivity SOI Wafer", *2012 International SOI Conference*.
11. S. Pornpromlikit et al., "A Watt-Level Stacked-FET Linear Power Amplifier in Silicon-on-Insulator CMOS," *IEEE Transactions on Microwave Theory and Techniques*, 2010.



High Power Passives Fit Emerging RF Energy Market

Anaren Inc.
Syracuse, N.Y.

In addition to the vast array of consumer electronics, wireless infrastructure, military and space-based communication applications that are enabled by microwave technology, RF waves are also used to heat dissipative objects and power physicochemical processes. One example is, of course, the microwave ovens ubiquitous in our residential and commercial kitchens. Another would be microwave-based dryers used for industrial tasks like drying or curing fruit or meat.



▲ *Fig. 1 Measured insertion loss and isolation of the 600 and 300 W 3 dB couplers.*

The "heating" market is where some of the most exciting new uses for microwave energy are emerging. Here, RF energy generated by solid-state semiconductor chains – rather than the traditional, inefficient, short-lived magnetrons – is being contained, controlled and directed with more precision than before, yielding a host of new uses for RF energy:

- Efficiently jumpstarting automotive ignition and industrial lighting systems
- Enabling more precise medical imaging and analysis (MRI and NMR equipment)
- Empowering a new generation of "smart," solid-state microwave ovens that are highly programmable, IoT-connected and able to distinguish among the components of your meal.

While several market-making suppliers, many of whom are founders of the RF Energy Alliance, have launched (or have in their near-term pipelines) many of the technologies needed to realize this potential, passive RF components have not kept pace with the power handling and performance requirements for these new applications. Until now.

A BETTER FIT ALL AROUND

Operating in the 2.4 to 2.5 GHz ISM band, a new family of passive RF components specifically designed for these high energy applications is now available from Anaren. The family currently comprises two Xinger®-brand 3 dB hybrid couplers (XEC24E3-03G and XEC24A6-03G), one Xinger 30 dB directional coupler (XEC24P3-30G) and a flanged, AlN termination (G300N50W4) optimized to work with the couplers. The new products offer excellent electrical and dimensional characteristics when compared to competitive discrete and PCB-printed solutions.

Measuring 0.560" × 0.350" (14.22 × 8.89 mm), the XEC24A6-03G is a low profile, high performance 3 dB hybrid coupler in an industry exclusive (patent pending) ceramic/soft board SMT package suitable for applications up to 600 W. The coupler has a maximum insertion loss of 0.15 dB, minimum isolation of 20 dB and an amplitude balance of ±0.3 dB maximum (see ***Figure 1***). It is available in a 6 of 6 ENIG RoHS-compliant finish. Handling up to 300 W, the XEC24E3-03G 3 dB hybrid is in a low profile SMT package measuring 0.560" × 0.200" (14.22 × 5.08 mm), also with a RoHS compliant ENIG finish. This hybrid has 0.15 dB maximum insertion loss, 23 dB minimum isolation and an amplitude balance of ±0.25 dB maximum (also shown in Figure 1).

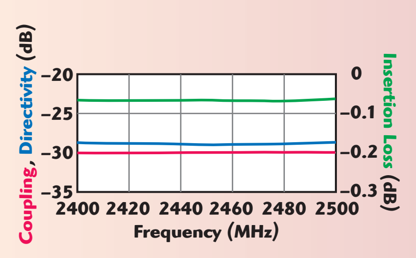
Most Valuable Product

The XEC24P3-30G directional coupler measures 0.250" × 0.200" (6.35 × 5.08 mm), operates up to 300 W, has a maximum insertion loss of 0.1 dB, tight coupling of 30 ±1.0 dB, high directivity of 20 dB minimum and frequency sensitivity of 0.25 dB maximum (see ***Figure 2***).

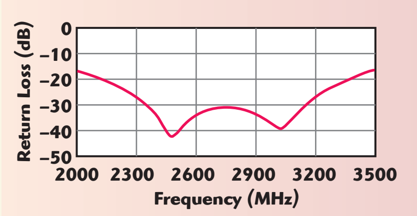
Designed to match and complement the couplers, the G300N50W4 is a high performance AlN flange mount termination with performance specifically tuned for the 2.4 to 2.5 GHz ISM band and intended for use in RF heating applications. Handling 300 W average input power, the RoHS compliant termination has a nominal impedance of 50 Ohms with a minimum return loss of 25 dB (see ***Figure 3***). It measures 0.975" × 0.500" (24.77 × 12.7 mm).

Of particular advantage to designers of high power and, thus, high heat-generating applications, the two high power 3 dB hybrids and the directional coupler in this family are manufactured using materials with coefficients of thermal expansion (CTE) that are compatible with common substrates such as FR-4, RF-35 and RO4350. In high power applications, where temperature variations can be extreme, the result of this material choice is a more durable and reliable physical connection between the component and the PCB during repeated, highly varied cooling and heating cycles. The operating temperature range for the 3 dB hybrids and directional coupler is -55° to +95°C, and the termination is designed to operate to +150°C.

Anaren's unique combination of heat-dissipating materials and the stripline construction used with this product family also allows for considerable space savings compared to traditional, connectorized high power couplers. This size advantage is most evident with the 600 W XEC24A6-03G hybrid: the 0.560" × 0.350" package is a fraction of the size of other couplers on the market, where footprints of 3" × 1" or larger are not unusual. The patent-pending technology used in this hybrid makes it an option for other applications and markets where high power handling or just high power density is needed.



▲ *Fig. 2 Measured coupling, insertion loss and directivity of the 30 dB directional coupler.*



▲ *Fig. 3 Measured return loss of the termination.*

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NASA Opens New CubeSat Opportunities for Low-Cost Space Exploration

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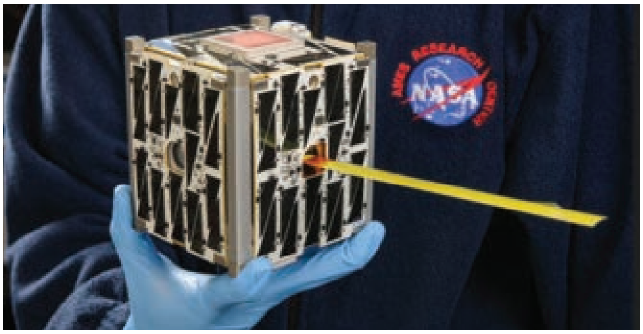
Space enthusiasts have an opportunity to contribute to NASA's exploration goals through the next round of the agency's CubeSat Launch Initiative. Applicants must submit their proposals electronically by 4:30 p.m. EST, Nov. 24, 2015.

The CubeSat Launch Initiative provides access to space for CubeSats developed by NASA centers, accredited educational institutions and non-profit organizations, giving CubeSat developers access to a low-cost pathway to conduct research in the areas of science, exploration, technology development, education or operations consistent with NASA's Strategic Plan. NASA does not provide funding for the development of the small satellites.

NASA plans to select the payloads by Feb. 19, 2016, but selection does not guarantee a launch opportunity. Selected experiments will fly as auxiliary payloads on agency rocket launches or be deployed from the International Space Station beginning in 2016 and running through 2019. To date, NASA has selected 105 CubeSats from 30 states. Thirty-seven CubeSats have been launched, and 16 more are scheduled to go into space in the next 12 months.

The agency has made progress on a goal established during the White House Maker Faire last year to launch a small satellite from at least one participant in each state over the next five years. For this round, NASA is focusing on gaining participation in the District of Columbia, Puerto Rico and 20 states not previously selected for the CubeSat Launch Initiative. These states are: Arkansas, Delaware, Georgia, Idaho, Iowa, Kansas, Maine, Minnesota, Mississippi, Nebraska, Nevada, New Hampshire, New Jersey, North Carolina, Oklahoma, Oregon, South Carolina, South Dakota, Washington and Wyoming.

CubeSats are in a class of research spacecraft called nanosatellites. The base CubeSat dimensions are 10 × 10 × 11 centimeters (about 4 × 4 × 4 inches), which equals one Cube, or 1U. CubeSats supported by this launch effort include volumes of 1U, 2U, 3U and 6U. CubeSats of 1U, 2U and 3U size typically have a mass of 1.33 kilograms (about three pounds) per 1U. A 6U CubeSat typically has a mass of 12 to 14 kilograms (26.5 to 30.9 pounds). The CubeSat's final mass depends on the selected deployment method.



Source: NASA

X-Band Radar Market Worth $5B by 2020

According ASDReports, "X-Band Radar Market by Type (Portable & Non-portable), Application (Defense, Government, & Commercial) - Global Forecasts, Trends & Analysis to 2015-2020," the X-Band radar market is estimated to be valued at $4.1 billion by the end of 2015 and is projected to grow at a CAGR of 3.56 percent to reach $5 billion by the end of 2020.

The key challenge faced by the X-Band radar market is that of the stringent government regulations. With an increase in the number of key manufacturers of X-Band portable radars, and the growing demand for these radars for commercial purposes, the X-Band frequency spectrum is getting congested. This factor results in the government agencies restraining from allocating this frequency range for commercial purposes.

North America is the leader in the worldwide market for portable X-Band radars. The region is expected to witness a CAGR of 5.47 percent from 2014 to 2020. The region witnesses a strong demand of portable X-Band radars in homeland and border security.

The European X-Band radar market is expected to reach $1,602.09 million by the end of 2015 and is projected to grow at a CAGR of 2.13 percent through the review period. The instability in Western Europe results in the need for procurement of military equipment like submarines, command and control systems, tactical helicopters, mobile artillery-hunting radar systems and next generation Gripen aircrafts loaded with surveillance radars, to meet the need for stability in Europe despite the political challenges driving the radar market expenditure.

Asia-Pacific is expected to emerge as a potential revenue pocket in the next five years due to the rising demand of portable X-Band radars for weather detection, border security, critical infrastructure monitoring, facility surveillance and several other applications. Hence, the APAC market is projected to reach $654.36 million by the end of 2015 and is expected to grow at a CAGR of 3.12 percent through the review period.

The major players in the X-Band radar market are SAAB AB (Sweden), Selex ES S.p.A (Italy), Thales-Raytheon Systems (U.S.), Kelvin Hughes Ltd. (UK) and Israel Aerospace Industries Ltd. (Israel), to name a few.

Source: DoD

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US Army and US Navy Award Lockheed Martin $66M for JAGM

The U.S. Army and U.S. Navy awarded Lockheed Martin a $66.3 million contract for the engineering and manufacturing development (EMD) phase of the Joint Air-to-Ground Missile (JAGM) program.

"Since the contract award in August, we conducted a fifth flight test that further demonstrated the high degree of design maturity and readiness for operational testing that will support future JAGM production," said U.S. Army Project Manager Col. James Romero. "The Aug. 25 test was the first JAGM test using the Active Fire and Forget, Lock-On After Launch engagement mode against a stationary armored target. Throughout all five tests, we have demonstrated that both sensors – onboard radar and semi-active laser – effectively operate together to provide an enhanced capability against stationary and moving targets for precision point or fire-and-forget targeting."

The 24-month EMD phase will include JAGM production, test qualification and integration on the AH-64 Apache and AH-1Z Cobra attack helicopters. The EMD phase also establishes an initial low-rate manufacturing capability in support of two follow-on low-rate initial production options.

JAGM is the next generation air-to-ground missile for use on joint rotary-wing and unmanned aircraft systems for the Army, Navy and Marine Corps.

Next Generation Jammer Prototype Powers Through Critical Test

In collaboration with the U.S. Navy, Raytheon Co. recently completed effective isotropic radiated power (EIRP) testing for its Next Generation Jammer (NGJ) array prototypes at the Benefield Anechoic Facility at Edwards Air Force Base, Calif.

The prototype testing, conducted over a six week period, indicated that the NGJ will fulfill the U.S. Navy's stringent requirements for EIRP, a prime indicator of the system's range and capacity for reaching and affecting multiple targets simultaneously.

The NGJ is built on a combination of high-powered, agile, beam-jamming techniques and cutting-edge solid-state electronics to achieve two goals: meet the U.S. Navy's electronic warfare mission requirements and provide a cost-effective open systems architecture for future upgrades.

Source: U.S. Navy

5G Innovation Centre Opens in UK

The University of Surrey, UK, opened its state-of-the-art 5G Innovation Centre (5GIC), securing the UK's role in leading the development of the next generation communications technology, 5G. Housing over 170 researchers and attracting over £70 million of investment, including £12 million from the Higher Education Funding Council for England (HEFCE), the 5GIC is claimed to be the world's largest academic research centre dedicated to next generation mobile and wireless connectivity.

The Centre brings together leading academic expertise and major industry partners to define and develop a global 5G network that will radically change lives across the world. Through their work, they have already developed a technology that enables speeds of one terabit per second (Tbps) – more than 1,000 times faster than the highest 4G speed, and filed over 15 patents.

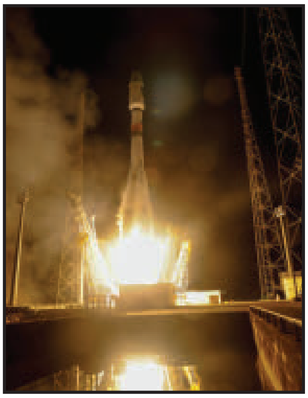
Professor Rahim Tafazolli, director of the 5GIC, said, "While we have already achieved record-breaking speeds, 5G is not only about delivering faster mobile internet. It is a transformative set of technologies that will radically change our private and professional lives by enabling innovative applications and services, such as remote healthcare, wireless robots, driverless cars and connected homes and cities, removing boundaries between the real and cyber worlds. These capabilities make 5G a 'Special Generation' of connectivity."

"The true impact of 5G will come from the innovative applications the new network will enable, some of which are yet to be realized. The opening of the Centre marks an important step in allowing those from across the globe to work with us in developing the new network and for partners, other universities and industry to test out their new applications in a real world setting, before they are brought to market."

"The ethos of the Centre is not built on competition but cooperation. 5G will be achieved through global collaboration so that everyone will benefit from working to a single standard. This technology will then be commercialized from 2020, driving economic development and research for the UK, while delivering research that will impact the world."

Source: The University of Surrey

Galileo Achieves Perfect 10 in Orbit



Source: European Space Agency

Europe's satellite navigation system came a step nearer to completion when Galileo 9 and 10 lifted off on September 11 from Europe's Spaceport in French Guiana, atop a Soyuz launcher. All the Soyuz stages performed as planned, with the Fregat upper stage releasing the satellites into their target orbit close to 23,500 km altitude.

"The deployment of Europe's Galileo system is rapidly gathering pace," said Jan Woerner, director general of ESA. "By steadily boosting the number of satellites in space, together with new stations on the ground across the world, Galileo will soon have a global reach. The day of Galileo's full operational capability is approaching. It will be a great day for Europe."

Two further Galileo satellites are still scheduled for launch by end of this year. These satellites have completed testing at ESA's ESTEC technical centre in Noordwijk, the Netherlands, with the next two satellites also undergoing their own test campaigns. More Galileo satellites are being manufactured by OHB in Bremen, Germany, with navigation payloads coming from Surrey Satellite Technology Ltd. in the UK, in turn utilizing elements sourced from all across Europe.

"Production of the satellites has attained a regular rhythm," said Didier Faivre, ESA's director of Galileo and Navigation-related Activities. "At the same time, all Galileo testing performed up to now – including that of the ground segment – has been returning extremely positive results."

He added, "With the European Commission, we are doing the technical work to ensure Galileo goes on 'forever' – locking in continuity of Europe's navigation services into the long term, to meet performance on a par with the other global satellite navigation systems."

Infineon Automotive Radar Chips Nominated for Innovation Prize

The high-frequency radar chip team at Infineon Technologies AG has been nominated for the Deutscher Zukunftspreis 2015 (German Future Award), the German President's Award for Innovation in Science and Technology. The jury has nominated Ralf Bornefeld, Dr. Walter Hartner and Dr. Rudolf Lachner for the Deutscher Zukunftspreis 2015 and, in doing so, has acknowledged two key innovations that have initiated the breakthrough of radar systems in the automotive market.

Infineon is the first company to develop highly integrated circuits for the 77 GHz frequency range based on silicon (Si)

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and silicon germanium (SiGe) instead of gallium arsenide (GaAs), typically used before. Using Si and SiGe material leads to much lower product costs of radar systems.

The second innovation is a new packaging technology known as embedded Wafer-Level Ball Grid Array (eWLB), which offers very good high-frequency characteristics and simplifies the further processing of radar chips at the automotive system provider. This means a substantial reduction in system costs of the radar system.

Dr. Reinhard Ploss, CEO of Infineon Technologies AG stated, "The nomination acknowledges our employees' outstanding achievements. It is an incentive for further innovations that will not only bring about technical novelties but also prevail on the market and improve people's lives."

HGI Requirements Will Strengthen Performance of Wi-Fi

The Home Gateway Initiative (HGI) has published new requirements that when implemented will improve the reliability and range of Wi-Fi networks for services operating on both 2.4 GHz and 5 GHz frequencies. The new document, RD-045: Wi-Fi requirements for Home Gateways - Automatic Channel Selection (ACS) and Repeaters, improve the clarity of Automatic Channel Selection (ACS) requirements. HGI's new requirements for the Home Gateway aim to make ACS implementations more consistent and effective in selecting the appropriate Wi-Fi channels in the 2.4 GHz and 5 GHz bands. Interference is another issue discussed. The requirements also examine how to extend the coverage of Wi-Fi networks without cabling.

> "...ensure a consistent user experience..."

"This is typically done with Wi-Fi repeaters but today's devices are either not certified or are Wi-Fi certified as Access Points (AP)," said HGI's chief technology and business officer Duncan Bees. "As multiple options exist for implementing Wi-Fi repeaters, the end-user experience can vary between different devices. HGI's aim was to write down the core high-level requirements that when implemented will ensure a consistent user experience with repeaters."

In order to produce the requirements, HGI undertook an examination of ACS technology operating on the Home Gateway, including Wi-Fi/non-Wi-Fi interference issues. Under HGI's new ACS requirements, each Wi-Fi AP with ACS must implement an ACS mechanism for each supported frequency band. When and how often the ACS solution should run is also covered by the requirements, in addition to regulating the monitoring of background noise.

Additionally, Wi-Fi repeaters must: support WPS push button for association with the primary AP; be able to extend all the announced AP WLANs on its supported bands when using the WPS procedure; and, after WPS configuration, create a WLAN with the same SSID and security settings as the AP it is extending.

Urban Population Growth Drives Demand for Smart City Solutions

VIEW VIDEO

Compass Intelligence recently released its latest study titled "Smart Cities: The New Frontier for Opportunities in IoT." The report covers various aspects of the Internet of Things (IoT) including hardware, software, connectivity and data analytics to study demand for smart energy, smart transportation, smart infrastructure and smart buildings, smart security, smart or connected homes, and smart healthcare across the globe. The study also provides insights into key drivers and challenges impacting smart cities.

With the continuing growth in urban population across the globe, both public and private sector stakeholders are coming together to develop and implement solutions that alleviate pressures on existing infrastructure and resources while also enhancing quality of life for urban dwellers.

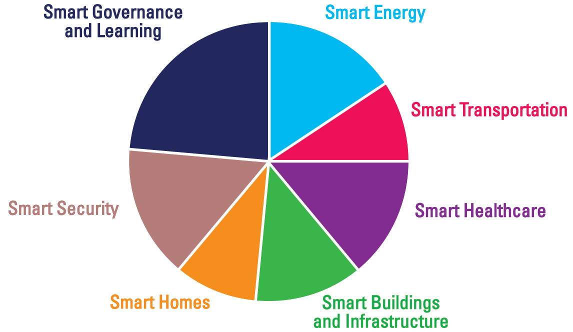
This study highlights steps that are being taken by hardware and software vendors, systems integrators, governments and other members of the smart city eco-system in creating sustainable solutions that effectively address challenges faced by modern day cities. Moreover, the study offers a review of the overall market opportunity for vendors involved in developing and delivering smart city solutions.

"Smart energy such as grids and supporting infrastructures have benefited from early adoption," states Lavanya Rammohan, senior analyst, M2M & IoT. "The use cases and ROI for smart energy solutions is straightforward and technology companies as well as political decision-makers are well aware of the benefits."

The smart cities market is expected to grow globally from $664 billion in 2015 to $1,420 billion in 2020 at a CAGR of 16.4 percent over the forecast period. Revenues include hardware, software and integration and value-added services. While North America currently accounts for a majority of revenues generated through deployment of smart city solutions, other regions such as Europe and Asia-Pacific also offer tremendous growth opportunities for a range of vendors involved. Key findings include:

1. Smart transportation segment accounted for a large portion of the revenues. The Smart Transportation solutions market is driven by the need for effective traffic as well as environmental management solutions in metropolitan areas.
2. Smart grids and renewable energy segments constitute another big area of focus for utility companies, governmental agencies, and the private sector. Smart grid solutions help utility companies reduce waste, reduce carbon footprint, and optimize asset usage.
3. Greater adoption of IoT-based technologies across consumer and industrial/commercial segments is further fueling interest in smart city deployments.
4. Within healthcare, migration to mHealth initiatives is driving adoption of wearable technology among consumers as well as healthcare providers. Such solutions aim at improving overall quality of healthcare while reducing costs.
5. Smart city eco-systems are comprised of network providers such as AT&T and Verizon, systems integrators such as IBM and Hewlett-Packard, hardware vendors such as Cisco and Ericsson, building management solutions providers such as Honeywell and General Electric, and others such as Big Data analytics' companies.
6. The smart city market is expected to experience some degree of vendor consolidation, as well as emergence of strategic alliances across hardware, software and services providers.

Global Smart Cities: Percentage of Revenue by Segments, 2015



Source: Compass Intelligence, August 2015

E/V-Band Microwave Equipment Sales Up 30 Percent

According to a recently published report from Dell'Oro Group, revenue from shipments of point-to-point microwave transmission equipment in second quarter 2015 did not improve over the year ago period. However, a bright spark in the microwave market was the continued growth in demand for ultra-high capacity systems that use E-Band and V-Band radio frequencies to deliver up to 3 gigabit-per-second (Gbps) of link capacity. Ultra-high capacity microwave revenue grew nearly 30 percent year-over-year in the second quarter of 2015, marking the 10th consecutive quarter of such high double-digit percentage growth. Huawei, Siklu and NEC lead the E/V-Band Market.

> "The current market for ultra-high capacity microwave systems is small but the potential is big."

"The current market for ultra-high capacity microwave systems is small but the potential is big," said Jimmy Yu, vice president of Microwave Transmission research at Dell'Oro Group. "Use of mobile broadband will continue to rise and installation of higher capacity LTE radios is a given. But what about backhauling when those capacity require-

For More Information Visit mwjournal.com for more commercial market news ments exceed standard microwave system capabilities and when fiber isn't available? This is where we think E-Band and V-Band microwave shines, especially in countries that have favorable spectrum lease terms," Yu added.

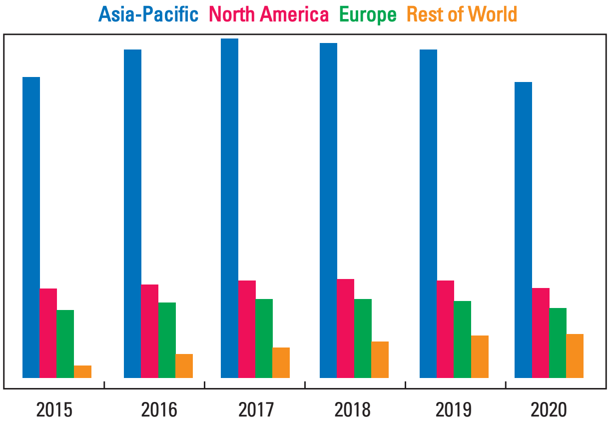
China Drives RF Power Amplifier Sales for Wireless Infrastructure to Nearly $5B

The year 2014 was a banner year for wireless infrastructure hardware, especially RF power amplifiers; and prospects look good for growth through 2020, according to ABI Research. The Asia-Pacific region, including Japan, continues to account for the majority of RF power amplifiers sold into the mobile wireless infrastructure segment. According to research director Lance Wilson, "For the foreseeable future the Asia-Pacific region, particularly China, will remain the most important region and focus for RF power amplifiers for wireless infrastructure."

> "...LTE is going to drive RF power sales in the wireless infrastructure space from 2015 onward."

LTE and TD-LTE have become increasingly important factors in this business and will continue to drive growth for the future. "Up until 2014, LTE had not significantly impacted RF power amplifier sales to the degree some would have wished," says Wilson, "but that has changed now and as 2014 demonstrated, LTE is going to drive RF power sales in the wireless infrastructure space from 2015 onward." The continuing overall need for wireless data remains an important driver for the overall market for RF power amplifiers for wireless infrastructure.

Total Cellular and Mobile Wireless Infrastructure RF Power Device Revenue by Region World Market Forecast: 2015 to 2020



Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Keysight Technologies Inc. announced it has purchased **Electroservices Enterprises Ltd.,** a U.K. company specializing in test equipment service and solutions. Based in Telford, Electroservices provides a broad range of electrical, mechanical and physical calibration, repair and asset management services to a large number of defense, telecom and industrial customers.

CommScope Holding Co. Inc. has completed its previously announced acquisition of **TE Connectivity's** Telecom, Enterprise and Wireless businesses, a leader in fiber optic connectivity for wireline and wireless networks. The all-cash transaction, valued at approximately $3 billion, strengthens CommScope's position as a leading communications infrastructure provider with deeper resources to meet the world's growing demand for network bandwidth.

COLLABORATIONS

POET Technologies Inc., developer of the planar optoelectronic technology platform for monolithic fabrication of integrated circuit devices containing both electronic and optical elements, announced that it had entered into a VCSEL Manufacturing Services Agreement with **ANADIGICS Inc.** for VCSEL process transfer and manufacturing. The agreement is significant as it accelerates the transition from lab-to-fab and enables successful prototype demonstrations in a mature and capable manufacturing environment.

MPI Corp. is partnering with T&M equipment manufacturer **Rohde & Schwarz** to provide customers with on-wafer measurements of semiconductor components in the RF and millimeter wave ranges. The two companies successfully achieved a seamless integration of Rohde & Schwarz vector network analyzers (VNA) and MPI engineering probe systems.

NEW STARTS

Cree Inc. announced that **Wolfspeed** is the new name for its Power and RF division. The company announced in May that it would be separating the Power and RF business into a stand-alone company. This change will provide both Cree LED and Lighting and Wolfspeed with increased focus, enabling them to unlock the value of each, as well as give Wolfspeed better access to capital markets to accelerate future growth.

P1dB Inc. launched its new e-commerce website, www.p1db.com, whose focus is product availability and fast shipment to its global customer base. The P1dB website has been designed to meet customer demand for an easy product search, consumer level e-commerce check-out and 24/7 availability. P1dB will continue to increase and develop its product line based on market feedback in order to become the leading RF and microwave component supplier supporting customers' immediate requirements.

GigOptix Inc. announced that it intends to offer newly issued shares of common stock in an underwritten public offering under an effective shelf registration statement on file with the Securities and Exchange Commission. The company expects to use the net proceeds from the offering of the shares which it is selling for potential acquisitions for strategic growth, including the acquisition of critical technologies and scalable businesses. The focus will be on multiple attractive global targets, including entities that the company has been tracking for the last couple of years.

ACHIEVEMENTS

Pasternack Enterprises Inc. has been awarded the 4-Star Supplier Excellence Award by Raytheon's Integrated Defense Systems (IDS) business. This is the third consecutive year that Pasternack has been honored with a Supplier Excellence Award from Raytheon IDS. Raytheon's IDS business instituted the annual Supplier Excellence Awards program to recognize suppliers who have provided outstanding service and partnership in exceeding customer requirements.

DiTom Microwave received its second space qualification with a U.S. manufacturer in 2015. DiTom Microwave, a designer and manufacturer of space qualified and high reliability connectorized ferrite isolators and circulators, has shipped over 500,000 ferrite devices to customers all over the world since its inception in 1987.

Peregrine Semiconductor Corp., founder of RF SOI (silicon on insulator) and pioneer of advanced RF solutions, announced that it has been awarded qualified manufacturers list (QML) certification, Class Q (military) and V (space). After a thorough evaluation, Peregrine demonstrated to the Defense Logistics Agency (DLA) Land and Maritime that it fully complies with MIL-PRF-38535, the performance specification used by the Department of Defense for monolithic integrated circuits that operate in severe environments.

Based on its recent analysis of the vector network analyzer (VNA) market, Frost & Sullivan recognized **Copper Mountain Technologies** (CMT) with the 2015 Global Frost & Sullivan Award for Competitive Strategy Innovation and Leadership. CMT's VNAs stand out for their high performance in a smaller form factor at much lower prices than existing mid-range network analyzers. While leading mid-range VNAs are too big, heavy, or expensive to be portable, CMT's VNAs can be easily transported and deployed in remote locations.

United States Patent 9,093,731 B2, recently awarded to **Empower RF Systems**, validates the uniqueness of the hardware architecture in use on the company's high power, next generation amplifiers. The embodiments of this patent protection are related to the design, associated materials, and integration of the high power combiner that is integral to delivering multi-kW broadband power (CW) and narrow band pulse in an air cooled, 5U chassis (and other combinations of power and chassis sizes utilizing this architecture).

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

Around the **Circuit**

Cavendish Kinetics announced that it has completed its final funding round with a strategic raise of $36 million, to accelerate the development of its next generation RF components. Cavendish's new generation of RF components fully leverages its proven RF MEMS technology, and adds a range of virtually loss-less RF MEMS switches to its growing portfolio of industry leading RF MEMS tuners. Together the new components will enable a wide range of radio front-end applications.

Anite, a global leader in wireless equipment testing technology, announced that it has played a pivotal role in accelerating the initial release of the CTIA standardized MIMO Over-the-Air (OTA) performance test plan published last month. Anite has contributed channel emulation expertise to the CTIA MIMO OTA subgroup since it was set up in 2011. Anite's Propsim Channel Emulator supports all CTIA channel model requirements (both MIMO and Transmit Diversity testing) allowing users to comprehensively and quickly verify that mobile devices meet expected industry requirements.

ANSYS and **Cray Inc.**, working in conjunction with two supercomputing centers, have smashed the previous simulation world record by scaling ANSYS® Fluent® to 129,000 compute cores – enabling organizations to spur innovation by creating complete virtual prototypes of their products. ANSYS achieved these breakthroughs by working with the National Center for Supercomputing Applications (NCSA) and the National Energy Research Scientific Computing Center (NERSC). Less than a year ago, ANSYS announced Fluent had scaled to 36,000 cores with the help of NCSA.

CONTRACTS

Harris Corp. has received a $97 million order to provide the **U.S. Naval Air Systems Command** (NAVAIR) with self protection jammers for the integrated defensive electronic countermeasures (IDECM) program. The order was received during the fourth quarter of Harris' fiscal 2015. Harris will provide its ALQ-214 radio frequency integrated countermeasure system, which is already used by the Navy to protect carrier-based F/A-18s, including both Hornets and Super Hornets, from sophisticated RF threats such as hostile radars and air defense systems.

The **U.S. Army** and **U.S. Navy** awarded **Lockheed Martin** a $66.3 million contract for the Engineering and Manufacturing Development (EMD) phase of the Joint Air-to-Ground Missile (JAGM) program. The 24-month EMD phase will include JAGM production, test qualification and integration on the AH-64 Apache and AH-1Z Cobra attack helicopters. The EMD phase also establishes an initial low-rate manufacturing capability in support of two follow-on low-rate initial production options.

The **U.S. Army** has awarded **Raytheon Co.** a $36 million contract to fund the certification and testing of a significant upgrade to the AN/ARC-231 Multi-Mode Communications System. The upgraded systems will provide the highest level of security for voice and data communications for more than 7,000 rotary, fixed wing and unmanned Army platforms – including Apaches, Blackhawks, Chinooks and Gray Eagles.

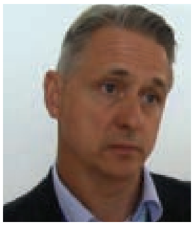
Phonon Corp. has received a $7 million order from a leading defense prime contractor for SAW radar pulse compression modules, for 2016 delivery, for an air defense system. Phonon Corp. designs and builds custom SAW devices and modules for defense and space. Custom SAW modules are the company's primary business. They are the largest exclusive defense and space supplier of SAW products. This technology provides the small size, weight and power required by defense airborne, space and portable systems.

Comtech Telecommunications Corp. announced that its Orlando, Florida-based subsidiary, **Comtech Systems Inc.,** received orders aggregating $4.8 million for its MTTS Troposcatter terminals, solid-state amplifiers (SSPA) and associated spare parts. This equipment is slated for use by the U.S. military overseas and is expected to ship in Comtech's fiscal 2016.

BAE Systems has delivered 12 new CV90 Infantry Fighting Vehicles (IFV) to the **Norwegian Army**. They are the first production batch of a total of 144 new and upgraded CV90s planned for the nation's Army and represent the next generation of advanced combat vehicles. The delivery of the CV90s occurred on schedule and took place during a ceremony at the Setermoen Military Camp in Northern Norway. The event was attended by several BAE Systems representatives.

PEOPLE

Raytheon Co. chairman and CEO Thomas A. Kennedy announced the appointment of **Wesley D. Kremer** as president, Integrated Defense Systems, effective immediately. Kremer, 50, previously served as vice president of the Air and Missile Defense Systems (A&MDS) product line of Raytheon Missile Systems. He succeeds Daniel J. Crowley, who informed the company of his intention to resign from Raytheon on December 31, 2015. Crowley will complete work on a special assignment for the company in the interim period prior to his departure.


▲ *Patric Erlandsson*

Sivers IMA has appointed new directors for the U.S. and Asia. **Patric Erlandsson** is the regional business director responsibile for direct and indirect sales in the U.S. He joins Sivers IMA from Ericsson where he managed a number of functions such as business development, product management and strategic sourcing within the microwave product area. **Susanne Segeland** is channel sales and marketing director responsibile for the global partner network program as well as sales in the Asian region. She joins Sivers IMA from Connode, a company specializing in wireless communication products for smart metering, where she was the sales director.


▲ *David Vye*

Former *Microwave Journal* editor, **David Vye** has joined **NI** as the new director of technical marketing for AWR Group of NI responsible for the outbound marketing/promotional activities and global messaging/positioning of the company's NI AWR Design Environment software solutions. Vye was recently the business development manager with the

Electronic Business Unit at ANSYS, which collaborates with NI in developing the Microwave Office/HFSS design flow for RF PCBs, MMIC/RFICs and multi-chip modules.


▲ *Serafin Morales*

Quintech Electronics & Communications Inc. announced the addition of **Serafin Morales** as the new international account manager, CALA. Morales joins the Quintech team as an experienced sales executive within the telecommunications industry across major service providers in the Latin American & Caribbean region. Quintech is confident in Morales' familiarity with major telco operators in the region to expand Quintech's footprint with both direct interaction and through the management of existing and new distributors.


▲ *John P. Hoeschele*

Smith Marketing Services, based in Ithaca, N.Y., announced it has hired **John P. Hoeschele** as creative director. Hoeschele will contribute to development of marketing and creative strategies for the company's national and regional clients, which include New York Air Brake (a Knorr Bremse company), the Corning Museum of Glass, Rochester Gas & Electric, among others. Most recently, he headed the marketing communications function for Syracuse, N.Y.-based Anaren Inc., a $170 million, global leader in wireless, space and defense technology.


▲ *Andrew Crofts*

Anokiwave Inc. announced the latest addition to its leadership team with the appointment of **Andrew Crofts** to the position of vice president of applications. This appointment supports Anokiwave's plans to extend product development by supporting new customers and applications for its portfolio of mmW products scheduled to release this fall. Crofts joined Anokiwave in June 2015 and will be responsible for supporting the overall sales operations strategies designed to help achieve the company's global business objectives through customer application support.

Resonant Inc., a late-stage development company creating innovative filter designs for radio frequency front-ends (RFFE) for the mobile device industry, announced it has added **Thomas R. Joseph**, Ph.D., 65, to its board of directors, bringing the number of independent board members to four and the total number of board members to six. Joseph brings deep expertise in the RF, compound semiconductor, cellular, fiber optics and surface acoustic wave (SAW) industries.

REP APPOINTMENTS

CRFS announced the opening of a new Technical Service Centre in South Korea in partnership with its approved South Korean partner, **SYSDYNE**. CRFS provides the most advanced 24/7 RF spectrum monitoring and analysis solu-

tions, with direction finding and geolocation capability, for in-building and wide area real-time spectrum and signals monitoring. Following significant sales growth in the region, CRFS has partnered with SYSDYNE to provide local high quality technical support for the complete range of RFeye™ products for customers in South Korea.

IQD Frequency Products has extended its distribution relationship with **Arrow Electronics** with the signing of a new agreement covering all the Americas (including Canada, USA, Central and South America). Arrow has been successfully distributing IQD's products throughout the European market for over 20 years as their largest frequency products franchise in that region. The addition of Arrow to IQD's distribution network within the Americas is part of their plans for further growth across this region and will provide their customers with extended product availability and service options.

Richardson Electronics Ltd. announced a new global distribution agreement with **Cornell Dubilier Electronics** (CDE), a manufacturer of quality, high-performance capacitors used in demanding industrial applications. The agreement aligns with CDE's efforts to advance capacitor technology for new applications, with Richardson Electronics' global sales team supporting these new opportunities.

TechPlus Microwave Inc., a designer and manufacturer of RF/microwave filters, announced the appointment of **The Thorson Company** of Southern California as their new representative in southern California.

PLACES

RFMW Ltd. announced the opening of a direct sales office in Sweden. The new sales organization will support customers in Denmark, Finland, Norway, Sweden and the Baltic states (Nordic).

Skyworks Solutions Inc. announced that it is expanding production capacity in Japan to meet the growing demand for its filter technology. Skyworks is facilitizing a two-story, 405,000 square foot facility in Osaka that will house the design, development and manufacture of filter devices to complement its industry leading front-end solutions and world-class assembly, test and packaging capabilities. With the additional capacity, Skyworks is well positioned to offer differentiated architectures for the most demanding customer applications.

Antenova Ltd., manufacturer of antennas and RF antenna modules for M2M and the Internet of Things, is opening a new base in Santa Rosa, Calif., and announced the appointment of **Norm Smith** who joins the company in the role of vice president, North America, and will lead the company's U.S. operation and further expansion in America. The new office will contain an RF laboratory and test equipment providing both technical and sales support.

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Hand Flex Cables conform to any shape required.

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Standard lengths in stock, custom models available. Standard lengths from 3 to 50" are in stock for same-day shipping. You can even get a Designer's Kit, so you always have a few on hand. Custom lengths and right-angle models are also available by preorder. Check out our website for details, and simplify your high-frequency connections with Hand Flex!

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482 Rev. K

INVITED PAPER

Engineered Substrates: The Foundation to Meet Current and Future RF Requirements

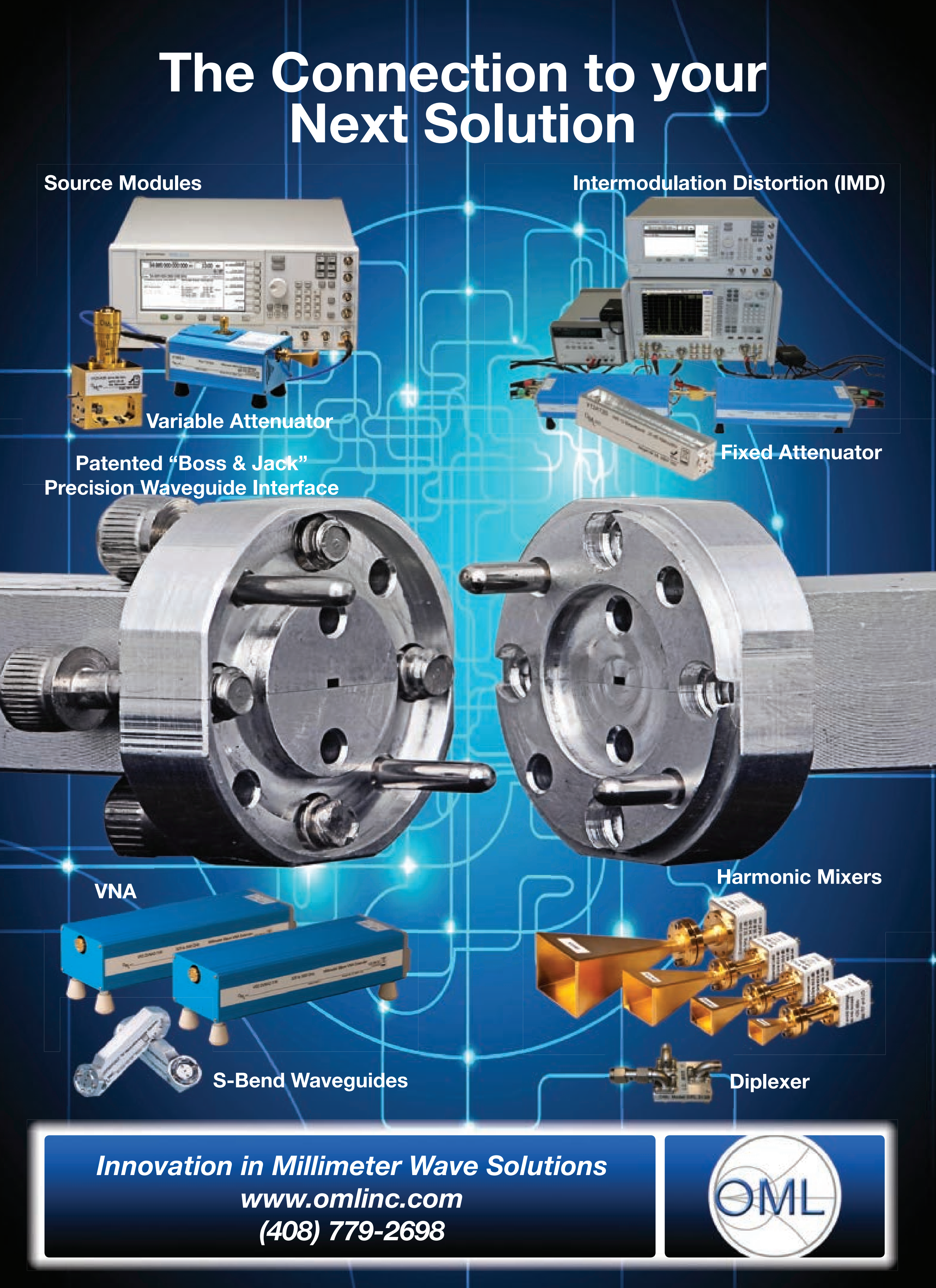
Eric Desbonnets and Christophe Didier
Soitec, Bernin, France

The growing usage of multimedia applications associated with consumers' desire for the ultimate mobility experience have propelled the smartphone IC device segment into the largest semiconductor market. Smartphone front-end modules (FEM), the interface between the phone and the external world as depicted in ***Figure 1***, is a key function of the mobile phone, and its design directly impacts the cellular network and critical handset performances: range, data rate, sound quality and battery life.[1] The FEM economic value and board footprint are comparable to phone processor and memory, making it a major focus of the phone industry.

FEMs are made up of many different functions such as filters, switches, power amplifiers, low noise amplifiers, couplers, duplexers, antenna tuners and antennas. The number and requirements of those functions increase with the number of bands the smartphone needs to support. Each one of these functions inside the FEM requires a specific engineered substrate to meet the optimal cost and performance target of the system. For example, as mainstream technologies, filters are based on piezoelectric materials: aluminium nitride (AlN), lithium tantalate (LiTaO3) and lithium niobate (LiNbO3). Power amplifiers are based on gallium arsenide (GaAs), switches are based on high resistive silicon on insulator (HR SOI) and antenna and FEM assemblies rely on advanced polymers, ceramics and metal materials structures.

ENGINEERED SUBSTRATE TOOL BOX

Engineered substrates are designed based on a generic tool box as illustrated in ***Figure 2***. The first tool, called Smart Cut™ technology, enables transfer to a thin (from few 10s of nm to 2 µm) and uniform mono-crystalline layer on a carrier substrate. The second tool called Smart Stacking™ technology enables stacking of partially or fully processed layers on a carrier substrate. The third tool, epitaxy, is a technology used to grow a semiconductor material on a carrier substrate. With this tool box, engineered substrates that are designed are typically made of three layers. The top layer is dedicated to the implementation of the electronic devices (transistor, passive components, etc.), the intermediate layer, an isolation interface usually made of an oxide called buried oxide (BOX) and the bottom layer which provides the mechanical support of the structure, usually called a handle substrate. It is important to note that those layers may also have some impact on characteristics such as thermal dissipation, reflection properties and signal attenuation, and they need to be carefully chosen and designed.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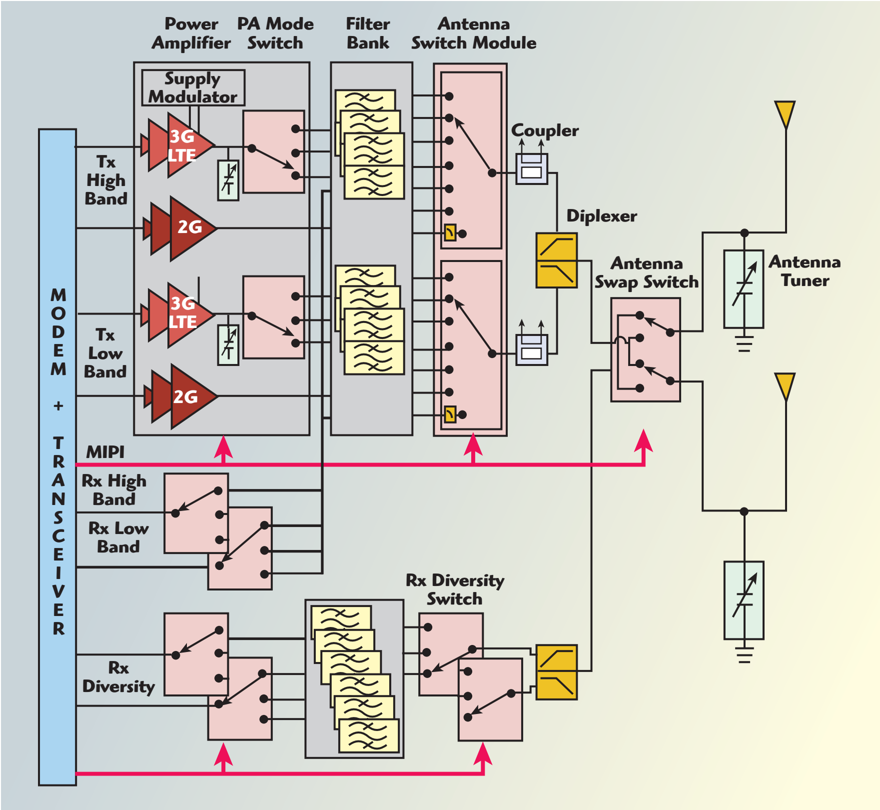
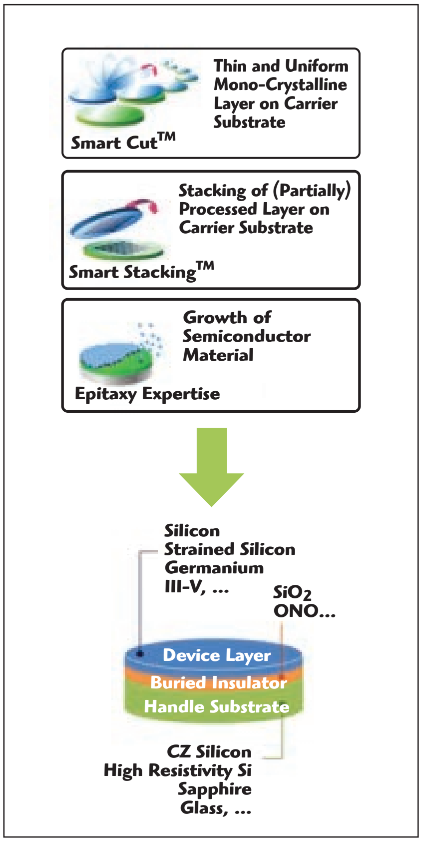


▲ *Fig. 1 FEM block diagram.*

LINEARITY CHALLENGE

According to Cisco,[2] mobile data traffic will grow at a 61 percent CAGR between 2013 and 2018, mainly driven by multimedia applications and, in particular, video exchange. The cellular roadmap is addressing this data traffic boom by improving spectral efficiency, increasing available spectrum and increasing network cell density. Key techniques to increase capacity are carrier aggregation and MIMO (multi-input-multi-output). To be efficient, those transmission techniques impose additional requirements on the FEM such as higher linearity, as shown in ***Table 1***.



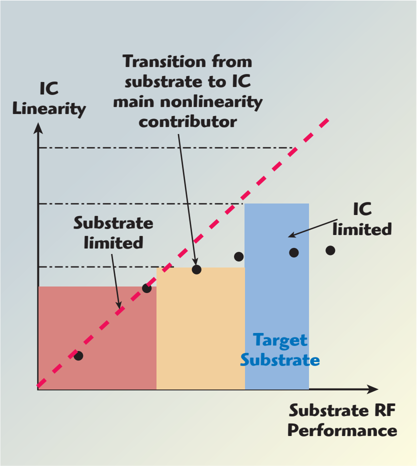
▲ *Fig. 2 Engineering substrate toolbox.*

TABLE 1

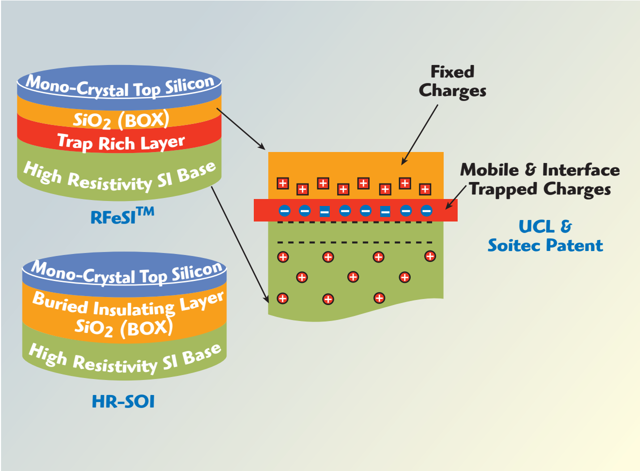
LINEARITY REQUIREMENTS PER CELLULAR GENERATION

Network	Linearity (IIP3 in dBm)
2G	55
3G	65
4G LTE	72
4G LTE + CA	Up to 90

Source: Intel Mobile, "Challenges For Radios Due To Carrier Aggregation Requirements," L. Schumacher, Nov. 2012.



▲ *Fig. 3 IC linearity vs. substrate RF performance.*



▲ *Fig. 4 Types of RF SOI: HR-SOI and RFeSI™.*

The entire ecosystem, from FEM makers, foundries, substrate suppliers and research centers, is working together to achieve those linearity requirements. Engineered substrate providers are trying to provide substrates that will enable better RF performance and not become the limiting factor for the device. ***Figure 3*** shows the contributions to linearity.

TABLE 2

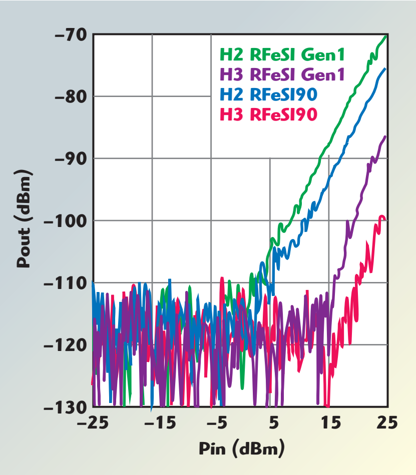
RF-SOI: THE BEST FRONT-END MODULE DEVELOPMENT PLATFORM

Process Figure of Merit	*RF SOI*	*GaAs*	*SoS*	*Bulk*	*MEMS*
CMOS Compatible	++	– –	+	++	=
Foundries Capacity Offering	++	+	–	++	–
RF Performance (Linearity,...)	+	++	+	–	++
Full FEM Integration/SoC	++	–	+	++	– –
Cost	+	=	–	++	–

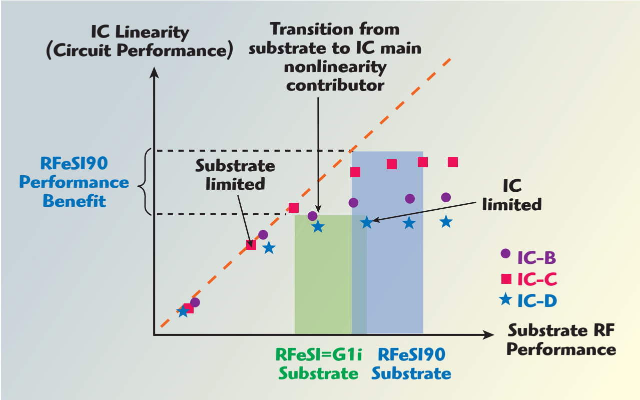
RF SOI SUBSTRATES

Depending on the architecture and partitioning of the FEM, device linearity requirements may change drastically from one component to the other. As a rule of thumb, the devices closer to the antenna or the devices on the path of stronger signals will need to exhibit higher linearity. RF SOI is an engineered substrate which comprises a thin film of mono crystalline silicon fully CMOS compatible as the top layer, an oxide as the isolation layer and a high resistive substrate as the handle substrate. The substrate resistivity can be several kΩ-cm and should be as high as 10 kΩ-cm to be considered as RF lossless. As shown in ***Table 2***, RF SOI offers a global design platform for FEMs with several advantages compared to other available options (CMOS compatibility, foundry offering, RF performance, integration and cost effectiveness).

RF SOI includes two different type of substrates: standard high resistive SOI (HR SOI) and enhanced signal integrity SOI (RFeSI™ SOI). In the RF SOI products, the oxide of the insulator BOX still contains positive charges in the range of a few 10E10 cm^2. As demonstrated by Prof. Raskin's work from Université Catholique of Louvain (UCL), those charges create a parasitic surface conduction at the interface between the BOX and the high-resistivity handle substrate, typically dropping its resistivity by a decade.[3,4] To recover the original resistivity of the handle substrate, UCL and Soitec have invented



▲ *Fig. 5 Second (H2) and third (H3) harmonics measured on RFeSI Gen1 and RFeSI90.*



▲ *Fig. 6 Linearity performance benefit depends on IC type and RFeSI substrate.*

a method consisting of adding a trap-rich layer on top of the handle wafer that can freeze those carriers as shown in ***Figure 4***. Depending on the linearity requirements, designers have then the option to choose one or the other substrate depending on the level of RF performance required for their application; they could even use the same design, optimizing the best cost performance trade-off.

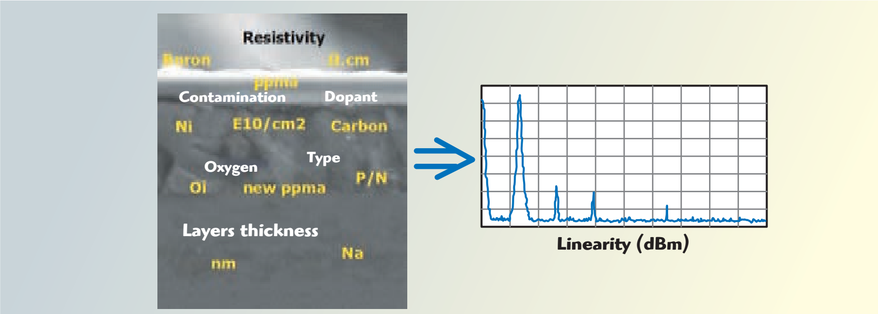
UCL and Soitec have widely published comparisons between bulk Si, HR SOI, RFeSI and quartz substrates.[5,6,7] As a summary, the RFeSI substrate addresses the critical FEM requirements: higher linearity, reduced crosstalk, lower insertion loss, better passive device quality factor and, to some extent, higher thermal dissipation. RF SOI substrates have become the mainstream substrate for switches with more than 85 percent market share in antenna switch modules.[8] After a few years of production of the first generation RFeSI substrate, a second generation (called RFeSI90 substrate) has been introduced this year in order to keep up with increasing market linearity requirements.

As shown in ***Figures 5*** and ***6***, RFeSI90 substrates offer 10 dB better linearity than RFeSI Gen1 substrates. This makes it suitable for the most advanced circuits in new LTE-A smartphone applications, while RFeSI Gen1 continues to serve the current market. Improvements have been achieved using a combination of increased handle substrate resistivity as well as a re-engineering of the trap-rich layer. The BOX thickness has also been reduced by a factor of two without impacting the RF device performance while improving manufacturability.

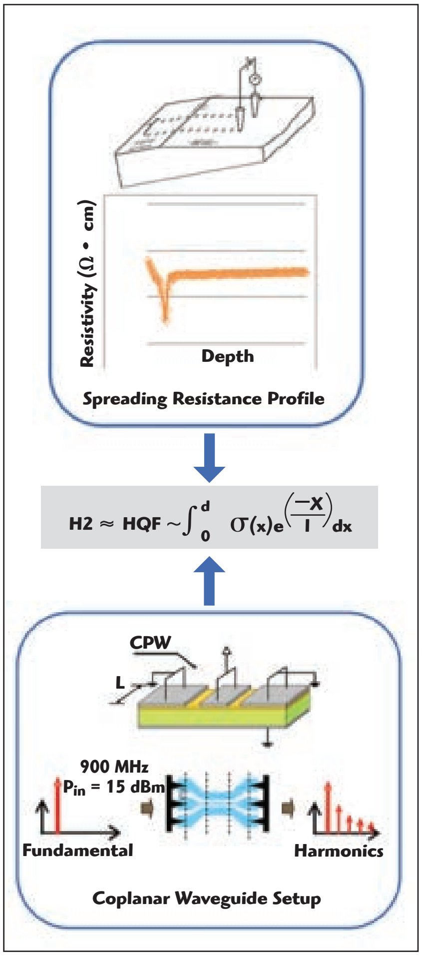
RF METROLOGY – HARMONIC QUALITY FACTOR

As shown in ***Figure 7***, there is a gap between the substrate world where we talk about contaminant, oxygen level, dopant, layer thickness and more material-oriented concepts and the RF designer's world more concerned about RF linearity, losses, power dissipation and IC design-oriented concepts. Bridging this gap between the engineered substrate specifications and the IC linearity specification is a concern for all foundries and RFIC designers when choosing an RF engineered substrate.

Materials engineering and RF engineering are two different domains, and specifying the resistivity of the handle substrate using an ohmic sheet resistance measurement at the backside of the substrate will not guarantee the RF performance of the wafer. There are many parameters that can change the RF performance of an RFeSI wafer: the trap-rich layer material and its characteristics, dopants that can migrate at interfaces between



▲ *Fig. 7 Improving RF performance requires understanding how wafer parameters affect linearity.*



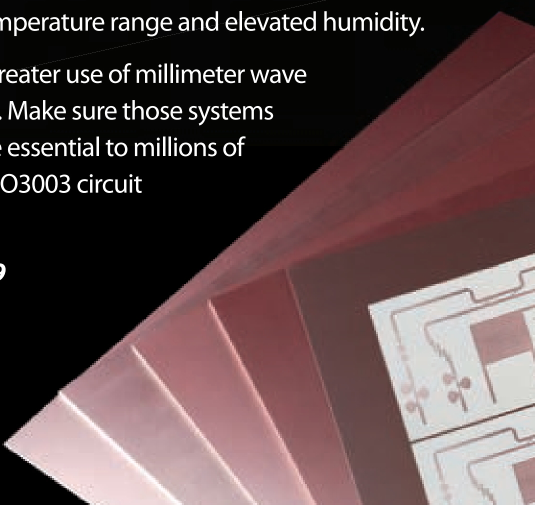
▲ *Fig. 8 The HQF correlates the SRP with the measured second harmonic.*

the layers, activation of thermal donors during the Smart Cut and foundry process temperature cycles, doping profile and thickness of the different layers, etc. To measure resistivity across the wafer, a technique called spreading resistance profile (SRP) is commonly used. To quantify the level of linearity of the material, manufacturers have traditionally measured the level of harmonics generated by a signal injected on a coplanar waveguide (CPW). Soitec has developed a proprietary algorithm which integrates the SRP profile weighted by the depth of the electrical field and matches it to the second harmonic generated through a CPW as shown on ***Figure 8***. This parameter is called harmonic quality factor (HQF) and is included in the RFeSI substrate specifications.

BEYOND RF SOI SWITCHES

Integrating more FEM devices is an on-going challenge for the industry. RF SOI is the ideal platform to


38GHz
60GHz
24GHz
79GHz



expand this roadmap. RF SOI is already a mainstream technology for switches used in all different configurations (antenna, antenna swapping, power amplifier mode, diversity, antenna tuner). Active components such as LNAs and passive components such as couplers are also being integrated on a single die with switches. Power amplifiers using RF SOI were launched in the market in 2013 addressing the LTE and LTE-A market, chosen by some first adopters like ZTE. Tunable filter solutions partly or fully integrated on RF SOI are in research and development. The competition with current piezoelectric filters, having quality factors of few thousands, is difficult with typical discrete and on-chip inductors that have quality factors of a hundred or less. The first phase is to lower the filter bill of materials by doing part of the filtering on chip.

Some RF SOI foundries have begun offering 300 mm diameter wafers. We expect future offerings of process nodes beyond 90 nm that will provide opportunities to address applications beyond the current FEM technology by combining advanced digital processing and analog SOI advantages: faster frequency operation at the same node compared to bulk silicon, lower supply voltage operation down to 0.4 V, high voltage handling, temperature operation much beyond 150°C, very low sensitivity to soft error rate and more. Recent switch technology history has demonstrated that in the high volume, highly competitive consumer electronics market, a new technology can very rapidly displace the incumbent technology, GaAs in this case. The engineered substrate tool box is extremely powerful, enabling the manufacture of the most adapted substrate for a very dynamic ecosystem ready to adopt new substrates when performance and cost warrants. ■

References

1. E. Desbonnets, S. Laurent, "RF Substrate Technologies for Mobile Applications," *Soitec White Paper*, 2011.
2. Cisco VNI Mobile, February 2014
3. D. Lederer and J.P. Raskin, "Effective Resistivity of Fully-Processed SOI Substrates," *Solid-State Electronics*, Vol. 49, No. 3, 2005, pp. 491–496.
4. D. Lederer and J.P. Raskin, "New Substrate Passivation Method Dedicated to HR SOI Wafer Fabrication with Increased Substrate Resistivity," *IEEE Electron Device Letters*, Vol. 26, No. 11, 2005, pp. 805–807.
5. K. Ben Ali, C. Roda Neve, A. Gharsallah, and J.P. Raskin, "RF Performance of SOI CMOS Technology on Commercial 200 mm High Resistivity Silicon Trap-Rich Wafers," *IEEE Transactions on Electron Devices*, Vol. 61, No. 3, March 2014., pp. 722–728.
6. C. Roda Neve and J.P. Raskin, "RF Harmonic Distortion of CPW Lines on HR-Si and Trap-Rich HR-Si Substrates," *IEEE Transactions on Electron Devices*, Vol. 59, 2012, pp. 924–932.
7. Yonghyun Shim, J.P. Raskin, C. Roda Neve and M. Rais-Zadeh, "RF MEMS Passives on High-Resistivity Silicon Substrates," *IEEE Microwave and Wireless Components Letters*, Vol. 23, No. 12, December 2013, pp. 632–634.
8. Sapphire Applications & Market: from LED to Consumer Electronic, Yole, 2014.

A Current-Reused GPS LNA in 0.2 µm RF SOI Technology

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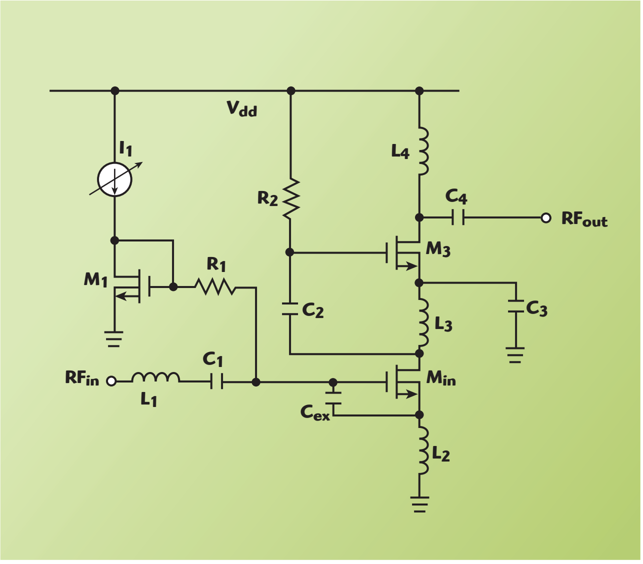
The design of a low power high gain current-reused CMOS low noise amplifier (LNA) for GPS applications employs a novel current-reused (CR) topology with three cascaded common source (CS) gain stages without increasing power dissipation. The LNA is fabricated using a 0.20 µm RF SOI CMOS process. It consumes 4.5 mA quiescent current from a 1.5 V supply. It has 26.4 dB of power gain, a 1.31 dB noise figure, -25.5 dBm P1dB and -12.8 dBm IIP3 at 1.575 GHz. Input/output return loss is 15.9 dB/13.2 dB respectively.

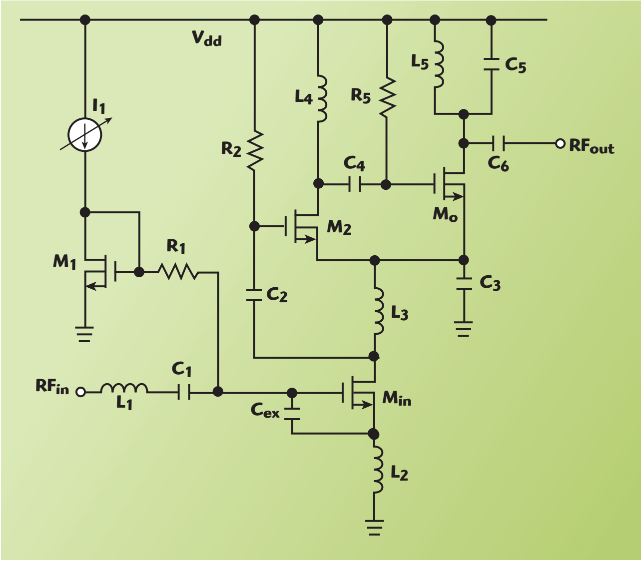
With advances in wireless communication systems technology in recent years, many wireless electronic products such as smart phones have become more portable, power-saving, and capable of providing a greater variety of services. Low noise figure (NF), low power consumption, high gain and high linearity, i.e., third-order intercept (IP3), for RF amplifiers such as LNAs are critical requirements that are nearly impossible to satisfy simultaneously. To date, a two-pronged design strategy has been used to achieve these goals: one is to optimize for high gain and low noise but with low linearity for small signals with low interference; the other is to optimize for low gain with high linearity but with high noise for large signals with high interference.

GPS has become an indispensable function for tracking and navigation in mobile communications applications.[1] The GPS market demands lower power and lower cost solutions for integrated receivers while the trend towards ultra-miniaturization requires the use of fewer, if any, external components.[2] To detect weak satellite signals, a GPS receiver must have superior sensitivity.[3] It is well known that the sensitivity of a receiver is determined mainly by the first amplifier, i.e., the LNA.[4] This first amplifier stage should have a very low NF and high gain, thereby preventing the following stages from significantly degrading the signal-to-noise ratio.[5,6,7] For that reason, previous GPS radios have been implemented in a bipolar or BiCMOS process due to its low noise characteristics.[3,5] Furthermore, the GPS RF front-end module must occupy the smallest possible area for integration in a multimode environment.[1] RF silicon on insulator (RF SOI) CMOS technology is now becoming an attractive RF front-end process for its low loss, low noise and high linearity.

This article describes an energy-efficient GPS receiver that employs a current reuse architecture; i.e., multiple RF circuits that use the same DC bias currents stacked to form a single cell.[2,5,7] Among the variety of conventional LNA input topologies, such as resistive match com-



▲ *Fig. 1 Typical CR LNA.*



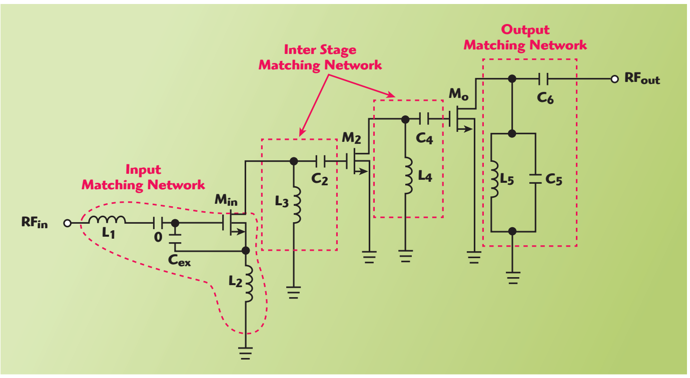
▲ *Fig. 2 Enhanced CR LNA topology with three CS stages.*

mon source (CS), common gate (CG), and resistive feedback CS topologies, the source inductive degeneration CS input topology shows the most promise for this application. At the circuit level, the current-reused structure is adopted to provide low power consumption and high gain simultaneously. The design and implementation of a novel 1.575 GHz CR topology having three cascaded gain stages without increasing power dissipation not only demonstrates the feasibility of the design methodology but also achieves high gain performance simultaneously with low power consumption.

CIRCUIT DESIGN

The evolution of LNA topology is from conventional cascade to CMOS inverter and CR. Conventional LNA topologies, such as cascade, cascode, and resistive feedback, have been proposed to achieve superior performance. Among the variety of topologies, CR shows the most promise for achieving high gain and low power simultaneously. ***Figure 1*** shows a typical CR LNA topology composed of two CS stages in which the bias current of transistor M_{in} is shared by transistor M_3 resulting in double the gain with the same bias current to the cascade.

Under similar bias conditions, amplifier gain can be further enhanced by increasing the number of cascaded stages. In this work, an enhanced CR topology with three cascaded CS gain stages is presented. A complete circuit schematic of the LNA, equivalent to a three stage CS amplifier, is shown in ***Figure 2***. The bias voltage and current of the second stage (M_2) and third stage (M_o) are the same and they together share bias current with the input stage (M_{in}). The transconductance of M_3 in Figure 1, g_{m3}, is equally shared by M_2 and M_o in Figure 2, i.e., $g_{m2} = g_{mo} = 0.5\ g_{m3}$. This novel design realizes a three CS amplifier cascade with the same current consumption of a typical CR LNA. ***Figure 3*** shows a circuit schematic of the equivalent three-stage cascaded amplifier with input, output, and inter-stage matching networks that provides high gain with low power consumption for GPS applications.



▲ *Fig. 3 Equivalent three-stage amplifier with the input, output and interstage matching networks.*

A CS topology is used for the first stage (M_{in}) to achieve simultaneously low noise figure and good input matching performance. The input matching network for M_{in} comprises an input series gate inductor L_1, source-degeneration inductor L_2, the C_{gs} of M_{in} and an added capacitor C_{ex}. This makes an LC ladder filter resonating at 1.575 GHz to achieve an input return loss greater than 10 dB. As the first stage of the proposed LNA, a power constrained simultaneous noise and input matching (PCSNIM) technique is used to achieve good input return loss (S_{11}) with low power consumption. The transistor size and Q of the input matching network can be decoupled with the extra capacitance for noise optimization and input matching at low power. L_3 and L_4 act as RF chokes to provide DC current as well as interstage matching. C_3 is an AC-grounded capacitor whose capacitance is chosen as large as possible. L_5, C_5 and C_6 are designed for matching of the output CS stage (M_o). C_2 and C_4 are for interstage signal coupling and interstage matching.

In order to provide a comparison of gain and power consumption, the typical CR LNA in Figure 1 is designed and built. An approximate small-signal model is also developed for the analysis and comparison of power gain. For a common source LNA, the voltage gain is $AV = g_{meff} \cdot R_{load}$ and the gains of a typical CR (A_{TCR}) and this design (A_{NCR}) are derived in Equations 1 and 2. This shows that the gain of the new LNA is higher than the typical CR LNA due to CR gain enhancement. Noting that $g_{m3}=2g_{m2}=2g_{mo}$, the boosted gain (A_E) is derived in Equation 3. In this new design, the transconductance $g_{m3} \approx 3di$ and $R_{load} = C_5||L_5 \approx 200\ \Omega$, so it improves the gain by 8 dB.

$$A_{C-R} = -\frac{g_{min} g_{m3}}{sL_2\left(sC_{gs,min} + g_{min}\right) + 1} \cdot \left(C_{gs,M2} \parallel L_3\right) \cdot SL_4 \quad (1)$$

$$A_{NC-R} = -\frac{g_{min} g_{m2} g_{m0}}{sL_2\left(sC_{gs,Min} + g_{min}\right) + 1} \cdot \left(C_{gs,M2} \parallel L_3\right) \cdot \left(C_{gs,Mo} \parallel L_4\right) \cdot \left(C_5 \parallel L_5\right) \quad (2)$$

$$A_E = \frac{A_{NC-R}}{A_{C-R}} = -\frac{g_{m3}}{4}\left(C_5 \parallel L_5\right) \quad (3)$$

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MEASURED RESULTS

The new CR LNA and the typical CR LNA are fabricated using the HH-Grace 0.20 µm 1P3M RFSOI CMOS process for a 1.575 GHz band GPS application. The aspect ratios of the transistors M_{in}, M_2, M_o and M_3 are 320 µm/0.20 µm, 200 µm/0.20 µm, 200 µm/0.20 µm and 400 µm/0.20 µm, respectively. C3 is a 4 pF capacitor in the second and third (AC grounded) CS stages. R1, R2 and R3 are 50 kΩ resistors providing bias voltage and RF signal blocking, eliminating the need for an RF choke. All capacitors are metal-insulator-metal and all inductors are implemented on the top metal (thickness of 4 µm) layer in octagonal forms to minimize resistive losses. The substrate is a trap-rich silicon on insulator (TR-SOI) wafer with good performance for noise and harmonic linearity.

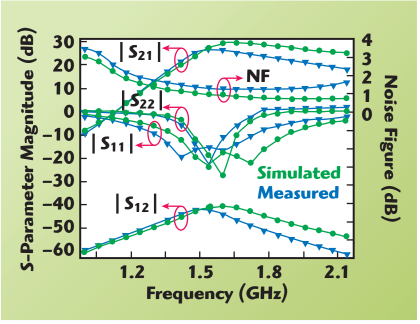

Fig. 4 Enhanced CR LNA simulated vs. measured S-parameters and noise figure.

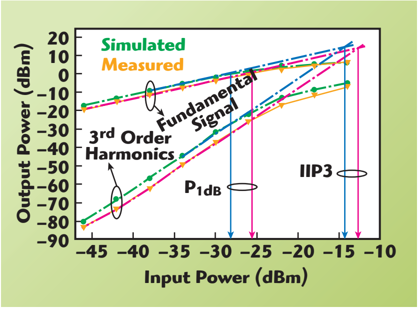

Fig. 5 Enhanced CR LNA simulated vs. measured input P_{1dB} and IP3.

Both the new CR GPS LNA and typical CR LNA consume 4.5 mA from a 1.5 V supply. Simulated and measured S-parameters and NF for the new CR GPS LNA are shown in ***Figure 4***, while ***Figure 5*** shows simulated and measured input P1dB and IIP3. Both figures show good agreement between measurement and simulation. Measured small signal power gain ($|S_{21}|$) and NF are 26.4 dB and 1.31 dB, respectively, at 1.575 GHz. Measured input return loss ($|S_{11}|$) is about 15.9 dB and output return loss ($|S_{22}|$) is about 13.2 dB. The measured input P1dB and IIP3 are -25.5 dBm and -12.8 dBm respectively. ***Table 1*** summarizes the characteristics and performance of previously reported GPS LNAs compared with the typical CR LNA and the new CR LNA described in this work. Figures of merit (FOM) are used for benchmarking LNA designs, and are defined as:

$$FOM_1 = \frac{Gain[dB]}{P_{dc}[mW]} \quad (4)$$

$$FOM_2 = \frac{Gain[abs]}{NF[abs]P_{dc}[mW]} \quad (5)$$

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TABLE 1: LNA PERFORMANCE COMPARISON

Reference	1	8	9	10	11	This Work	CR
P_{dc} (mW)	10.8	9	6	5.5	10.1	6.8	6.8
Gain (dB)	14.2	16.5	14.8	19.5	19	26.4	19.2
NF (dB)	1.85	1.3	1.75	1.95	1.1	1.3	1.2
P_{1dB} (dBm)	-1	-	-20	-14.7	-13	-25.5	-23.3
IIP3 (dBm)	12	-5	21	-	-2	-12.8	-11.5
FoM 1	1.3	1.8	2.5	3.5	1.9	3.9	2.8
FoM 2	0.31	0.55	0.61	1.1	0.68	2.3	1.71
Technology	0.5 µm InGaAs	0.25 µm CMOS	0.18 µm CMOS	0.18 µm CMOS	0.18 µm CMOS	0.20 µm RF SOI	0.20 µm RF SOI

CONCLUSION

A GPS LNA achieves high gain simultaneously with low power consumption as compared to previously reported CMOS LNAs for GPS applications. Gain enhancement is realized with the three CS cascade amplifiers and power consumption is economized with the CR topology. The design and implementation of a 1.575 GHz CR desgn with three cascaded gain stages is described. The LNA not only demonstrates the feasibility of the design methodology but also achieves a 1.31 dB NF, -12.8 dBm IIP3, and 26.4 dB power gain. It consumes 4.5 mA from a 1.5 V power supply. ■

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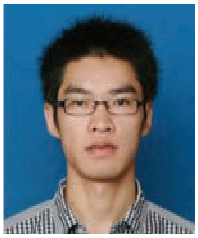
References

1. Y.C. Hsu, C.F. Jou and G.C. Lin, "A Fully Integrated GPS LNA Module," *Proceedings of the Asia-Pacific Microwave Conference*, December 2012, pp. 944–946.
2. K.W Cheng, K. Natarajan and D.J. Allstot, "A Current Reuse Quadrature GPS Receiver in 0.13 µm CMOS," *IEEE Journal of Solid State Circuits*, Vol. 45, No. 3, March 2010, pp. 510–523.
3. H. Moon, S.C. Heo, H. Yu, J. Yu, J.S Chang, S.I. Choi, S. Lee, W.S. Choo and B.H Park, "A 27 mW 2.2 dB NF GPS Receiver Using a Capacitive Cross-Coupled Structure in 65 nm CMOS," *IEEE Custom Integrated Circuits Conference*, September 2010, pp.1–4.
4. H. Jalili, A. Fotowat-Ahmady and M. Jenabi, "A 1-mW Current Reuse Quadrature RF Front-End for GPS L1 Band in 0.18 µm CMOS," *IEEE International Conference on Electronics, Circuits and Systems*, December 2012, pp.157–160.
5. C. Stedler, S. Werker and R. Kronberger, "Rugged High Linearity Low Noise Amplifier for 1.57 GHz GPS Band," *IEEE Microwave Magazine*, Vol. 14, No. 1, January 2013, pp. 102–107.
6. S. Wang and W.J. Lin, "Design of Low-Power and High-Gain CMOS LNA With Current-Reused Topology," *Microwave and Optical Technology Letters*, Vol. 55, No. 10, October 2013, pp. 2429–2431.
7. R. Dai, Y. Zheng, H. Zhu, W. Kong and S. Zou, "A High Gain and High Linearity Current-Reused CMOS LNA Using Modified Derivative Superposition Technique With Bulk-Bias Control," *Micro-*

wave and Optical Technology Letters, Vol. 56, No. 10, October 2014, pp. 2444–2446.

8. P. Leroux, M. Steyaert, V. Vassilev and G. Groeseneken, "A 1.3 dB NF CMOS LNA for GPS With 3 kV HBM ESD-Protection," *European Solid State Circuits Conference Proceedings*, September 2002, pp.335–338.
9. M.B. Thacker, M. Awakhare, R.H. Khobragade and P.A. Dwaramwar, "Multi-Standard Highly Linear CMOS LNA," *International Conference on Electronic Systems, Signal Processing and Computing Technologies*, January 2014, pp. 63–68.
10. H. Liu and Q. He, "Design of 1.8 V 1 GHz 0.18 µm CMOS LNA for GPS," *International Conference on Wireless Communications, Networking and Mobile Computing*, October 2008, pp.1–4.
11. Y. Xiang, Y.B. Luo, R.J. Zhou and C.Y. Ma, "A Low Noise Amplifier with 1.1 dB Noise Figure and +17dBm OIP3 for GPS RF Receivers," *Applied Mechanics and Materials*, Vols. 336-338, July 2013, pp. 1490–1495.



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MWJ REVIEW BOARD APPROVED

Simple Synthesized Harmonic Matching Strategy in Broadband PA Design

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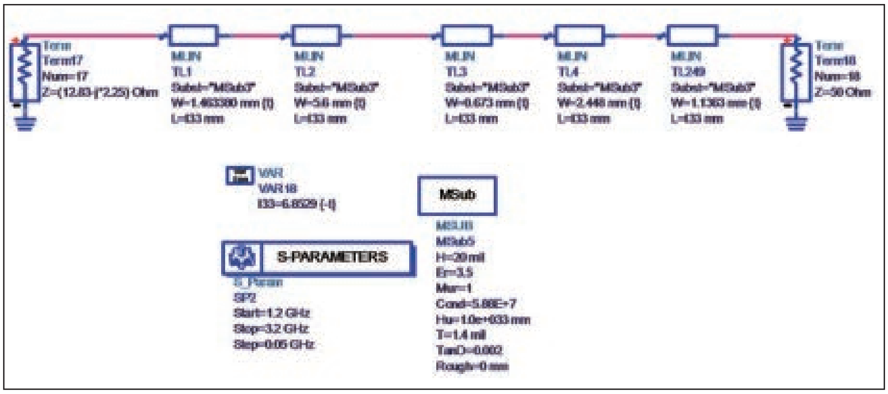
A design methodology for a power amplifier (PA) with harmonic control is based on the simplified real frequency technique (SRFT). This is validated with a compact broadband power amplifier that has a maximum output power of 42.8 dBm and an efficiency of 55 to 70 percent in the 1.7 to 3 GHz band. With a 100 MHz LTE-A signal, linearization is accomplished using digital predistortion (DPD). With DPD linearization, -47.0/-48.5, -47.0/-47.7 and -47.6/-46.4 dBc ACLR are measured at 1.95, 2.15 and 2.55 GHz respectively at an average output power of 33 dBm.

Important components in communication systems, broadband power amplifiers must cover more and more frequency bands with low distortion to accommodate complex signal modulation. Common methods utilize Class J, continuous Class F and Class E operation,[1-5] which include magnetic coupling networks, multistage ladder networks or the use of multiple transmission line sections (i.e., SRFT). Magnetic coupling and multistage ladder networks, however, employ a real-to-real resistance matching strategy that requires substantial tuning to match the PA's complex output impedance. SRFT matching, on the other hand, uses a real to complex design methodology that provides a broadband matching structure without further tuning.

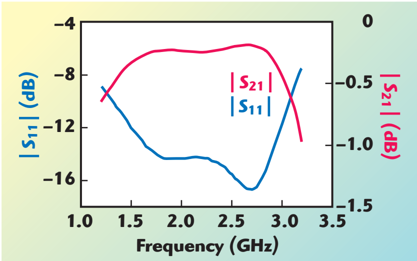
In a high efficiency/high power PA design, harmonic control is a critical factor. The original SRFT design process[6-8] synthesizes a broadband transfer network in the fundamental region to meet the bandwidth requirement. This greatly simplifies the broadband PA design, but does not include harmonics.

This development combines the SRFT with harmonic control in matching a real 50 Ω load to the device's complex output impedance. In this approach, the stopband frequency is swept

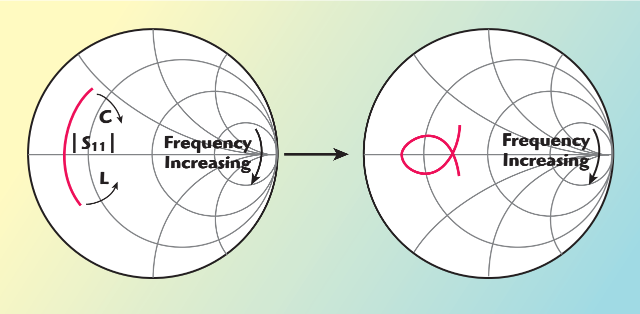


▲ *Fig. 1 Output matching network simulation schematic.*

and harmonic matching is carried out within the SRFT process. Matching network physical dimensions are obtained directly and employed without the need for optimization. For input matching, the device's small resistive component and large reactive component make the Q too high to be matched over a broad band using common techniques; so, a resonator created with open and short circuited stubs is used to broaden the matching bandwidth.



▲ *Fig. 2 SRFT simulation results.*



▲ *Fig. 3 Short and open stub input matching.*

A compact 50 × 60 mm broadband power amplifier in the 1.7 to 3 GHz band with a 10 W Cree CGH40010 GaN HEMT device is designed, built and tested. Experimental results show close agreement with simulation, while demonstrating the effectiveness of the design strategy.

DESIGN AND IMPLEMENTATION

The load impedance is determined in ADS using the load-pull technique with CREE's large signal model for the CGH40010 power HEMT over the fundamental band 1.7 to 3 GHz and the harmonic band 3.4 to 9 GHz. This is then used to define the transducer power gain (TPG) through the SRFT algorithm.[6-8] The parameters of the SRFT program are set to provide a lowpass characteristic with five transmission line elements. The output topology is initialized and the objective TPG is set to 0.95. The frequency sweep across the stopband is run from 0.6 to 6.6 GHz and circuit parameters are optimized to obtain the best solution. In this sweep, the harmonic TPG (i.e., the TPG of the network by harmonic impedance) is calculated and averaged at all harmonic frequency points. This data is examined to ensure the matching network can support the required harmonic impedances. Finally, we choose f_e =5.85 as the design parameter for the best harmonic control matching function.

The characteristic impedance of each transmission line element (see ***Table 1***) is determined by normalization and Richard Extraction. For the selected PCB material (ε_r = 3.5), the physical length of every transmission line element is determined to be 6.85 mm by Equation 1.

$$L = v\tau = \frac{1}{\sqrt{\mu\varepsilon}} \cdot \tau = \frac{1}{\sqrt{\mu\varepsilon}} \cdot \frac{1}{4f_{stop}} \qquad (1)$$

where $\mu = \mu_r\mu_0$ and $\varepsilon = \varepsilon_r\varepsilon_0$ denote the permeability and permittivity of the substrate and τ denotes the actual delay of every transmission line element.

For the stopband, a compact sized output matching network is realized. This network is tested with the complex fundamental impedance obtained through load-pull in ADS and its schematic is shown in ***Figure 1***. From the simulation results (see ***Figure 2***), the network exhibits a maximum of 0.4 dB loss over the 1.7 to 3 GHz frequency band.

For stability, an RC network is added to the input circuit, a 100 Ω resistance in parallel with a 1.8 pF capacitor. A very slim transmission line is employed for the internal connection as an inductive component to provide an additional RLC resonance. In addition, paralleled short and open stubs are used to broaden the bandwidth of the input match by twisting the input S_{11} curve on the Smith Chart around the center frequency. This is shown in ***Figure 3***. Using the resonant network, the knotted curve can be easily matched to the 10 dB return loss circle on the Smith Chart.

IMPLEMENTATION AND MEASUREMENT

The broadband compact GaN PA is shown in ***Figure 4***. Its size is just 50 × 60 mm. The output matching structure, determined by the SRFT process, is shown in the ***Table 2***. After adding the bias networks, further optimization of the output matching and input matching circuit is carried out. It is fabricated on a TACONIC RF-35 substrate with copper metallization. To reduce the transformation loss and provide a precise parasitic model for simulation, capacitors of ATC 100B series and 600S series are chosen. The

TABLE 1

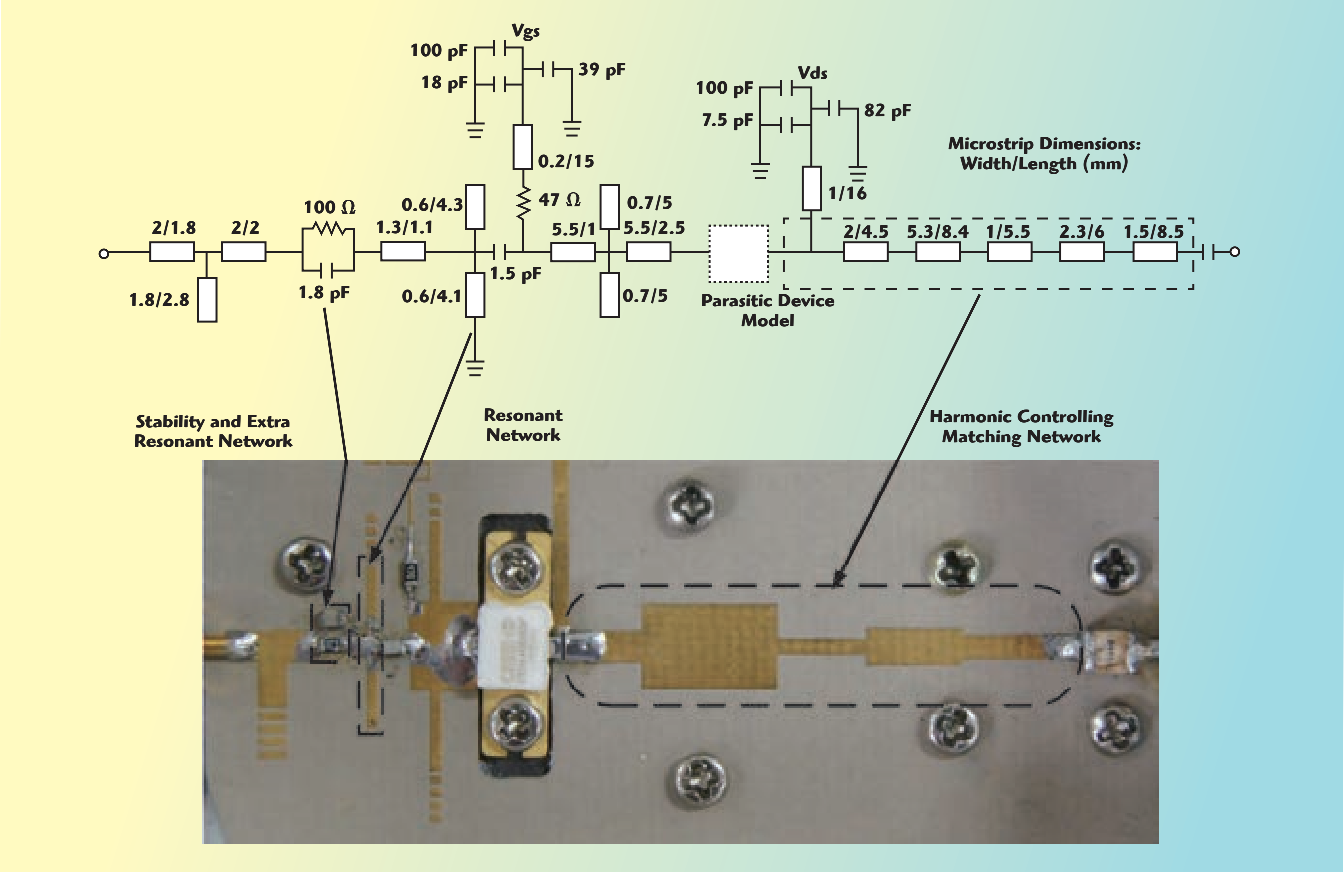
STOPBAND FREQUENCY AND SYNTHESIZED MATCHING NETWORK RESULTS WITH HARMONIC TPG

k=5	TPG	Harmonic TPG	TL1(Ω)	TL2(Ω)	TL3(Ω)	TL4(Ω)	TL5(Ω)
f_e=2.1	0.93799	0.73375	26.42	85.07	198.7	165.9	79.35
f_e=2.85	0.95375	0.64246	14.63	24.78	58.92	84.51	65.01
f_e=3.6	0.95085	0.71468	13.27	6.899	8.910	15.39	37.84
f_e=4.35	0.95220	0.68085	28.75	20.34	48.61	35.33	54.35
f_e=5.1	0.95200	0.63995	35.76	17.40	58.07	31.09	52.42
f_e=5.85	0.95193	0.59042	41.89	15.07	65.82	29.21	49.15

TABLE 2

OUTPUT MATCHING TOPOLOGY PARAMETER

Length (mm)	Width of Transmission Line (mm)				
	TL0	TL1	TL2	TL3	TL4
6.85	1.46	5.60	0.67	2.45	1.14



▲ *Fig. 4 GaN PA schematic and implementation.*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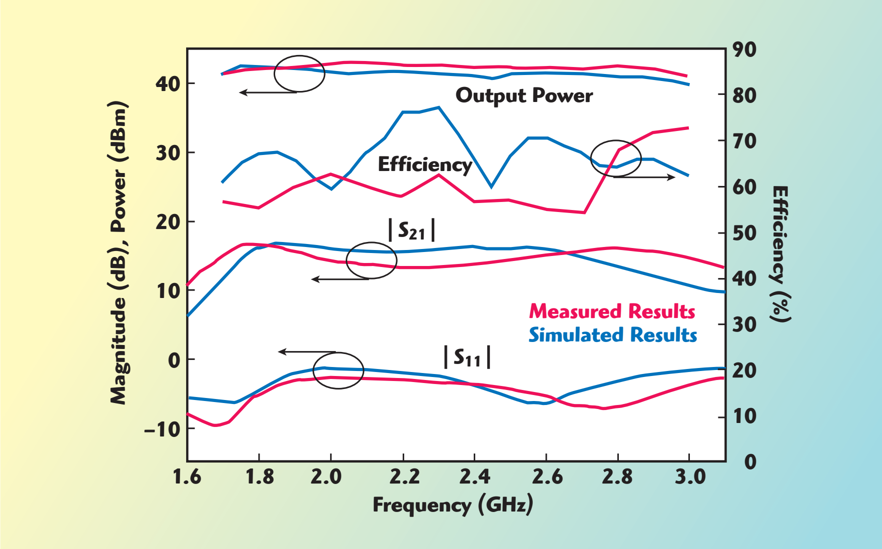
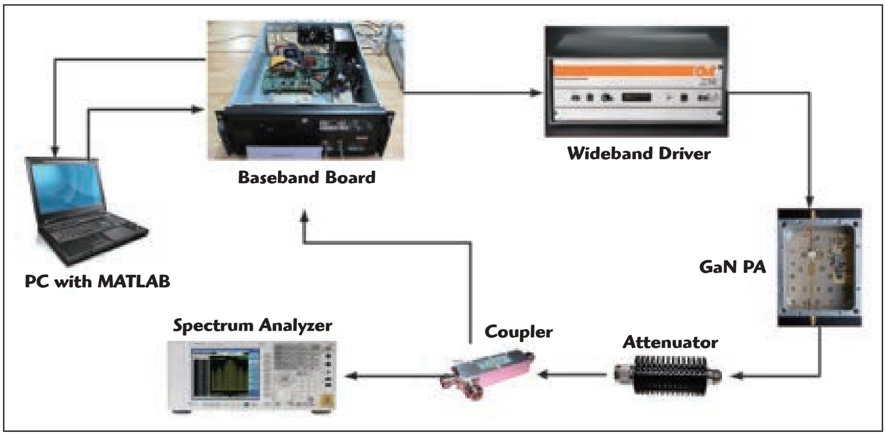


▲ *Fig. 5 Measured vs. simulated performance.*



▲ *Fig. 6 Linearization test setup.*

TABLE 3
AVERAGE OUTPUT POWER, EFFICIENCY AND ACLR

Frequency (GHz)	Average Output Power (dBm)	Efficiency (%)	ACLR without DPD (dBc)	ACLR with DPD (dBc)
1.95	33.6	24.8	-38.4/-36.8	-47.0/-48.5
2.15	33.1	22.1	-38.2/-36.4	-47.0/-47.7
2.55	33.0	23.4	-35.1/-32.0	-47.6/-46.4

TABLE 4
BROADBAND AND MULTI-BAND POWER AMPLIFIER COMPARISON
(* ESTIMATED FROM A PHOTOGRAPH OF THE PA)

Reference	Frequency Region (GHz)	Efficiency (%)	Size (mm)	Signal Bandwidth (MHz)	DPD Performance (dBc)
[9]	0.7 to 1.5	33 to 38	–	–	–
[10]	2.0 to 2.5	53 to 66	11 × 16	–	–
[2]	1.4 to 2.2	60 to 70	70 × 50	–	–
[3]	1.45 to 2.45	70 to 81	*120 × 60	40	-52.1/-52.3
[11]	2.0 to 4.0	57 to 72	65 × 65	20	-42.0/-42.0
This work	1.7 to 3.0	55 to 70	60 × 50	100	-47.0-48.5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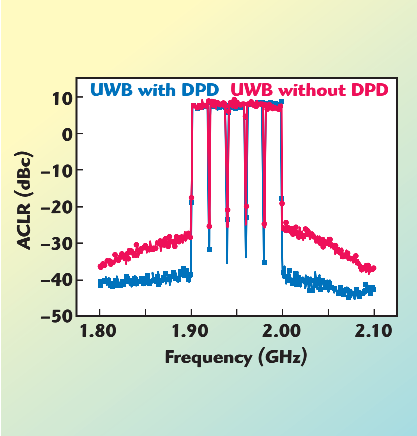
circuit is characterized with both continuous wave (CW) and modulated signals to evaluate.

CW Measurements

The PA is biased with V_{ds} = 28 V and the quiescent drain current set at at 120 mA (V_{gs} = -3.2 V). The results of simulation versus small-signal measurement are shown in the measurements of S_{11} and S_{21} (see the lower curves in ***Figure 5***). The measurements are carried out with a vector network analyzer. Gains of 12.1 to 16 dB in the measured band of 1.6 to 3.1 GHz are achieved with a maximum 10 dB return loss. This agrees closely with simulation.

Large signal measurement is carried out with a Keysight E4426B signal generator and E4445A spectrum analyzer. The upper curves in Figure 5 show power at saturation greater than 42 dBm from 1.7 to 2.9 GHz,



▲ *Fig. 7 Output spectrum of a 100 MHz LTE-A signal at 1.95 GHz, showing the effect of DPD linearization.*

with the efficiency between 55 and 70 percent.

Modulated-Signal Measurements

The single-ended PA is excited by a 100 MHz bandwidth modulated LTE-Advanced signal with a 7.5 dB peak-to-average power ratio and linearized at 1.95, 2.15 and 2.55 GHz. The test setup is shown in ***Figure 6***. Measured average output power, efficiency and ACLR, with and without DPD, in three frequency bands are summarized in ***Table 3***.

An isolator or 3 dB attenuator is inserted in the front of the PA to reduce the impact of input reflection on DPD. The measured spectra of the PA with and without the DPD for an average 33 dBm output power at 1.95 GHz is plotted in ***Figure 7***. From Table 2, this PA should provide excellent ACLR performance in the three bands.

Table 4 compares several broadband and multiband power amplifiers. This compact PA has the smallest structure, excellent efficiency and high linearity.

CONCLUSION

A compact broadband power amplifier is designed with harmonic control based on the SRFT methodology. A single-ended PA is simulated, designed and measured over 1.7 to 3 GHz. Experimental results show good agreement with simulation. This modified SRFT strategy facilitates PA design, and the resulting amplifier's compact size provides advantages for many applications.■

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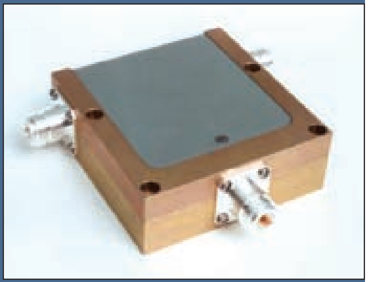

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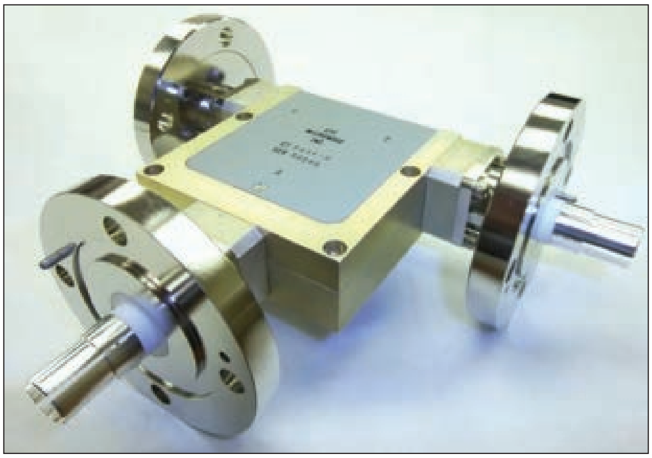

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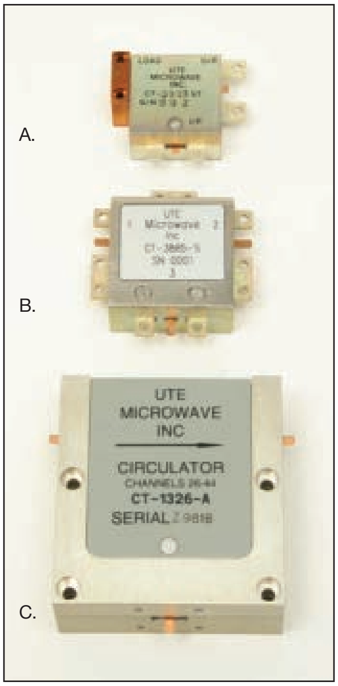

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CT-3838-N	5 Kw Pk 500 W Av	N Conn.	2.7–3.1 GHz
CT-1645-N	250 W Satcom	N Conn.	240–320 MHz
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References

1. V. Carrubba, J. Lees, J. Benedikt, P. J. Tasker and S. C. Cripps, "A Novel Highly Efficient Broadband Continuous Class-F RFPA Delivering 74 Percent Average Efficiency for an Octave Bandwidth," *IEEE MTT-S International Microwave Symposium Digest*, June 2011, pp. 1–4.
2. P. Wright, J. Lees, J. Benedikt, P. J. Tasker and S. C. Cripps, "A Methodology for Realizing High Efficiency Class-J in a Linear and Broadband PA," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 57, No. 12, December 2009, pp. 3196–3204.
3. N. Tuffy, L. Guan, A. Zhu and T. Brazil, "A Simplified Broadband Design Methodology for Linearized High-Efficiency Continuous Class-F Power Amplifiers," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 60, No. 6, June 2012, pp. 1952–1963.
4. P. Wright, J. Lees, P. J. Tasker, J. Benedikt and S. C. Cripps, "An Efficient, Linear, Broadband Class-J-Mode PA Realized Using RF Waveform Engineering," *IEEE MTT-S International Microwave Symposium Digest*, June 2009, pp. 653–656.
5. J.H. Kim, S.J. Lee, B.H. Park, S.H. Jang, J.H. Jung and C.S. Park, "Analysis of High-Efficiency Power Amplifier Using Second Harmonic Manipulation: Inverse Class-F/J Amplifiers," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 59, No. 8, August 2011, pp. 2024–2036.
6. B.S. Yarman, "*Design of Ultra Wideband Antenna Matching Networks via Simplified Real Frequency Technique*," 1^{st} edition, Springer, Germany, 2008.
7. B.S. Yarman, "*Design of Ultra Wideband Power Transfer Networks*," 1^{st} edition, Wiley, Hoboken, N.J., 2010.
8. K.L. Chen and D. Peroulis, "Design of Broadband High-Efficiency Power Amplifier Using In-Band Class-F-1/F Mode-Transferring Technique," *IEEE MTT-S International Microwave Symposium Digest*, June 2012, pp. 1–3.
9. S. Azam, R. Jonsson and Q.Wahab, "Designing, Fabrication and Characterization of Power Amplifiers Based on 10-Watt SiC MESFET and GaN HEMT at Microwave Frequencies," *Proceedings of the 38^{th} European Microwave Conference*, October 2008, pp. 444–447.
10. M. van der Heijden, M. Acar and J. Vromans, "A Compact 12-Watt High-Efficiency 2.1–2.7 GHz Class-E GaN HEMT Power Amplifier for Base Stations," *IEEE MTT-S International Microwave Symposium Digest*, June 2009, pp. 657–660.
11. P. Saad, C. Fager, H. Cao, H. Zirath and K. Andersson, "Design of a Highly Efficient 2–4 GHz Octave Bandwidth GaN-HEMT Power Amplifier," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 58, No. 7, July 2010, pp. 1677–1685.

Temperature Compensation of Microwave Resonators and Filters for Space Applications

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The performance over temperature of a microwave resonator and of a filter made of several resonators in cascade is an important design driver. This is especially true for on-board satellite applications, where thermal excursions can be relatively large and thermal control techniques are difficult to implement. Other characteristics that can make temperature compensation necessary are the handling of high power levels and narrow filter bandwidth.

Conceptually, there are three different approaches possible when dealing with thermal stability:

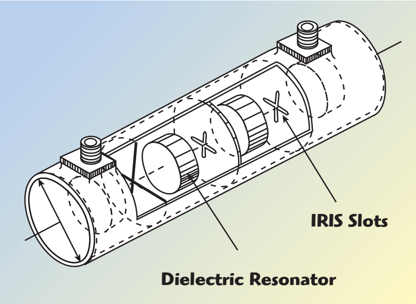
1. Use materials with high thermal stability in the design of the microwave resonator or filter, both in terms of physical dimensions and in terms of electrical characteristics (e.g., dielectric constant).
2. Implement some sort of temperature control of the component environment, thus removing the cause of the thermal drift.
3. Design the component with some built-in compensation technique, based on the use of materials with different physical and/or performance characteristics over temperature.

The first approach achieves low temperature sensitivity for the electrical characteristics by using materials with high thermal stability (see ***Table 1***).[1] A material very suitable for the realization of resonating cavities and filters for space applications is aluminum; due to its relatively low density, good thermal conductivity, good machinability and low cost. Unfortunately, aluminum has a rather high thermal expansion coefficient (CTE) of 23 ppm/°C. Con-

TABLE 1

TYPICAL CTE OF COMMONLY USED METALS

Material Name	*CTE (ppm/°C)*
Invar	< 1.3
Titanium	8.5
Stainless Steel 410	10.2
Stainless Steel 316	16.0
Copper	16.8
Beryllium Copper	16.7
Brass	18.4
Aluminum 7075-T6	23.4
Aluminum 6061	23.6



▲ *Fig. 1 Dielectric-loaded dual-mode filter.*

versely, a material like invar is nearly ideal from the standpoint of mechanical stability, with a CTE of about 1.6 ppm/°C (or lower, depending on the alloy). But invar, which is an iron-nickel alloy (i.e., some sort of stainless steel), has a number of drawbacks: a high density (8050 kg/m^3 as compared to aluminum's 2700 kg/m^3), poor machinability, low thermal conductivity (more than one order of magnitude lower than aluminum) and poor electrical conductivity (in order to achieve a high Q value, it is essential to silver plate an invar cavity).

The mass penalty for using invar versus aluminum should not be underestimated, especially in satellite applications. Given the density ratio of the two materials (close to 3), a 30 kg invar multiplexer would weight 10 kg if made from aluminum. Assuming launch costs of 15 k€/kg for GTO missions (Arianne V), deploying the aluminum multiplexer would result in launch cost savings of about €300,000. Notwithstanding all of its drawbacks, invar remains the often-selected solution in the realization of thermally stable filters in satellite payloads.

Active and passive temperature control techniques for reducing the temperature range experienced by the microwave component are obviously well suited for ground applications but are much less suitable for on-board use. Fancy solutions based on heat-pipes[2] or even high temperature superconductor (HTS) materials have been proposed but are rarely implemented in practice.

Promising alternatives to the use of invar in space rely on different techniques, all aiming at achieving an overall high thermal stability at the component level, while using materials with low thermal stability that are suited for space applications. The most widely adopted approaches are based on the use of bimetal or trimetal temperature-sensitive materials or on shape memory alloys (SMA). In general, a temperature compensation technique for microwave resonators and filters is often based on some degree of ingenuity associated with a good knowledge of the electromagnetic modeling of resonators and of the physical properties of materials.

MICROWAVE DIELECTRIC RESONATORS AND PRINTED CIRCUIT FILTERS

Dielectric Resonators

Dielectric resonators based on microwave ceramic materials are often used in frequency stabilized oscillators (DRO) or as resonators in microwave filters and antennas. Their adoption has been greatly favoured after the development of new dielectric compositions, achieving high permittivity, high quality factor, low temperature coefficient of permittivity and low fabrication cost. Dielectric resonators are also used to load the cavities of dual-mode filters, thus shrinking their dimensions (see ***Figure 1***).[3,4]

The temperature coefficient of the resonant frequency of a dielectric resonator, τ_f, is given by:

$$\tau_f = \frac{1}{f_0}\frac{\Delta f}{\Delta T}\left[\text{ppm/°C}\right] \qquad (1)$$

where f_0 is the resonant frequency and Δf is the total frequency variation corresponding to a temperature shift ΔT. The temperature coefficient τ_f is a function of three other temperature coefficients: τ_ε, the temperature coefficient of the dielectric constant, τ_c, the temperature coefficient of the cavity surrounding the dielectric resonator and α_L, the temperature coefficient of thermal expansion of the dielectric material. With a proper design, very low values of τ_f can be achieved.

Microwave Printed Circuit Filters

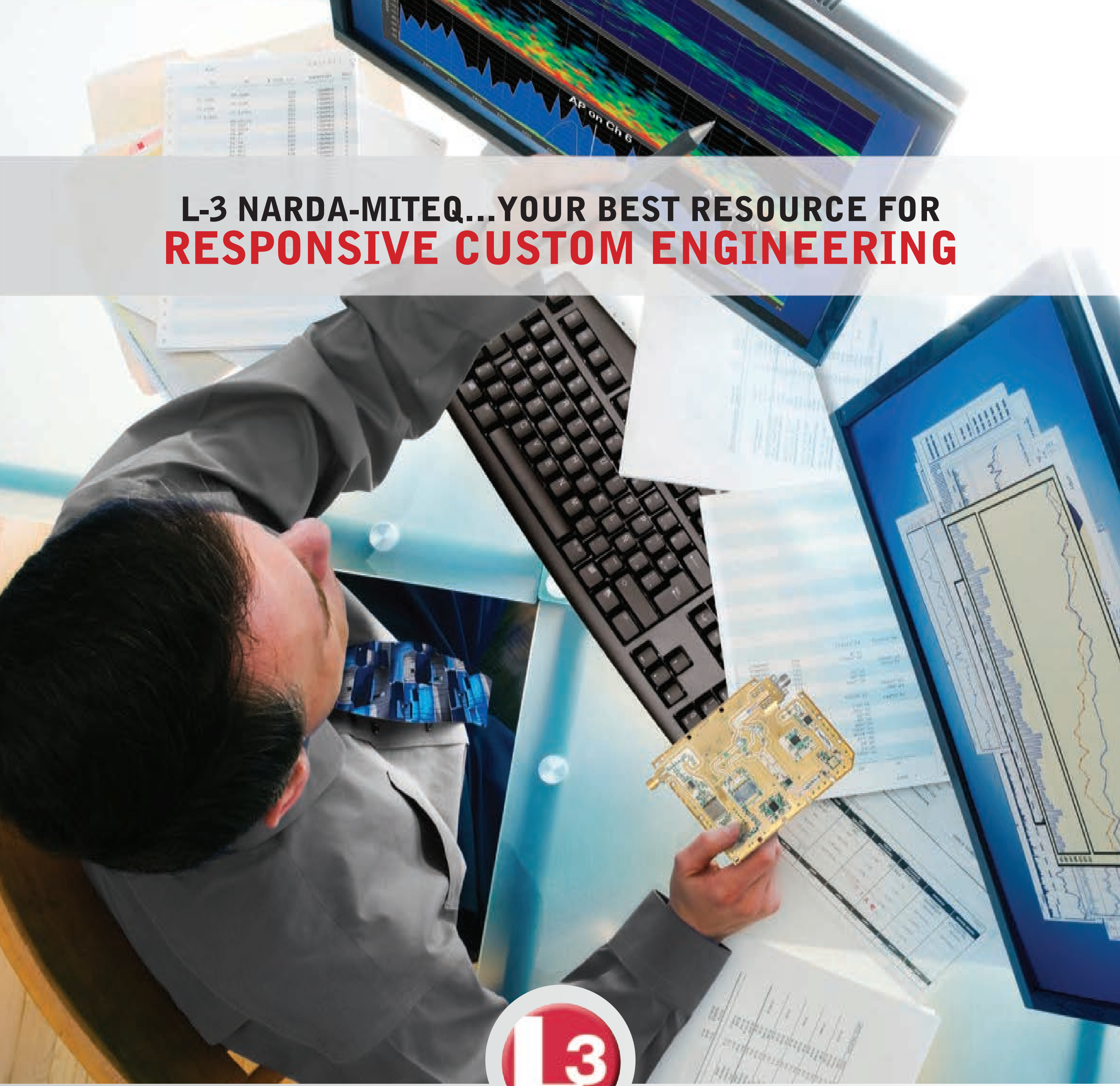
The same materials used for microwave dielectric resonators are often used to realize microwave printed-circuit thin film filters. High dielectric constant ceramic substrates enable a substantial size reduction (particularly useful at lower microwave frequencies, e.g., L and S-Bands), while also achieving excellent temperature stability (a few ppm/°C) over wide temperature ranges (typically -55° to +125°C).

Regarding substrates for microwave applications, a general distinction is made between non-organic (hard) materials, such as quartz, alumina or barium titanate, and organic (soft) materials, such as FR-4, quartz polyimide and all the PTFE-based materials (e.g., Duroid).[5] ***Table 2*** summarizes the properties of some

TABLE 2

ELECTRICAL PROPERTIES OF NON-ORGANIC AND ORGANIC DIELECTRIC SUBSTRATES

Material	Composition	ε_r	Tgδ (10^{-4})	TC (ε_r) (ppm/°C)
Non-Organic Dielectric Substrates				
Quartz	SiO_2	3.75	1.5	+0.5
Alumina (96%)	Al_2O_3	10.2	2	+7.5
Barium Titanate	$BaTiO_3$	85	3	+8
Organic Dielectric Substrates				
Standard FR-4	Fiberglass	4.5	260	+200
Rogers Duroid 5870	PTFE Random Glass Fiber	2.33	12	-115
Rogers 4003	Woven Glass Reinforced Hydrocarbon/ Ceramics	3.38	27	+40
Rogers Duroid 6002	PTFE with Ceramic Fillers	2.94	12	+12
Arlon CLTE-XT	Ceramic Powder-Filled Woven Micro Fiberglass Reinforced PTFE	2.94	12	-9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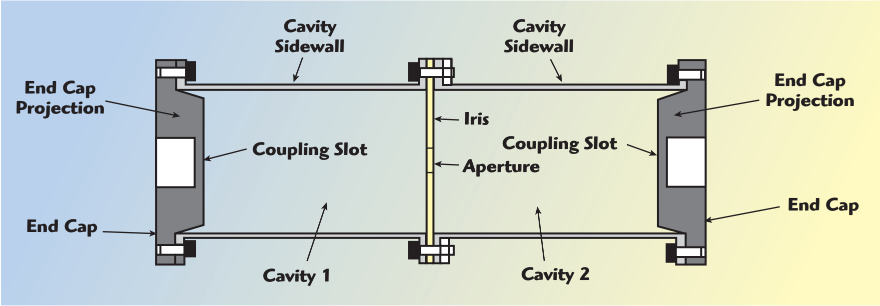


▲ *Fig. 2 Temperature compensated cavity filter.*

commonly used materials.

Soft substrates, with ε_r in the range of 2 to 10, exhibit different thermal behaviours depending on their compositions. Traditional woven and non-woven "fiberglass reinforced PTFE" materials (ε_r = 2 - 2.5) have typical thermal coefficients of ε_r of about -150 ppm/°C (but in some cases they can be as much as -350 ppm/°C). More recent microwave substrates, i.e., glass, PTFE and micro-dispersed ceramic, can achieve much better performance, with thermal coefficients of ε_r as low as -10 ppm/°C.

MICROWAVE CAVITY RESONATORS AND FILTERS

Cavity resonators are, in general, subject to resonant frequency shifts with temperature, due to corresponding changes in cavity dimensions. Various schemes have been proposed to compensate for this shift. The most obvious would seem that of manufacturing the resonators out of invar or similar materials that have low temperature expansion coefficients; however, invar is expensive, very dense, difficult to process and prone to generating passive intermodulation products (PIM).

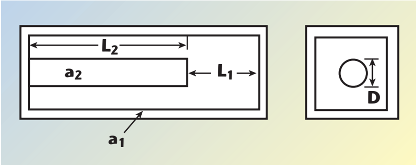
An alternative is to partially fill the cavity with dielectric material having a temperature coefficient of permittivity that compensates for the resonant frequency variation. Yet another approach is to construct the cavity from materials having different temperature expansion coefficients. This is done for coaxial re-entrant cavity resonators, but at frequencies above 10 GHz they exhibit relatively poor quality factors. Tuning screws with thermal expansion coefficients different from that of the cavity metal have also been proposed.[6,7] A "brute force" approach might be to design the cavity of the resonator in such a way that geometric changes normally resulting from a temperature change are locally restricted or "de facto" suppressed. These types of resonators are referred to as "clamped cavity" resonators.

Some temperature compensated cavity filters have end caps made of a material with a more positive thermal expansion than the CTE of the cavity side walls. This causes the end caps to bend into the filter cavity when temperature increases. In this way, the net change in volume of the cavity is reduced and, with proper design, actually compensated. An example of this approach is shown in ***Figure 2***.[8]

Many schemes envision either a tuning screw (or screws) or a plunger introduced into the cavity when the cavity is undergoing dimensional changes due to thermal expansion. The tuning elements are usually solidly joined to a temperature sensitive actuator (typically bimetal). Some temperature compensated cavity filters have bimetal or trimetal end caps that bend into a cavity of the filter when temperature increases.

A bimetal is a planar component with two (or more) layers of metallic materials with substantially different CTEs. Over temperature, the differential expansion in the planar dimensions causes a large out-of-plane deflection. Bimetals are commercially used in inexpensive thermostats and temperature sensors (e.g., those used in electric boilers).

As an alternative to bimetal compensation techniques, spring-biased SMA actuators have been proposed. SMAs are materials that can revert to a memorized shape when heated above some threshold. The two major types of shape-memory alloys are copper-aluminum-nickel and nickel-titanium (NiTi). One potential drawback of these materials is their hysteresis, causing actuation to occur at a higher



▲ *Fig. 3 Coaxial cavity resonator geometry.*

temperature than relaxation.[9]

Temperature Compensation of a Coaxial Cavity Resonator

Coaxial cavity resonators are the main elements of combline filters (see ***Figure 3***). With an appropriate selection of materials for the housing and the rod, perfect temperature compensation of the resonant frequency can be achieved. The resonating frequency of a coaxial cavity resonator is given by:

$$\omega_0 C = \frac{1}{Z_0 \mathrm{tg}\upsilon} \quad (2)$$

where ω_0 = resonant frequency at temperature T_0

C = capacitance of the gap L_1

Z_0 = characteristic impedance of the coaxial line

υ = electrical length of the inner conductor

If L_1 is small, then:

$$C = \varepsilon_0 \varepsilon_r \frac{\pi D^2}{4L_1} = \frac{k}{L_1} \quad (3)$$

At temperature T, the capacitance gap becomes:

$$(L_1 + L_2)(1 + \alpha_1 T) - L_2(1 + \alpha_2 T) \quad (4)$$

where α_1 and α_2 are the CTEs of the walls and inner conductor, respectively. It can be shown that:

$$\frac{\omega_{0T}}{\omega_0} \cong \frac{(1+\alpha^*)\mathrm{tg}\upsilon}{\mathrm{tg}\left[\upsilon(1+\alpha_2 T)\right]} \quad (5)$$

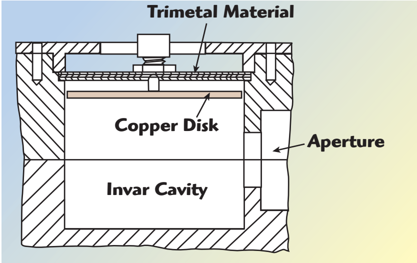
where:

$$\alpha^* = \alpha_1 + \frac{L_2}{L_1}(\alpha_1 - \alpha_2)$$

In order to have perfect compensation of the resonant frequency over temperature, the following condition must be verified:

$$(1+\alpha^*)\mathrm{tg}\upsilon = \mathrm{tg}\left[\upsilon\left(1+\alpha_2 T\right)\right] \quad (6)$$

An example of this compensation technique is reported by Yao and Atia,[10] where a temperature compensated 8-pole combline elliptic function filter was designed and tested. An equivalent temperature coefficient of -2.8 ppm/°C was achieved.



▲ *Fig. 4 Temperature compensated TE_{011} cavity resonator.*

Built-In Temperature Compensation of a Ku-Band Output Filter

One example of a temperature compensation technique is shown in ***Figure 4***, where a cavity resonator, based on a TE_{011} mode, is tuned by a plunger plate. The plunger itself is rigidly fixed to a disk of temperature dilatable material, so that temperature variations cause an axial movement of the cavity wall and tunes the resonating frequency. This temperature compensated cavity was part of a complete pseudo-elliptic four-pole filter, in extracted pole configuration, meant to be part of an output multiplexer (OMUX) at 12 GHz for a television broadcast satellite payload.[11]

The use of invar in this application was particularly disadvantageous. Due to the high power handling requirement (450 W CW) and the low thermal conductivity of invar, localized temperature rises (hot-spots) of several tenths of degrees above ambient could be generated in the filter. The design takes advantage of a characteristic feature of the TE_{011} mode resonant cavity that no current flows between the cavity bottom and top walls and the side walls, thus allowing a non-contacting plunger to form one of the end walls without degrading cavity performance.

Knowing that the relationship between the resonant frequency of the cavity F_0 and its length L is:

$$F_0 = c\sqrt{\left(\frac{1}{2L}\right)^2 + \left(\frac{R_m}{\pi D}\right)^2} \quad (7)$$

where: L = cavity length;
D = cavity diameter;
R_m = Bessel root for TE_{011} mode;

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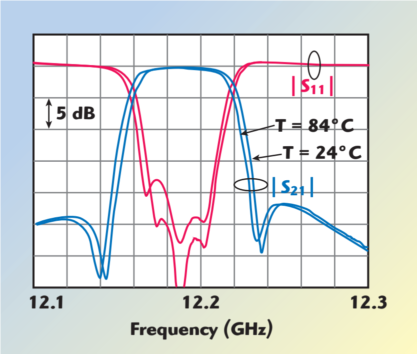


▲ *Fig. 5 Temperature compensated filter performance at +24°C and +84°C.*

it is possible to calculate the plunger displacement needed to compensate any frequency shift caused by temperature variations.

The temperature sensitive actuator is a disk of thermostatic trimetal material clamped in the cavity structure and connected to a copper disk that acts as cavity top wall. The thermostatic trimetal consists of three layers of metal bonded together across the entire interface, each layer having a different CTE. On heating, the composite metal disk changes its curvature, following a law that is linearly proportional to temperature over a wide temperature range. The resulting displacement in the z axis can be calculated so as to compensate for the cavity frequency drift over temperature.

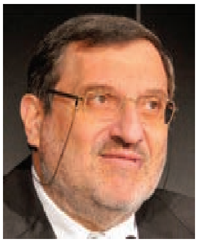
Figure 5 shows the measured performance of the compensated filter, at ambient and high temperatures. An overall frequency shift of 2 MHz over a ΔT of 60°C was measured, corresponding to an equivalent CTE of 2.3 ppm/°C. This value is very close to the CTE of invar (1.3 ppm/°C) and an order of magnitude smaller than that of aluminum (23 ppm/°C).

CONCLUSION

The general topic of thermal stability in microwave structures (mainly resonators and filters) for satellite on-board applications was discussed. Temperature compensation techniques are often products of design ingenuity and creativity associated with an in-depth knowledge of the electromagnetic structures and of the physical properties of materials.■

References

1. C. Wang, "Temperature Compensations for Microwave Resonators and Filters," *IEEE International Microwave Symposium*, June 2005.
2. B.F. Keats, "Bimetal Temperature Compensation for Waveguide Microwave Filters," *Ph.D. Thesis at University of Waterloo*, Waterloo, Ontario, Canada, 2007.
3. C. Kudsia, R. Cameron and W.C. Tang, "Innovations in Microwave Filters and Multiplexing Networks for Communications Satellite Systems," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 40, No. 6, June 1992, pp. 1133–1149.
4. S.J. Fiedziuszko, "Miniature Dual-Mode, Dielectric-Loaded Cavity Filter," *US Patent 4489293 A*, 1984.
5. Alcatel Alenia Space, "Microwave Organic PCBs for Space Applications," *3rd CTB WG Hybrids Technical Presentation Day*, ESTEC, May 2006.
6. R.V. Basil, L. Ondrups and J. K. Shimizu, "Thermally Compensated Microwave Resonators," *US Patent 4,057,772*, November 1977.
7. R. E. Jachowski and L. E. Brown, "Compensating Device for Tuned Cavities," *US Patent 4,423,398*, December 1983.
8. S.B. Lundquist, "Temperature Compensated Filter," *US Patent 5,867,077*, 1999.
9. B.F. Keats, R.B. Gorbet and R.R. Mansour, "Design and Testing of SMA Temperature-Compensated Cavity Resonators," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 51, No. 12, December 2003, pp. 2284–2289.
10. H.W. Yao and A.E. Atia, "Temperature Characteristics of Combline Resonators and Filters," *IEEE International Microwave Symposium Digest*, Vol. 3, May 2001, pp. 1475–1478.
11. R. Cameron, M. Lisi and S. Strijk , "Resonateur à Cavitès avec Dispositive de Compensation Thermique," *Brevet d'invention n. 8607497*, 16 May 1986, ESA Patent.



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Frequency Agile Diplexer

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A miniaturized ultra-wideband (UWB) frequency agile diplexer filter (bandpass/lowpass) is based on conventional microstrip line, lumped components and a composite dual right- and left-handed resonator in a distributed-tapped D-CRLH microstrip structure. In the right-handed mode it is weakly coupled, while in the left-handed mode it is tightly coupled, achieving quasi 0 dB coupling. Its insertion loss is less than 5 dB, and port-to-port isolation is greater than 20 dB.

A reconfigurable software defined cognitive radio (SDCR) system represents a potential solution for interference, cost, size and power consumption problems encountered in wireless communications systems. A reconfigurable radio system must be frequency agile in order to dynamically select frequency bands or channels, and one of its enabling components is the radio frequency (RF) transceiver diplexer.

The diplexer is generally composed of two bandpass filters tuned to different frequency bands that appear electrically open with respect to each other over their passbands. Frequency agile RF front-end components that have been extensively studied for this application include RF filters,[1,2] couplers[3] and demodulators.[4] It is challenging, however, to design a diplexer with a tuning range wide enough to cover the operating frequencies needed for practical applications. This article describes a varactor-tuned diplexer based on two frequency agile dual-mode bandpass filters for IEEE 801.16 standard system applications over 2.3 to 2.69 GHz and 3.3 to 3.8 GHz.[4]

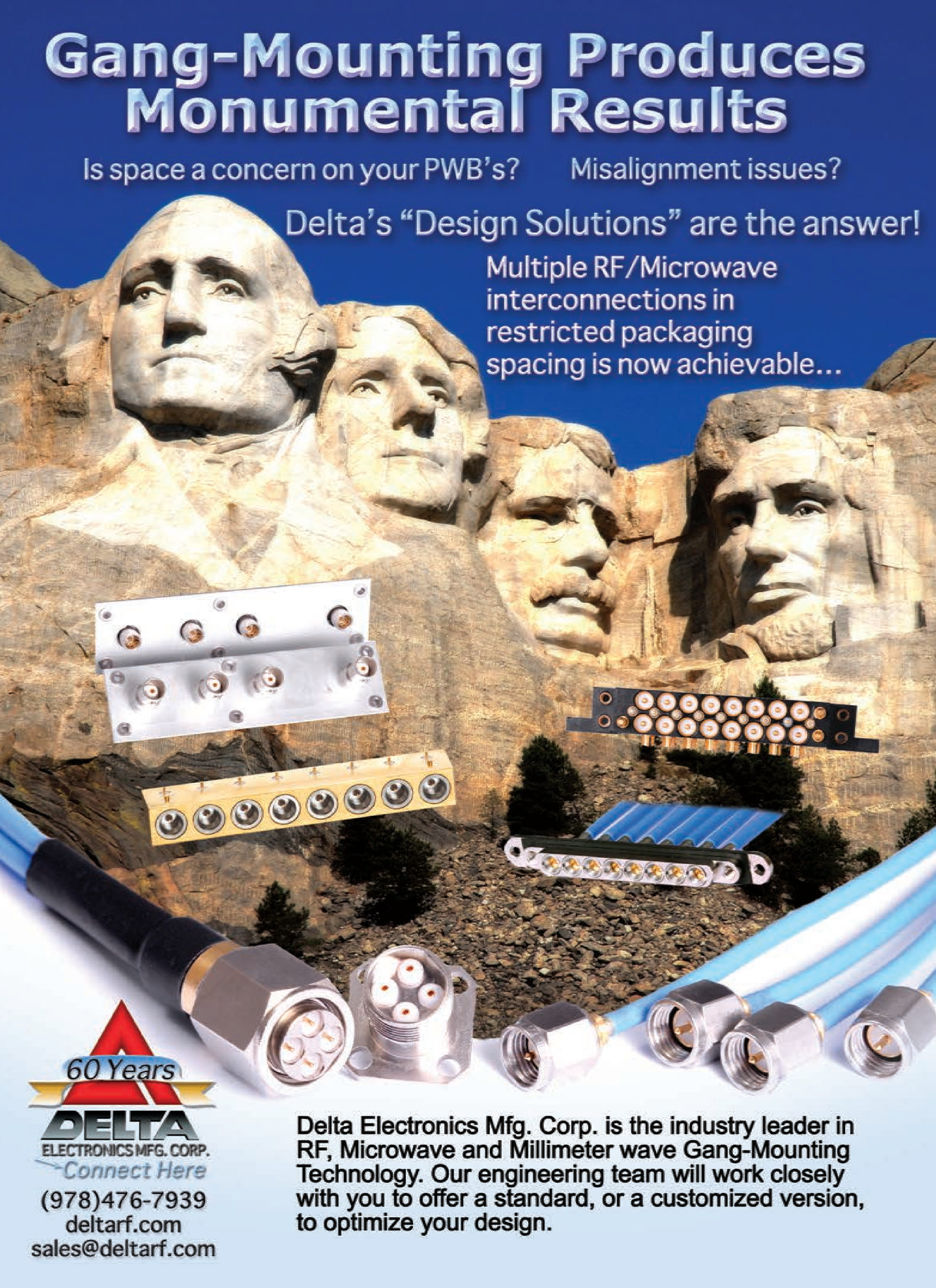
BACKGROUND

The performance of tunable diplexers and filters may be specified using the same criteria as for fixed-frequency filters with additional requirements for tuning range, tuning speed and tuning linearity. Not all may be satisfied simultaneously, so priorities should be established.

Currently, these requirements are best met with mechanical tuning. As an example, Rohde & Schwarz FU221 and FD221 filters are each made up of two coaxial resonators, fixed coupled to form a compact two-section filter plug-in. Following a frequency change input from the radio, the gear is driven by a microprocessor-controlled stepping motor.[5] A robust and mechanically stiff layout using temperature-stable invar (iron-nickel alloy) for filter bodies, spindles and coupling loops, in combination with silver plating, guarantees its specifications over a wide temperature range and under high power, 100 percent duty-cycle operation.

If system requirements call for multioctave tuning, a yttrium iron garnet (YIG) filter is a likely choice.[6] It has a relatively spurious-free response and low insertion loss due to the high quality factor (Q) of the resonator; however, its structure is not planar. Also, magnetic hysteresis limits its tuning speed.[6,7] As with any mechanical high Q structure, microphonic noise can also be a problem.[8]

Newer component technologies such as micro-electromechanical systems (MEMS) and barium strontium titanate (BST) varactors have been applied to tunable filters. MEMS varac-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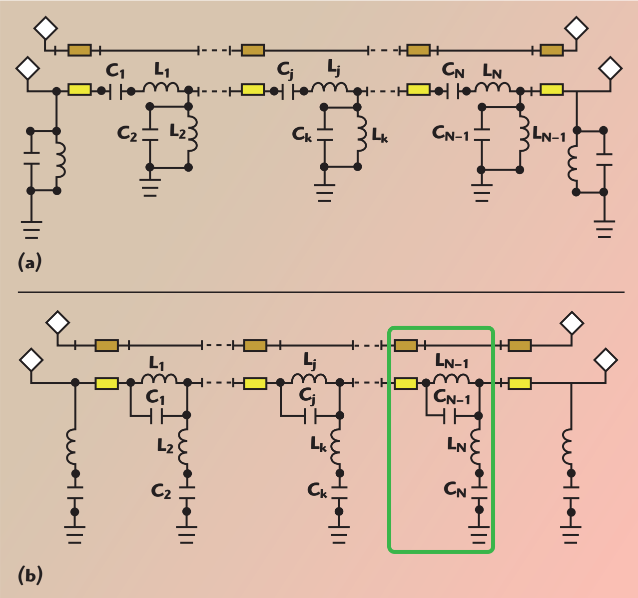
tors are small, have a wide tuning range and provide fast tuning speed with low insertion loss; but they also have a poor capacitance ratio resulting in low frequency resolution.[9] BST varactors are small and can be easily implemented in integrated circuits. They may be suitable for high power applications, but have a relatively low Q.[10]

There is no tunable filter that will satisfy all requirements simultaneously. Most research activities have focused on the methodology for changing the center frequency of the filter, concentrating less on its frequency response.[2,6]



▲ *Fig. 1 Circuit models of CRLH (a) and D-CRLH (b) transmission lines.*

CRLH TRANSMISSION LINES

Metamaterial transmission lines, also known as composite right/left–handed (CRLH) transmission lines or negative refractive index (NRI) transmission lines, have some unique characteristics such as backward wave propagation, simultaneous negative permittivity and permeability, zeroth order resonance and tight coupling.[11]

A widely used microstrip metamaterial transmission line consists of a series of interdigital capacitors and shunted transmission line inductors. These are practical at high frequencies, but because the structures become large, lumped components are used at lower frequencies.[12] At the center, or transit, frequency there is no phase shift. It is right-handed in the region above the transit frequency and left-handed in the region below it.

A counterpart of the CRLH transmission line, the dual CRLH (D-CRLH) transmission line,[11] has a stop band between the right-handed and left-handed regions. It is right-handed below the stop band and is left-handed above it, i.e., the inverse of a CRLH transmission line.

D-CRLH Transmission Line

CRLH and D-CRLH transmission line equivalent circuits are shown in **Figure 1**. The D-CRLH transmission line model has parallel LC resonators in series branches and series LC resonators in parallel branches, while the CRLH transmission line model has series LC resonators in series branches and parallel LC resonators in parallel branches.

For the D-CRLH transmission line, LC circuits are [1]

$$\begin{cases} C_j = C_L, L_j = L_R, \text{series} \\ C_k = C_R, L_k = L_L, \text{parallel} \end{cases} \quad (1)$$

The resonant frequencies of the series and shunt resonators are

$$\omega_{sh} = \frac{1}{\sqrt{L_L C_R}} \text{ and } \omega_{se} = \frac{1}{\sqrt{L_R C_L}} \quad (2)$$

The resonant frequencies of the left/right handed circuits are

$$\omega_R = \frac{1}{\sqrt{L_R C_R}} \text{ and } \omega_L = \frac{1}{\sqrt{L_L C_L}} \quad (3)$$

To minimize the band gap between the left/right handed regions, the following condition should be satisfied

$$\omega_{sh} = \omega_{se} = \omega_0 \text{ or } L_L C_R = L_R C_L \quad (4)$$

which is identical to the balanced case of the CRLH transmission line. From image impedance analysis, the characteristic impedance ZC of the D-CRLH transmission line in the balanced case is

$$Z_C = Z_0\sqrt{1-\frac{1}{4\varepsilon^2}\frac{\omega_L}{\omega_R}} \qquad (5)$$

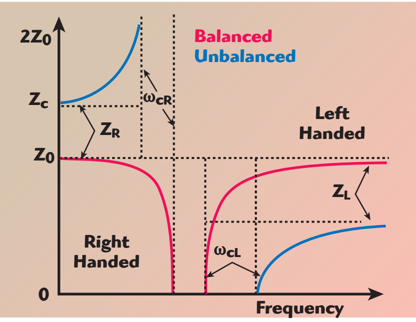
Where $\varepsilon = \frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}$[1].

The characteristic impedances of a D-CRLH transmission line in the balanced and unbalanced cases are shown in ***Figure 2***.

The stopband of the D-CRLH transmission line is determined with the condition that ZC is real. In the balanced case, the cut-off frequencies are then obtained from Equation 5 as

$$\begin{cases} \omega_{cL} = \omega_0\left(\sqrt{1+\frac{1}{16}\frac{\omega_L}{\omega_R}}+\frac{1}{4}\sqrt{\frac{\omega_L}{\omega_R}}\right) \\ \omega_{cR} = \omega_0\left(\sqrt{1+\frac{1}{16}\frac{\omega_L}{\omega_R}}-\frac{1}{4}\sqrt{\frac{\omega_L}{\omega_R}}\right) \end{cases} \qquad (6)$$

The band gap between right-handed and left-handed regions is desirable with various left/right handed frequencies.[11]

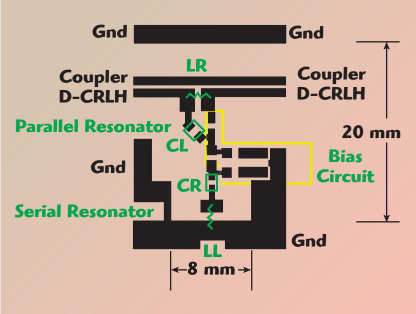


▲ *Fig. 2 Characteristic impedance of a D-CRLH transmission line.*

$$\pounds(f) = 2f_{HW} = 2\pi f_{osc}^2 c \qquad (7)$$

A microstrip realization of a D-CRLH transmission line is shown in ***Figure 3***. The parallel LC resonator is composed of a pad, chip capacitor (CL) and a lumped inductor (LR). The series LC resonator is composed of a pad, chip capacitor (CR) and a lumped inductor (LL), chip or otherwise. LC components are adjusted at both ends to optimize impedance match and bandwidth.[11,14]

A single varactor diode and an antiparallel pair have been considered. BST varactors are suitable for use in a single diode configuration since they do not have a rectifying effect,[10] but they are difficult to procure and are lossy. A similar characteristic may be achieved with an anti-parallel pair of semiconductor varactors, but this is also lossy. Despite possibly larger nonlinearities, one diode per tank is chosen.



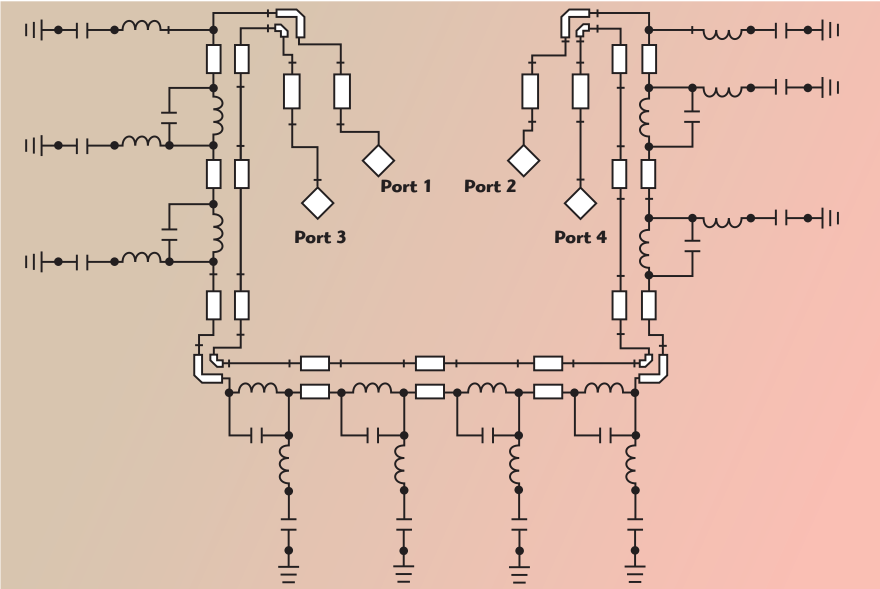
▲ *Fig. 3 Microstrip realization of a D-CRLH transmission line.*

DIPLEXER SIMULATION

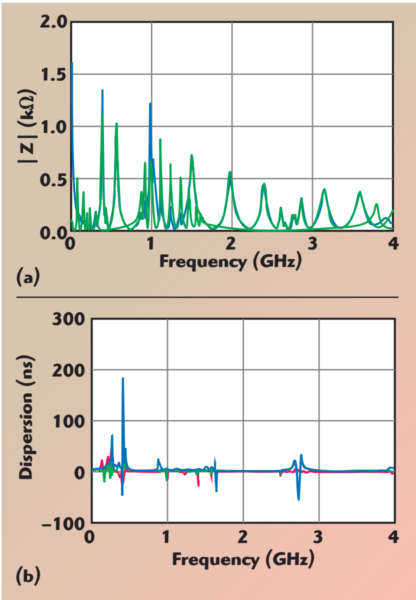
A distributed coupled D-CRLH circuit is used for the purpose of forming a frequency agile passband for the UWB bandpass/lowpass (BPF/LPF) diplexer. This is realized with a new D-CRLH coupled line diplexer structure (see ***Figure 4***). A balanced D-CRLH is adopted to achieve a multiple broadband characteristic with no discontinuity between cutoff frequencies of the bandpass and lowpass filters.

The design is carried out with Z_0 = 45 Ω, ωcL = 1.2 GHz and ωcR = 2.7 GHz. The parameters in Equation 1 are calculated with CR=1.7 pF to 17 pF, LR = 1.91 nH, CL=1.7 pF to 17 pF and LL = 0.817 nH. A frequency agile passband of the UWB BPF/LPF diplexer is assumed and the corresponding geometrical values are found through iterative electromagnetic (EM) simulations using Ansoft Designer EM. The simulated performance of the circuit over the frequency band is shown in ***Figure 5***. To verify performance over the entire frequency band, both impedance and the dispersion are shown. Multiple spikes are due to metamaterial structure of the filters consisting of multiple variable lossy resonators.

Both filters can be independently set (see ***Figure 6***). The BPF has a tunable center frequency with a constant bandwidth. The LPF has a tunable 3 dB cutoff frequency and is capable



▲ *Fig. 4 Schematic of a metamaterial tunable D-CRLH diplexer.*



▲ *Fig. 5 Metamaterial tunable diplexer simulated Z_{11}, Z_{22}, Z_{33} and Z_{44} impedance (a) and port 12, 13 and 14 dispersion (b).*

of passing DC, if necessary. The LPF is intended to be the transmit path, as the current consumption is much higher than in the receive path. The "T" is not a "lumped T" nor is it tunable, but is distributed by the coupler.

Due to large impedance mismatches over the passband and discontinuities between the circuit and EM structures, a matching circuit is added to the frequency agile D-CRLH diplexer increasing its total size to 0.12 × 0.1 λg. Stop band rejection may be improved by adding stopband filters,[5] but in tunable diplexer these must be tunable as well.

The prototype D-CRLH transmission line contains eight unit elements. This provides sufficient out-of-band attenuation for most purposes. The directional coupler is distributed among them. Increasing the number of segments for higher out-of-band attenuation increases the size, which may adversely affect coupler operation.

The coupling coefficients differ. When the frequency is below the band gap, it works in the right-handed mode and weak coupling is obtained, as shown in ***Figure 7***. When the frequency is above the band gap, it works in the left-handed region and strong coupling is achieved. The coupling difference between left-handed and right-handed modes can be higher than 20 dB. If coupling is nearly 0 dB in the left-handed mode, it may reach -20 dB in the right-handed mode. Thus, microwave energy at different frequencies is directed to different ports depending on the mode.

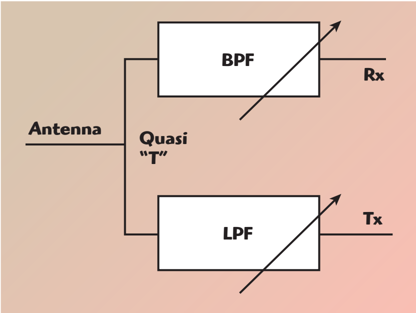


Fig. 6 Simplified block diagram of the frequency agile diplexer.

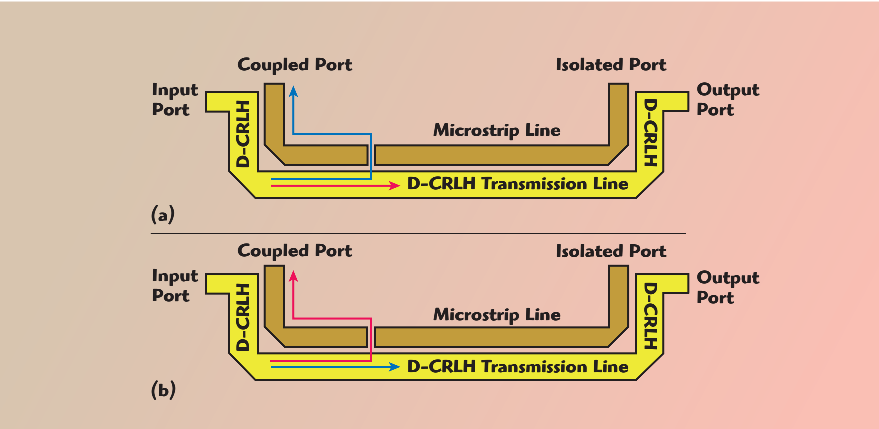


Fig. 7 Directional coupler from D-CRLH transmission lines in right-handed (a) and left-handed mode (b). Red line indicates strong coupling; blue line indicates weaker coupling.

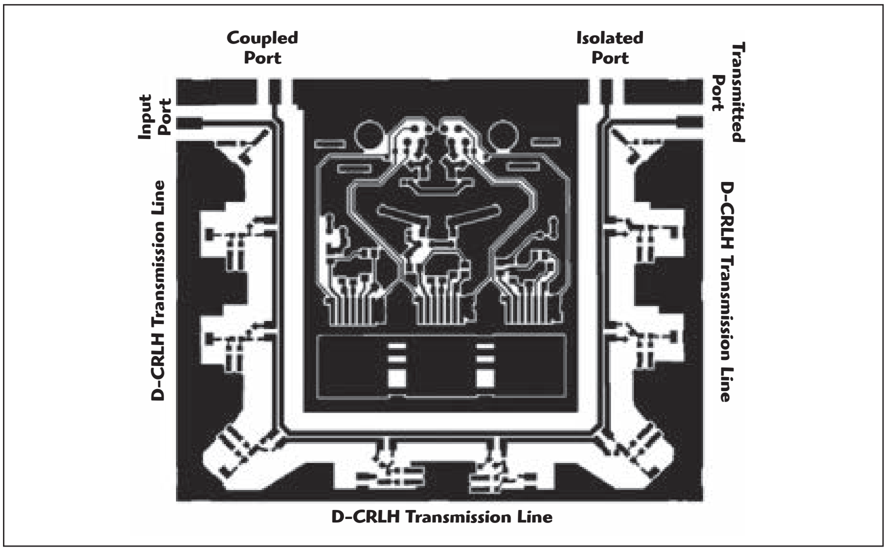


Fig. 8 Layout of the proposed distributed directional coupler and frequency agile D-CRLH transmission lines with drivers. Board dimensions are 80 × 100 mm.

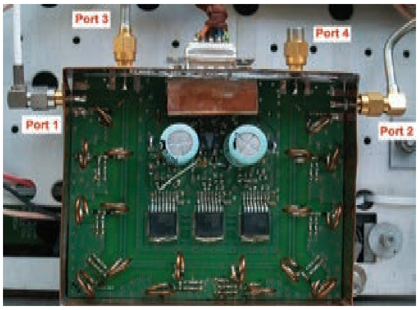


Fig. 9 Fabricated frequency agile diplexer on a test fixture.

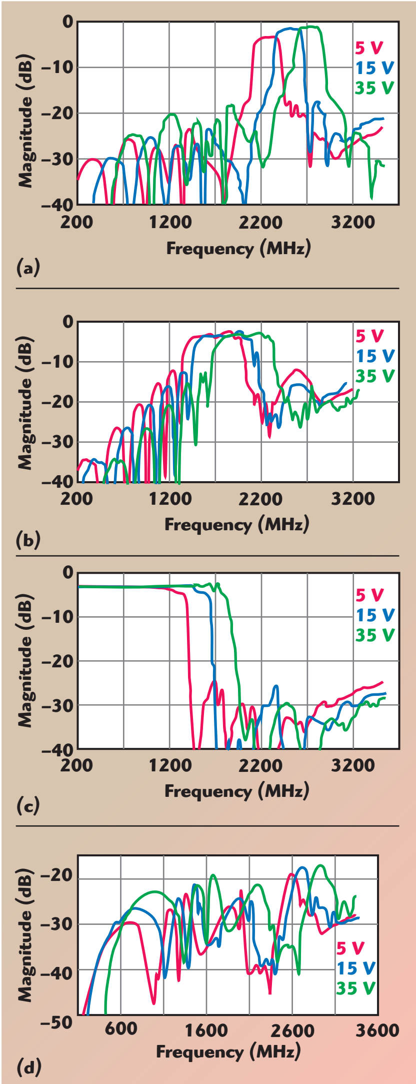


Fig. 10 Measured results of BPF transmission of port 2 output (a), BPF reflection of port 3 output (b), LPF transmission of port 3 output (c) and isolation between port 2 and 3 outputs (d).

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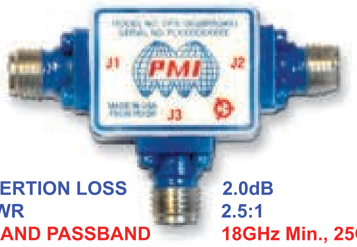
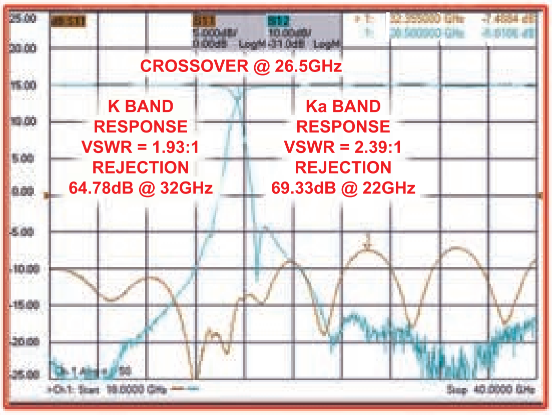


INSERTION LOSS	2.0dB
VSWR	2.5:1
K BAND PASSBAND	18GHz Min., 25GHz Max
Ka BAND PASSBAND	28GHz Min., 40GHz Max
K BAND REJECTION	32 to 46GHz, >60dBc
Ka BAND REJECTION	DC to 22GHz, >60dBc
SIZE	0.80" X 0.60" X 0.38"

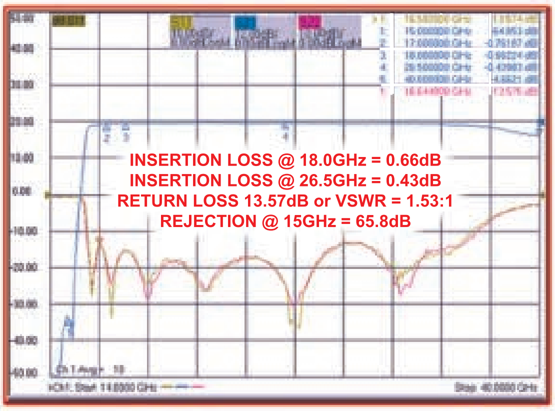
SWEPT DATA ON DPX-18G26R5G40G



18GHz to 26.5GHz
HIGH PASS FILTER
PMI MODEL No: HPF18G-DC15G

INSERTION LOSS	1.5dB
PASSBAND	18 to 26.5GHz
VSWR in PASSBAND	2.0:1
REJECTION	DC to 15GHz, >60dBc
SIZE	0.64" X 0.58" X 0.38"

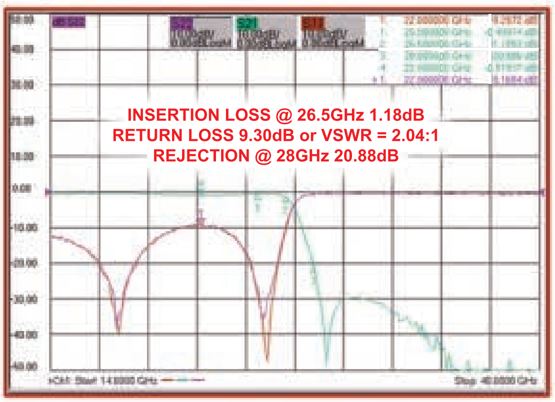
SWEPT DATA ON HPF18G-DC15G



DC to 26.5GHz
LOW PASS FILTER
PMI MODEL No: LPF26R5-28R5G40G

INSERTION LOSS	1.5dB
PASSBAND	DC to 26.5GHz
VSWR in PASSBAND	2.2:1
RIPPLE	+/-0.75dB Max
REJECTION	28.5 to 40GHz, >25dBc
SIZE	0.45" X 0.38" X 0.50"

SWEPT DATA ON LPF26R5-28R5G40G



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DIPLEXER PROTOTYPE

The prototype layout is shown in ***Figure 8*** and a photograph of the circuit is shown in ***Figure 9***. The substrate is Rogers RT/duroid 6010 with thickness of 0.635 mm and relative permittivity of 10.2. Input and transmitted ports on the tunable D-CRLH coupler are physically separated and the isolated ports are terminated in 50 Ohms in order to preserve port-to-port isolation.

Three high voltage DC Burr–Brown OPA548 amplifier varactor drivers are mounted at the center of the PCB. The output voltages are limited with Zener diodes to the maximum ratings of NXP's BB135 silicon varactors (-5V to +35V). Their 10:1 capacity ratio supports UWB operation, allowing 20 percent (LPF) and 22 percent (BPF) center-frequency tunability in transmit and receive filters bands, respectively.

Hand wound air core and commercially available ferrite core (EPCOS B82422A3100K10013) versions were evaluated. Since there are no essential differences between their performance characteristics, and both support UWB operation, hand wound cores are used. This increases the required height, which in future versions will be reduced with a multilayer PCB.

EXPERIMENTAL RESULTS

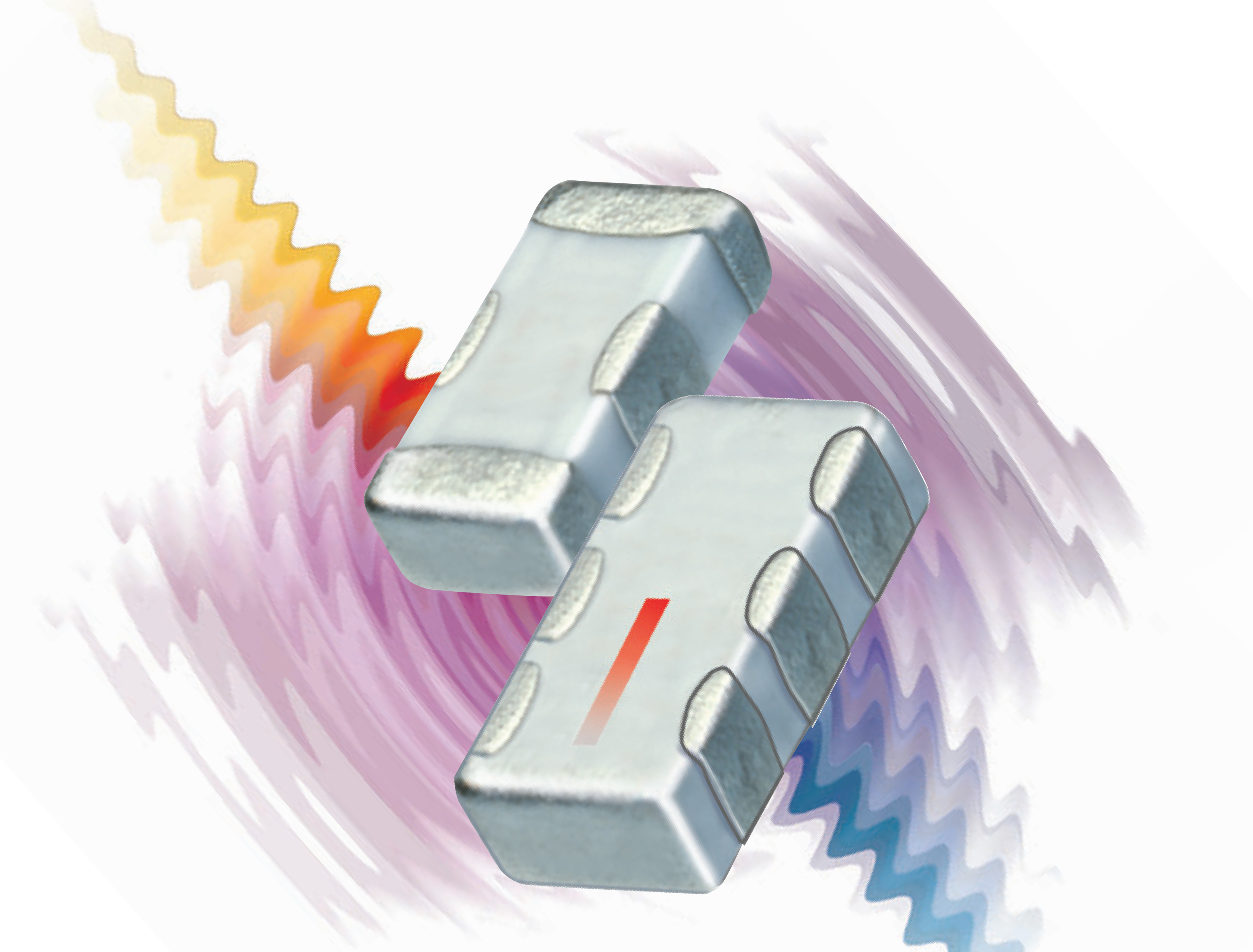
The D-CRLH has a fractional bandwidth greater than 100 percent with an insertion loss of less than 5 dB over the entire tuning range (see ***Figure 10***). High isolation is achieved over a wide frequency band from DC to 1.1 GHz.

CONCLUSION

A frequency agile UWB BPF/LPF diplexer is designed to have an improved stopband by cascading it with a compact tunable matching element. It has potential applications in various microwave and UHF systems. Its size can be further reduced using multilayer technology; in this case, unwanted coupling must be tightly controlled for simultaneous receive/transmit systems. ■

References

1. H. Wang, L. Zhu and W. Menzel, "Ultra-wideband Bandpass Filter with Hybrid Microstrip/CPW Structure," *IEEE Microwave and Wireless Components Letters*, Vol. 15, No. 12, December 2005, pp. 844−846.
2. B.E. Carey–Smith and P.A. Warr, "Distortion Mechanisms in Varactor Diode-Tuned Microwave Filters," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 54, No. 9, September 2006, pp. 3492−3500.
3. T. Zelder, E. Valles Lluch, B. Geck, I. Rolfes and H. Eul, "A Tunable Directional Coupler," *Proceedings of the European Microwave Association*, Vol. 4, Sup. 1, December 2008, pp. 66−72.
4. E.E. Djoumessi and K. Wu, "Electronically Tunable Diplexer for Frequency-Agile Transceiver Front-End," *IEEE International Microwave Symposium Digest*, May 2010.
5. "VHF/UHF Filters/Multicouplers," *Overview for Ground–to–Air and Naval Radio Communications, Automatically Tuned*. Rohde & Schwarz. Web. 19 August 2014. www.rohde-schwarz.com.vn/file_2767/11356cat.pdf.
6. J. S. Lee, "Microwave Resonator Filters for Advanced Wireless Systems," University of Michigan, 2009.
7. D. Crunkilton and T.R. Kuphaldt, AC MOTORS, *"Lessons in Electric Circuits*," Vol. 2, Ch. 13. February 2015, www.ibiblio.org/kuphaldt/electricCircuits/AC/AC_13.html, 2014.
8. Micro Lambda Wireless Inc., "Technology Description YIG Tuned Oscillators." December 2014, www.microlambdawireless.com/apppdfs/ytodefinitions2.pdf.
9. X. Liu, L.P.B. Katehi, W.J. Chappell and D. Peroulis, "High-Q Tunable Microwave Cavity Resonators and Filters using SOI-Based RF MEMS Tuners," *Journal of Microelectromechanical Systems*, Vol. 19, No. 4, July 2010, pp. 774−784.
10. R.A. York, "Tunable Dielectrics for RF Circuits," Scitech Publishing, 2009.
11. C. Liu and W. Menzel, "A Microstrip Diplexer from Metamaterial Transmission Lines," *IEEE International Microwave Symposium Digest*, June 2009, pp. 65−68.
12. Paratec Microwave, "Small Tunable RF Filters Provide Low Loss, Broad Coverage, and High IIP3, Next–Generation ParaTune™ Passive Tunable ICs Yield New Applications," August 2014, www.businesswire.com/news/home/20080104005378/en/Small-Tunable-RF-Filters-Provide-Loss-Broad#.U_s08KPC4tD.
13. EPCOS AG, München, SMT Inductors, SIMID series, SIMID 1210-100, B82422A*100. January 2015, http://en.tdk.eu/inf/30/db/ind_2008/b82422a_100.pdf.
14. S. Kahng and D. Lim, "A Center–Tapped CRLH ZOR UWB Bandpass Filter with Improved Stopband," *Microwave Journal*, Vol. 55, No. 6, June 2012, pp. 86−92.



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A Dual-Channel X-Band Receiver for MIMO Systems

Weichen Huang, Liang Ma, Zhiqiang Yu and Jianyi Zhou
State Key Laboratory of Millimeter Waves, Southeast University
Nanjing, China

A wideband high dynamic range low noise dual channel receiver front-end operates at 8.6 ± 0.4 GHz and has a 600 MHz intermediate frequency. It exhibits a maximum conversion gain of over 90 dB with 63 dB controllable. Over its entire 800 MHz bandwidth, gain fluctuation is less than 2.1 dB and noise figure is better than 1.8 dB. Its two channels are consistent with respect to gain, voltage standing wave ratio (VSWR) and noise figure. Its performance is suitable for high speed wireless communication or phased array applications.

Rapid growth in the communication technologies applied to third-generation networks is occurring throughout the world. CDMA2000 and other networks can currently provide data rates of several megabits per second (Mbps) or higher to individual users.[1] According to the IMT-Advanced system definition, however, networks should support data rates up to 100 Mbps; so there is further work to be done.[2-3] Yu et. al., describe a receiver operating at 6.1 GHz with 100 MHz bandwidth designed for a TDD system capable of supporting 1 Gbps wireless service,[2] while Chen et. al., introduce a receiver designed to operate in Ku-Band with 100 MHz bandwidth for an FDD system.[3] These are typical of high performance receivers for next generation multiple-input-multiple-output (MIMO) wireless communication.

In the pursuit of much higher data rates, the wireless communication standard Beyond 4G (B4G) is in deliberation. Massive MIMO is likely to be one of the key technologies in the B4G network. In order to deal with more devices and higher bit rates, massive MIMO uses hundreds of antennas at the base station that can serve many tens of terminals simultaneously. With a much greater scale, massive MIMO can reap all the benefits of conventional MIMO, while increasing capacity and significantly improving energy efficiency.[4] High frequency, broad bandwidth, OFDM as well as MIMO technologies may all be employed in the B4G network.

One of the most important subsystems is the receiver front-end that amplifies the signal received by the antenna while suppressing interference and noise. Several hallmarks of a good receiver front-end include low noise figure, large dynamic range, high conversion gain and good image rejection.[5] For systems consisting of multi-channel receivers such as massive MIMO or phased arrays, the emphasis is on channel size and weight reduction, power consumption, cost, reproducibility and reliability.[6]

X-Band has been exploited for use in many applications such as fire control radar, airborne systems, vehicle location systems and satellite communications.[7-11] In this article, a dual-channel X-Band receiver front-end is designed for use in a massive MIMO system.

FRONT-END DESIGN

Architecture and Link Budget

The receiver front-end consists of several


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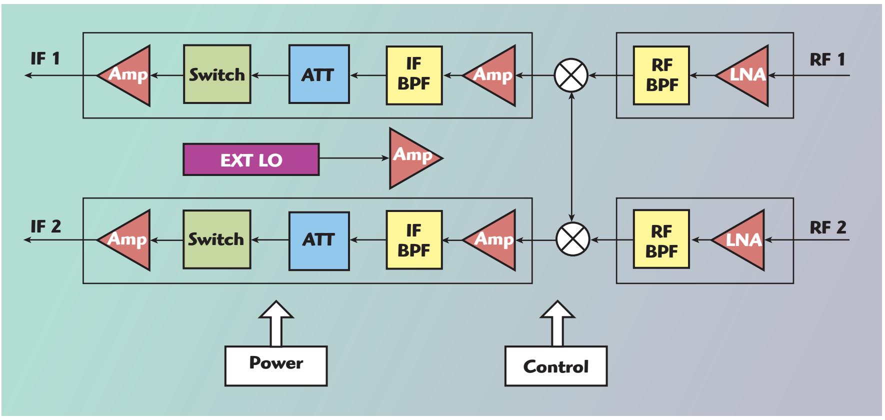


▲ *Fig. 1 Simplified block diagram of the dual-channel RF receiver front-end.*

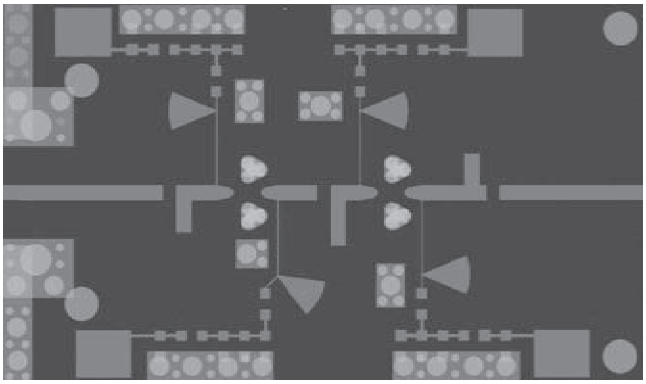
major components, including low noise amplifiers, RF bandpass filters, mixers, IF amplifiers with digital attenuators, switches and IF filters. ***Figure 1*** is a simplified block diagram. Using Keysight Advanced Design System (ADS) software, the link budget is simulated and optimized (see ***Table 1***).

TABLE 1
LINK BUDGET OF THE RECEIVER FRONT-END

	NF (dB)	Gain (dB)	Input P1dB (dBm)
LNA	1.1	26	-18
RF Filter	2	-2	> 80
Mixer	8	-8	12
IF Amplifier and Attenuator	6	17 to 80	0
IF Filter	2	-2	> 80
Switch	1	-1	31
Total	**1.5**	**30 to 93**	**-28.3**

Low Noise Amplifier

The performance of the first amplifier is extremely important to ensuring a low receiver noise figure. In this X-Band two-stage design, a low noise Mitsubishi InGaAs HEMT (MGF4941) is used. Although this transistor is optimized at 12 GHz where R_n is at its lowest value, we chose it for its low cost and outstanding X-Band performance. Since the transistor itself is not unconditionally stable, a short-circuited microstrip line is placed at the source to improve stability. In addition, a quarter wavelength high resistance transmission line with a radial stub is used in the DC bias network as an RF choke.



▲ *Fig. 2 Two-stage LNA PCB layout.*

Theoretically, to obtain low noise with high associated power gain, the first stage should use noise matching and the second stage should use complex conjugate matching. Considering the receiver front-end's input return loss, however, a trade-off is made between optimal noise matching and gain matching for the first stage. Because the relative bandwidth of this LNA is not wide, all matching networks are L-type for simplicity.

Simulation is done carefully because the transistor's R_n at 8.6 GHz is larger than 5. This causes the S-parameters to be sensitive to errors in simulation and manufacturing. Mitsubishi's nonlinear model is used. LNA S-parameters and noise figure are optimized through small signal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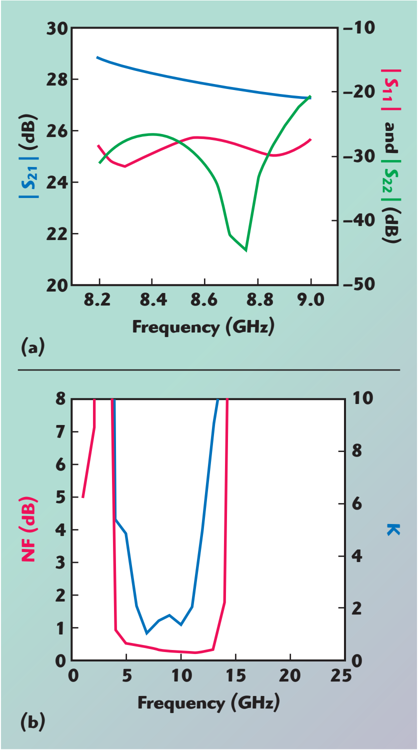


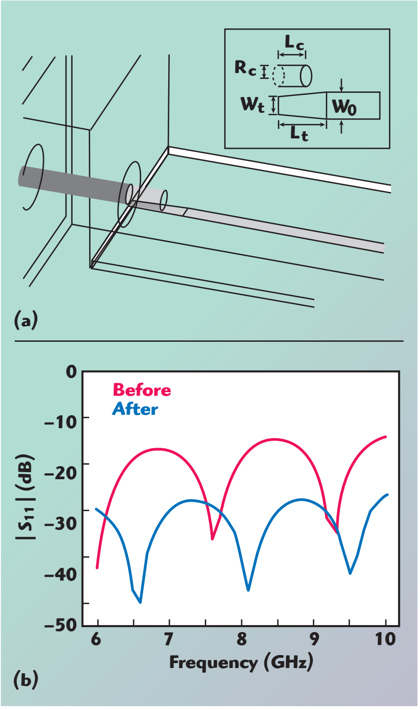
▲ *Fig. 3 Two-stage LNA ADS simulation results: S-parameters (a) noise figure and stability factor (b).*

analysis in ADS. ***Figure 2*** shows the PCB layout of the two-stage LNA. ***Figure 3*** summarizes the simulation results showing that the input and output VSWR is better than 1.2, the noise figure is less than 0.5 dB and the gain is larger than 27.2 dB. The LNA is unconditionally stable from 0 to 24 GHz.

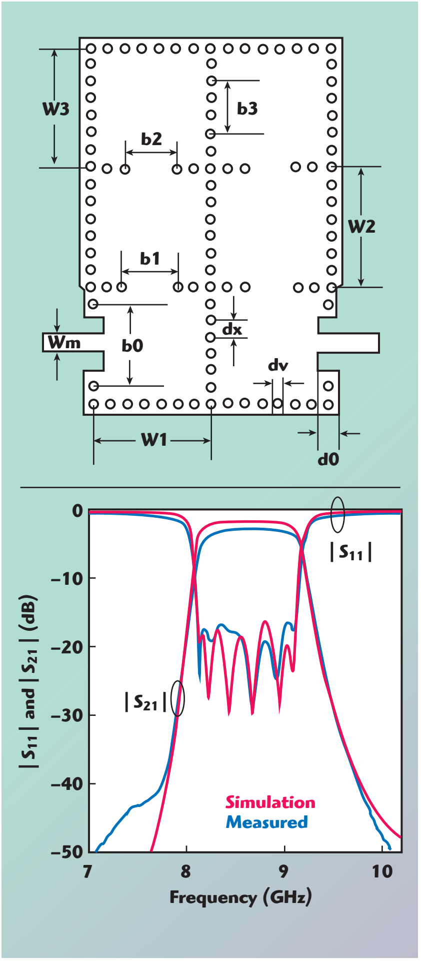
Return loss performance is optimized by building the SMA connector model and microstrip line in HFSS, which shows that return loss can be increased with a tapered transition (see ***Figure 4a***). W_0 is chosen based on the characteristic impedance while R_c and L_c are the radius and length of the SMA connector's inner conductor, respectively. According to the simulation, improvement is greater than 10 dB in comparison with an abrupt transition (see ***Figure 4b***).

RF Filter

Image rejection must be sufficient to mitigate the effects of jamming and interference.[6] With the low noise amplifier preceding the image rejection filter, SSB noise figure is improved without degrading the receiver's dynamic range. In some systems, high image rejection as well as good spurious signal suppression is accomplished



▲ *Fig. 4 3D view of modified SMA-microstrip transition (a) and simulation results (b).*



▲ *Fig. 5 Fundamental mode RF filter with square cavity: structure (a) and response (b).*


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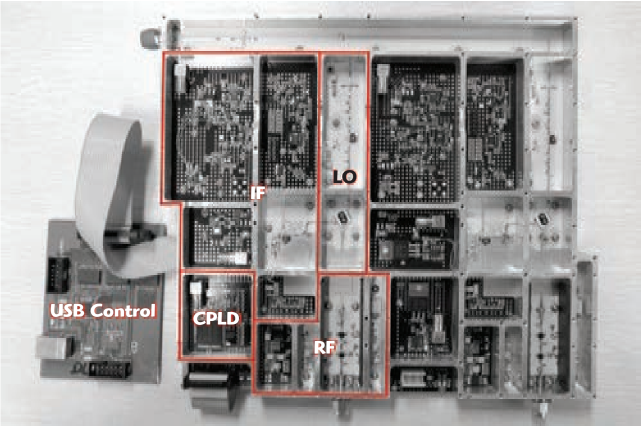
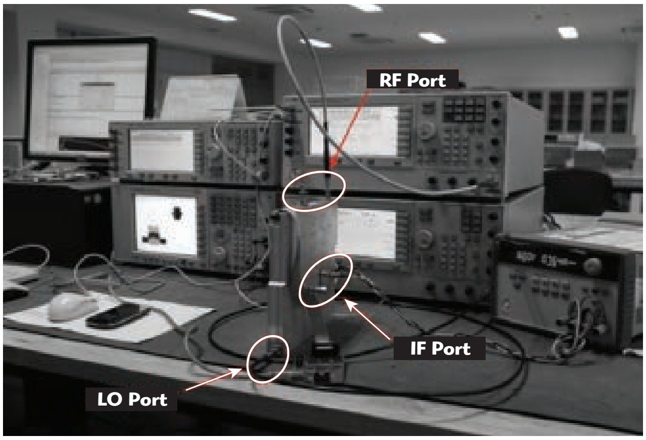
TABLE 2

SIW FILTER DIMENSIONS (MM)

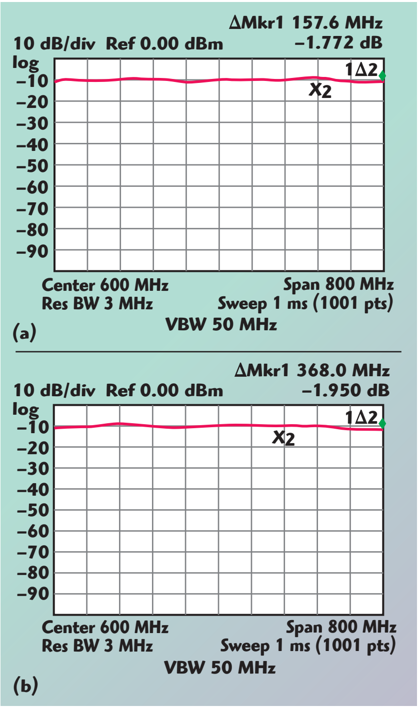
Wm	W1	W2	W3	b0	b1	b2	b3	dx	dv	d0
1.17	11.55	12.35	12.35	8.59	6.7	6.24	5.94	1	0.6	1.34



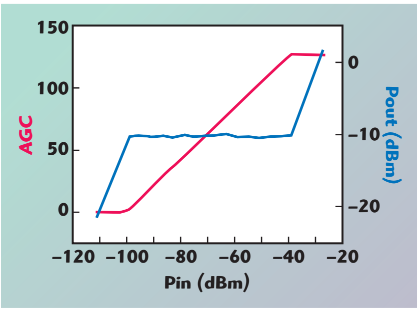
▲ *Fig. 6 Assembled receiver front-end connected to the control board.*



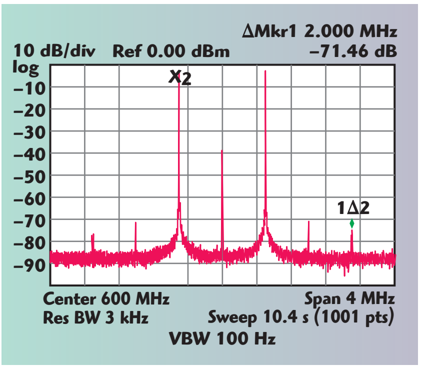
▲ *Fig. 7 Dual-channel X-Band receiver being tested.*



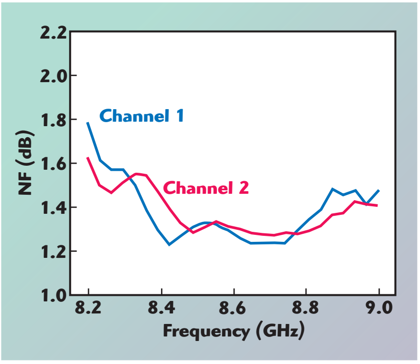
▲ *Fig. 8 Channel 1 (a) and Channel 2 (b) gain variation.*



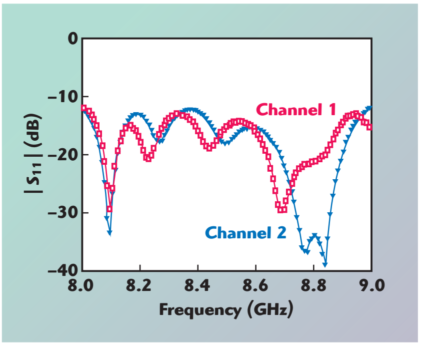
▲ *Fig. 9 Receiver front-end AGC control and output power.*



▲ *Fig. 10 Measured receiver linearity.*



▲ *Fig. 11 Measured receiver noise figure.*



▲ *Fig. 12 Measured receiver input match.*

by using a bandpass filter in combination with an image rejection mixer. In this design, a SIW bandpass filter alone is used for simplicity and low cost.

The SIW filter has low radiation loss and is easily integrated within a shielded enclosure. Because the filter's metallic cavity is part of the ground system, the metallic framework of the enclosure makes direct contact, greatly simplifying its design. A sixth order fundamental mode SIW filter with a compact square cavity is used to achieve a good image-rejection ratio (IRR). ***Figure 5a*** shows the topology and its dimensions are provided in ***Table 2***. Measured results agree closely with simulation, exhibiting a low VSWR in the passband from 8.2 to 9 GHz and meeting system requirements with a high IRR below 7.8 GHz (see ***Figure 5b***).

IF Link

The use of an external LO is feasible for a massive MIMO system. This eliminates sources of phase noise due to the LO module, especially in a TDD system, such as the power supply and reference signal distortion. Due to its relatively high linearity and large dynamic range compared with an active mixer, a passive mixer is used to convert RF signals to IF. It requires

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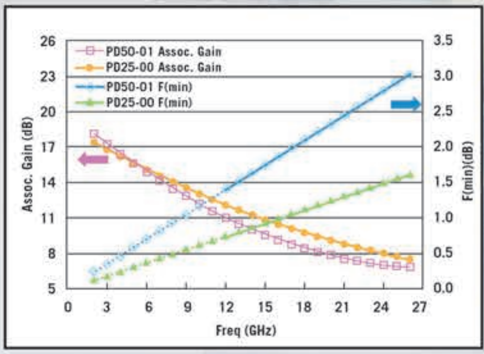
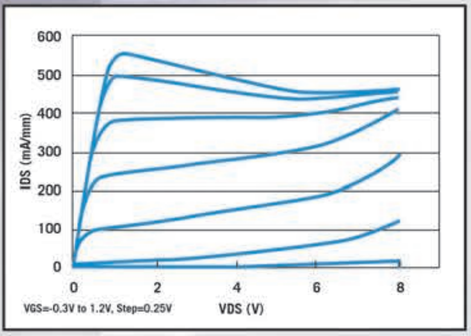
- D-mode device: Compact layout and low Ron-Coff product

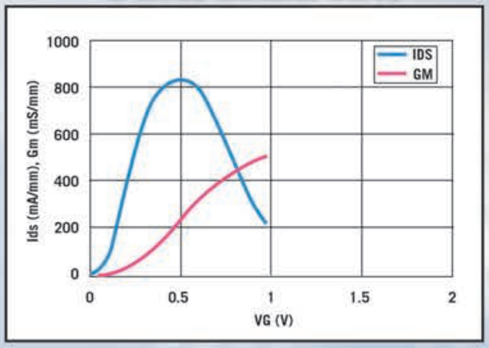
Fmin and Gain



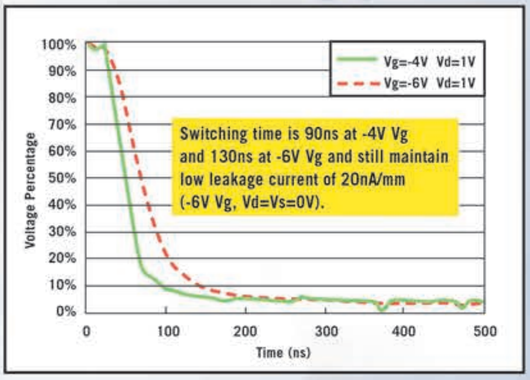
E-mode I-V Characteristics



E-mode Transfer Curve



D-mode Switching Speed



D-mode Device Performance

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

DUT: NOF x UGW= 5 x 12μm

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an LO as high as +17 dBm, so an amplifier with high P1dB is chosen.

The IF link is composed of four main component types: IF amplifiers, IF filters, digital control attenuators and switches. Sufficient IF gain is assured with five amplifiers in each channel. When a channel is turned off, the system removes power to all five amplifiers in the chain for power savings and isolation enhancement. Automatic gain control ensures sufficient dynamic range. This is realized by arranging the five IF amplifiers with two digital controlled attenuators in the proper order. The IF stage achieves 63 dB of gain control with 0.5 dB per step. In this way, the IF output is adjusted with changing input.

The IF filters suppress adjacent channel interference and spurious

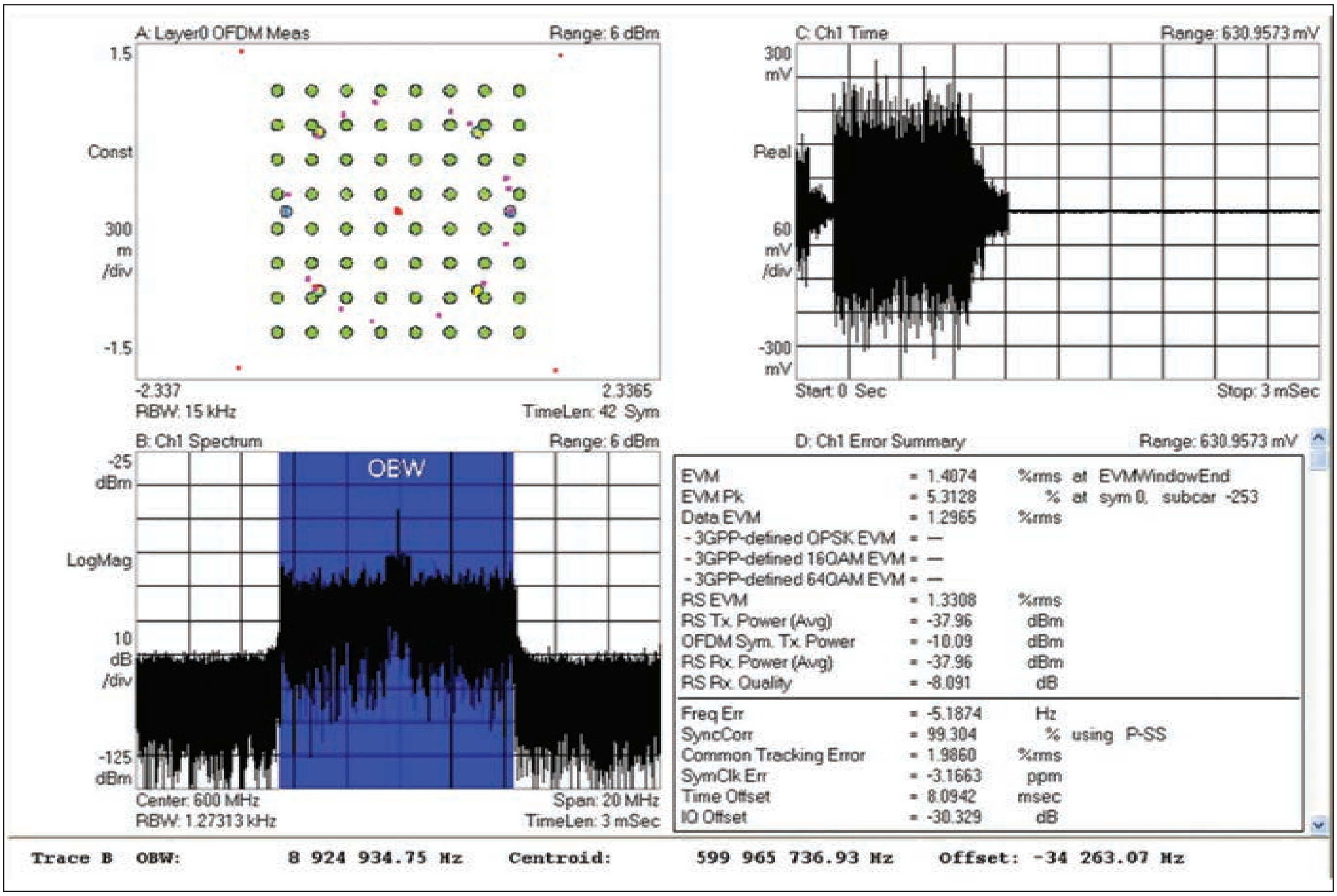


Fig. 13 Constellation diagram, spectra and error summary of the MIMO test signal.

caused by nonlinear components such as mixers. One filter is realized with a stepped-impedance resonator (SIR) structure while the other two are constructed using lumped elements.

Two switches in each channel further enhance isolation between RF and IF ports when a channel is turned off. Test result shows that each switch provides isolation greater than 60 dB.

Other Modules

For practical considerations, the power interface uses only one 6 V power supply. The power module converts this to other voltages needed by the system and supports "hot plugging." All control signals such as AGC and channel on/off are generated by a single-chip complex programmable logic device (CPLD) and each channel can be controlled separately through the CPLD-to-PC interface. Along with other protection circuits, the control module also determines the power up/down sequence of all the transistors and chips in the system.

To avoid potential interference between PCB modules and to meet EM shielding requirements, the total circuit is assembled within a single metallic housing with separate compartments. In the RF stage, absorbing material is also used. ***Figure 6*** is a photograph of the assembled receiver front-end with the cover removed.

IMPLEMENTATION AND MEASUREMENT

All circuits are fabricated on single-layer Rogers 4003C substrate material with a dielectric constant of 3.55 and thickness of 0.508 mm.

Figure 7 is a photograph of the fabricated receiver front-end in the test environment, including a signal generator, signal analyzer, noise figure analyzer, network analyzer and PC to control the receiver front-end.

In order to measure conversion gain, Keysight PSG E8267D and E8251A signal generators provide the LO signal and a single tone RF signal that is swept across the 800 MHz channel bandwidth. The IF signal is connected to a Keysight N9020A MXA signal analyzer. Test results (see ***Figure 8***) show a maximum gain fluctuation of less than 2.1 dB with different AGC values over the 800 MHz frequency bandwidth of both channels.

The receiver must provide a stable output at baseband over a wide range input power. This is shown in ***Figure 9***. With the AGC under PC control, output power is nearly constant at around -10 dBm while the input power of RF signal changes from -38 to -101 dBm. The input 1 dB compression points of these two channels are -25.8 and -26.1 dBm, respectively.

Linearity is tested using a two-tone signal with 1 MHz spacing and an input power of approximately -70 dBm (see ***Figure 10***). Third-order intermodulation distortion remains less than -70 dBc up to an output power of 0 dBm.

Noise figure is measured with a Keysight N8975A noise figure analyzer. Noise figures for both channels are less than 1.8 dB with a minimum value of about 1.2 dB (see ***Figure 11***). Due to the response of the RF bandpass filter, there is some deterioration near the band extremes.

Input return loss, measured with the Keysight N5230A PNA-L series network analyzer, is shown in ***Figure 12***. Both channels are better than -12 dB, however, the mea-

sured results are worse than simulated (see Figure 4b). This may be due to several reasons such as errors in the active device model used for simulation and manufacturing tolerances of the connector interface.

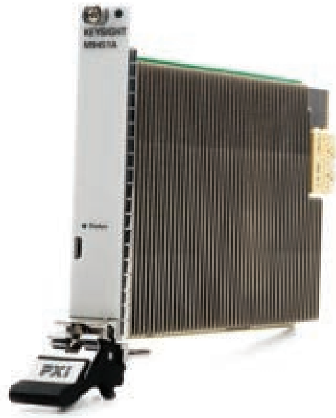
Finally, error vector magnitude (EVM) is used to quantify front-end performance using a representative input. The RF test signal is a standard TDD-LTE signal generated by the N7625B Signal Studio software. The symbol rate is 10 MHz limited by available test equipment. In addition, the front-end is switched continuously between its on and off states controlled by the E4438C signal generator. Using the model 89600A vector-signal-analyzer (VSA) software, with -70 dBm input power at the receiver front-end's RF port, the measured EVM level is less than 1.4 percent, and a clear constellation is achieved while the output power in the occupied band is around -10 dBm. This can be seen in the error summary table of ***Figure 13***.

CONCLUSION

A high performance dual-channel, X-Band receiver front-end demonstrates suitability for use in a MIMO system for future high speed communications or for phased array applications. The RF center frequency is 8.6 GHz with a 600 MHz IF and an 800 MHz bandwidth. Noise figure is less than 1.8 dB. Maximum conversion gain is 93 dB with 63 dB of gain control. The two channels are well matched with a passband gain variation of less than 2.1 dB.■

References

1. Z. Yu, J. Zhou, J. Zhao, T. Zhao and W. Hong, "Design of a Broadband MIMO RF Transmitter for Next-Generation Wireless Communication Systems," *Microwave Journal*, Vol. 53, No. 11, November 2010, pp. 22–26.
2. Z. Yu, J. Zhou, L. Zhao and L. Dai, "The Design of a 6 GHz Band RF Receiver with Excellent I/Q Image Suppression," *International Conference on Microwave and Millimeter Wave Technology*, May 2012, pp. 124.
3. Z. Chen, W. Hong, J. Zhou and J. Chen, "Design of Miniature RF Transceivers for Broadband MIMO Systems in Ku-Band," *Microwave Journal*, Vol. 55, No. 11, November 2012, pp. 108–118.
4. E. G. Larsson, O. Edfors, F. Tufvesson and T. Marzetta, "Massive MIMO for Next Generation Wireless Systems," *IEEE Communications Magazine*, Vol. 32, No. 2, February 2014, pp. 186–195.
5. P. J. Meier, H. C. Okean and E. W. Sard, "Integrated X-Band Sweeping Superheterodyne Receiver," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 19, No. 7, July 1971, pp. 600–609.
6. A. Gustafsson, M. Alfredsson, M. Danestig and R. Malmqvist, "A Fully Integrated Radar Receiver Front End Including an Active Tunable Bandpass Filter and an Image Rejection Mixer," *Asia-Pacific Microwave Conference*, December 2000, pp. 99–102.
7. A.M. Madni, P.T. McDonald, R.K. Hansen and L.A. Wan, "High-Dynamic-Range Airborne Tracking and Fire Control Radar Subsystem," *IEEE Transactions on Microwave Theory and Techniques*, December 1989, pp. 1942–1948.
8. N. Billstrom, "Compact Receiver Module for X-Band Radar Applications," *33rd European Microwave Conference*, Vol. 3, October 2003, pp. 1127–1130.
9. J. Shefer and G. S. Kaplan, "An X-Band Vehicle-Location System," *IEEE Transactions on Vehicular Technology*, Vol. 21, No. 4, November 1972, pp. 117–120.
10. D. Gupta, D.E. Kirichenko, V.V. Dotsenko and R. Miller, "Modular, Multi-Function Digital-RF Receiver Systems," *IEEE Transactions on Applied Superconductivity*, Vol. 21, No. 3, June 2011, pp. 883–890.
11. J. Wong, R. Dunnegan, D. Gupta, D. Kirichenko, V. Dotsenko, R. Webber, R. Miller, O. Mukhanov and R. Hitt, "High Performance, All Digital RF Receiver Tested at 7.5 Gigahertz," *Military Communications Conference*, October 2007, pp. 1–5.



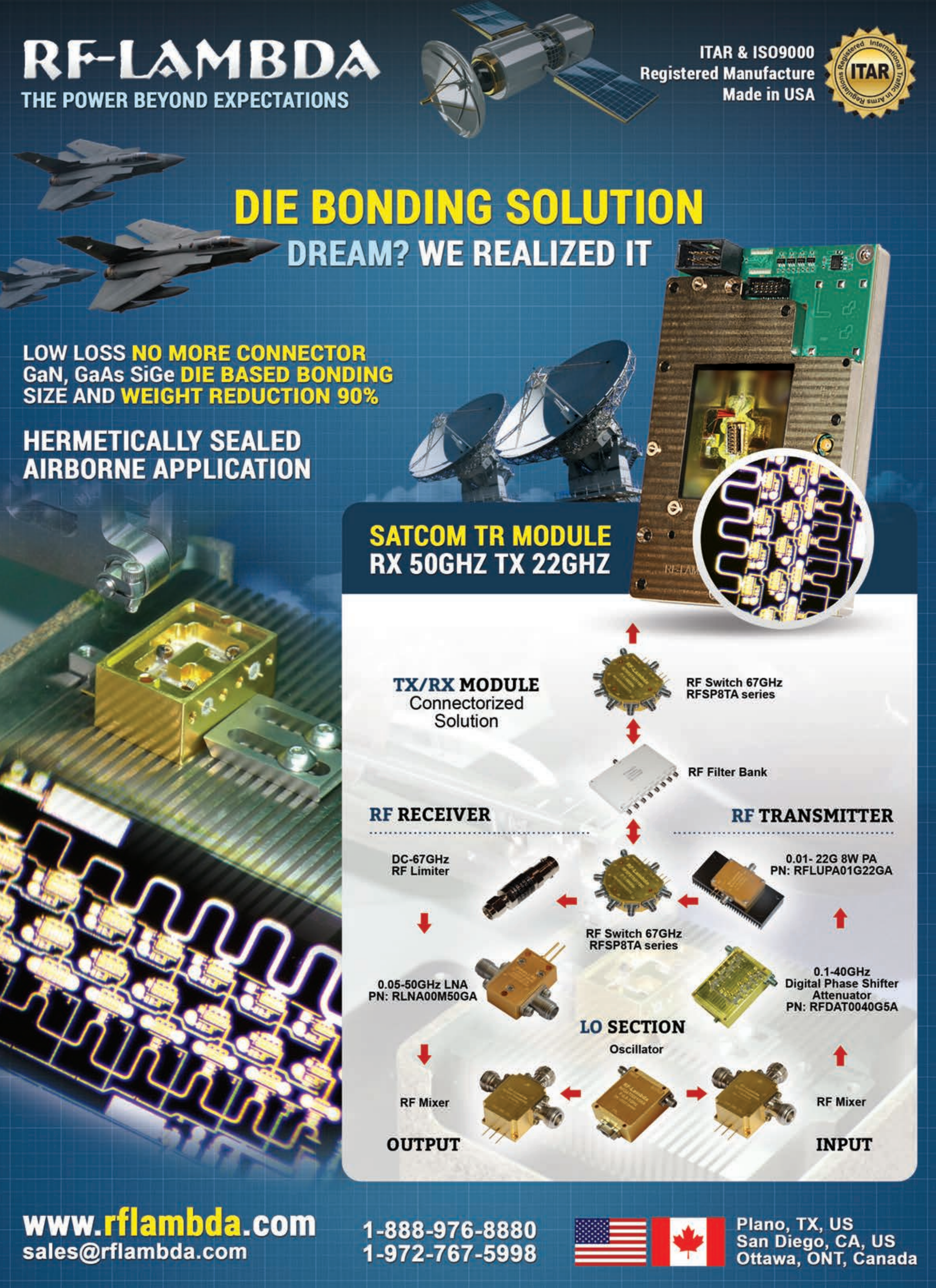
PXIe Measurement Accelerator Speeds RF Power Amplifier Test

Keysight Technologies
Formerly Agilent Technologies Electronic Measurement Business
Santa Rosa, Calif.

Greater demand for longer battery life and improved data throughput for wireless devices challenges designers and test engineers to find new approaches to address linearity, bandwidth and power efficiency in wireless components. These engineering teams are often asked to improve the efficiency of the RF power amplifier (PA), an essential component of wireless communication systems and one of the largest consumers of power in wireless devices. Another significant PA design and test challenge looms just around the corner, as modulation formats supporting 160 MHz bandwidth will drive the need for even wider measurement bandwidth. Of course, device manufacturers are pushing for ever-faster test times to increase production throughput.

PAs are inherently nonlinear. The nonlinearity generates spectral regrowth, which leads to adjacent channel interference and potential violations of the out-of-band emissions standards mandated by regulatory bodies. It also causes in-band distortions which degrade the bit-error-rate (BER) and data throughput of the communications system. Higher peak-to-average power ratios (PAPR) of the newer OFDM transmission formats have more infrequent outlying peak powers that can cause hard clipping in the PA. This degrades the spectral mask compliance, error vector magnitude (EVM) and BER for the entire waveform. Designers often address these infrequent intervals of higher peak power levels by purposely operating the PA at a lower power. Horribly inefficient, it is typical to see PAs operating at less than 10 percent efficiency, as much as 90 percent of the DC power lost.

Today's RF PA typically supports multiple modes, frequency ranges and modulation formats, increasing the number of required tests. Thousands of tests are not uncommon. Newer techniques like crest factor reduction (CFR), digital predistortion (DPD) and enve-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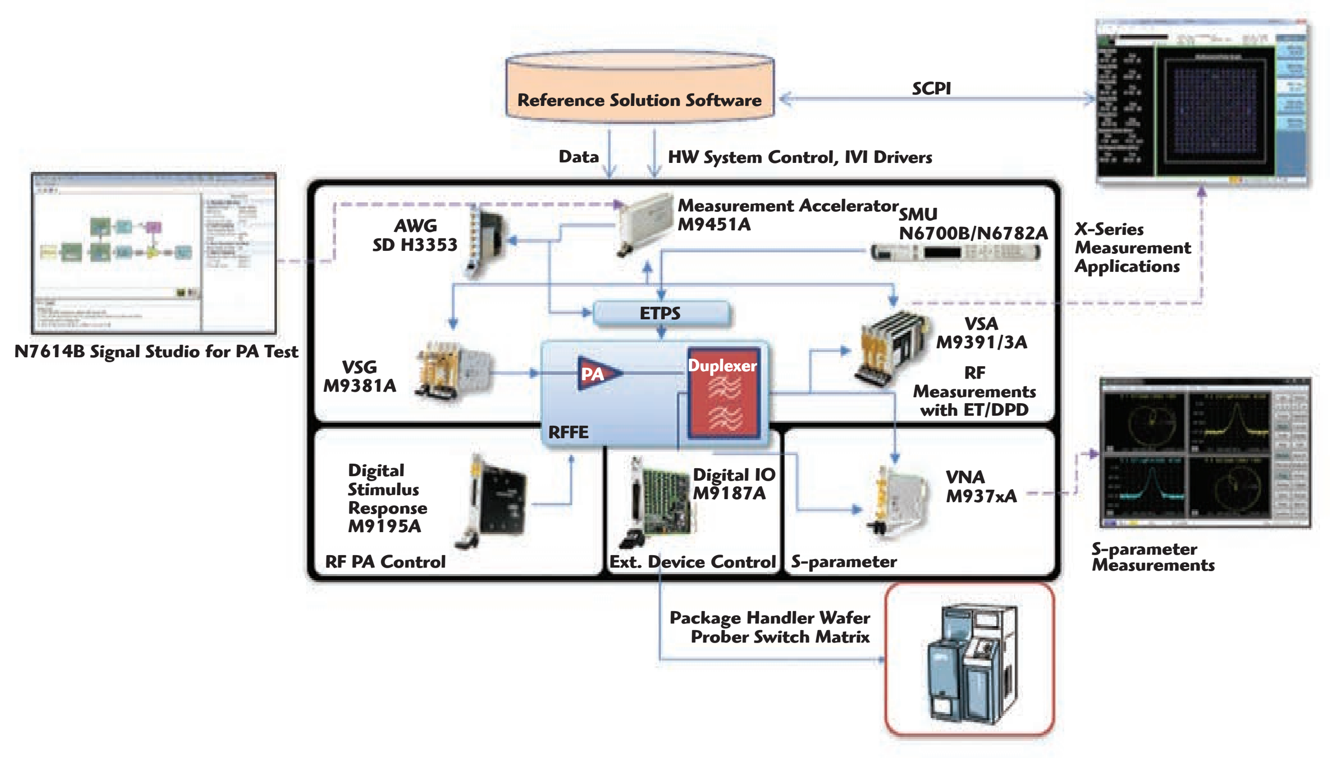


▲ *Fig. 1 Reference solution architecture.*

lope tracking (ET) can be employed to optimize the PA's performance and power efficiency, but these techniques only add complexity to the tests, further slowing down the design and test process. Adding wider bandwidth support to the RF PA can drive up required DPD measurement bandwidths by five times, to beyond 1 GHz, complicating test even more.

The trend towards greater integration of components on the RF PA and front-end module (FEM) helps improve efficiency, while supporting a wider range of frequency bands and modulation formats by a single FEM. Incorporating the ET power supply, or modulator, on the FEM is another logical step to reduce the overall real estate required inside the mobile device. A larger number of filter/duplexer banks to support a wide range of operating frequencies will add to the device complexity and number of tests.

SPEEDING TEST DEVELOPMENT AND EXECUTION

Through a collaborative effort between a test equipment vendor and its customer – an industry-leading RF PA design engineering team – working to solve the team's most critical test issues, the RF PA/FEM reference solution was born. Developed by Keysight Technologies, the test equipment vendor, the reference solution is a combination of Keysight and non-Keysight hardware and software with open source example test code optimized for RF PA and FEM characterization and test.

Key hardware elements, shown in ***Figure 1***, include Keysight's PXIe vector network analyzer(s), vector signal generator(s) and vector signal analyzer(s), selected for speed and performance. Keysight's Signal Studio signal creation software for power amplifier test (N7614B) provides the backbone for this solution: a test flow with techniques for CFR, ET and DPD. Engineers can select from pre-loaded Signal Studio or user-defined I/Q waveforms that can be imported. The open source reference solution control software enables tight synchronization between the signal source and arbitrary waveform generator, resulting in optimal alignment between RF and ET signals.

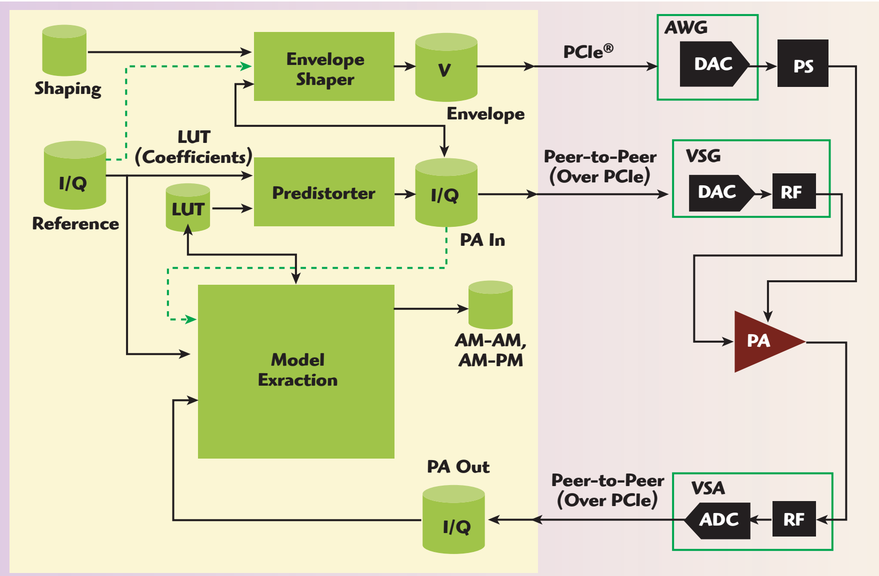
Early speed improvements were realized by taking advantage of the FPGA technology in both the source and receiver components to reduce the time the servo loops need to achieve the required output power from the device under test (DUT). Since power servos are non-deterministic, list mode – typically the quickest method of executing test steps – cannot be used to correct output power based on input RF levels. Keysight developed a fast baseband tuning mechanism in its PXIe vector signal generator (VSG) which programmatically performs iterations until the correct output power is achieved, typically in less than 200 µs. Keysight later implemented its fast Fourier transform (FFT) data acquisition mode in its M9391A PXIe vector signal analyzer (VSA). Using the FFT mode, the internal FPGA of the VSA is used to generate an FFT from the acquired data. This FFT can be used both in the measurement of the signal power for the servo loop and then, from the same acquisition data, for an Adjacent Channel Power Ratio (ACPR) measurement.

Even greater speed improvements were realized when Keysight introduced the M9451A PXIe measurement accelerator. An FPGA-based PXIe module, the M9451A measurement accelerator clocks closed/open loop DPD and ET measurements at tens of milliseconds, providing up to a 100 times speed improvement over software-based measurements when

TABLE 1

TIME TO ANALYZE VSA MEASUREMENT, EXTRACT DPD LUT AND APPLY TO VSG

	Without PXIe Measurement Accelerator		With PXIe Measurement Accelerator	
LTE Signal	Extract	Apply	Extract	Apply
5 MHz	415.4 ms	48.7 ms	4.9 ms	21.8 ms
20 MHz	1676.1 ms	172.5 ms	6 ms	63 ms



▲ *Fig. 2 M9451A PXIe measurement accelerator block diagram.*

used as part of the RF PA and FEM reference solution. The enhanced version of the reference solution enables higher throughput while maintaining highly accurate S-parameter, harmonic distortion, power and demodulation measurements. Examples of digital predistortion model extraction and application speeds are shown in ***Table 1***. Source waveforms were 5 and 20 MHz LTE signals with a truncated waveform length of 500 µs. The "extract" time in the table represents the time to analyze the VSA measurement data and extract the DPD look-up table (LUT) coefficients. "Apply" represents the time to apply the newly predistorted signal back to the VSG.

The M9451A PXIe measurement accelerator achieves this speed through its fast Altera Stratix V FPGA and dedicated processing gateware for DPD and ET with fast peer-to-peer (P2P) data transfer to and from the PXIe VSAs and PXIe VSGs that are included in the reference solution configuration (see ***Figure 2***). Hardware accelerated ET waveform generation is performed alongside the DPD waveform. Fast data transfer to the arbitrary waveform generator (AWG) is similarly achieved over the PXI backplane. The shaded area in Figure 2 highlights the key functions of the DPD and ET gateware in the PXIe measurement accelerator. Data cylinders represent allocated blocks of I/Q data in the M9451A memory, and rectangles represent algorithms implemented in the accelerator. Test software controls how data is processed by passing data handles associated with each data cylinder to the API method associated with each algorithm rectangle. P2P PCI Express® technology is used to achieve fast data transfers between the M9451A memory and the M9381A PXIe VSG hardware.

The ideal reference waveform, without predistortion, is first loaded into the M9381A PXIe VSG address resolution buffer (ARB) memory and then transferred to the M9451A using P2P. After the model extraction algorithm computes an LUT or associated coefficients, the predistorter creates a predistorted waveform in the PA I/Q cylinder. The predistorted waveform data is then transferred directly to the VSG ARB

TABLE 2

SINGLE POWER SERVO ITERATION TOTAL TEST TIME (mS), INCLUDING SETUP AND MEASUREMENT (10 MHz FDD LTE WAVEFORM)

	Swept Acquisition, Software Processing	*Fast I/Q Acquisition, Mixed Hardware and Software Processing*	*FPGA Accelerated Processing, VXT PXIe Vector Transceiver*
Power Servo W-CDMA	70	20	5.5
Power Servo FDD LTE	110	20	5.5

memory over PCI. The P2P PCI Express technology is also used to transfer measurement data from the M9391A or M9393A PXIe VSA hardware to the M9451A hardware. To simplify test software porting, the measurement accelerator's application programming interface (API) is leveraged from the Keysight Signal Studio API. For example, the measurement accelerator supports the same LUT and memory order polynomial (MOP) DPD methods, operated in either open- or closed-loop modes.

These fast test times do not come at the expense of measurement accuracy and repeatability. Keysight's reference solution provides programming examples for test techniques to optimize repeatability and test time when making power measurements.

NEW PXIe VECTOR TRANSCEIVER SPEEDS MANUFACTURING TEST

The Keysight M9420A VXT PXIe vector transceiver (VXT) aims to more than double manufacturing test throughput for PAs without increasing test system floor space. A single PXI chassis can be configured with up to four of the four-slot VXTs, or a custom system can be developed with a DIO card and one-slot VNA module.

To minimize test system development time and reduce time-to-first-measurement, the VXT can be used with the PA reference solution. The built-in servo routine accurately determines the final PA output power to control PA distortion and accurately determine whether the device is ready to ship. Traditional methods for power measurements have involved either swept or I/Q acquisitions followed by software processing. Though the software processing speed can scale with the capability of the processor, FPGA-based measurements have more recently been utilized to enhance the speed of measurements even more than what today's processors can achieve. The VXT, with high speed PXI form factor coupled with real-time FFT processing in the FPGA, compresses total test time as shown in ***Table 2***.

Communications system architects, RF PA designers and test engineers attempting to improve the efficiency of PAs should consider the measurement and analysis techniques in Keysight's RF PA/FEM reference solution. The RF PA/FEM reference solution is a combination of Keysight's measurement hardware and measurement software. In addition to providing test methods that address the specific requirements for ET and DPD, the reference solution provides an industry-proven approach for faster test system development and test throughput from design to manufacturing. When used with Keysight's new M9451A PXIe measurement accelerator, the reference solution delivers unprecedented performance for demanding envelope tracking and digital predistortion measurements.

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VNAs Support Need for Higher Frequencies

Copper Mountain Technologies
Indianapolis, Ind.

To resolve product performance issues related to operation in crowded, interference-filled low frequency bands, the global electronics industry is designing and building an increasing number of devices that utilize higher frequencies. A typical example is Wi-Fi, transitioning from 2.4 to 5 GHz channels. Device providers also face booming worldwide demand for wireless technology components.

In all cases, device manufacturers test their products and components with vector network analyzers (VNA). These manufacturers need VNAs that can handle advanced test applications and provide fast measurements to expedite production processes. To fulfill this demand, Copper Mountain Technologies recently introduced its Cobalt series of VNAs. The initial C1220 and C1209 models offer S-parameter measurement between 100 kHz and 20 GHz.

With a frequency range of 100 kHz to 20 GHz, the C1220 VNA represents the industry's first USB-based, modular, laboratory grade, 20 GHz VNA. The analyzer offers a typical dynamic range of 145 dB, an output power range of -60 to +10 dBm, up to 500,001 measurement points per sweep and a measurement speed up to 10 microseconds per point. The size of the C1220 is 14.8" × 16.3" × 5.5" (376 × 415 × 140 mm). Typical applications for the C1220 include signal integrity measurements for high speed digital systems, where 18 to 20 GHz is needed to accommodate system operating frequencies. As new technologies enable lower power operation at higher frequencies, other devices will operate in the range of 14 to

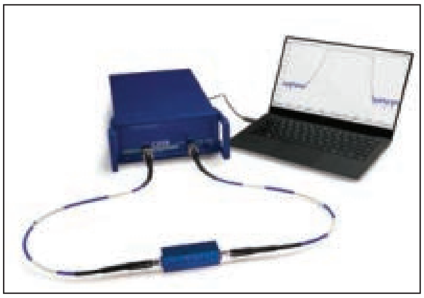


Fig. 1 The VNA transfers measurement data to a PC, via USB, for processing.

18 GHz, so component vendors have to test there as well.

The C1209 VNA is capable of analyzing from 100 kHz to 9 GHz and incorporates many of the same technical specifications as the C1220 in a compact half-rack size (14.8" × 8.3" × 3.7" or 377 × 210 × 95 mm) that weighs 4.8 kg.

All Copper Mountain VNAs have separate measurement and processing modules and offload the processing of measurement results to an external PC, via USB (see ***Figure 1***). The design provides improved processing power and better display and data management, paired with extremely reliable performance.

The performance of the Cobalt instruments benefits from several new design, manufacturing and test approaches. Innovative test-grade coaxial connector technology for internal interconnects and tighter tolerances enhance measurement accuracy. Advanced electromagnetic modeling optimizes the 20 GHz Cobalt's ultra-wideband directional coupler design, providing excellent stability with varying temperature and long time intervals. The analyzers' hybrid dual-core DSP+FPGA signal processing engine combined with new frequency synthesizer technologies enable measurement speeds comparable to the most advanced instruments in the industry.

To facilitate high speed measurements, the C1220 and C1209 analyzers have new, wider IF bandwidth options and advanced input/output triggering. A greater IF bandwidth shortens the measurement sweep time and can eliminate production line bottlenecks. The analyzers' advanced trigger output also speeds production by enabling the measuring process to be synchronized with robotic automation systems.

Semiconductor testing is a key application for the analyzers, where measurement speed is a critical issue. The wireless industry produces around 2 billion cellular handsets every year, and every handset contains numerous semiconductor chips – many of which require a VNA manufacturing test. The measurement speed of the analyzers translates directly to the overall throughput of the chip-producing facility.

The compact size and operational flexibility of the Cobalt analyzers also contribute to efficient use of space on the manufacturing floor.

Copper Mountain Technologies
Indianapolis, Ind.
www.coppermountaintech.com

Line-of-Sight Verification Kit for Microwave Field Engineers

SAF Tehnika
Riga, Latvia

A new line-of-sight (LoS) kit consisting of the Spectrum Compact handheld microwave spectrum analyzer, an SG Compact signal generator and two portable beacon antennas is claimed to be the first dedicated microwave link LoS verification kit. It is designed to make sure there are no obstacles or interference disrupting the microwave hop. The main purpose of the kit is to make long distance link installation faster, more reliable and less expensive. It is aimed at installers, system integrators and network owners, as well as mobile operators.

▲ *Fig. 1 The Spectrum Compact is no larger than a cell phone and weighs only 10.6 oz.*

Typically, installers have to physically survey the whole distance of the longest links to make sure there are no obstacles within the planned path. It can be a time-consuming and expensive process that can't guarantee that the link is effectively deployable within the chosen path. With the LoS kit, it is possible to verify distances up to 85 km with high accuracy. Additionally, the kit enables the lowest possible antenna height on the tower to be ascertained, decreasing the total cost of link ownership. Also, if a newly installed link isn't operating, it is difficult for installers to discover whether it is due to technical issues or obstacles in the chosen path. SAF's LoS verification kit eliminates the possibility of the latter.

The process of LoS verification requires a 6 GHz SG Compact signal generator that transmits the signal to the far side of the proposed link at up to 13 dBm output power. The Spectrum Compact spectrum analyzer (shown in ***Figure 1***) serves as the receiver and has -105 dBm/MHz sensitivity. The two wide-angle beamwidth beacon antennas included in the kit have 22 dBi amplification for easier long distance link verification.

▲ *Fig. 2 To verify the LoS for a long-distance link, simply attach the antenna to the SG Compact signal generator and point it towards the Spectrum Compact spectrum analyzer on the far side of the link.*

SG COMPACT SIGNAL GENERATOR

The SG Compact signal generator is a tool for antenna alignment, testing and LoS verification. It has intuitive controls, an interactive GUI and instant on/off functionality. It has the same form factor as the Spectrum Compact (5.04" × 3.2" × 0.94") and weighs 10.6 oz. Currently there are three devices covering frequencies from 6 to 40 GHz.

It is an effective and easy solution when it's not clear whether the planned radios will have LoS when installed. For verification, SG Compact sends a CW signal at the chosen frequency to a Spectrum Compact unit at the remote site (see ***Figure 2***) and is able to verify line of sight with 100 percent accuracy.

For antenna alignment prior to radio installation, a SG Compact is attached to one of the installed antennas and a Spectrum Compact to the other to perform a quick and easy alignment. The SG Compact and Spectrum Compact can also verify that waveguides are not defective before installing the link, something that previously required expensive laboratory equipment. Also, by attaching the SG Compact to an antenna and placing a Spectrum Compact in close proximity (depending on the size of the antenna), the setup can measure the antenna gain.

SPECTRUM COMPACT ANALYZER

The Spectrum Compact spectrum analyzer is an ultra light and easy-to-use measurement solution for the 2 to 40 GHz licensed microwave frequency bands. Designed specifically for comfortable outdoor use in a variety of challenging environments, this battery-powered device is specifically designed for microwave radio engineers performing equipment installation, link troubleshooting or gathering data for site planning. One of its most prominent features is its form factor – the dimensions of the device don't exceed those of a cell phone, and it weighs only 10.6 oz.

Instead of focusing on features that would only be useful in a laboratory environment, this device has the qualities and functionality needed by microwave field engineers to efficiently perform their daily tasks: radio parameter verification, antenna alignment, interference and multipath detection, in-band power measurements, link troubleshooting and saving the spectrum curves for reports and later analysis.

Spectrum Compact utilizes a resistive touch screen for ease of use in the field, allowing engineers to wear gloves when using the device. Furthermore, its high sensitivity (-105 dBm/MHz) and low noise floor enable field engineers to detect even exceptionally weak signals. It facilitates the performance of a multitude of tasks from the ground level and enables link troubleshooting without site traffic interruptions.

A standard kit includes the spectrum analyzer, RF cable and a waveguide adapter. The waveguide adapter can be used as a low gain antenna – the Spectrum Compact will detect and visualize the incoming signal just by pointing it towards the transmitting radio. SAF also provides a set of handheld horn antennas for use with Spectrum Compact as an additional accessory to detect interference when a parabolic antenna is not onsite. It is compatible with any manufacturer's antenna.

SAF Tehnika
Riga, Latvia
www.saftehnika.com

Efficient, Broadband Distributed LO Driver Amplifiers

The new ADM line of distributed amplifiers from Marki Microwave is a convenient and economical way to drive our broadband mixers for all LO drive levels. Each amplifier is efficient and broadband, capable of producing square wave signals for our T3 mixers in saturation mode or efficiently amplifying sine wave signals for driving Microlithic and MMIC double balanced mixers.

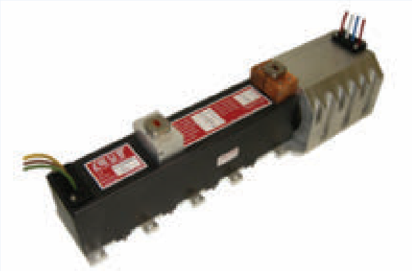
These GaAs PHEMT low noise amplifiers were designed "in house" for optimal operation with our mixers. Further, these chips are fully passivated and designed with significant stability margin to guarantee stable operation regardless of termination impedance or operating frequency. They can be biased with a single +5 to 8 V supply or with an added -0.2 V gate bias for reduced drain current. Available as die, in QFN packages or as connectorized modules with integrated bias tees and bias capacitors, the MMICs are a convenient alternative to bare die amplifiers offered by fabless MMIC companies.

The initial launch of the ADM line comprises various amplifier models, including the following typical performance:

- 15 dBm saturated output power, 10 dB gain, 52 mA DC bias current and bias tee limited to 26 GHz
- 17 dBm saturated output power, 11 dB gain, 75 mA DC bias current, covering 1 to 26 GHz
- 19 dBm saturated output power, 13 dB gain, 112 mA DC bias current and bias tee limited to 27 GHz
- 20 dBm saturated output power, 12 dB gain, 150 mA DC bias current and bias tee limited to 35 GHz.

The MMIC amplifiers are currently available in connectorized modules. Pre-production samples are available in QFN packages and as unpackaged die.

Marki Microwave Inc.
Morgan Hill, Calif.
(408) 778-4200
www.markimicrowave.com



700 W HPA for Satellite Uplinks

A new coupled cavity traveling wave vacuum device (VTA-6427S2) from the Microwave Power Products (MPP) division of CPI provides 700 W saturated CW power optimized for any 3 GHz instantaneous bandwidth within the 27 to 31 GHz frequency range. The output power can be backed off for applications that require more linearity.

Operating at a fixed cathode voltage, the coupled cavity design of the VTA-6427S2 delivers higher output power with greater instantaneous bandwidth than alternative high power amplifier (HPA) technologies, such as helix traveling wave tube (TWT) and extended interaction klystron (EIK).

The VTA-6427S2 requires 25 dBm input power (maximum) to drive the output to the rated saturated output; small-signal gain tapers from approximately 45 to 37 dB across 27 to 30 GHz. The HPA consumes 1200 W of prime power and uses 17 kV beam voltage. The RF input and output interfaces are WR-28 waveguide and are located on the top of the unit, which measures 4.0" wide, 3.9" high and 14.5" long and weighs 12 lbs.

Communications & Power Industries LLC
Microwave Power Products Division
Palo Alto, Calif.
www.cpii.com/mpp

Space-Saving Flange-Mount Probes

One of the big challenges in the production-line test of printed circuit boards is to have enough “real estate” to place probes on a test point or on a connector. When the engineering team at Ingun was challenged to come up with a very compact, yet robust passive high frequency contacting solution to cover various RF connectors with spring-loaded probes, the result was the HFS-856 and HFS-837 probe series.

The HFS-856 probe series was designed to be a modular passive 50 ohm probe which retains the same mechanical body geometry for each variant but has a head section that can be easily modified by the engineers to cover a huge variety of miniature RF connectors. Currently the series is available to mate with small print connectors, such as U.FL, and switch connectors, such as MM8030 and MM8430, as well as with other popular miniature connectors, such as MMCX.

All HFS-856 probes have an integrated float mechanism to overcome device under test (DUT) misalignment due to tolerance issues, which can be caused by the reflow process and several other factors. The probe is rated from DC to 12 GHz with excellent insertion and return loss. HFS-856 probes have an industry-standard SMA connector to attach the test cable.

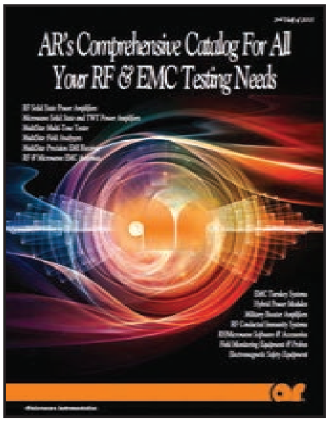
A smaller brother to the HFS-856 series is the HFS-837, which has an even smaller form factor and an SMPM interface to connect very thin, lightweight and space-saving cable assemblies. Lightweight assemblies using micro-coax cables put less force on the snap-in SMPM connector. Depending on the configuration at the mating side of the probe, HFS-837 series probes can be used up to 18 GHz with the same stringent specifications regarding insertion and return loss. The real estate needed is just 4 × 10 mm, and the probe can be configured as an even more compact version if one-hole flange mount options are used.

INGUN USA Inc.
Lake Wylie, S.C.
(803) 831-1200
www.ingun.us

CatalogUpdate

EMC & RF Testing

VENDORVIEW



AR has completed another revision of their sought-after full line product catalog. The new catalog features new products and new intro sections for both microwave and solid-state amplifiers. Navigate your way to the hybrid power modules and see photos of the expanded microelectronics lab, read about AR Europe's new partnership with 3ctest. Please contact your local AR sales associate for a hard copy or visit www.arworld.us/html/catalogRequest.asp for a free download, in full or by section.

AR RF/Microwave Instrumentation

www.arworld.us

Solid State High Power

VENDORVIEW

Empower RF continues technology advancements that have leapfrogged the old amplifier establishment while offering refreshing and long overdue performance and feature set enhancements with patented hardware technology and software control. These technological advancements are derived from a highly talented engineering staff with proven success in defense, communications, aerospace and broadcast industries. To learn more please download their newest catalog from the company's home page www.EmpowerRF.com or call to request your copy at (310) 412-8100.

Empower RF

www.EmpowerRF.com

RF Equipment and Engineering

VENDORVIEW

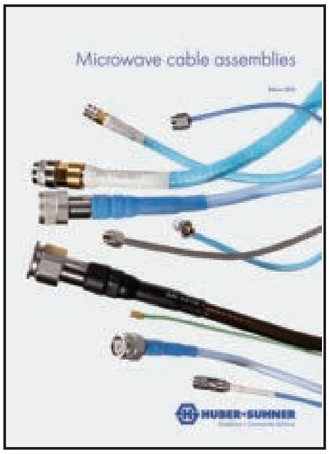
Exodus Advanced Communications is a multinational RF communication equipment and engineering service company serving both commercial and government entities and their affiliates worldwide. Headquartered in Henderson, Nev., the company utilizes its global network of both in-house and outside resources to effectively serve customer requirements. Their in-house resources include RF circuit designs up to 40 GHz, prototype verification, system level mechanical & electrical design, digital circuit design, and control software development. Outside resources include custom made RF components and manufacturing service for both small and large volume production.

Exodus Advanced Communications

www.exoduscomm.com

Microwave Cable Assemblies

VENDORVIEW



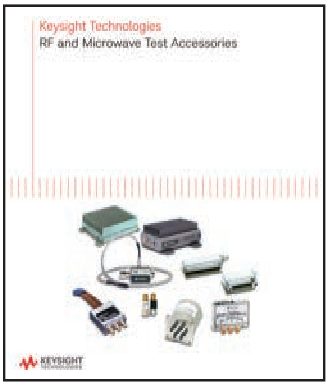
The extended microwave cable and assembly portfolio from HUBER+SUHNER Astrolab is introduced in the brand new microwave cable assemblies catalogue. The 185-page catalogue is a complete resource guide for products which are used for aerospace, defense, test & measurement, industrial and communication applications. The catalogue offers an easy product look-up and is organized by main characteristics of the cable assemblies.

HUBER+SUHNER

www.hubersuhner.com

RF & Microwave Test Accessories

VENDORVIEW



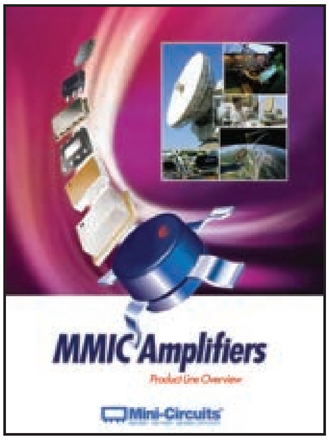
Keysight Technologies' new RF & Microwave catalog offers over 200 pages of in-depth information on the most reliable and repeatable RF & microwave switches, attenuators, amplifiers and other test accessories. This includes mixers, detectors, directional couplers, power dividers, splitters and PXI modular test accessories. New product highlights and easy-to-read product selection and comparison tables help users find the right Keysight accessory to complement their test and measurement environment. The English version is currently available for download.

Keysight Technologies Inc.

www.keysight.com/find/mta

MMIC Amplifiers

VENDORVIEW



Mini-Circuits announced the publication of its MMIC Amplifiers Product Line Overview, a 24-page, full-color brochure showcasing their extensive MMIC amplifier product line. The new product guide provides a complete overview of their MMIC amplifier offerings and highlights key differences in design approach between Mini-Circuits' MMIC amplifiers and typical products on the market. It features helpful details on semiconductor materials, circuit architectures, qualification processes, advanced packaging technology and other informative content. With over 170 different MMIC amplifier models covering DC to 26.5 GHz, chances are Mini-Circuits has your application covered.

Mini-Circuits

www.minicircuits.com

2016 RF Product Guide

VENDORVIEW

Pasternack released their new 2016 RF Product Guide. The 264-page catalog contains thousands of in-stock products including an expanded portfolio of RF amplifiers and electromechanical switches, the industry's largest selection of RF cable assemblies, and hundreds of other passive, active and test & measurement components, all available for same-day shipping worldwide. New additions include GaN, GaAs and LDMOS amplifiers, SPDT through SP12T switches, waveguide components, VNA calibration kits, test cables and ultra-high frequency RF adapters. The catalog also features product selection guides as well as other useful charts and resources.

Pasternack Enterprises Inc.
www.pasternack.com

Filters, Multiplexers and Multi-Function Assemblies

VENDORVIEW

When being first to react makes all the difference in the world, choose Reactel for your mission-critical filter requirements. You can count on Reactel to satisfy the most demanding requirements for units used in extremely harsh environments. Their full-line catalog features RF and microwave filters, multiplexers and multi-function assemblies for the military, industrial and commercial industries. To request your copy, please e-mail reactel@reactel.com or visit www.reactel.com.

Reactel Inc.
www.reactel.com

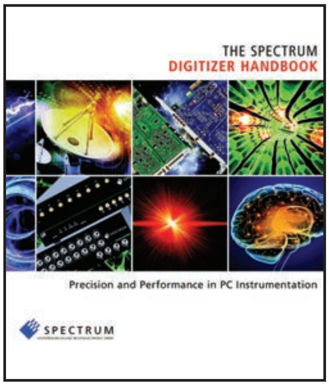
Test & Measurement Catalog 2015

VENDORVIEW

The Rohde & Schwarz Test & Measurement Catalog 2015 features more than 200 pages of information about Rohde & Schwarz test & measurement instruments, systems and software. It includes a short description and photos of each product, the most important specifications and the ordering information. You can download this catalog as a PDF from the Rohde & Schwarz website or order from customer support (Order number: PD 5213.7590.42 V 05.00).

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

Digitizer Handbook



To keep engineers and scientists up to date with the latest developments in PC based digitizer technology, Spectrum has published a handbook that covers the major product features of this powerful class of instrument and also explains when a digitizer can replace an oscilloscope. The 120-page booklet is printed in full color and includes a number of graphical images that highlight and explain key digitizer concepts and their applications. Topics include how and when to select a digitizer, understanding the various terms and comparing their performance with other instruments.

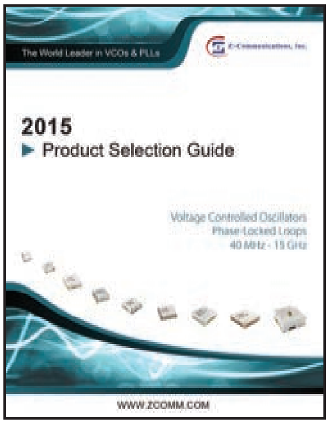
Spectrum Systementwicklung Microelectronic GmbH
www.spectrum-instrumentation.com

Rapid Response Cable Assemblies

SV Microwave released the application note for their rapid response cable assemblies. Use their interactive RF cable builder to build cables that ship in 5 business days. These cables can be custom configured and purchased on the company's website. Customers can choose from a variety of in-stock standard connector series and cable types for miniature and low loss coaxial assemblies. The RF Cable Builder generates a custom datasheet complete with part number, technical specifications and pricing. Go to www.svmicrowave.com/products/rf-cable-builder.

SV Microwave
www.svmicrowave.com

Product Selection Guide



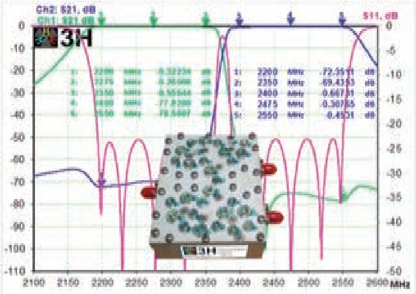
Z-Communications Inc. announced the release of a new Product Selection Guide. This short form catalog includes a wide variety of surface mount VCO (voltage controlled oscillator) and (PLL) phase locked loop synthesizer modules ranging from 40 MHz to 15 GHz. Users can download an electronic version of the product guide in PDF format or contact the company for a hard copy version. A complete listing of all available parts and specifications can be found on the company's website.

Z-Communications Inc.
www.zcomm.com

Components

High Power Wi-Fi Diplexer

VENDORVIEW



3H Communication Systems' new high power Wi-Fi diplexer offers high performance while maintaining 50 W CW in the transmit band. The diplexer offers low passband insertion loss of < 0.85 dB and rejection levels of > 50 dB within a 3" × 2.7" × 1" connectorized package. Other frequency bands are available from DC to 50 GHz.

3H Communication Systems
www.3Hcommunicationsystems.com

SMA and N-Type Fixed Attenuators

Fixed attenuators are offered in straight jack to plug configurations and operate from DC to 6 GHz. The SMA attenuator series have an attenuation range from 1 to 10 dB with ± 0.5 dB accuracy and can handle an average input power up to 2 W with low VSWR precision performance. The N-Type series have attenuation values from 3 to 30 dB and offer accurate, repeatable performance for 2 and 5 W power levels.

Amphenol RF
www.amphenolrf.com

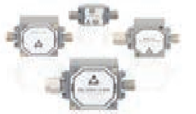
Space Qualified Isolator

VENDORVIEW

DiTom Microwave has released a new X-Band (7.25 to 7.75 GHz) space qualified isolator. The DS1005 is manufactured to meet or exceed environmental space-level reliability including thermal shock, sine and random vibration, temperature cycling and thermal vacuum survivability over a specified qualification and acceptance test plan. DiTom's current space-level manufacturing process allows for delivery in as quickly as four weeks depending on the test requirements.

DiTom Microwave
www.ditom.com

RF Limiters



The new high power limiters operate over broad frequencies ranges from 0.5 to 40 GHz depending on the model. This release contains seven limiter designs featuring limiting thresholds between 3 and 10 dBm and low leakage power of 10 to 15 dBm. Fairview's new selection of coaxial limiters exhibits high CW power handling up to 200 W peak power and fast recovery times of 10 to 100 nanoseconds.

Fairview Microwave
www.fairviewmicrowave.com

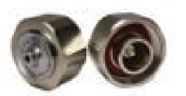
V-Band High Pass Filter

Marki Microwave is extending its line of high pass filters to V-Band with the introduction of the FH-5500. This new filter offers excellent rejection of low frequencies and low insertion loss for signals from 55 GHz to above 67 GHz.

Marki Microwave
www.markimicrowave.com

1 and 10 W Terminations

VENDORVIEW



MECA offers a new compact 2 W (2 kW peak), 4.1/9.5 (Mini-DIN) male 50 ohm load optimized for wireless bands covering up to 4 GHz. VSWRs of 1.10:1 typical up to 2 GHz and 1.20:1 typical up to 4 GHz. Made in the U.S. 36-month warranty.

MECA Electronics Inc.
www.e-MECA.com

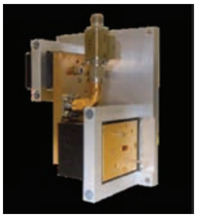
Absorptive Switch

VENDORVIEW

Mini-Circuits' USB-SP4T-63 is a low cost, high speed, solid-state RF SP4T absorptive switch, controlled and powered via USB. The model contains an electronic, high speed (3 µsec typical switching time), high linearity (IP3 54 dBm typical) SP4T. The RF switch can be operated remotely using the supplied GUI software or programmed by the user with the included API objects or the supplied command codes for Linux systems.

Mini-Circuits
www.minicircuits.com

Up/Down-Converters



OML has leveraged the design of its fundamental mixer technology in its converters to satisfy the needs for optimized performance criteria. Its converters optimize performance for size, output power, conversion loss, stability, group delay, noise figure and bandwidth. Contact OML to discuss your specific requirements.

OML Inc.
www.omlinc.com

Hi-Q/Low ESR Capacitors

VENDORVIEW

Passive Plus Inc. now offers extended-values for the traditional NP0, Hi-Q 0505 (0.055" × 0.055") – now available up to 1,000 pF; and 1111 (0.110" × 0.110") – now available up to 10,000 pF (0.01 uF). These parts exhibit low ESR/ESL, low noise, high self-resonance as well as ultra-stable performance over temperature. Usually used for wireless broadcasting equipment, mobile base stations, GPS, MRI, and radar applications and offered in magnetic and non-magnetic terminations.

Passive Plus Inc.
www.passiveplus.com

Wideband 2-Way Power Divider

RADITEK's newest model, the R2PD-500-6000M-Nf-150W-w18 (wideband) power divider can operate at 500 MHz to 6 GHz at 150 W. It comes standard with N-female straight connectors. It has an operating temperature to -10° to +70°C. Adequate heatsinking is required for continuous use at full power. Dimensions are: length 8.5" × width 2.0" × thickness 0.9".

Raditek
www.raditek.com

Directional Coupler

VENDORVIEW

To support development of C-Band radar subsystems, REC has developed a 5 to 6 GHz 40 dB coupler with very low insertion loss and high directivity. Other coupling values are also variable in the same package size. The coupler improves systems performance, accurately determines signal-to-noise and transmit power when used in radar and reduces subassembly size and weight.

Renaissance Electronics & Communications LLC
www.rec-usa.com

NewProducts

High Power Multi-Position Switch

RLC Electronics introduced SP7T and SP8T switches with N connectors. These switches operate up to 6 GHz, and are designed for both low power and high power applications (500 W CW at 6 GHz, 2000 W CW at < 500 MHz). In addition to long life, the switch also features extremely low insertion loss (0.1 dB to 4 GHz and 0.3 dB to 6 GHz, typically) and VSWR over the entire frequency range, while maintaining high isolation (> 80 dB).

RLC Electronics Inc.
www.rlcelectronics.com

E-Band Balanced Harmonic Mixer

VENDORVIEW

Model SFH-12SFSF-A1 is an E-Band balanced harmonic mixer especially designed for Keysight's spectrum analyzer series. The mixer employs high performance GaAs, Schottky flip chip diodes and balanced configuration to produce superior RF performance. The required LO frequency range is 3.0 to 6.1 GHz and power is +16 dBm, which translates the harmonic number 16 and resultants IF frequency range is DC to 1.3 GHz. Typical conversion loss is less than 40 dB.

SAGE Millimeter Inc.
www.sagemillimeter.com

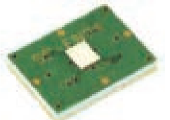
SPST Non-Reflective Switch

VENDORVIEW

Through its Isolink subsidiary, Skyworks introduced a low-loss, high performance wideband DC to 6 GHz hermetic GaAs IC single-pole, single-throw (SPST) non-reflective switch. The ISO13316 is ideal for high reliability space, satellite and defense applications. The device performs with 45 dB isolation at 2 GHz and low loss of 1.1 dB at 6 GHz. Testing is available to the screening requirements of MIL-PRF-38535 Class B and S, in addition to the required quality conformance inspection (QCI).

Skyworks Inc.
www.skyworksinc.com

Ultra-Wideband Double Balanced Mixer



The SGM-2-13 mixer is a wideband, surface-mount mixer designed to cover the frequency range of 250 MHz to 3.25 GHz. This makes it ideal for radar and fixed microwave radio and instrumentation applications. Further full band characteristics are typical conversion loss of 6.5 dB with local oscillator power of +13 dBm, typical LO to RF isolation of 25 dB, and a typical input third order intercept point of +14 dBm. The overall dimensions of the mixer is 0.53" × 0.405" × 0.098" (L × W × H).

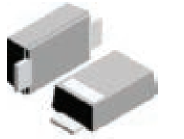
Synergy Microwave Corp.
www.synergymwave.com

USB/Ethernet Controlled Miniature Switch Modules

The MMA, MMB & MMC series are an ideal solution that incorporate Teledyne Coax Switches with remote control via USB and/or TCP/IP (Ethernet). Remote operation is accomplished via Ethernet or via the USB virtual serial port (command set provided). The miniature switch modules will feature a graphical user interface (GUI) that will enable to user to control switches through graphical icons and have visual indicators instead of text-based interfaces or types command labels. The Series MMA will offer a maximum of 4 SPDT switches with 3 available operating frequencies: DC to 18 GHz, DC to 26.5 GHz and DC to 40 GHz.

Teledyne Relays
www.teledynerelays.com

Ultrafast Recovery Rectifiers



Vishay Intertechnology Inc. introduced four new 1 A and 2 A FRED Pt® Ultrafast recovery rectifiers in the compact low profile SMF (DO-219AB) eSMP® series package. Combining extremely fast and soft recovery characteristics with low leakage current and low forward voltage drop, the AEC-Q101-qualified devices reduce switching losses and power dissipation in automotive and telecom applications. The Vishay semiconductors VS-1EFH01HM3, VS-1EFH01-M3, VS-2EFH01HM3 and VS-2EFH01-M3 offer reverse voltages of 100 V. The VS-1EFH02-M3 and VS-2EFH02-M3 offer reverse voltages of 200 V.

Vishay Intertechnology Inc.
www.vishay.com

6-Way Power Divider

The 6-way power divider model WMPD06-0.5-6-S is the newest edition to the 500 to 6000 MHz family of power dividers from Werbel Microwave LLC. This unit comes with SMA connectors; type N is also available. Measures 9" × 6" × 0.9". Input and output return loss is -11 and -15 dB typical respectively, isolation is -20 dB typical and insertion loss is 2.2 degrees max. Phase and amplitude balance are typically 3 deg/0.4 dB. Rated at 50 W input power as a splitter only.

Werbel Microwave LLC
www.werbelmicrowave.com

2-Way Combiner/Divider

Model D10262 is a 2-way combiner/divider, covering the full 1 to 3 GHz band, and is rated at 600 W CW. This robust design operates with full port-to-port isolation of 17 dB minimum, and less than 0.5 dB insertion loss. The D10262 is designed to handle an input failure, at rated power, while operating at a +70°C base plate temperature. Ideal for coherent or non-coherent combining, the D10262 is suitable for multiple military applications.

Werlatone
www.werlatone.com

Cables & Connectors

Ultra Low Loss Cable Assemblies

The ultra low loss W1 series is a complete line of high performance flexible microwave cable assemblies. The new series comprises an extruded low density PTFE dielectric structure that offers a low dielectric constant together with fast velocity propagation of 83%. The 18, 26.5 and 40 GHz cable assemblies are claimed to have excellent insertion low loss, low VSWR and phase stability in relation to temperature.

Withwave
www.with-wave.com

Amplifiers

Second Generation GaN SSPA/SSPB

Advantech Wireless announced the release of the second generation GaN technology based 400 W Ku-Band SapphireBlu™ SSPA/SSPB, ultra HD and DVB-S2X ready. Advantech Wireless is leading the industry by designing smarter solutions for any teleport broadcast activity, such as content contribution, distribution and ultra high definition television. Content distributors have trusted Advantech Wireless to make the most of their resources by maximizing quality and reach, while minimizing operational costs.

Advantech Wireless
www.advantechwireless.com

1 to 6 GHz Benchtop and Hybrid Amplifiers

VENDORVIEW

Now you can achieve high linear output power up to 350 W over the 0.7 to 6 GHz instantaneous frequency band in one benchtop amplifier. This Class A unit requires only 0 dBm input power to achieve its rated output power and offers low harmonic distortion and excellent noise figure. These instruments as well as its hybrid power modules are available in both Class A and AB configurations for demanding EMC, wireless or EW applications.

AR RF/Microwave Instrumentation
www.arworld.us

NewProducts

Solid-State Power Amplifier Module

Comtech PST introduced a new high power density solid-state RF module is 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 introduces 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

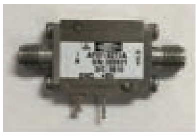
GaN RF Transistors

Cree Inc. has introduced two industry-leading GaN high electron mobility transistor (HEMT) devices that solve a number of long-standing issues for radar systems employing traditional travelling wave tube (TWT) amplifiers. GaN-based solid-state amplifiers operating at 50 V are not prone to the failure mechanisms seen with high voltage (kV) TWT power supplies, and thus provide longer lifetimes. Also, such solid-state systems provide near instant on capability — with no warm up, longer detection ranges and improved target discrimination.

Cree Inc.

www.cree.com

Broadband Low Noise Amplifier

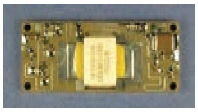


Offering a wide bandwidth from 100 MHz to 18 GHz, model AF0118273A is a broadband low noise amplifier (LNA) that can be used in a multitude of commercial and military applications. It features 27 dB gain across the frequency range, with gain variations reaching a maximum of ±1.2 dB. The noise figure is a respectable 2.8 dB even at 18 GHz, while the VSWR is 2.0:1 across the full frequency range. The output power at 1 dB compression is +10 dBm.

Herotek Inc.

www.herotek.com

380 W, S-Band GaN Pallet



Integra Technologies Inc. announced the release of a 380 W pallet, IGNP2730M380, for S-Band radar systems. IGNP2730M380 operates over the instantaneous bandwidth of 2.7 to 3 GHz. With 150 µs pulse width and 15% duty-cycle pulsing conditions it supplies a minimum of 380 W of peak output power with typically > 11 dB minimum gain and 58% efficiency from a 50 V supply voltage.

Integra Technologies Inc.

www.integratech.com

GaN Power Amplifier

Microsemi announced the AML218P4013, a new GaN power amplifier product supplied in a compact hermetic 3.5" × 1.9" × 0.45" connectorized module housing. Ideal for electronic warfare (EW), radar and test and measurement applications, the AML218P4013 power amplifier provides frequency coverage from 2 to 18 GHz, and delivers 38 dB gain, and 20 W of saturated output power at 16 percent PAE. The power amplifier operates from a +32 V DC single bias supply and is specified for operation over the -40° to +85°C military temperature range.

Microsemi

www.microsemi.com

Bidirectional RF Amplifiers

VENDORVIEW

The new bidirectional RF amplifiers from Pasternack consist of 2 narrow band models that operate in L-Band (1.35 to 1.39 GHz) and S-Band (2.4 to 2.5 GHz). These designs utilize highly linear Class AB LDMOS semiconductor technology. A general purpose broadband model is also featured which covers 30 MHz to 3 GHz and uses Class A GaAs semiconductors. Typical gain levels for these amplifiers range from 20 to 23 dB with ±0.5 dB gain flatness.

Pasternack

www.pasternack.com

Portable Amplifier

VENDORVIEW

PMI's model PTB-42-1G40G-12-292FF-DC12 is a portable amplifier that operates over the 1 to 40 GHz frequency range. This model provides 40 dB of typical gain with an OP1dB of +22 dBm typical (1 to 18 GHz) and +18 dBm typical (18 to 40 GHz). This amplifier features an on/off switch that is located on the front panel. This amplifier can operate on either 120 VAC or via an external +12 VDC supply.

Planar Monolithics Industries Inc.

www.pmi-rf.com

Systems

Compact, Multiband Transceiver

LPRS announced the availability of the circuit design STD-601 400MHz transceiver module for telemetry, remote control and industrial applications. The advanced design has many innovative features including four frequency ranges conforming to various ISM bands available in the single device without sacrificing the superior performance of circuit design's conventional RF modules. Featuring high performance narrowband, blocking and sensitivity, the module is suited for rugged, noisy industrial environments where good channel selectivity is required.

LPRS

www.lprs.co.uk

Sources

Voltage-Controlled Oscillator

Crystek's CVCO55FL-0271-0310 VCO (voltage-controlled oscillator) operates from 271 to 310 MHz with a control voltage range of 0.5 to 4.5 V. This VCO features a typical phase noise of -114 dBc/Hz at 10 KHz offset and has excellent linearity. Output power is typically +0 dBm. Engineered and manufactured in the U.S., model CVCO55FL-0271-0310 is packaged in the industry-standard 0.5" × 0.5" SMD package.

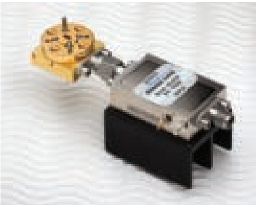
Crystek
www.crystek.com

Low ADEV OCXO

With a new 10 MHz MV341 type OCXO, Morion achieves ultimate Allan Deviation values down to 2E-13 per 1 second and excellent close in phase noise of <-120 dBc/Hz at 1 Hz and <-146 dBc/Hz at 10 Hz. All in a package size of just 2" × 2" × 0.63". MV341 is an ideal solution for various scientific, test & measurement, radar and signal clean-up applications. Additionally it guarantees stability level vs. operating temperature range up to 1E-9 and aging up to 2E-8/year. MV341 is available with 12 V voltage supply and SIN output.

Morion US LLC
www.morion-us.com

Active E-Band ×4 Multiplier

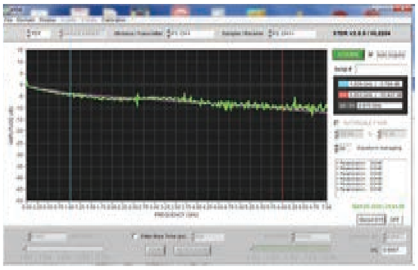


The model AE 4XW is an active ×4 multiplier that covers all of E Band (60 to 90 GHz). Input power is +10 to +15 dBm at 15 to 22.5 GHz. The typical output power for the full band unit is +4 dBm with a minimum output power of +2 dBm and can be tuned to higher output power for narrow band operation. This active quadrupler can also be delivered with an amplifier to achieve +10 dBm minimum output power across the entire E-Band.

Spacek Labs Inc.
www.spaceklabs.com

Software

XTDR™ Software



HYPERLABS has added S-parameter capabilities (S11, S21) to Version 2.0 of its XTDR™ software. These features complement the existing time domain features (TDR, TDT, NEXT, and FEXT) already found in the HL2200 and HL5200 Series Signal Path Analyzers. The latest version of XTDR™ is available as a free download from the HYPERLABS website.

HYPERLABS Inc.
www.hyperlabsinc.com

Application Note

EMC Standards Overview

VENDORVIEW

With so many different categories of electrical components and systems with their own specific needs in terms of electromagnetic compatibility (EMC) compliance, it is no surprise that there are a significant number of EMC test standards. Unfortunately, keeping track of and knowing which standard to use to demonstrate EMC compliance can be a difficult task. This application note serves as a guide to familiarizing yourself with some of the more common standards used across various industries.

AR RF/Microwave Instrumentation
www.arworld.us

Test Equipment

Bird Technologies introduced the channel power monitor, a compact rack-mount system that in conjunction with Bird sensors monitors each radio, power combiner, transmission line, and antenna in an analog or digital land-mobile radio system operating between 144 and 960 MHz. It alerts users to out-of-spec conditions via the web or Bird's Android smartphone app and can monitor 16 channels with the ability to expand as needed to accommodate a radio system of any size.

Bird Technologies Group
www.birdrf.com

Cross-Correlation Phase Noise Test System

Berkeley Nucleonics introduced a new signal source analyzer providing accurate measurements of SSB phase noise as well as full time domain analysis capability and several different modes of noise, spectrum and transient analysis. The 7000 Series offers both residual and absolute noise measurements from 5 MHz to 30 GHz, providing operation with either internal or external reference sources and measurements from 0.1 Hz to 50 MHz frequency offset.

Berkeley Nucleonics
www.BerkeleyNucleonics.com

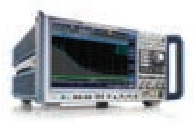
MFA Micro Probe

The MFA probes have been developed for measurements at the smallest SMD components (0603-0201) on printed circuit boards. Particularly fine conductor runs and SMD or IC pins can be measured. These near-field micro probes help you localize EMC phenomena up to 6 GHz (IEC-55022, CISPR) in electronic circuits and minimize interference emissions from the device. The probes include special, electrically shielded active miniature heads. A pre-amplifier stage is integrated in all of the MFA 01 heads.

Langer EMV-Technik GmbH
www.langer-emv.de

FSWP Phase Noise Analyzer and VCO Tester

VENDORVIEW



With the R&S FSWP phase noise tester, users can measure the spectral purity of signal sources such as generators, synthesizers and voltage-controlled oscillators (VCO) more quickly than with any other solution. The high-end instrument covers a frequency range up to 50 GHz and offers a top dynamic range. The extremely low phase noise of its local oscillator coupled with cross-correlation makes it possible to easily measure signal sources that in the past required complex test set-ups or could not be measured at all.

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

Materials

Two Component Epoxy

Master Bond Polymer System EP30AN-1 is a two part epoxy for high performance potting, sealing, coating and bonding featuring exceptionally high thermal conductivity, excellent electrical insulation properties and NASA low outgassing approval. It will cure at room temperature or more rapidly at elevated temperatures. Other attractive properties include superb dimensional stability and superior physical strength properties. Its low viscosity and excellent flow characteristics make it an ideal thermally conductive potting epoxy.

Master Bond
www.masterbond.com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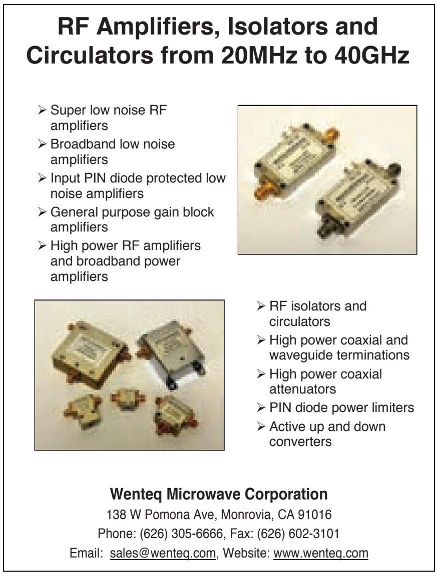
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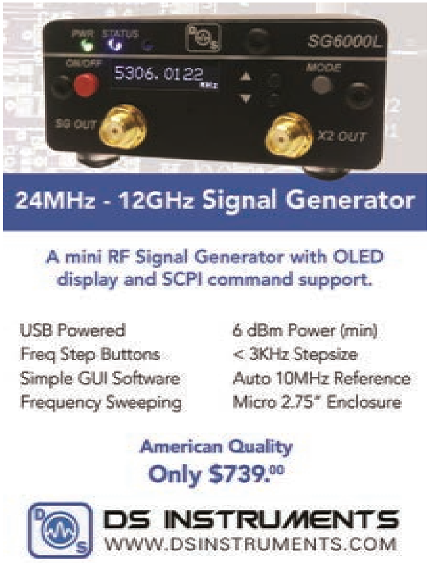
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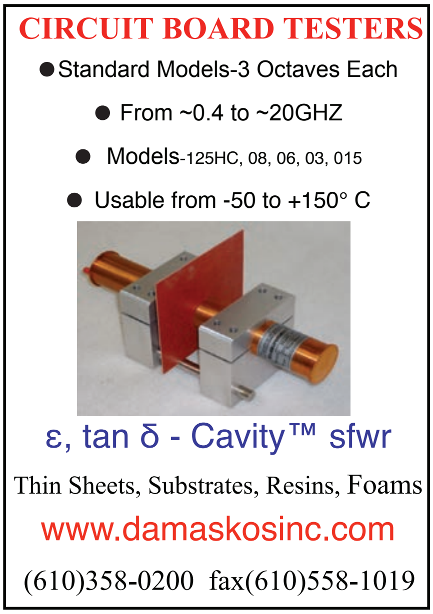
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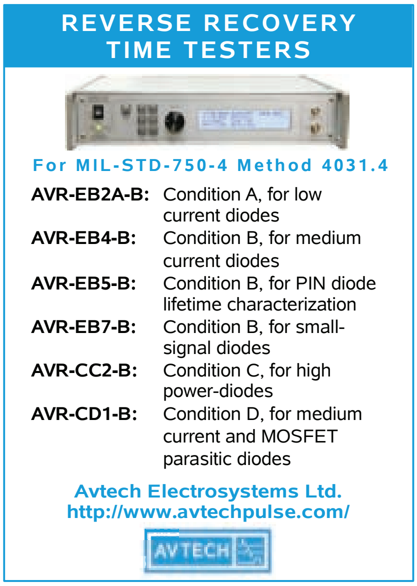
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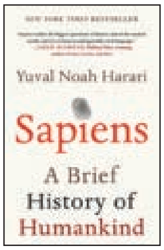

Sapiens: A Brief History of Humankind

Yuval Noah Harari

If you lived around 1600 – Galileo was 36 and had not yet built his 3× telescope – and if you were one of the few who were educated, you would probably have "known" all that civilization knew about philosophy, history, math and the natural sciences. Those living now inhabit a world of ultra specialization, when it is impossible to fully comprehend even our chosen area of expertise. If you were like me, in college you paid scant attention to the liberal arts, engrossed in your technical classes. That makes my knowledge of history more informed by what I have witnessed during my life, supplemented with what I have read and scattered remnants from K-12 classes.

Perhaps this explains my amazement with "Sapiens: A Brief History of Humankind," a comprehensive treatment of the history of human life. Yuval Noah Harari, a history lecturer at the Hebrew University of Jerusalem, has written a fascinating and often disturbing chronology of the development of civilization and the ideas that shape, bind and may undo us. Harari's account begins with the six human species that walked the planet when "modern cognition" evolved some 70,000 years ago. He explores why five of these human species disappeared and left just one: us homo sapiens (although you may have traces of other species' DNA). He outlines the life of the hunter-gatherer, which apparently was not a difficult existence. While the development of agriculture was good for society, creating production capacity to support population growth, Harari claims that the individual's quality of life suffered. Tribes grew into cities and empires with ever more complex structures and interactions. He posits that this growth and the increasing complexity of society were only possible because people adopted common ideas – "figments of our collective imagination" – like money, corporations, countries and, more recently, concepts like human rights. Surveying the history of the past 500 years, Harari argues that the success of western civilization over the Ottoman Empire and China reflects the west's adoption of the scientific method and free enterprise, with their attendant competition for ideas and economic gain.

Harari doesn't stop when he arrives at the present. He extends his view to the future of our species, predicting that medical technology will soon enable people to live "forever," unless killed by sudden trauma. He wonders about the ethical and societal implications of this capability to "design" human life, along with technology's ability to perform more and more of our daily activities. We will be able to live forever, yet doing what?

Sapiens is a provocative read that will expand your perspective and stir your emotions. You might not agree with all of Harari's arguments and conclusions, yet they are thoughtful and worthy of consideration and debate. For that reason, the book should be required reading for high school and college students. You, too.

To order this book, contact:

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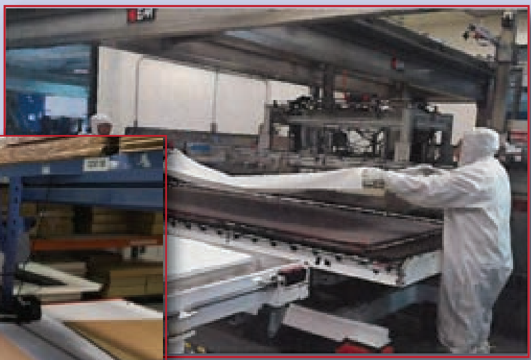
FABS and LABS

Getting Laminated Rogers Corp.



At IMS2015 in Phoenix, it was only a short ride over to Chandler, Ariz. for a tour of Rogers Corp.'s U.S. production facility. The Chandler manufacturing site does relatively low volume, high mix products for the company, in contrast to the Asian facility that is automated for higher volume products. About half of Rogers' business is in the U.S./European markets with the other half from Asia, totaling about $600 million in revenue. Rogers has segmented their business into three main groups – Power (e.g., power electronics), Protect (e.g., high performance foams) and Connect (e.g., PCB laminates).

The tour took everyone through the steps to produce PCB laminate products such as RO3000®, RT/duroid® 5000 and RT/duroid 6000. The raw material for these products is made in Rogers' corporate headquarters in Rogers, Conn. and shipped to Chandler for processing. For these products, sheets of the dielectric are plied together in a Class 10,000 clean room to achieve the final dielectric thickness desired by the customers (final thicknesses can range from .001" to 0.5"). Then, cladding is performed, where the dielectric plies are assembled with sheets of copper foil and built into a "book." Each laminate stack-up is interleafed with a stainless steel separator or "caul plate." Depending on the application, they also add layers of PTFE, woven glass or thick metal plate.

Next, the books are grouped together into a lamination press where they experience heat and pressure over a specified time causing the layers of dielectric and copper foil to bond together. The cycle properties vary depending on the materials and thicknesses involved. Following the lamination process, the books are disassembled and the finished laminates are sent for shearing/sawing into their finished sizes. Test sheets from each press load are sent to QA for electrical testing.

Laminates with very thick dielectric or with heavy metal backing are cut to size on a radial arm saw while thinner laminates are cut with a shear. Dimensional measurements are made on each product and entered into the statistical process control database. A visual inspection also takes place prior to packaging. The packaging team members use wireless barcode scanners to ensure the correct material is going into each order that is heat sealed with shrink wrap, boxed and sent to shipping.

Other laminate types utilize the treater where woven fiberglass is impregnated with different grades of RO4000® resin. The prepreg is then used as a bond ply or in the construction of copper clad laminate. Stacks of RO4000 prepreg are interleaved with copper foil and laminated in a large press.

Rogers has a R&D lab equipped with a high frequency network analyzer, a PIM test for testing passive intermodulation, power amplifiers for RF power testing, a thermal imaging camera for thermal management studies and multiple test fixtures and set-ups for electrical characterization. The engineers use the lab for testing new materials and methods for future products.

With more than 180 years in business, Rogers is one of the oldest companies in our industry. They supply a wide variety of high performance PCB laminates along with many other products that help power, protect and connect our society using unique, tightly controlled processes to provide the best products to their customers.

www.rogerscorp.com