Vol. 56 • No. 11

November 2013

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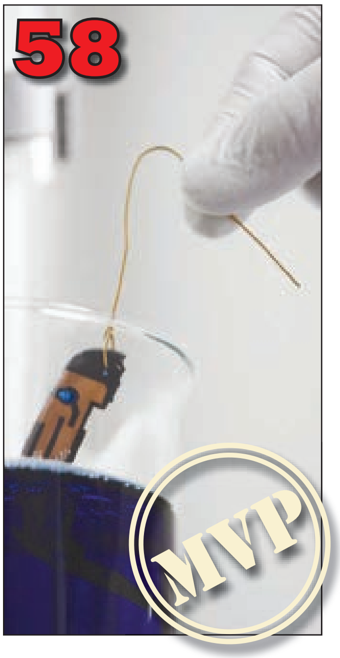

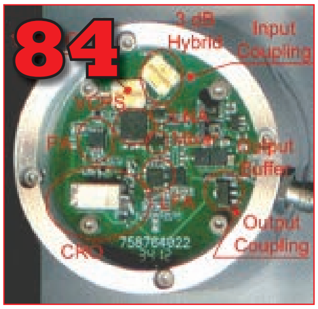

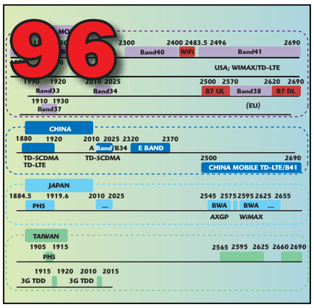

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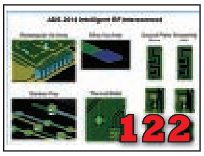

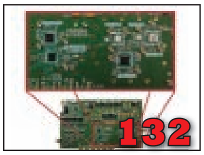

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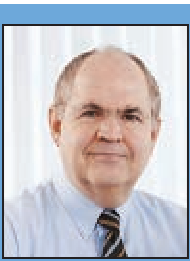
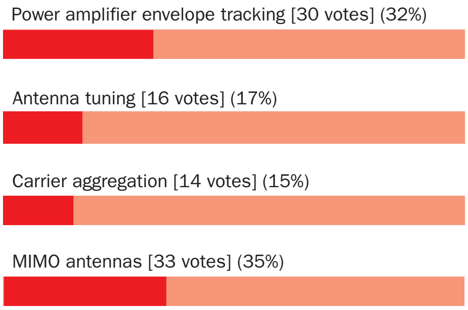
Executive Interview



Dr. Ingo Bretthauer, CEO of **LPKF Laser & Electronics AG**, explains how the PCB prototyping and micromachining company has developed from its early days in Germany in the 1970s to become a 21st century operation with a global reach.

September Survey

What technology will have the biggest impact on next generation mobile devices?



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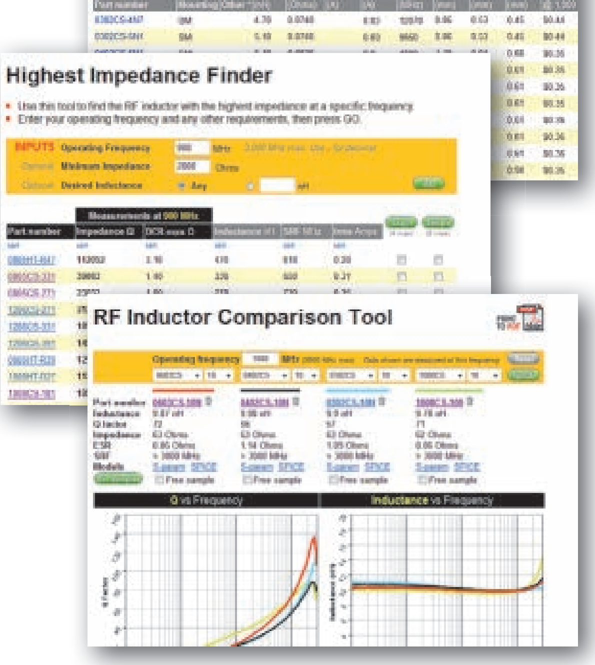

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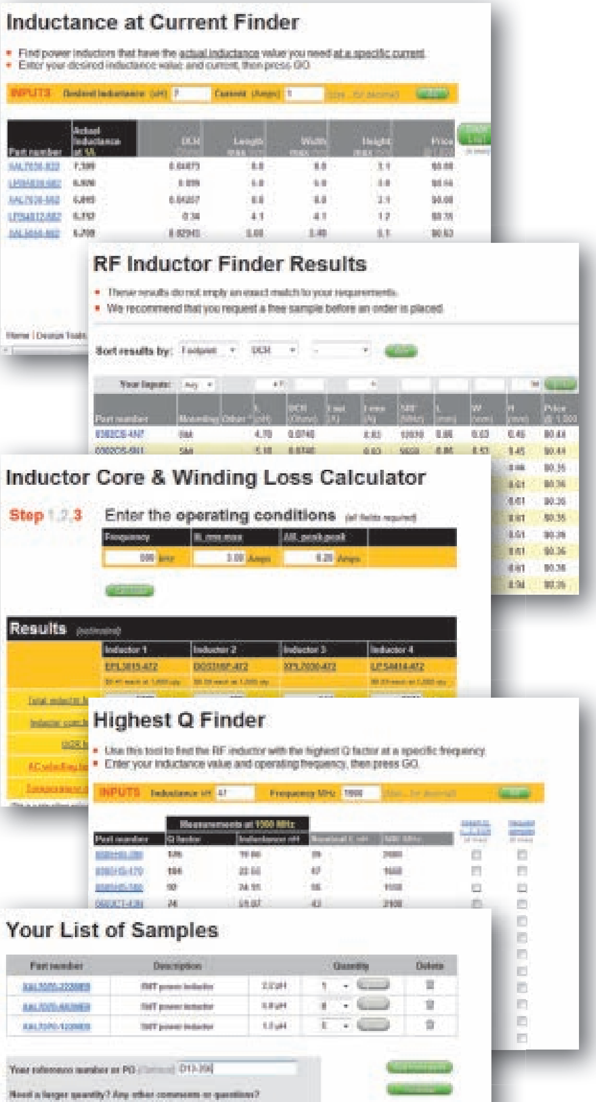

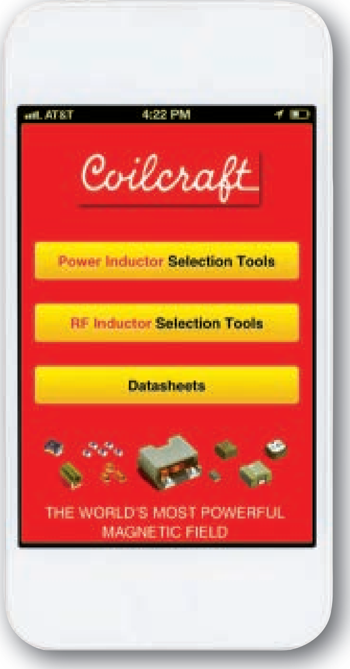

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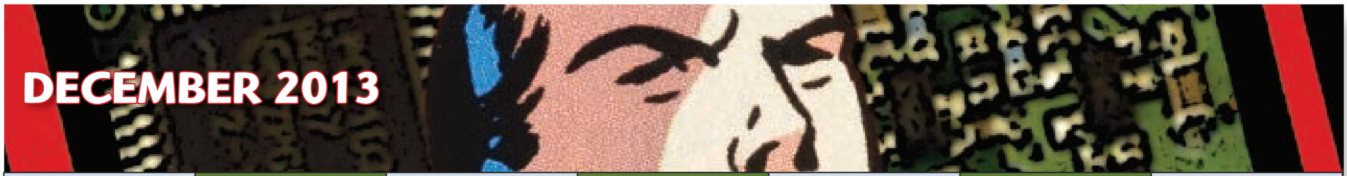

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1	2	3 **Webinar: EEsof** Agilent Technologies	4 **Webinar: High Efficiency Small Cell RF Solutions** freescale Scintera	5 **Webinar: Train Signaling Interference Simulation** CST **Webinar: Spectrum Management** Tektronix	6	7
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15 IMaRC New Delhi, India	16	17	18	19 AEnC Microwaves 2013 for a wireless World KIIT University, Bhubaneswar, India 18 – 20 Dec' 2013	20	21
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November 18–22, 2013 • Columbus, OH
www.arftg.org

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IMaRC 2013
IEEE International Microwave and RF Conference
December 14–16, 2013 • New Delhi, India
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AEMC 2013
4th Applied Electromagnetics Conference
December 18–20, 2013 • Bhubaneswar, India
www.ieee-aemc.org

JANUARY

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Radio Wireless Week
January 19–22, 2014 • Newport Beach, CA
www.radiowirelessweek.org

FEBRUARY

ISSCC 2014
International Solid-State Circuits Conference
February 9–13, 2014 • San Francisco, CA
www.isscc.org

SPACOMM 2014
6th International Conference on Advances in Satellite and Space Communications
February 23–27, 2014 • Nice, France
www.iaria.org

MWC 2014
Mobile World Congress
February 24–27, 2014 • Barcelona, Spain
www.mobileworldcongress.com

NATE UNITE 2014
Annual Conference for the National Association of Tower Erectors
February 24–27, 2014 • San Diego, CA
www.natehome.com/annual-conference

MARCH

ISQED 2014
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www.isqed.org

SATELLITE 2014
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www.satellite2014.com

TAEECE 2014
2nd International Conference on Technological Advances in Electrical, Electronics and Computer Engineering
March 18–20, 2014 • Kuala Lumpur, Malaysia
www.sdiwc.net/conferences/2014/taeece2014

ACES 2014
30th International Review of Progress in Applied Computational Electromagnetics
March 23–27, 2014 • Jacksonville, FL
www.aces-society.org/conference/2014

IWCE 2014
International Wireless Communications Expo
March 24–28, 2014 • Las Vegas, NV
www.iwceexpo.com

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www.ediconchina.com

MAY

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International Conference on Numerical Electromagnetic Modeling and Optimization for RF, Microwave and Terahertz Applications
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IMS 2014
IEEE International Microwave Symposium
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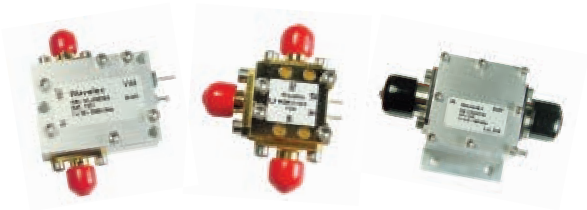

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Building Relationships

EDI CON 2014 is about six months away and commitments to participate in the conference and exhibition are well over half way toward our goal. Doubling the size of the exhibition, next year's EDI CON has already attracted more exhibitors than it did in its successful first year and is on track to be another sold-out exhibition next April. The same holds true for the reserved workshops and other speaking opportunities in the expanded three-day event. The long term goal for EDI CON is to grow organically into a leading, world-class event in terms of size, focus of participants and quality of content. The expected growth of next year's show is on track with the development of EDI CON into a major gathering of microwave professionals including the component/test instrument/software supply chain and the designers/system integrators that work in this space. A vibrant and sizable trade show is a healthy reflection of an industry's support of a given market. The existence of such an event should be welcome news to everyone conducting business in China.

Establishing EDI CON's leadership status now is critical to connecting technologists just as the number of RF/microwave companies operating in China reaches critical mass and the local customer base, technical communities and new marketing channels are becoming increasingly influential. In just under two years, *Microwave Journal China* has established itself as the leading microwave-focused print magazine with over 10,000 qualified subscribers. The magazine, closely linked to the editorial in our English edition, is providing Chinese engineers with access to the same content consumed by our North American and European readers. In addition, our China edition allows editors and contributors to update readers on the technology presented at EDI CON throughout the year. Together, EDI CON and *MWJ China* will educate working engineers, making for better end-users (customers) and spreading the demand for more technology.

A study by the management consulting firm Bain & Company found that companies that set up operations in countries offering lower cost manufacturing are also better equipped to build new markets in that host country. One case study of an electronics company doing $900 million worth of manufacturing and sourcing in China is now realizing more than $1 billion in annual sales of products there. Its increased presence in China deepened the company's knowledge of the market and helped it build the connections necessary to thrive in the country. China is evolving from a manufacturing center to a region capable of indigenous design and system integration. The Beijing government's efforts to promote education in science and engineering on a massive scale have produced a highly skilled labor force, creating a sizable and growing market for microwave electronics.

Engineering achievement is fueled by information as much as inspiration. To provide the China market with up-to-date content, we are looking to all industry-related organizations to contribute to EDI CON and *Microwave Journal China*. Our outreach efforts include local and multi-national companies, academia, Chinese engineering societies, government research centers, telecommunication OEMs, carriers and even other media outlets. Multi-national companies such as our premium EDI CON 2014 sponsors, Agilent (Host), Rohde & Schwarz (Diamond) and National Instruments/AWR (Corporate), will provide support and emphasis on the tools and techniques necessary for successful design of RF/microwave and high-speed digital-based systems. Similarly, integrated device manufacturers, semiconductor foundries and component vendors are also assuming leading roles in defining the EDI CON technical program. Together, we will create an event with an unprecedented level of integration between the technical conference and exhibition and maximize the educational opportunities offered by both.

Over the next few months, we will be announcing the keynote speakers for next year's plenary sessions. These speakers will be selected based on their high-level perspective of technology and business trends in China. We are building EDI CON around a supply chain ecosystem most of us recognize in North America and Europe. From our vantage point as publisher and event organizer, we take great pleasure in watching this network evolve as connections are made and relationships are formed. After all, one cannot overstate the importance of relationships in doing business.

David Vye
Microwave Journal *Editor*

HISTORY IN THE MAKING

1988

Ron Reedy, Mark Burgener and Graham Garcia publish their advanced SOI (silicon on insulator) research findings in IEEE Electron Device Letters in a paper titled, "High Quality CMOS in Thin (100 nm) Silicon on Sapphire." These findings served as the "aha moment" in the development of what is known today as Peregrine's UltraCMOS® technology – a patented, advanced form of SOI.


High-Quality CMOS in Thin (100 nm) Silicon on Sapphire

1990

Peregrine Semiconductor officially opens its doors for business and continues to perfect the UltraCMOS technology. The company obtains fundamental UltraCMOS patent from HP and Caltech.

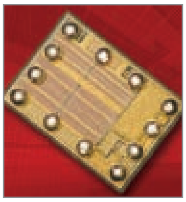
1991

Naval Ocean Systems Center (NOSC) and Peregrine sign a Cooperative Research and Development Agreement (CRADA) allowing Peregrine to commercialize UltraCMOS technology.

2003

With a high-performance Peregrine PLL, the European Space Agency (ESA) launches the Mars Express Orbiter.

2004



Peregrine enters the handset market with an SP6T switch and then introduces the world's first flip-chip SP4T switch for dual-band GSM handset applications. Through advanced packaging technology, the fully integrated RF UltraCMOS handset switch reduced the printed circuit board (PCB) area by a factor of nine when compared to conventional wire bonding. The company also announces an RF switch for broadband applications that exceeded the strict FCC 15.115 regulations. Peregrine continues to innovate and introduces the world's first single chip digital step attenuator (DSA), the best chip of its kind for nearly a decade. Peregrine expands its extensive IP portfolio with the issuance of the first patent in the RF switch family.

2005

Peregrine announces a major breakthrough for 3G cellphones, the patented HaRP™ design technology. Peregrine's revolutionary HaRP technology enhancements enabled dramatic improvements in harmonic results, linearity and overall RF performance.

2006

Peregrine is selected by the European Space Agency (ESA) to develop the first PLL device for integration into European space applications. NASA's New Horizons heads to Pluto; it is scheduled to arrive July 2015.

2008

Peregrine announces the UltraCMOS DTC technology for mobile antenna tuning. This breakthrough solved one of the biggest challenges in RF design – antenna impedance matching. With two critical Peregrine chips inside, Motorola announces multi-band two way radios for first responders.

2010

Japan Aerospace Exploration Agency's Hayabusa (literally "Peregrine Falcon" in Japanese) returns in June 2010 with a sample of material collected from an asteroid. The unmanned spacecraft, Hayabusa, relied on Peregrine's technology to complete the mission. Peregrine partners with Soitec to develop a new, bonded silicon-on-sapphire (SOS) substrate that was qualified for use in manufacturing Peregrine's next-generation STeP5 UltraCMOS RF IC semiconductors.

Driving the RF SOI Revolution

1993

Peregrine files its first UltraCMOS patent and begins building its IP portfolio.

1994

Peregrine selects Asahi Kasei Microsystems (AKM) as its new fab.

1995

Peregrine hand delivers its first 100 chips to Sciteq Electronics, a 2.5GHz fractional-N frequency synthesizer chip.

1996

Jim Cable, now CEO, joins the company as VP of Technology and Operations.

1999

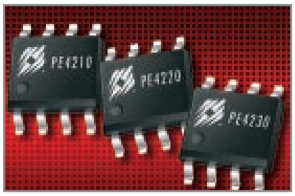
The first Peregrine product is literally launched into space by NT Space.

2000

Peregrine launches the world's most linear MOSFET quad mixer and ships its first million piece order. The company purchases an Australian fab.

2001

Peregrine ships its first RF SOI fully integrated switches.

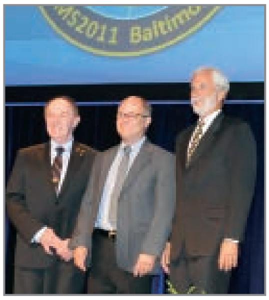


2002

The semiconductor company introduces the industry's highest performance PLL synthesizers with embedded EEPROM memory. Peregrine and Oki Electric sign an UltraCMOS partnership agreement.

2011

Peregrine ships its one billionth chip and scores design wins from the top 10 smartphone manufacturers worldwide. With a Peregrine PLL serving as a key component, NASA's Juno launches on a one-way mission to Jupiter. Peregrine founders, Mark Burgener and Ron Reedy, receive the IEEE Daniel E. Noble Medal for Emerging Technology. For test and measurement applications, Peregrine announces an SPDT device that operates from 9 kHz to 6.0 GHz. The RF switch was used by Rohde & Schwarz in the R&S SMA100A signal generator.



2012

On August 8, 2012, Peregrine stock begins trading on the NASDAQ under the ticker symbol "PSMI," raising $77 million for the company.

2013

Peregrine signs a collaborative sourcing and license agreement with Murata Manufacturing Company, the leading supplier of RF front-end modules for the global mobile wireless marketplace.

NEW FOR 2013 – ULTRACMOS 10

Peregrine, the founder of commercialized RF SOI, announces UltraCMOS 10, once again setting the worldwide performance standard for RF CMOS.

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Peregrine Semiconductor

Printed Resonators: Möbius Strip Theory and Applications

The geometrical phenomenon of anholonomy depends on failure of a quantity to recover its original value, when the parameters on which it depends are varied round a closed circuit. A Möbius strip provides one of the simplest examples of anholonomy, as the normal to the surface of the strip does not return to its original direction even though the radius vector does.[1,2] The strip therefore deforms in such a way that its metrical properties are barely changed, some nanostructures have the same elastic properties. A necessary and sufficient condition for a Möbius surface to be developable is that its Gaussian curvature must vanish everywhere. Given a curve with non-vanishing curvature, there exists a unique flat ruled surface (the so-called rectifying developable) on which this curve is a geodesic curve (see ***Figure 1***) is described by[1]

$$\vec{x}(s,t) = \vec{r}(s) + t\left[\vec{b}(s) + \eta(s)\vec{t}(s)\right] \qquad (1)$$

$$\tau(s) = \eta(s)k(s), \qquad (2)$$

$$s = [0, L], t = [-w, w]$$

where $\vec{r}$ is a parameterization of a strip with r as centerline and of length L and width 2w, where $\vec{t}$ is the unit tangent vector, $\vec{b}$ the unit binormal, k the curvature and τ the torsion of the centerline, the parameterized lines s = constant are the generators, which make an angle $\beta = \mathrm{arc}[\tan(1/\eta)]$ with the positive tangent direction.

The unique properties of Möbius strips, the shape minimizes the deformation energy which is entirely due to bending, can be described by

$$V = \frac{1}{2} D \int_0^L \int_{-w}^{w} k_1^2(s,t)\, dt ds \qquad (3)$$

where $D = 2h^3E/[3(1\text{-}v^2)]$, with 2h the thickness of the strip, and E and v Young's modulus and Poisson's ratio of the material.

In this section, a planar Möbius-coupled resonator is described, and the method for miniaturization can be applied to tunable oscillator circuits and memory devices used for receivers, filters, antenna and matching networks.

MÖBIUS STRIP RESONATOR: THEORY

A typical Möbius is a surface with only one side and only one boundary component, the

ULRICH L. ROHDE[1,2], AJAY K. PODDAR[1,2] AND D. SUNDARARAJAN[3]
Brandenburgische Technische Universitat[1], Cottbus, Germany
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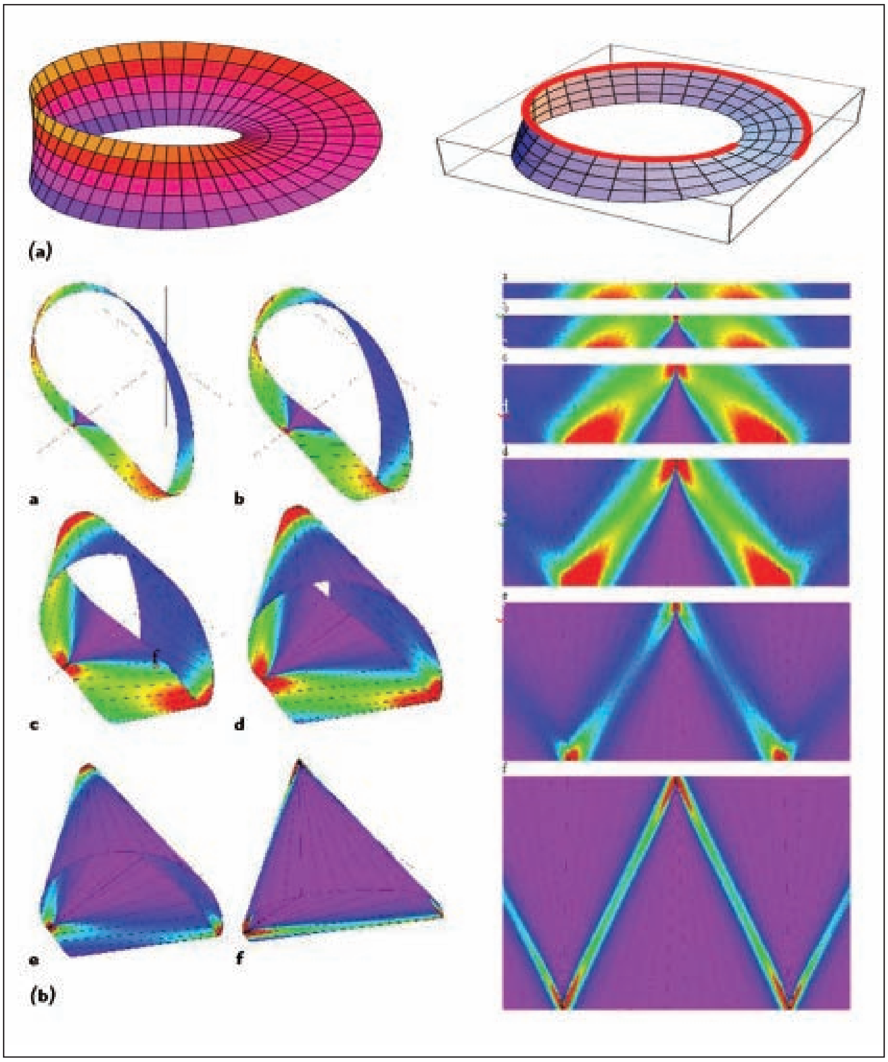
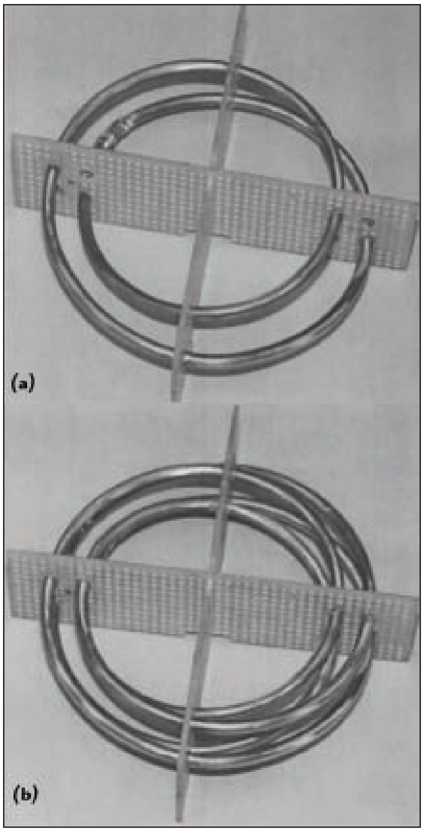
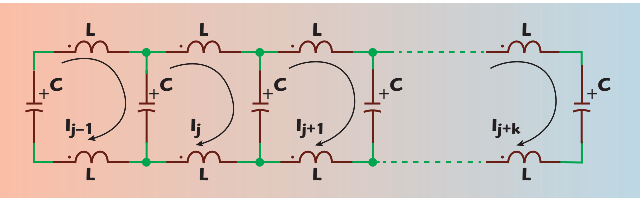


▲ *Fig. 1 A typical representation of a Möbius strip (a) and computed Möbius strips for different values of width[1] (b).*



▲ *Fig. 2 Photograph of the non planar 3D Möbius dual mode wire resonator (a) and quad-mode (b).*



▲ *Fig. 3 Typical lowpass ladder network consisting of a series of inductances L and capacitances C along the line.*

mathematical property of being non-orientable (as shown in ***Figure 1***). A unified system of differential-algebraic equations that describes models of this type was first published in 2007 together with its numerical solution and many technical applications.[1-15] The concept of Möbius strips is based on the fact that a signal coupled to a strip shall not encounter any obstruction when travelling around the loop, the loop shall behave like an infinite transmission line, enabling compact high Q-factor resonators. This characteristic enables many radio and microwave applications, including (i) a compact resonator with the resonance frequency which is half that of identically constructed linear coils,[2] (ii) a Tesla Coil for global transmission of electricity without wires[3], and (iii) high temperature superconductors.[4]

For a typical Möbius strip, one can move along the length of the strip and return to its starting point having traversed the entire length of the strip without ever crossing an edge as shown in Figure 1a. Figure 1b shows computed Möbius strips (coloring changes according to the local bending energy density, from violet for regions of low bending to red for regions of high bending). The left panel shows their 3D shapes for w = 0.1 (a), 0.2 (b), 0.5 (c), 0.8 (d), 1.0 (e) and 1.5 (f), and the right panel the corresponding developments on the plane.[1]

Recent publications describe the Möbius strip resonator[2-5] but the surface is a non planar 3D structure (see ***Figure 2***), not suitable for MMIC integration and surface mounted device (SMD) technology applications. Printed resonators are a special class of transmission lines of finite extent with well-defined boundary conditions. The particular interest here is a 1-dimensional printed ring resonator that can be equivalently represented by the simple lumped L-C network shown in ***Figure 3*** (printed resonators are a special class of transmission lines of finite extent with well-defined boundary conditions, the 1-dimensional printed ring resonator can be equivalently represented by the simple lumped L-C network).[14] In solving, the electric currents on the resonator can be formulated by a periodic boundary condition of the form described by

$$I_{j+k} = I_j \qquad (4)$$

where I_k represents the electric current around the n^{th} closed loop on the periodic ladder structure of k-elements. The boundary condition of the general form shown in Equation 4 governs that I_k is a conserved quantity that gives invariance of solutions under a 2π rotation with a definite handedness.

The 1-dimensional non-dissipative wave equation of LC network shown in Figure 3 for the k^{th} element is given by

$$I_k = A_1 e^{\left(\frac{p2\pi kM}{k}\right)} + A_2 e^{-\left(\frac{p2\pi kM}{k}\right)} \qquad (5)$$

$$\left(\omega^2 - \frac{1}{LC}\right) I_k - \left(\gamma\omega^2 - \frac{1}{2LC}\right)\left(I_{k+1} + I_{k-1}\right) = 0 \qquad (6)$$

$$\omega^2 = \left\{ \frac{2\sin^2\left(\frac{p\pi}{k}\right)}{LC\left(1 - 2\gamma\cos\frac{2p\pi}{k}\right)} \right\} \qquad (7)$$

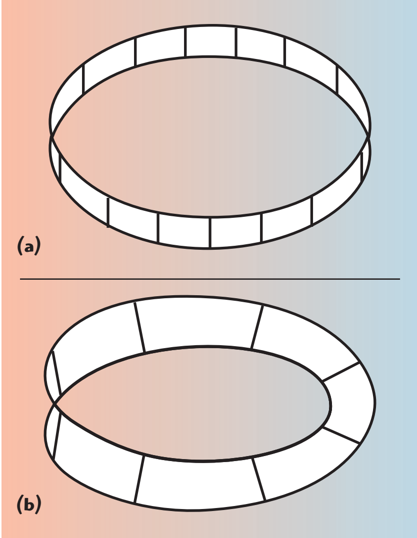


Fig. 4 Typical closed loop ring resonator (a) and the Möbius strip resonator (b) a topological transformation of ring resonator into a Möbius strip resonator.[15]

where p is an integer specifying the normal mode, γ is mutual coupling coefficient (mutual inductance 'M'=2γL) and k is the number of element structure.

From Equations 5 to 7, for even value of k, there are k-1 eigenvalues, including (k-2)/2 degenerate doublets and one singlet. A typical ring resonator, whose Eigen function satisfies Equation 4, defines a distinct inner and outer surface of the ring, shown in ***Figure 4a***. ***Figure 4b*** shows a topological transformation resulting in a Möbius strip resonator, whose current dynamics can be formulated by applying twisted boundary condition as

$$I_{j+k} = -I_j \qquad (8)$$

From Equation 8, a simple topological transformation on the resonator ring (4) results in a sign reversal of current (I_j) upon a 2π rotation of the solutions, and a 4π rotation is now required for invariance of the Eigen functions.[6-16] Note that the eigenfunctions satisfying the condition for twisted boundary are of the same form as Equation 5 provided that the mode indices are given half-integral values (p = 1/2, 3/2, 5/2,… (k-1)/2) relative to a ring consisting of identical components. The dispersion relation for the Möbius ring is the same as Equation 7; however, the wave-vectors are shifted by

$$\Delta\lambda = -\left(\frac{\pi}{k}\right) \qquad (9)$$

The two distinct topologies shown in Figures 4a and 4b can be considered

Cover Feature

as a complementary pair related by a single transformation. From Equations 4 and 8, it is evident that there is no additional structure associated with the Möbius ring resonator, since a second topological half-twist transformation on the Möbius resonator leads back to the boundary condition of Equation 4. Their description divides into half-integral and integral normal mode indices. The Eigen functions of the Möbius resonator form an orthogonal basis set, presenting an interesting possibility for the design of metamaterial for the application in tunable oscillators, antenna and filter circuits[6]. The oscillator's loaded Q factor Q_L is given by[15]

$$Q_L = \frac{\omega_0}{2}\left|\frac{d\varphi(\omega)}{d\omega}\right|_{\omega=\omega_0} = \frac{\omega_0}{2}\tau_d\,;\tau_d = \left|\frac{d\varphi(\omega)}{d\omega}\right|_{\omega=\omega_0} \quad (10)$$

$$\tau_d = \left.\frac{d\varphi(\omega)}{d\omega}\right|_{\omega=\omega_0} = \frac{\varphi(\omega_0+\Delta\omega)-\varphi(\omega_0-\Delta\omega)}{2\Delta\omega} \quad (11)$$

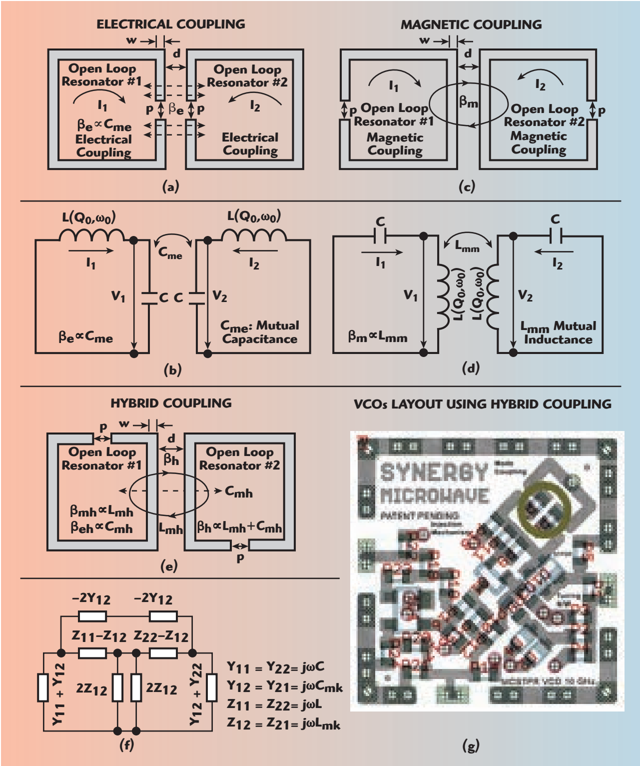
where $\varphi(\omega)$ is the phase of the oscillator's open loop transfer function at a steady state and τ_d is the group delay of the resonator.

From Equations 10 and 11, Q_L is proportional to the group delay; therefore, for low oscillator phase noise application, the design goal is to maximize the group delay of a Möbius strip resonator by incorporating phase-injection techniques. The unique characteristic of a Möbius strip is self-phase-injection properties along the mutually coupled surface of the strips, which enables higher quality factor for a given size of the printed transmission line resonator.

PRINTED RESONATOR BASED SIGNAL SOURCES

It is important to achieve a signal source with low phase noise in various applications. The phase noise increases the bit error rate in telecommunication links, degrades stability of the beam in particle accelerators and decreases sensitivity of radars. When high data-rates have to be transferred, as with M-QAM modulation in LTE, LMDS, and fixed frequency point-to-point digital radio and satellite-links, these systems need low phase noise signal sources either free running or phase-locked.

The printed coupled resonator based oscillator offers cost-effective solutions except the poor phase noise performance due to inherent low Q-factor associated with a printed transmission line resonator.[17-30] The Q-factor of the coupled planar resonator network can be enhanced by introducing an optimum coupling mechanism (electric/magnetic/hybrid) in conjunction with slow wave propagation, however, the large physical size and mode-jumping restricts the application especially at lower frequencies.[30] ***Figure 5***



▲ *Fig. 5 Typical simplified structure of open loop microstrip line coupled resonator networks: (a) electrical coupling, (b) equivalent lumped model of electrical coupling, (c) magnetic coupling, (d) equivalent lumped model of magnetic coupling, (e) hybrid coupling, (f) equivalent lumped model of hybrid coupling and (g) layout of VCO using electric and magnetic coupling.*

shows the typical coupling mechanism (electric/magnetic/hybrid) of printed coupled transmission line resonators for tunable oscillator applications.

As described in Figure 5, the coupling dynamics can be characterized by proximity effect through the fringing fields, which exponentially decays outside the region; electric and magnetic field intensity tends to concentrate near the side having maximum field distribution.

The coupling coefficient 'β_j' depends upon the geometry of the perturbation, and it can be given by

$$\beta_j = \left[\left(\frac{\int \varepsilon E_a E_b \, dv}{\sqrt{\int \varepsilon E_a^2 dv \int \varepsilon E_{bd}^2 \, dv}} \right)_{\text{electrical-coupling}} + \left(\frac{\int \mu H_a H_b \, dv}{\sqrt{\int \mu H_a^2 \, dv \int \mu H_b^2 \, dv}} \right)_{\text{magnetic-coupling}} \right] \quad (12)$$

where E_a and H_a are the electric and magnetic fields, respectively, produced by the square loop ring resonator, and E_b and H_b are the corresponding fields due to the perturbation ($d \neq 0$) or nearby adjacent resonator (second square loop resonator).

From Equation 12, the first term represents the coupling due to the interaction between the electric fields of the resonators and the second term represents the magnetic coupling between the resonators. Depending on the strength of interaction, multimode dynamics exist related to electrical, magnetic and hybrid coupling.

The configuration shown in Figure 5a produces an electric coupling, resulting in the electric field being strongest near the open ends, maximizing the numerator of the first term of Equation 12. As depicted in Figure 5b, when the resonators are operating near their first resonant frequency, the pair of resonators interacts mainly through their magnetic field, this is because the magnetic fields are maximum near the center of the resonator opposite to its open ends, maximizing the numerator of the second term of Equation 13. The coupling produced by the two configurations (open loop resonator #1 and open loop resonator #2) as shown in Figure 5c are referred to as mixed coupling or hybrid coupling because neither the electric fields nor the magnetic fields dominate the interaction between the resonators.

The definition of 'β_j' given in Equation 12 involves complex mathematical analysis and is not suited for practical calculation since it requires the knowledge of the electromagnetic fields everywhere. A useful alternative expression for 'β_j' can be obtained from a well known fact in physics: when multiple resonators are coupled to each other they resonate together at different distinct frequencies (f_{ee}, f_{em}, f_{eh}, f_{mh}) which are in general different from their original resonant frequency f_0. Furthermore, these frequencies are associated with corresponding to their normal modes of oscillation of the coupled system (electric/magnetic/hybrid), and their difference increases as the coupling 'β_j' (β_e: electric, β_m: magnetic and β_h: hybrid) between the resonators increases.[30] The main interaction mechanism between resonators is proximity coupling and can be characterized by

a coupling coefficient 'β_j' that depends upon the ratio of coupled energy to stored energy, described by

$$\beta_e \cong \frac{\text{coupled}-\text{electrical energy}}{\text{stored}-\text{energy of uncoupled}-\text{resonator}} \cong \frac{f_{me}^2 - f_{ee}^2}{f_{me}^2 + f_{ee}^2} \cong \frac{C_{me}}{C} \tag{13}$$

$$\beta_m \cong \frac{\text{coupled}-\text{magnetic energy}}{\text{stored}-\text{energy of uncoupled}-\text{resonator}} \cong \frac{f_{em}^2 - f_{mm}^2}{f_{em}^2 + f_{mm}^2} \cong \frac{L_{mm}}{L} \tag{14}$$

$$\beta_h \cong \frac{\text{coupled}-\text{electro}-\text{magnetic energy}}{\text{stored}-\text{energy of uncoupled}-\text{resonator}} \cong \frac{f_{eh}^2 - f_{mh}^2}{f_{eh}^2 + f_{mh}^2} \cong \frac{CL_{mh} + LC_{mh}}{LC + L_{mh}C_{mh}} \tag{15}$$

where

$$f_{ee} = \frac{1}{2\pi\sqrt{L(C+C_{me})}}, f_{me} \frac{1}{2\pi\sqrt{L(C-C_{me})}}, C_{me}\text{: Mutual Capacitance} \tag{16}$$

$$f_{em} = \frac{1}{2\pi\sqrt{C(L-L_{mm})}}, f_{mm} \frac{1}{2\pi\sqrt{C(L+L_{mm})}}, L_{mm}\text{: Mutual Inductance} \tag{17}$$

$$f_{eh} = \frac{1}{2\pi\sqrt{(L-L_{mh})(C-C_{mh})}}, f_{mh} \frac{1}{2\pi\sqrt{(L+L_{mh})(C+C_{mh})}},$$

$$L_{mh}\text{: Hybrid Inductance} \tag{18}$$

$$f_0 = \frac{1}{2\pi\sqrt{LC}}, f_0\text{: fundamental resonance frequency of uncoupled resonator} \tag{19}$$

The time average loaded Q-factor of coupled resonantor: $\overline{Q_{cr}(\omega)}_{\omega\to\omega_0}$ can be described by

$$\overline{Q_{cr}(\omega)}_{\omega\to\omega_0} = \left[\frac{\omega}{2(I_{max} - I_{min})} \int_{I_{min}}^{I_{max}} Q_{cr}(\omega, i)\, di\right]_{\omega\to\omega_0} \tag{20}$$

where I_{min} and I_{max} are the minimum and maximum resonator currents associated with the fundamental modes of the coupled resonator networks, the $Q_{cr}(\omega,i)$ is the instantaneous quality factor at frequency ω and current i provides an effective means to quantify the Q-multiplier effect when operated in a evanescent-mode coupling conditions, especially in printed coupled resonator based oscillator circuits.

From Equation 20, the loaded quality factor Q_L of the coupled resonator network is given in terms of unloaded quality factor Q_0 as

$$Q_L(\omega_0) = \frac{\omega_0}{2}\left[\frac{\partial\phi}{\partial\omega}\right] \tag{21}$$

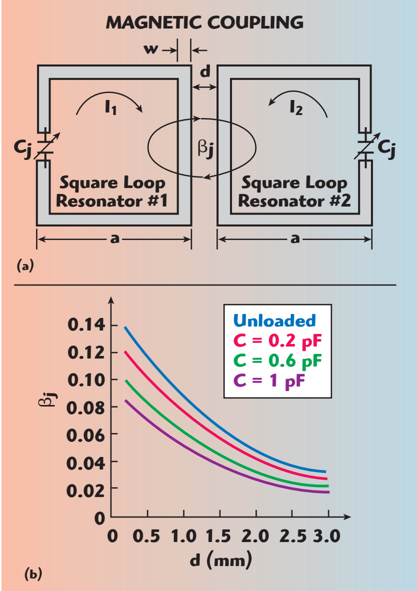
$$[Q_L(\omega_0)]_{\text{electrical-coupling}} \cong 2\left[\frac{Q_0}{(1+\beta_e)}\right]_{\beta_e<<1} \cong 2Q_0 \tag{22}$$

$$[Q_L(\omega_0)]_{\text{magnetical-coupling}} \cong 2[Q_0(1+\beta_m)]_{\beta_m\to1} \cong 2Q_0 \tag{23}$$

$$[Q_L(\omega_0)]_{\text{hybrid-coupling}} \cong 2\left[Q_0\frac{(1+\beta_{mh})}{(1+\beta_{eh})}\right]_{\beta_e<<1,\beta_m\to1} \cong 4Q_0 \tag{24}$$

where $\frac{\partial\phi}{\partial\omega}$ is the rate of change of the phase, and Q_0 is the unloaded Q-factor of the uncoupled single open loop microstrip line resonator. From Equations 22 to 24, there is trade-off between improving the Q factor and the permissible attenuation required (which is compensated by active device for oscillation build up).

The coupling mechanism described in Figure 5 shows improvement in quality factor in comparison to single uncoupled planar resonator but drawback is limited tuning range (less than 1 percent). By introducing tunable capacitor across the open end of uncoupled planar open loop resonator, dynamic unloaded Q-factor can be improved but limited in tuning range (< 25 percent). This is due to minimization of the radiation losses from the open ends of the resonator because of capacitor loading, causing dielectric polarization in the capacitor since most of the electric field resides inside it.[31-35] Therefore, a high Q capacitor could actually increase the unloaded quality factor of the whole resonator. This is analogous to the case of dielectric resonators where the fields are constrained to a small volume dielectric with high permittivity and low loss tangent resulting in a high overall Q.[37-42]



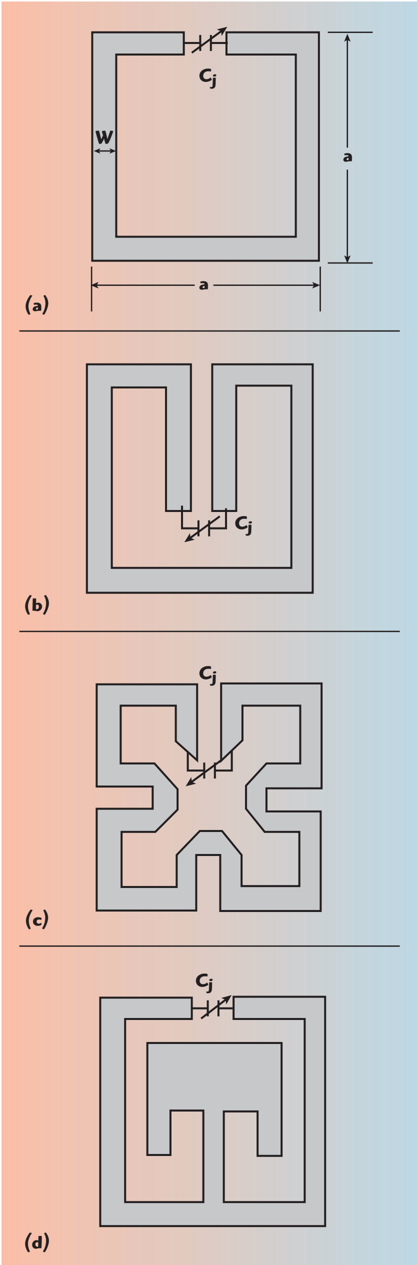
▲ *Fig. 6 A typical capacitive loaded magnetic coupled square loop resonator layout (a) and plot of magnetic coupling β_j (b).*

For wideband tunability (> 100 percent tuning), adjacent coupled open loop resonator network is preferred but at the cost of large real estate area. In general, the miniaturization of the open loop resonator reduces its capacity to couple to adjacent structures. This is due to the fact that smaller resonator size represents a smaller volume of electromagnetic interactions between its coupled arms; reason being a smaller size represents a smaller volume of electromagnetic interaction between coupled resonators. The fact that the majority of the electric field that existed in the volume surrounding the open ends of a resonator is now confined to the interior of a capacitor limits its possibility to interact with a neighboring resonator.

It can be seen in ***Figure 6*** that the effect on the magnetic and mixed

coupling is less severe than for the electric coupling, where the magnetic coupling coefficient is plotted against the separation between resonators for different loading capacitors.[37-42] Figure 6b is a plot of magnetic coupling β_j as a function of the distance between resonators for a given capacitive (C_j) loading with resonator physical dimension ω = 2 mm and a = 26 mm, fabricated using Roger RO4003c substrate with a dielectric constant of 3.55 and a thickness of 60 mil.[37]

The microstrip square open loop resonator is one of the most used structures for multi-mode oscillator resonator applications due to its compact size (a=λ/8). For low phase noise multi-octave band tunability, the loaded quality factor (Q_L) as described in Equations 21-24 can be maximized by either lowering the value of mutual capacitance (C_m) and inductance (L_m) or maximizing the self-capacitance (C) and inductance (L), therefore, the upper limit of the loaded Q-factor is dependent on the coupling β_j (β_e: electric, β_m: magnetic and β_h: hybrid) that can be optimized by controlling the width of the transmission line (w), gap of the open line resonator (p), and spacing between the two open line resonators (d).[43-48] For low phase noise tunable oscillators, the coupling coefficient β_j should be dynamically tuned over the operat-



▲ *Fig. 7 Typical layout of a tunable square open loop resonator: conventional square open loop hairpin resonator (a), folded arms square open loop resonator (b), meander line square open loop resonator (c), dual mode square open loop resonator (d).*[36]

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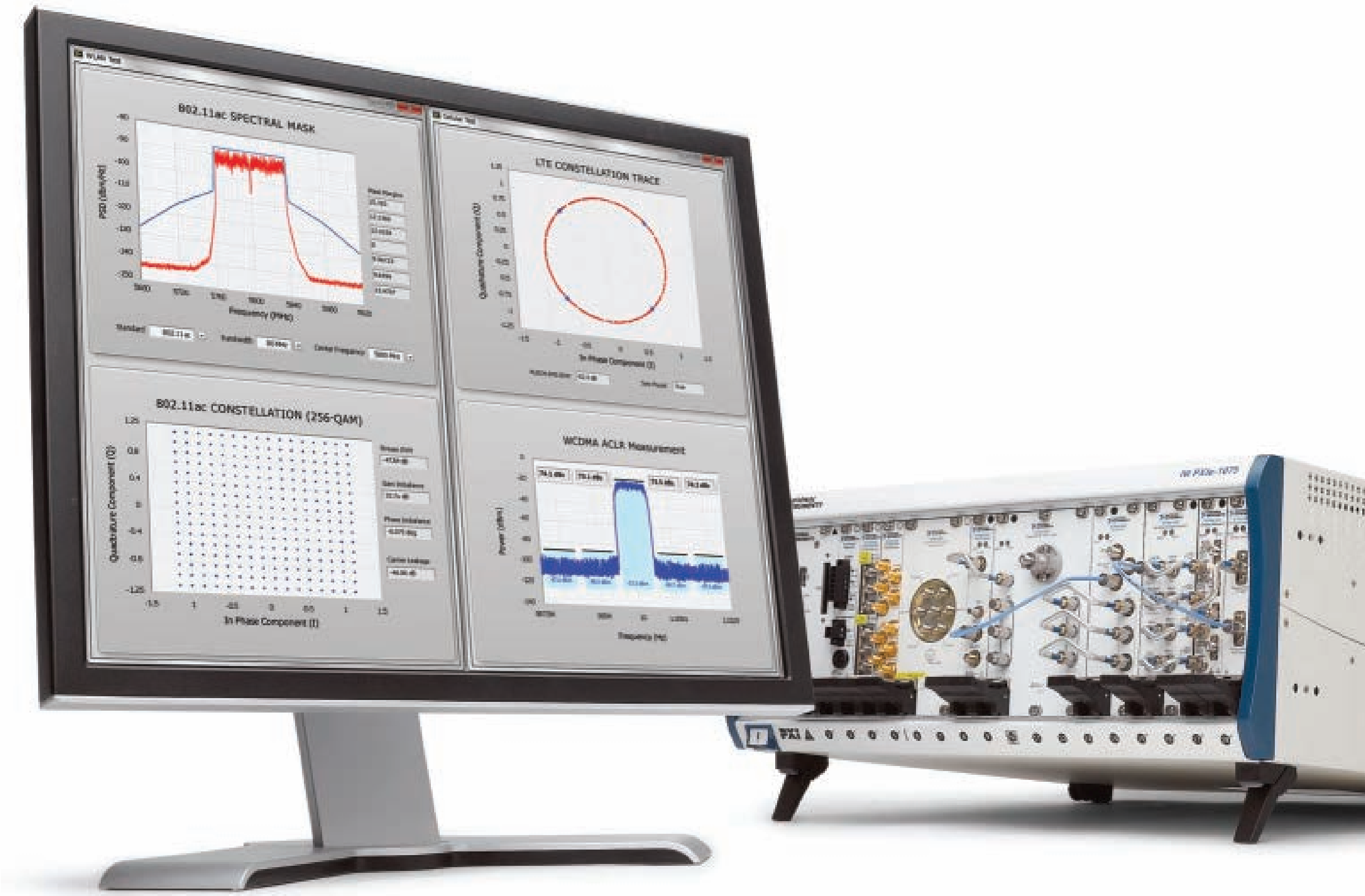

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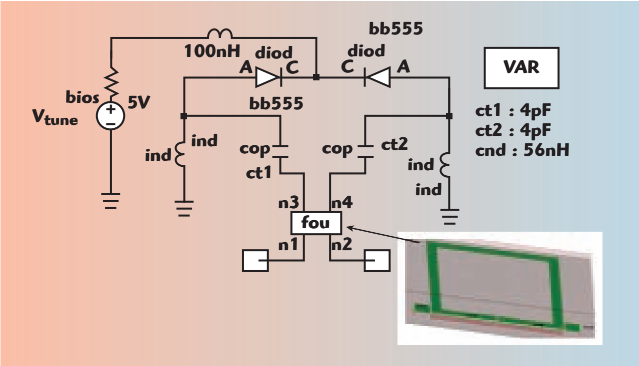


Fig. 8 A typical setup for carrying out the measurement of the transmission coefficient S_{21} (ω) for analyzing the coupling characteristics of the varactor loaded tunable open loop resonator.

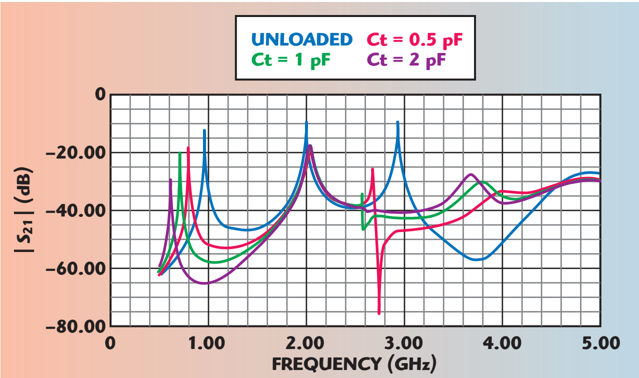


Fig. 9 A CAD simulated (Ansoft Designer) plot of S_{21} (ω) of a varactor loaded open loop resonator for different capacitance values.

ing frequency band. However, dynamic controlling and tuning of the parameters (w, p, a and d) as shown in Figure 5 at high frequency is a challenging task. The alternative tuning mechanism is capacitive loading by incorporating tuning diodes.[31-37]

Figure 7 shows a typical tunable square open loop resonator in compact size (λ/8 by λ/8) for applications in oscillator circuits. As shown in Figure 7c, the goal is to minimize the real estate area by using a meander line into inner part of the resonator. To optimize the geometry of the coupled resonator, they are excited with a pair of loosely coupled feed lines to obtain a transmission parameter S_{21}(ω) from which the two resonant frequencies f_1 and f_2 can be obtained for a given geometry and values of d between resonators. The resonator shown in Figure 7d offers compact size and exhibits two independent modes (dual-modes), the coupling between them can be optimized by the geometry of the inner structure. This tunable dual-mode resonator can then function as two independent tunable resonators providing an immediate size reduction of 50 percent.

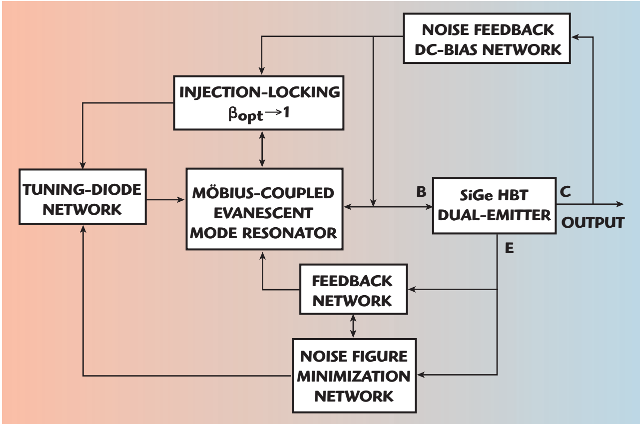
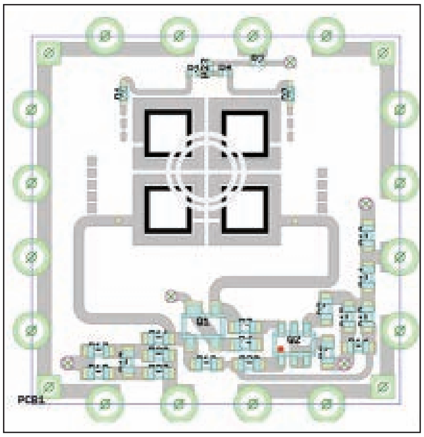


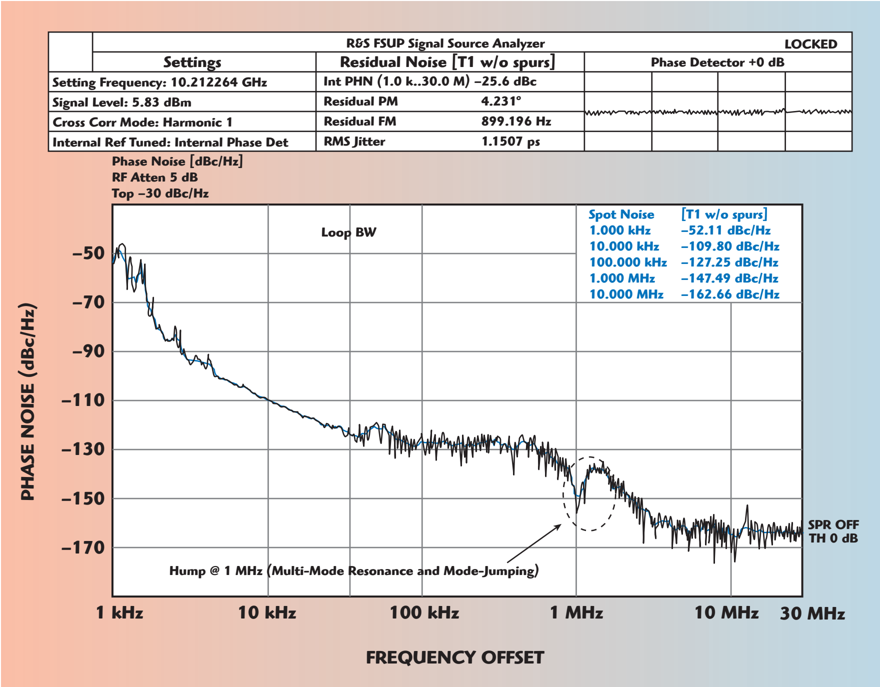
Fig. 10 A typical block diagram of an X-Band Möbius-coupled evanescent mode resonator (MCEMR) oscillator.

Figure 8 shows the typical setup used for measurement of the S_{21}(ω) for deriving the coupling characteristics of the tunable open loop resonator loaded with the varactor diode. The parameter of interest is the transmission coefficient S_{21}(ω), where the resonant frequencies are manifested as peaks of maximum transmission between ports.

Figure 9 shows CAD simulated (Ansoft Designer) plot of the varactor loaded open square loop printed resonator



▲ *Fig. 11 Layout of 10.2 GHz MCEMR VCO (0.9" × 0.9" × 0.2").*



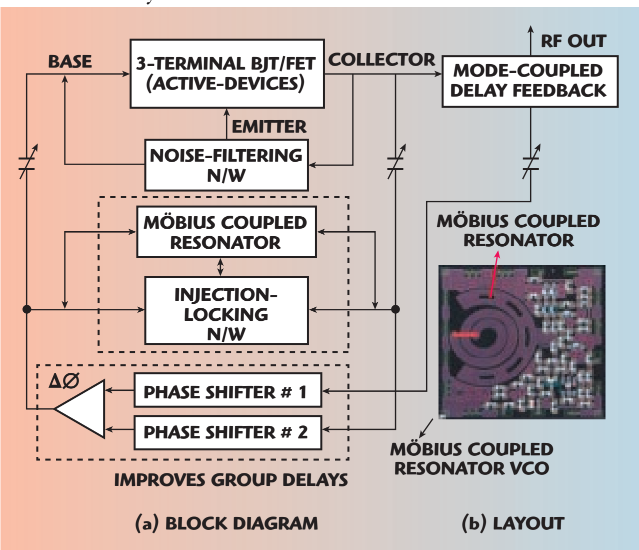
▲ *Fig. 12 Measured phase noise plot of 10.2 GHz MCEMR VCO.*

with ω = 2 mm and a = 26 mm, fabricated using Roger RO4003c substrate with a dielectric constant of 3.55 and a thickness of 60 mil (1.524 mm).[37-43] As shown in Figure 9, the first resonant frequency is shifted down with different values of C, whereas the second resonance frequency remains at the same location. Nevertheless, as varactor diode capacitance increases beyond a certain value (for example, 1.4 pF), a couple of frequencies where the transmission coefficient S_{21} is zero appear between the first and second resonant frequencies, which is observed in Figure 9 for C = 2 pF. As shown in Figure 9, the physical size of the resonator (ω = 2 mm and a = 26 mm) is kept constant while C is varied causing a shift in the first resonant frequency. This frequency shift can be capitalized into miniaturization if we let the size of the resonator vary but at the cost of increase in insertion loss. A novel Möbius strip resonator can overcome these problems and offers promising and cost-effective solutions. The concept of the Möbius strips is based on the fact that a signal coupled to a strip shall not encounter any obstruction when travelling around the loop; enabling compact high Q-factor resonators.

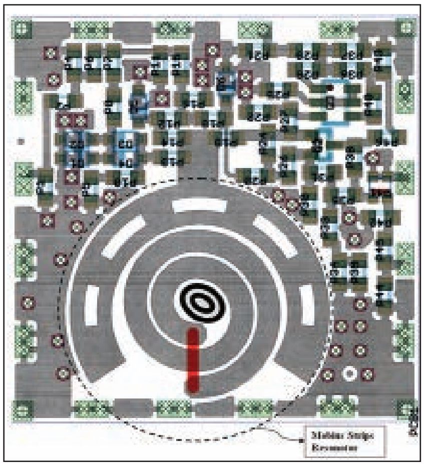
MÖBIUS-COUPLED EVANESCENT-MODE RESONATOR OSCILLATOR

A novel mode-coupled self-injection locked oscillator is developed in response to improve the insertion loss and loaded Q-factor of the printed resonator network shown in Figure 7 for the application in modern communication systems.

Figures 10** to **12 show the typical block diagram, layout and measured phase noise plot, respectively, of the 10.2 GHz oscillator using a SiGe HBT active device fabricated on Rogers substrate material with a dielectric constant of 2.2 and thickness of 20 mils (microstripline/stripline) for the validation of the approach. The prototype oscillator circuit shown in Figure 11 works at DC bias of 10 V and 30 mA, measured output power exceeds +5 dBm. The phase noise plot shown in Figure 12 exhibits hump and dip between 100 kHz and 10 MHz offset from the carrier, possibly due to the resonator mode-jumping and mode-degeneration phenomena. By incorporating mode-injection-locking, mode-jumping can be suppressed and stable oscillation can be achieved.



▲ *Fig. 13 Shows the typical block diagram 10 GHz Möbius coupled resonator VCOs using a SiGe HBT active device, built on 20 mil substrate material.*



▲ *Fig. 14 Layout of 10 GHz oscillator (depicts the phase-injection-mode-locked) Möbius strips resonator (22 mil substrate thickness with 2.22 dielectric constant, 0.7" × 0.75" × 0.18").*

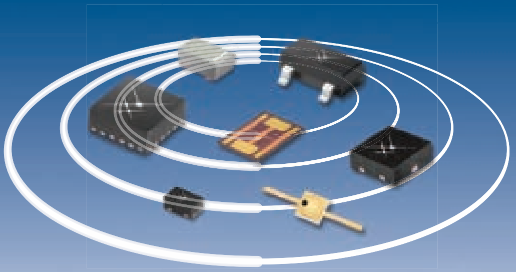


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Figure 13 shows the typical block diagram of mode-injection-locked Möbius strip resonator VCO topology that can offer integration and low cost solutions. ***Figure 14*** shows the typical layout of 10 GHz Möbius resonator based oscillator for building low phase noise signal source for radar applications.

Figure 15 shows the measured phase noise plot (–110 dBc/Hz at 10 kHz offset) from the carrier frequency of 10 GHz offers significant improvement in figure of merit (FOM) for a given phase noise, tuning range and power consumption. A spot phase noise number is difficult to compare, unless it is compared at the same frequency offset from the carrier and the same carrier frequency for a given tuning range and output power. Comparing oscillators operating at different frequencies, tuning range and output power levels, a FOM with a single number has long been desired.

In order to make a fair comparison of the performances of VCOs at different operating frequencies, a $\left(\frac{\text{dBc}}{\text{Hz}}\right)$ FOM is used. The FOM in and power-frequency tuning-normalized (PFTN) in dB are defined as[49]

$$\text{FOM}\big|_{f_{offset}} = \left[\pounds\left(f_{offset}\right) - 20\log_{10}\left(\frac{f_0}{f_{offset}}\right) + 10\log_{10}\left(\frac{P_{DC}}{1\text{mW}}\right)\right]\left(\frac{\text{dBc}}{\text{Hz}}\right) \tag{25}$$

$$\text{PFTN} = -\left[\pounds\left(f_{offset}\right) - 20\log_{10}\left(\frac{\Delta f}{f_{offset}}\right) - 10\log_{10}\left(\frac{P_{DC}}{kT}\right)\right](\text{dB}) \tag{26}$$

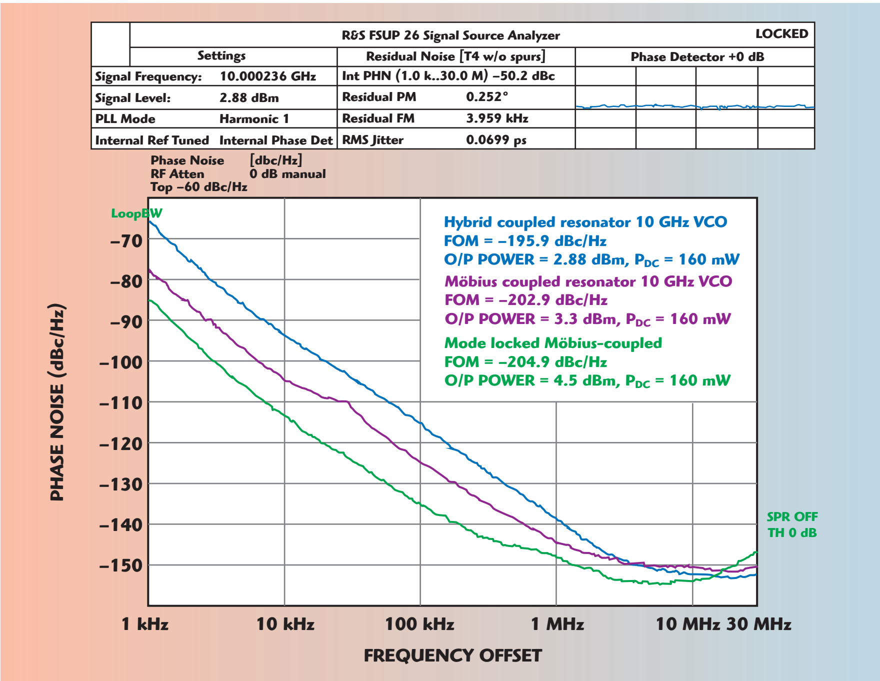
where f_0 is the oscillation frequency, $\pounds(f_{offset})$ is the phase-noise at the offset frequency f_{offset}, k is the Boltzmann constant, $\Delta f = f_{max} - f_{min}$ is tuning range, T is temperature in Kelvin, and P_{DC} is the total consumed DC power in milli-watts.

Larger $|\text{FOM}|\left(\frac{\text{dBc}}{\text{Hz}}\right)$ and PFTN(dB) values relate to superior oscillators. From Equations 25 and 26, the FOM for integrated phase noise in dBc from 1 kHz to 1 MHz can be given by

$$\text{FOM}\big|_{\text{Integrated}(1\text{kHz}-1\text{MHz})} =$$

$$10\log\left(P^2(\varnothing)\right) + 10\log_{10}\left(\frac{P_{RF}}{P_{DC}}\right) - 20\log\left(\frac{2\Delta f}{f_{max} + f_{min}}\right) \tag{27}$$

where $\Delta f = f_{max} - f_{min}$;$f_{max}$ = maximum oscillation frequency; f_{min} = minimum oscillation frequency; $P^2(\varnothing)$ = integrated phase noise from 1 kHz to 1 MHz; P_{RF} = signal output power averaged over frequency; P_{DC} = DC power consumption of the oscillator.



▲ *Fig. 15 Measured phase noise plot of the 10 GHz oscillator using: hybrid coupled resonator, Möbius coupled resonator, mode-locked Möbius coupled resonator network.*

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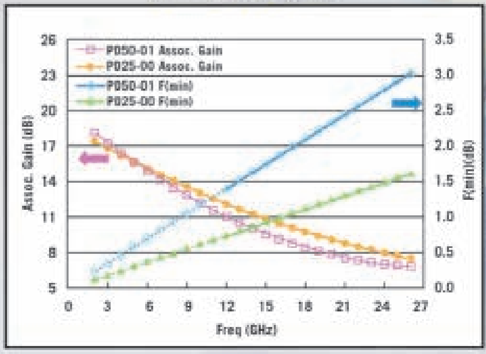
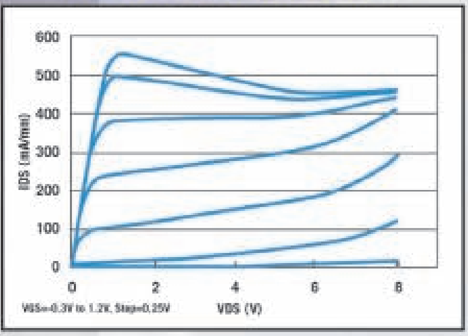
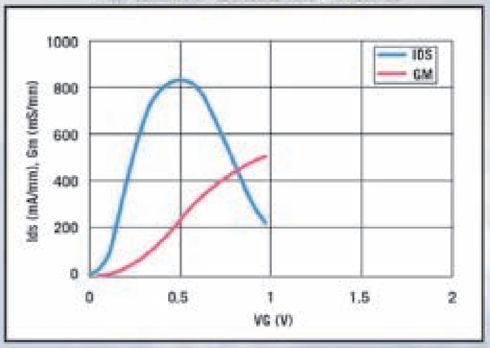


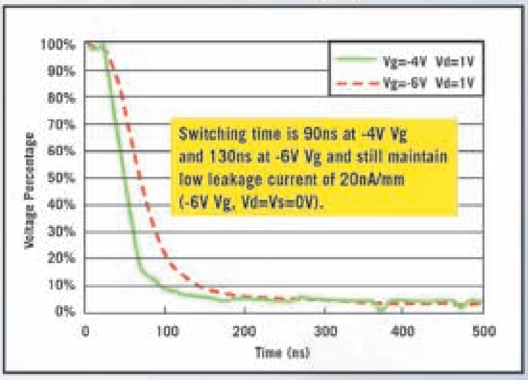
E-mode I-V Characteristics



E-mode Transfer Curve



D-mode Switching Speed



D-mode Device Performance

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

DUT: NOF x UGW= 5 x 12µm

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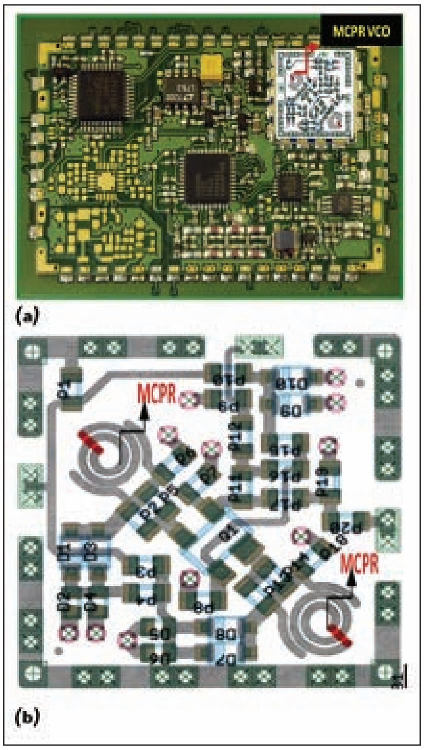
As shown in Figure 14, the frequency is set at the fundamental resonance of Möbius-coupled evanescent mode resonator (MCEMR) and can be electrically tuned by using varactor network (tuning voltages of 1 to 24 VDC enable variations in the center frequency by ±400 MHz to compensate for frequency drift in phase-locked systems).

Figure 15 shows the measured phase noise plot of 10 GHz MCEMR VCO. The measured phase noise at 10 kHz offset is better than –110 dBc/Hz, validates the tuning capability without degrading the phase noise performance in SMD packaged version. From Equation 25, the measured FOM at 1 MHz is –195.9 dBc/Hz for hybrid coupled resonator, –202.9 dBc/Hz for Möbius coupled resonator, and –204.9 dBc/Hz for Mode-locked Möbius coupled resonator network; with power consumption of 160 mW (V_{cc}=5 V, I_c=32 mA). The DC-RF conversion efficiency is 1.2 percent for hybrid coupled resonator, 1.3 percent for Möbius coupled resonator, 1.7 percent for mode-locked Möbius coupled resonator network; with DC power consumption of 160 mW (V_{cc}=5 V, I_c=32 mA).

SYNTHESIZED FREQUENCY SOURCES USING MÖBIUS COUPLED RESONATOR (MCPR) VCOS

Figure 16 shows a 2 to 8 GHz broadband synthesizer using wideband (2 to 8 GHz) tunable MCPR VCO (layout of VCO is shown in Figure 16b, built on 22 mil substrate with a dielectric constant of 2.2). It offers a viable cost-effective solution for expensive YIG resonator oscillator with less susceptibility to thermal drift, vibrations and microphonics.

As shown in Figure 16a, the synthesizer circuit draws typically 200 mA current from a 5 V supply, uses multi-band/multi-mode MCPR VCO (operating at 5 V, 32 mA) resulting in a low-cost power-efficient configurable synthesizer. The typical measured phase and the mode stabilized synthesizer circuit as illustrated is typically better



▲ *Fig. 16 Typical PCB layout of 2 to 8 GHz configurable synthesizer module (a) and layout of a 2 to 8 GHz Möbius coupled planar resonator VCO (b).*

than –112 dBc/Hz at 10 kHz offset for 2 to 8 GHz operations. The reported synthesizer module shown in Figure 16a offers wide bandwidths with excellent performance in terms of phase noise, harmonics (> –20 dBc), settling time (< 1 millisecond), and sideband spurious content (> –60 dBc), with low power consumption in compact size (1 × 1 × 0.2 inches) built on 22 mil substrate material with a dielectric constant of 2.2 for the validation of the new approach. The synthesizer using tunable oscillators with Möbius strip resonators yields compact VCOs with excellent phase-noise performance and in configurations that can be readily adapted to modern RF integrated circuit (RFIC) and MMIC semiconductor manufacturing processes.

REAL TIME SIGNAL RETENTION DEVICE

The signal retention characteristics of Möbius coupled strip resonators are useful in RF and microwave applications, including radio astronomy, medical fields and software driven radios. Conventionally, high Q cavity echo box is used in radar testing to retain the input signals but this technique has bandwidth limitation.[4] The frequency memory loop (FML) technique is used in military electronics for retention of signals; this is an expensive solution with considerable digital signal processing and invariably noisy and bandwidth limited.[11] The Möbius strip configuration (back to back coplanar waveguide) reported here shows how the characteristic is non-resonant unlike open or shorted transmission lines, which have the ability to store broadband frequencies in a compact size.

A typical back to back coplanar waveguide (CPW) in the form of a Möbius strip was constructed which resulted in an infinite transmission line capable of retaining a large bandwidth of frequencies that can be useful for real time signal retention device (RTRD).[14] By providing a Möbius twist to CPW, a continuous phase change was reported instead of abrupt phase change by using shorting pins between two parallel transmission lines. It is observed that the device retains the injected signal in time domain over a broadband of frequencies. The signal can also be a pulsed signal as in ultrawideband (UWB) or a modulated microwave signal to retain transient signals encountered in radio astronomy, medical applications and many others. ***Figure 17*** shows a photograph of the prototype Möbius strips for the application as signal retention device.

As shown in Figure 17, the central partition plane acts more as a separa-

▲ *Fig. 17 A prototype Möbius strip with SMA connectors.*[14]

tion between the top and bottom layers to prevent coupling. The spacing between the central conductor and ground plane on the coplanar side is much smaller than the thickness of the substrate leading to maximum field confinement on the surface. There exists a discontinuity in the partition ground planes. This characteristic is taken into account for futuristic study while developing the mathematical model for the infinite strip. Ground looping was avoided to realize the infinite transmission line at the cost of generation of higher order modes.

Agilent FieldFox RF Analyzer N9912 was used to test the proof of concept.[17-19] This instrument has a single port S-parameter testing capability (VNA) along with cable testing facility; in addition it contains a spectrum analyzer up to 6 GHz. The test setup is as shown in ***Figure 18***. First, the return loss was tested from 2 to 6 GHz with one of the ports terminated with 50 ohms. It was observed that the device has a return loss between 8 and 20 dB over the frequency range. This indicates that the device is exhibiting broadband behavior and the signal is getting coupled to it. In other words, the continuous central conductor is getting excited over a broadband of frequencies. The Smith Chart display shows the excitation of the signal to the continuous center conductor of the device over a bandwidth of 4 GHz. In this way, the device exhibits an infinite transmission line. The return loss response of more than 10 dB indicates that the energy is efficiently coupled to the device over a bandwidth of 4 GHz.

The VNA shown in Figure 18 was switched to cable and antenna testing mode to check the delay response in real time (see ***Figure 19***). In this way the retention of the signal can be tested. The instrument converts the measured frequency response into time domain response by performing inverse fast Fourier Transform (IFFT). The measured results as expected are a gradual decay of the signal after every transit around the loop. Thus test-

▲ *Fig. 18 Agilent FieldFox RF analyzer N9912 with the device connected — the Smith Chart indicates the broadband coupling of signal into the device.[14]*

▲ *Fig. 19 The VNA was switched to cable and antenna testing mode to check the delay response in real time of the Möbius strips shown in Figure 16.[14]*

ing of the device has confirmed the retention of the signal in real time over broadband of microwave frequencies. The total span time is around 200 milliseconds. The physical length of the loop is 30 cm. The markers as indicated are at 0.72, 0.89, 0.98, 1.05, 1.13 and 1.46 m. This indicates multiple transit of the signal around the loop. It also shows the broadband retention characteristics since it is derived from the frequency response of the device.

To verify the effect of signal retention device (SRD) performance, different loop lengths (45, 60 and 75 cm) was made and the testing is reported in Big Loop. The performance was similar to 30 cm SRD with edge coupled input.

The signal travels twice around the loop before arriving at the feeding point, the first signal is at twice the length of the loop which is at 72 cm. The decay of the signal over the time indicates the coupling of the power at the output port along with the losses, considering the radiation losses are minimal. This behavior calls for extensive mathematical modeling of the device. The unusual behavior could be due to the magnetic field coupling between the top and bottom layers. This will result in a distributed mutual inductance between the layers. This characteristic is similar to non-inductive resistor design.[9] The interesting frequency response of the device calls for rigorous three dimensional mathematical modeling and analysis using Maxwell's equations and shall lead to considerable research in the field of signal retention.

The Möbius co-planar structure proposed in Figure 17 for signal retention is analog by nature and is an economical solution for signal retention.[14] It is observed that the device retains the injected signal in time domain over a broadband of frequencies. The signal can also be a pulsed signal as in UWB or a modulated microwave signal. It can retain transient signals encountered in radio astronomy, medical applications and many others. The device is truly analog and can improve the performance of an analog to digital converter (ADC). One can use a lower speed digital signal processing (DSP) since one has the same signal available for a considerable duration of time in a repetitive manner. It is also feasible to fabricate the device using rapid prototyping MEMS applications. This will open up many more exciting millimeter wave applications such as microwave sensors for remote sensing and detection of hidden objects, to find concealed explosives and hazardous chemicals.

MÖBIUS COUPLED RESONATOR STRIPS: DISCUSSION

Abnormal Behavior: Unlike any resonant structure, the return loss was observed to be around the center of the Smith Chart, which is non-resonant behavior from 2 MHz to 6 GHz. Based on our observation, any loop was exhibiting resonant nature and the response was touching the outer edge of the Smith Chart, in other words the input impedance moved from short to open.

Testing of Loop: A CPW guide with quadrature coupler was made

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MSW2001–200	T-R Switch, TX Left	+V Only	MPD2T28125-700	400 to 4,000
MSW2002–200	T-R Switch, TX Left	+V Only	MPD2T28125-700	2,000 to 6,000
MSW2022-200	T-R Switch, TX Right	+V & -V	MPD2T5N200-702	2,000 to 6,000
MSW2050–205	T-R Switch, TX Left	+V Only	MPD2T28125-700	20 to 1,000
MSW2051–205	T-R Switch, TX Left	+V Only	MPD2T28125-700	400 to 4,000
MSW2030–203	Symmetrical SP2T	+V Only	MPD2T28125-700	10 to 1,000
MSW2031–203	Symmetrical SP2T	+V Only	MPD2T28125-700	400 to 4,000
MSW2032–203	Symmetrical SP2T	+V Only	MPD2T28125-700	2,000 to 6,000
MSW2040–204	Symmetrical SP2T	+V Only	MPD2T28125-700	50 to 1,000
MSW2041–204	Symmetrical SP2T	+V Only	MPD2T28125-700	400 to 4,000
MSW2060-206	Symmetrical SP2T	+V & -V	MPD2T5N200-702	10 to 1,000
MSW2061-206	Symmetrical SP2T	+V & -V	MPD2T5N200-702	400 to 4,000
MSW2062-206	Symmetrical SP2T	+V & -V	MPD2T5N200-702	2,000 to 6,000
MSW3100–310	Symmetrical SP3T	+V Only	MPD3T28125-701	10 to 1,000
MSW3101–310	Symmetrical SP3T	+V Only	MPD3T28125-701	400 to 4,000
MSW3200-320	Symmetrical SP3T	+V & -V	MPD3T5N200-703	10 to 1,000
MSW3201-320	Symmetrical SP3T	+V & -V	MPD3T5N200-703	400 to 4,000
MSW4102-410	Symmetrical SP4T	+V Only	MPD2T28125-700 (2 each)	4,000 to 6,000
MSW5000-500	Symmetrical SP5T	+V Only	MPD2T28125-700 & MPD3T28125-702 (1 each)	30 to 512
MSW6000-600	Symmetrical SP6T	+V Only	MPD3T28125-702 (2 each)	30 to 512
MSWLM2420-242	Asymmetric T-R with Rx limiter	+V Only	MPD2T28125-700	2,000 to 4,000

+V Only = +5 V and +28 V to +125 V
+V & -V = +5 V and -28 V to -200 V

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into a simple loop and tested for performance. The purpose of this was to isolate the effect of the twist. It was found that the loop behaves like a resonant circuit with multiple frequencies and S11 touched the 0 dBm axis.

Video Recording: The Yagi antenna was connected to the spectrum analyzer with and without the signal retention device. This is to check whether the device retains pulsed RF waveforms. A cell phone was kept nearby and the filming was done using a digital camera. The uplink from the cell phone is a burst signal. There is a repetitive appearance of the signal on activating the cell phone when the device was connected indicating the retention of burst signal.

CONCLUSION

The signal retention device developed here has the ability to store a very broad band of frequencies. It also has the ability to store a transient signal for delayed analysis. This property of the device is extremely useful in many applications including radio astronomy, medical fields and software driven radios, real-time retention of signals for signal processing, and frequency memory loop in electronic warfare. This device will be less 'noisy' compared to digital storage devices, can be very useful in software driven radios and help in soft handover from one system to another and other applications. ■

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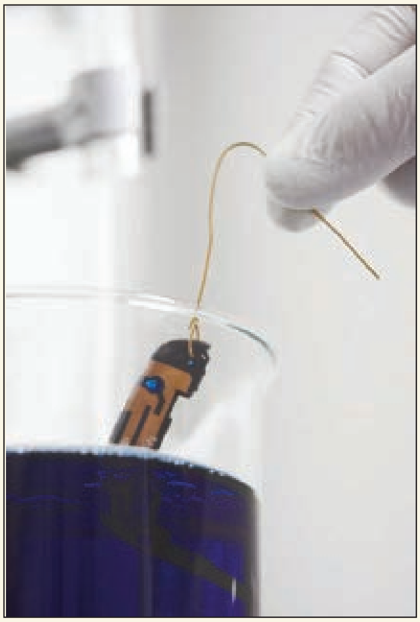
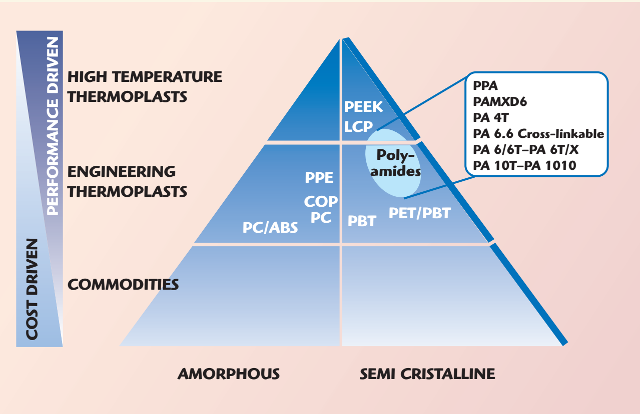


A Shortcut to 3D-MID Prototypes

Laser Direct Structuring (LDS) has become well established, especially in the field of antennas. However, through development work at LPKF, new procedures and a simplified prototyping process are now expanding the possibilities for its application. Three-dimensional molded interconnect devices are particularly suitable when mechanical and electronic functions need to be combined with one another or if the space requirement and weight of the component is a major factor.

Laser direct structuring has established a good name for itself with molded interconnect devices (MID). In the process, a plastic containing an additive is structured by a laser, whereby the laser process exposes the additive and creates a micro-rough surface. The surface has fine cavities that ensure good adhesion with the material of the conductor layers.

In the subsequent currentless metallization bath, which is the next sequence in the



▲ *Fig. 1 The material range of deliverable LDS plastics.*

LPKF Laser & Electronics AG
Garbsen, Germany

process, a conductor layer is built up on the structures. In this process, strip conductor thicknesses of circa 10 µm are possible; a finish with nickel and gold can follow. In the standard version, the laser systems in the LPKF Fusion3D line can securely create conductor structures with a pitch of 200 µm (100 µm/100 µm line/gap); optional fine pitch systems with modified fine focus optics can reach a pitch of 150 µm (75 µm/75 µm line/gap).

For the RF sector, the broad range of materials is interesting. Nearly all well-known manufacturers have LDS-capable variants of their plastics on offer, including polyamides that can be cross-linked by irradiation and are thus solderable. ***Figure 1*** shows the material range of deliverable LDS plastics.

This state of LDS technology is well known and proven. A range of well-known OEMs utilize LDS technology in order to attach antennas for smartphones or tablet computers on existing structural components. A radar system also uses an LDS component for an adaptive speed control system.

COMPREHENSIVE PROTOTYPING

The basic idea of the new LDS prototyping process is in coating a component with an activatable surface. Any additively produced plastic components can be used as base bodies. The resolution is what matters: the processes – selective laser sintering (SLS) and stereolithography (SLA) – have roughness values that allow reliable further processing.

The base body thus produced is coated with paint. This paint includes the LDS additives. In contrast to the process previously offered, usually a single thorough coating of paint suffices. The new LPKF ProtoPaint LDS paint comes in a spray can (see ***Figure 2***) and is activated before the first painting.

For RF applications, MID materials replace the substrate material. RF substrate materials have well known electric properties over the entire frequency range. The same can be achieved for LDS-MID materials or by using general purpose materials and painting them with LPKF ProtoPaint LDS.

For the second step, LPKF presents a completely new laser system, which structures the coated prototypes. The laser optics used correspond to those

▲ *Fig. 2 Circuits from a spray can: LPKF ProtoPaint LDS.*

of production systems but are placed in a compact enclosure. The proven LPKF ProtoLasers serve as the basis for PCB prototyping.

Their working range is decoupled from the carrier structure by means of damping elements and they can be moved on rollers through any laboratory door. The ProtoLaser 3D (shown in ***Figure 3***) requires only a socket outlet and an exhaust. It has a height-adjustable work platform so as to structure components of different dimensions. The working range is 300 × 300 × 50 mm and the scanning field is 100 × 100 × 25 mm.

The third step to a functional prototype is metallization and a ready-to-use solution is also available for this. With LPKF ProtoPlate LDS, a process can now be delivered for currentless metallization of structured LDS components. It consists of a protective enclosure for process guidance and an already prepared combination of bath chemicals as the consumable component. The metallization process (see ***Figure 4***) is as easy as making coffee.

The base metallization is poured into the beaker from the canister that is supplied and brought to the working temperature of around 44°C in the beaker. A pre-proportioned activator solution starts the process and the components are then simply immersed in the bath. The thickness of the copper layer – generally in the range of

▲ *Fig. 3 The LPKF ProtoLaser 3D can structure LDS parts in different angles.*

▲ *Fig. 4 The LPKF ProtoPlate LDS systems make metallization of LDS parts easy.*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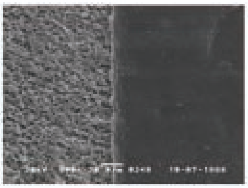
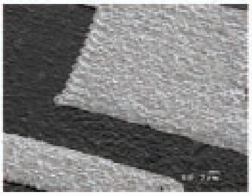
THE LDS PROCESS

The injection-molded component from a thermoplast with LDS-activated additive.



The laser activates the additive and creates a micro-rough surface for good adhesive strength.



Metal layers on the activated paths are built up in metallization.

▲ *Fig. 5 LDS antennas offer full 3D shaping for maximum design freedom (Image: Leibnitz University Hannover, C.Orlob).*

3 to 10 μm – depends on the bath temperature and the dwell time. This can be easily seen on a graph. After metallization, the consumed bath chemicals are put back into the canister, marked with a label that is supplied and then can be easily disposed of.

With the new prototyping process, the gap between design and serial production is closed. With respect to three-dimensional antennas (see ***Figure 5***) or circuits, various layouts can be quickly and inexpensively created on components and checked for their suitability. The costs of the prototyping process is also considerably lower than with previous processes, since neither tools nor component fittings have to be built and the prototyping laser is considerably less expensive than the more complex systems for industrial production.

Finally, RF developers don't have to do without their trusted materials: with ProtoPaint LDS, each component becomes LDS-capable and can be protected from environmental influences by protective paint, Metal Organic Fragmentation (MOF) or Electroless Nickel Electroless Palladium Immersion Gold (ENEPIG) coatings.

LPKF Laser & Electronics AG, Garbsen, Germany, www.lpkf.com.

Executive Interview

__Dr. Ingo Bretthauer__, CEO of __LPKF Laser & Electronics AG__, explains how the PCB prototyping and micromachining company has developed from its early days in Germany in the 1970s to become a 21st century operation with a global reach. Visit www.mwjournal.com to read this in-depth interview.

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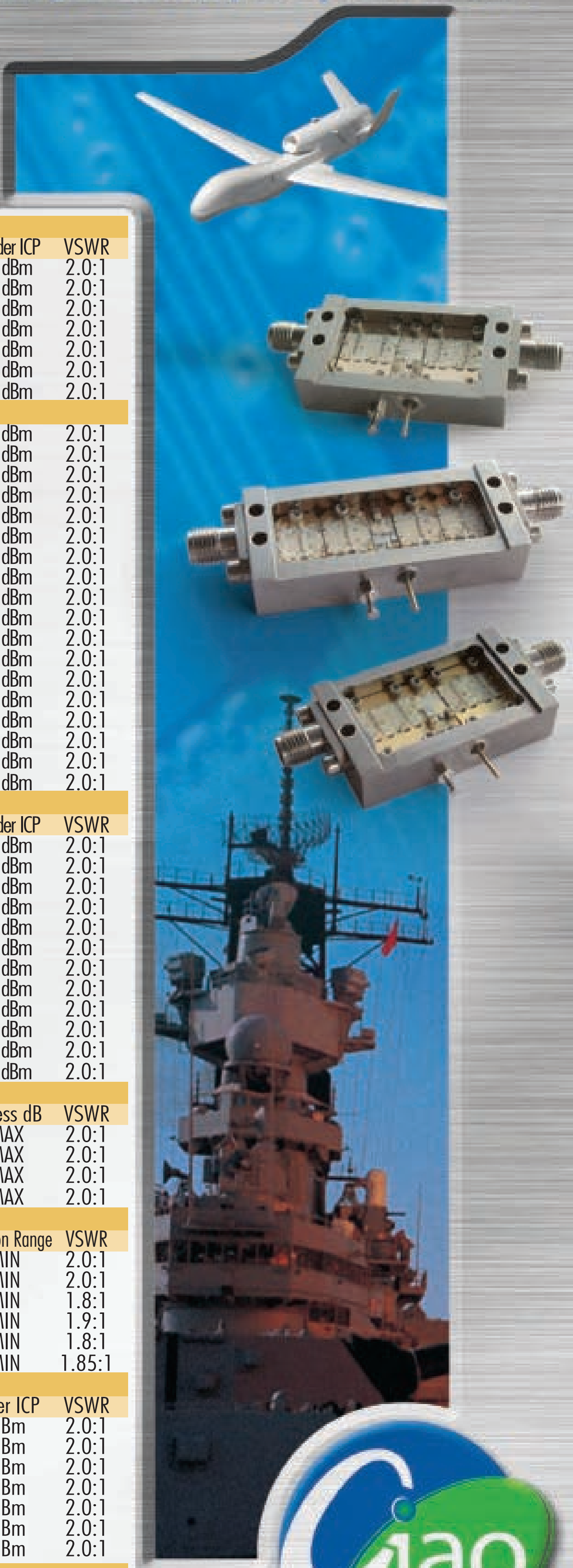

OCTAVE BAND LOW NOISE AMPLIFIERS

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

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

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

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

LIMITING AMPLIFIERS

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

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

LOW FREQUENCY AMPLIFIERS

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

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EW Technology to Detect and Counter Emerging Radar Threats

On the modern battlefield, the use of electronic warfare (EW) is essential to deceiving and jamming enemy radar. As part of a program known as Adaptive Radar Countermeasures (ARC), BAE Systems will develop technology for a next-generation EW algorithm suite that will enable existing EW systems to operate against emerging radar threats, providing an essential capability to achieve air dominance. The company was awarded phases 1A and 1B of a three-phase, $34.9 million five-year effort.

"This technology will provide a revolutionary capability to EW systems on U.S. military airborne platforms to counter adaptive radar threats and significantly improve survivability," said Joshua Niedzwiecki, director of strategic development at BAE Systems. "To rapidly detect and characterize a never-before-seen radar threat, synthesize an electronic countermeasure, and then assess effectiveness in a tactically relevant timeframe is a major battlefield advantage."

Particular emphasis will be on countering never-before-seen threats…

Funded by the Defense Advanced Research Projects Agency (DARPA), the ARC program will leverage advances in signal processing and machine learning to develop intelligent algorithms that detect and counter emerging adaptive radar threats. Particular emphasis will be on countering never-before-seen threats with waveform characteristics and behaviors that are unknown. By focusing on algorithms, the ARC program will develop technology that can be implemented as a software upgrade to a wide range of existing and emerging EW systems, providing a major capability enhancement without the need for costly hardware upgrades.

Raytheon's SM-3, AN/TPY-2 Successful in Operational Ballistic Missile Defense Test

Raytheon Co.'s Standard Missile-3 Block IA guided missile and AN/TPY-2 ballistic missile defense radar played integral roles in the success of Flight Test Operational-01, the Missile Defense Agency's operational test of the U.S. Ballistic Missile Defense System.

During the test, a SM-3 Block IA guided missile fired from the USS Decatur (DDG 73) intercepted a medium-range ballistic missile target. An AN/TPY-2 radar, operating in forward-based mode, detected, discriminated and tracked the target throughout the target's trajectory.

"The SM-3 and AN/TPY-2 are two indispensable elements of the Ballistic Missile Defense System," said Dr. Taylor W. Lawrence, president of Raytheon Missile Systems. "This operational test proves our nation has capable, reliable systems deployed today defending the U.S. and its allies against the growing ballistic missile threat."

Adding to the complexity of the test, a terminal-mode AN/TPY-2 radar also detected, tracked and discriminated the threat. This capability enables additional engagement opportunities, allowing for a "shoot-access-shoot" layered missile defense if necessary.

"As ballistic missiles continue to proliferate and the weapons become more sophisticated, it's imperative the U.S. and our allies have proven, reliable defensive systems like SM-3 and AN/TPY-2," said Dan Crowley, president of Raytheon's Integrated Defense Systems business. "SM-3 and both modes of the AN/TPY-2 are deployed around the world today, protecting warfighters, civilians and critical infrastructure."

"The SM-3 and AN/TPY-2 are two indispensable elements of the Ballistic Missile Defense System..."

AN/TPY-2 is a high resolution, mobile, rapidly deployable X-Band radar capable of providing long-range acquisition, precision track, and discrimination of short-, medium- and intermediate-range ballistic missiles. The AN/TPY-2 may be deployed globally in either terminal or forward-based mode.

AN/TPY-2 has performed flawlessly in both terminal and forward-based mode in all major tests.

On October 25, 2012, two AN/TPY-2 radars – one terminal and one forward-based – participated in FTI-01, the MDA's largest and most complex exercise. In a complex raid scenario involving multiple targets, both radars met or exceeded all test objectives.

On April 15, 2011, a forward-based AN/TPY-2 extended the battlespace by providing fire control-quality track data to an Aegis BMD ship, which fired a Standard Missile-3 using launch on remote capability, which resulted in a successful intercept of a separating intermediate range ballistic missile.

Raytheon has delivered eight AN/TPY-2s to the Missile Defense Agency. Some of those radars are currently helping defend the U.S. and its allies in the European, Pacific and Central Command areas of responsibilities.

The SM-3 destroys incoming ballistic missile threats by colliding with them, a concept sometimes described as "hitting a bullet with a bullet." The impact is the equivalent of a 10-ton truck traveling at 600 mph.

Aegis BMD has demonstrated 26 successful intercepts in 32 at-sea events, including the successful intercept of a non-functioning satellite during Operation Burnt Frost in February 2008.

Aegis BMD 3.6 Weapon System and the SM-3 Block IA were assessed as operationally suitable and effective by an independent operational test agency in 2008.

More than 160 SM-3s have been delivered to U.S. and Japanese navies.

Go to mwjournal.com for more defense news items

LONGBOW LLC Receives $51M for RoK Apache Radar Systems

The LONGBOW Limited Liability Co., a joint venture of Lockheed Martin and Northrop Grumman, received a $51 million foreign military sales contract to provide the Republic of Korea with LONGBOW Fire Control Radars (FCR) for the AH-64E Apache attack helicopter.

The contract includes six LONGBOW FCR systems, spares and in-country support. Production is scheduled through 2016, with assembly of the LONGBOW FCR performed at Lockheed Martin's Ocala and Orlando, FL, facilities, and Northrop Grumman's Baltimore, MD, facility.

Source: U.S. Army

"The Republic of Korea is the 10th international customer for LONGBOW systems," said Tom Eldredge, LONGBOW LLC president and director of LONGBOW programs at Lockheed Martin Missiles and Fire Control. "The LONGBOW FCR is a battle-proven radar system that will provide Republic of Korea Apache pilots with increased situational awareness, survivability and lethality."

U.S. Army Issues GD New Order

The U.S. Department of Defense has authorized the Army to proceed with a follow-on order of Warfighter Information Network-Tactical (WIN-T) Increment 2 (Inc 2). The Army awarded General Dynamics C4 Systems a delivery order valued at approximately $111 million to procure the next lot of WIN-T Inc 2 network nodes for additional brigade combat teams and division headquarters units. WIN-T Inc 2 is a central component of current and future capability sets.

Continued fielding of the WIN-T Inc 2 network builds on the system's success achieved over the summer when WIN-T Inc 2 was deployed in its first combat patrol in Afghanistan, using its on-the-move capability between several network nodes. The first brigade-level deployment of the WIN-T Inc 2 system is currently supporting soldiers with the 4th Brigade, 10th Mountain Division (4/10) in Afghanistan. Their mission to support Afghan security forces involves communications across dispersed forces in some of the most rugged, remote locations in Afghanistan.

In response to the system's first combat deployment over the summer, Maj. Gary Pickens, communications officer for the 4/10, said in a previously published Army article, "The enhanced situational awareness given to us by this suite of technology has allowed us to maintain a 'digital guardian angel' as we conduct our advising duties and missions… The various platforms of (Capability Set 13) give us a digital reach like we've never had before."


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European Electronics Companies Set to Invest €100B

A newly formed group of electronics CEOs met to begin a new push to put Europe on the leading edge in the design and manufacturing of micro-electronics and nano-electronics. The recently adopted European Electronics Strategy aims to achieve a number of milestones by 2020: to facilitate industry investment of €100 billion; to double the value of EU micro-chip production; and, in the process, to create 250,000 new direct jobs in Europe.

The Electronics Leaders Group (ELG) brings together the leaders of Europe's 10 largest semiconductor and design companies and equipment and materials suppliers and of the three largest research technology organisations. These include STMicroelectronics, Infineon, NXP, ASML and imec. The ELG will establish, by the end of 2013, a strategic roadmap showing how they can reverse the downward trend of chip production in Europe.

"European Electronics Strategy aims to…double the value of EU micro-chip production…"

Speaking ahead of the meeting, European Commission vice president Neelie Kroes said: "The October European Council will discuss the digital revolution that is changing the way we live. Europe's industry, from cars to healthcare increasingly depends on electronics. They are part of people's lives in a way we could not have predicted 10 years ago. The role that European companies play in that digital revolution depends on your ideas and on your products".

In preparing their roadmap, the core ELG will work closely with an open Stakeholder Engagement Forum which will bring together representatives of the industries which depend on the electronics, which the ELG's members produce, equipment and materials suppliers, foundries and integrating companies, all of whom have operations in Europe and who, together, make up the European Electronics sector which employs 2.46 million people in Europe today.

ITU Reveals Growth in ICT

Mobile broadband over smartphones and tablets has become the fastest growing segment of the global information and communication technology (ICT) market, according to the International Telecommunication Union (ITU) annual report, "Measuring the Information Society 2013." The report reveals buoyant global demand for ICT products and services, steadily declining prices for both cellular and broadband services and unprecedented growth in 3G uptake.

By the end of 2013, there will be 6.8 billion total mobile-cellular subscriptions – almost as many as there are people on the planet. An estimated 2.7 billion people will also be connected to the Internet – though speeds and prices vary widely, both across and within regions.

Mobile broadband connections over 3G and 3G+ networks are growing at an average annual rate of 40 percent, equating to 2.1 billion mobile-broadband subscriptions and a global penetration rate of almost 30 percent. Almost 50 percent of all people worldwide are now covered by a 3G network.

The report reveals …unprecedented growth in 3G uptake.

New data reveals that the Republic of Korea leads the world in terms of overall ICT development for the third consecutive year, followed closely by Sweden, Iceland, Denmark, Finland and Norway. The Netherlands, the United Kingdom, Luxembourg and Hong Kong (China) also rank in the top 10.

"This year's ICT Development Index (IDI) figures show much reason for optimism, with governments clearly prioritizing ICTs as a major lever of socio-economic growth, resulting in better access and lower prices," said ITU secretary-general Dr. Hamadoun I. Touré. "Our most pressing challenge is to identify ways to enable those countries which are still struggling to connect their populations to deploy the networks and services that will help lift them out of poverty."

New European Research Database Launched

A new public database of Europe's finest scientific research facilities has been launched to better inform policy makers about the deployment of science funding and to help scientists locate and access the most appropriate equipment and services to support their research. This new tool is likely to contribute significantly to the success of Horizon 2020 – the European Commission's €70 billion programme for research and innovation for the period 2014 to 2020.

The Mapping of the European Research Infrastructure Landscape (MERIL) database aims to provide a comprehensive inventory of high quality research infrastructures in Europe across all scientific domains, accessible through an interactive online portal. It will provide a better picture of Europe's existing scientific capacities and foster collaboration amongst the European scientific community by compiling information on high quality facilities of any size and profile, from specialised university laboratories and historical archives to biobanks and experiments at large establishments.

Research infrastructures indexed in the MERIL portal have been identified as being of high quality and of greater than national relevance by responsible national and international 'Data Intermediaries;' they are also required to

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offer access to external scientific users, nationally and internationally, through a transparent selection and admission process. The database will be continuously open to the addition of research infrastructures that meet the criteria for inclusion.

"Research excellence requires high quality facilities..."

Martin Hynes, chief executive, European Science Foundation, commented, "Research excellence requires high quality facilities which not only support research but also create an attractive environment for researchers. MERIL is a unique resource for the scientific community and we hope it will foster greater interaction, mobility and a sense of partnership across the region."

MIPI Alliance Pushes the Envelope

The MIPI® Alliance, an international organization that develops interface specifications for mobile and mobile-influenced industries, announced the availability of its Analogue Reference Interface for Envelope Tracking (eTrak) specification. eTrak is a multi-source vendor, independent interface that provides interoperability between multiple 3G/4G modem chipsets and envelope tracking power supplies (ETPS), enabling wide deployment of envelope tracking technology.

By integrating eTrak into RF modem chipsets and ETPS, the specification allows modem ICs to control the supply voltage of RF power amplifiers, which improves the efficiency of the transmitter, one of the three large power consuming elements in a mobile device. Previous fixed proprietary alternatives did not allow manufacturers the benefits of an industry standard solution including improved efficiency and lower costs. eTrak is said to be unique in that unlike other MIPI specifications, it provides a full analogue interface, not just a PHY.

...enabling wide deployment of envelope tracking technology.

"MIPI's eTrak specification benefits any 3G or 4G mobile device – cell phones, tablets, data cards, to name a few. We do expect the greatest benefit of envelope tracking to be in lowering power consumption and improving battery life for high data rates communications like LTE and LTE-Advanced," said Joel Huloux, board chairman of the MIPI Alliance. "We are already seeing modem vendors and ETPS vendors incorporating the specification into their products to ensure compatibility. OEMS have also expressed excitement for eTrak as well because it gives them flexibility in selecting components for their products and platforms."

More Than 50% of Remote Controls Shipped in 2018 will be RF Enabled

In 2013, 10 percent of the remote controls shipped with major home consumer equipment will be RF-enabled. Over the next five years there will be a major surge in RF technology adoption for remote controls as vendors look to differentiate their products, and/or drive growth in smart home services. While at the same time RF solutions continue to fall in price, implementations become more simplified and lower powers are achieved.

"RF technology has been considered for use in remote controls for many years but its adoption has been limited by a lack of perceived need among device vendors and prohibitive increases in associated costs when compared to IR solutions," according to Peter Cooney, ABI Research practice director. "However, over the last five years there has been an upswing in technology development and a rise in the need to make home consumer devices smart that has led to resurgence in using RF."

"The remote control market represents a massive growth opportunity for wireless connectivity technology…"

Initially proprietary RF technology was used but equipment vendors have been quick to understand the benefits of using a standardized RF technology in remote control design. Three main interoperable standards are seeing adoption: Bluetooth, Wi-Fi and ZigBee RF4CE. Each technology is seeing use in certain sections of the market with vendors choosing to implement a particular technology due to its individual strengths, be it ultra-low power, high bandwidth, or another important feature.

Bluetooth and ZigBee have been the most widely used technologies to date and are expected to see significant growth, with increasing competition from Wi-Fi as lower power solutions continue to be developed.

"The remote control market represents a massive growth opportunity for wireless connectivity technology vendors," added Cooney. "Over 3.2 billion remote controls will be shipped from 2013 to 2018 with flat panel TVs, set-top boxes, DVD/Blu-ray devices and games consoles alone."

9.7 Million Carrier Wi-Fi Access Point Shipments in 2018

Carrier Wi-Fi started to gain momentum in 2013 driven by increasing data demands and new Wi-Fi advancements. Cable operators are enthusiastically adopting the technology as an entrance into the wireless market. ABI Research forecasts Carrier Wi-Fi access point shipments in 2018 to reach 9.7 million with the Asia-Pacific region accounting for 70 percent of that number.

In the U.S., a very successful model was deployed by Cable WiFi: an alliance formed of five of the biggest cable operators in the country including Bright House Networks, Comcast, Cablevision, Cox and Time Warner Cable. Customers of any of the alliance members can roam seamlessly in the biggest Wi-Fi network in the U.S. with more than 150,000 hotspots. "While it is a great marketing strategy allowing cable operators to retain their customers and enhance the service, Cable WiFi also shows that monetization is a possibility for roaming," commented Ahmed Ali, research analyst at ABI Research.

"The significant improvements in Wi-Fi capacity and data rates make adopting Wi-Fi solutions, in general, more appealing to operators…"

Deploying carrier Wi-Fi can be more challenging for mobile operators due to the complexities of integrating Wi-Fi with wireless networks. Nevertheless, mobile operators in markets like the U.S., Japan and South Korea, such as AT&T, KDDI and SK Telecom, are driving forward with plans, having already built extensive Wi-Fi networks in their markets and also feeling the most pressure from the data tsunami.

Both carrier Wi-Fi and Wi-Fi technology experienced significant technical developments in 2013. The standardization process sponsored by the Wireless Broadband Alliance is gaining more recognition as it finishes its 2nd phase and enters the 3rd phase. The Wi-Fi Alliance has also been very active preparing for Release 2 of Passpoint and announcing new Wi-Fi certification programs, Wi-Fi CERTIFIED™ ac and WiGig CERTIFIED™. Both programs focus on the provisioning of high data rates – 1.3 and 7 Gbps respectively. "The significant improvements in Wi-Fi capacity and data rates make adopting Wi-Fi solutions, in general, more appealing to operators. Seamless access to high data rate Wi-Fi is helping to shape user expectations and behavior in the cellular network creating a traffic onload effect counter to offload benefits," continued Ali.

Worldwide Total Semiconductor Market to Grow 3% in 2013 to Reach $298 Billion

The worldwide semiconductor market is expected to grow 3 percent from 2012 to 2013. There has been sequential market growth from 1Q13 to 2Q13 and the vast majority of the top 20 vendors are expecting 3Q13 to grow revenues again.

"It has been a tough few years for the semiconductor industry. While we haven't seen a dramatic decline in overall revenues since the 2008/2009 period, the market has been pretty stagnant since 2010," comments Peter Cooney, practice director. "We will see some growth in 2013 as the wider economic environment improves but major market

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growth is not expected until later in 2014/early 2015."

Consolidation continues to be rife in the industry: a number of major mergers and acquisitions are expected to take place in the second half of 2013; these include the merger of Fujitsu and Panasonic semiconductor divisions and the acquisition of Elpida by Micron. There have also been many smaller M&A transactions such as Intel's acquisition of ST-Ericsson GPS business and Broadcom's acquisition of Renesas Mobile's LTE assets as major vendors exit the mobile device semiconductor market.

"As the semiconductor market has been squeezed we have seen an increase in consolidation amongst the major players," adds Cooney. "Margins are falling and the competitive environment is tough – especially in the mobile device market – this is driving vendors to re-evaluate their overall strategy and pull out of some of their once major markets. We have seen a number of major vendors exit the mobile device market – Freescale, TI, STMicroelectronics and Renesas and we expect there are more to come."

140 Million Unit Shipments of FCWS and LDWS by 2020

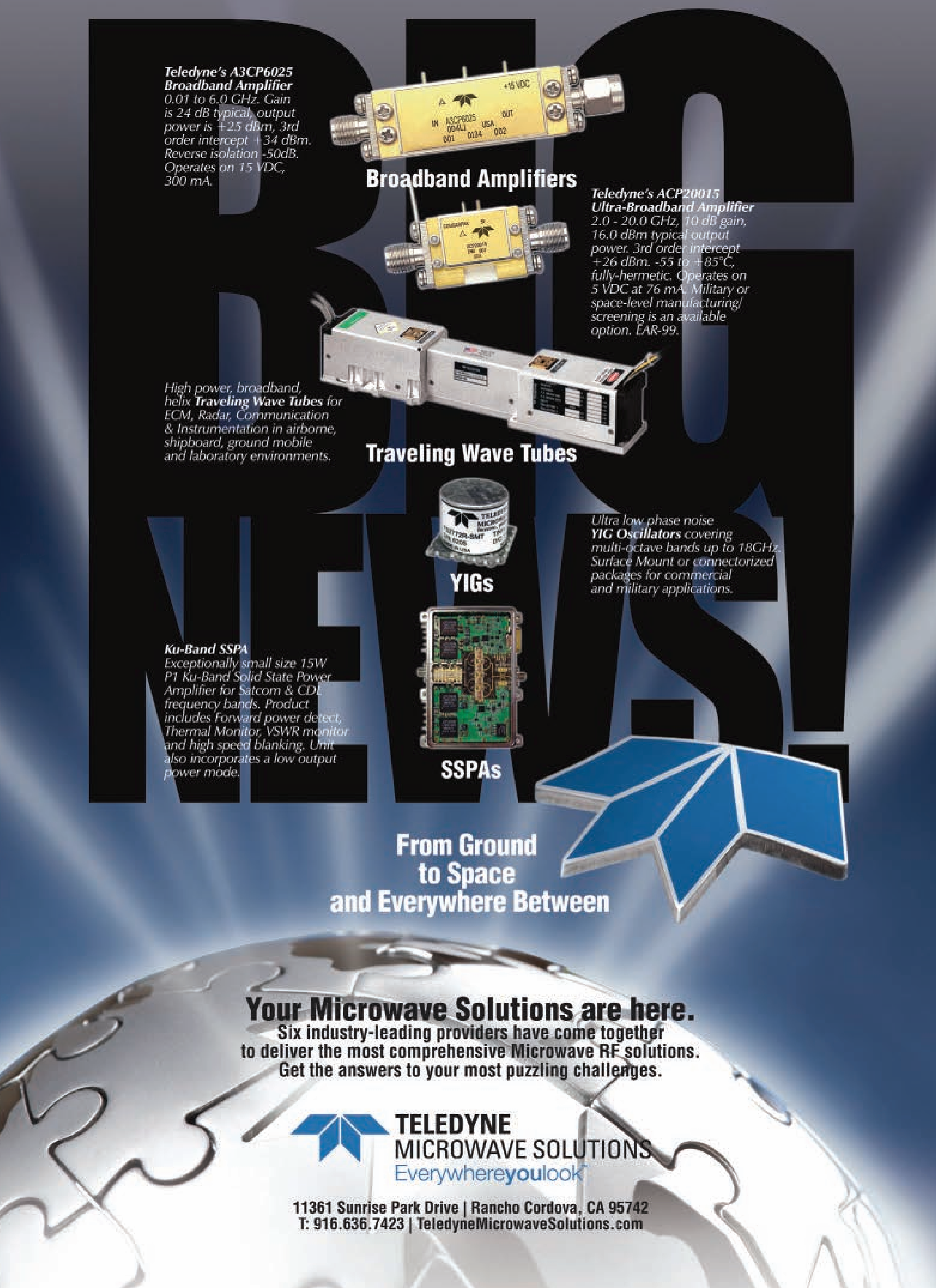
ABI Research forecasts that the global market for front collision warning systems (FCWS) and lane departure warning systems (LDWS) will increase from 6.6 million units at the end of 2012 to 140.1 million units by the end of 2020.

Although a number of OEMs already offer speed assist and driver monitoring systems as standard in their vehicles, the main focus of OEMs currently is on FCWS and LDWS, both of which are key ADAS systems specified in the EuroNCAP specifications.

The present EuroNCAP specifications for ADAS systems are mainly focused on low-speed or urban-type driving environments which means that optical cameras, (despite their limitations in poor visibility conditions) will be the most popular sensor used for obstacle detection, lane departure warning and blind spot detection.

However, advancements in technology coupled with an expected drop in prices, means that radar sensors will increasingly be deployed in mass-market vehicles over the next three years. "Radar sensors work in all weather conditions, but until now have been confined to front-facing applications in luxury car brands," comments Gareth Owen, principal analyst at ABI Research. "As volumes increase and costs decrease, multiple radar sensors will be fitted all around a vehicle which will be used for other applications."

The increasing adoption of ADAS systems is an essential part of the drive toward autonomous vehicles. In fact, semi-autonomous vehicles are already a reality today with a number of OEMs deploying or announcing plans to include innovations such as traffic jam assistants (which can control the steering and keep a car 'in-lane' at low speeds) and parking assistants (which can park a car automatically without any intervention from the driver).


BIG NEWS!
Teledyne's A3CP6025 Broadband Amplifier
0.01 to 6.0 GHz. Gain is 24 dB typical, output power is +25 dBm, 3rd order intercept +34 dBm. Reverse isolation -50dB. Operates on 15 VDC, 300 mA.
Broadband Amplifiers
Teledyne's ACP20015 Ultra-Broadband Amplifier
2.0 - 20.0 GHz, 10 dB gain, 16.0 dBm typical output power. 3rd order intercept +26 dBm. -55 to +85°C, fully-hermetic. Operates on 5 VDC at 76 mA. Military or space-level manufacturing/ screening is an available option. EAR-99.
High power, broadband, helix Traveling Wave Tubes for ECM, Radar, Communication & Instrumentation in airborne, shipboard, ground mobile and laboratory environments.
Traveling Wave Tubes
YIGs
Ultra low phase noise YIG Oscillators covering multi-octave bands up to 18GHz. Surface Mount or connectorized packages for commercial and military applications.
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Around the Circuit

Laura Glazer, Staff Editor

MERGERS & ACQUISITIONS

Agilent Technologies announced plans to separate into two publicly traded companies: one in life sciences, diagnostics and applied markets (LDA) that will retain the Agilent name, and the other that will be comprised of Agilent's current portfolio of electronic measurement (EM) products. The separation is expected to occur through a tax-free pro rata spinoff of the EM company to Agilent shareholders. Bill Sullivan is president and CEO of Agilent, and Didier Hirsch continues as CFO. Ron Nersesian, who has been Agilent's president and COO, is executive VP of Agilent and president and CEO-designate of the new EM company. Neil Dougherty, who has been Agilent's VP and treasurer, is VP of Agilent and CFO-designate of the new EM company.

Bird Technologies announced that is has acquired **DeltaNode** from Scandinavian Health Ltd. (SHL Group) for an undisclosed amount of cash. The transaction was completed on September 1. Founded in 2005 by a group of engineers with decades of wireless experience, DeltaNode is a supplier of RF-over-fiber distributed antenna systems and repeaters designed to enhance the coverage of commercial wireless and public safety communication systems. DeltaNode will continue to operate from its facilities in Stockholm, Sweden.

Molex Inc. announced that it has completed the acquisition of **FCT Electronics Group**, based in Munich, Germany. FCT Electronics Group specializes in designing and manufacturing custom mixed-layout connectors and cable assemblies. This strategic acquisition is expected to expand the presence of Molex solutions in the global medical electronics, industrial, telecom and aerospace industries.

COLLABORATIONS

L-3 TRL Technology (L-3 TRL) announced that it is working with **Avanti Communications** to provide secure Ka-Band satellite services to government and military agencies that use L-3 TRL's CATAPAN® encryption devices for direct high-speed connectivity. Coverage includes parts of Europe, the Middle East, the Caucasus region and Africa.

Alcatel-Lucent and **Corporacion Nacional de Telecomunicaciones** (CNT) deployed the first 4G LTE high-speed mobile broadband network in Ecuador, covering the cities of Guayaquil, Cuenca, Machala and Loja, as well as most of the major cities in the country's Pacific Coast and Southern area. The new network will provide the increased capacity of high-speed mobile broadband at download speeds of up to 100 Mbps and upload speeds of 40 Mbps.

NASA and the **U.S. Department of Homeland Security** are collaborating on a first-of-its-kind portable radar device to detect the heartbeats and breathing patterns of victims trapped in large piles of rubble resulting from a disaster. The prototype technology, called Finding Individuals for Disaster and Emergency Response (FINDER) can locate individuals buried as deep as 30 feet (about 9 meters) in crushed materials, hidden behind 20 feet (about 6 meters) of solid concrete, and from a distance of 100 feet (about 30 meters) in open spaces.

ACHIEVEMENTS

NuWaves Engineering announces it has achieved both ISO 9001:2008 and AS9100:2009 Rev C certifications for its Quality Management System by EAGLE Registrations Inc. With an effective date of August 15, 2013, the registration is valid for three years and its scope includes research and development as well as design and production of RF systems and subsystems.

East Coast Microwave (ECM) announced its certification to AS9100 Rev. C Quality Management System (QMS) for Aviation Space and Defense organizations. Certification to this standard places ECM in a select group of world-class microwave industry suppliers that are registered to this rigorous aerospace and defense standard. The AS9100 quality standard is based on ISO 9001, adding stringent requirements specific to the aviation, space and defense industry. Among other changes, revision C brings the standard in line with ISO9001:2008 and expands the scope of coverage to include land and sea based systems for defense applications.

The ARTISAN 3D radar capable of cutting through interference equal to 10,000 mobile phone signals has successfully commenced integration trials at **BAE Systems**' electromagnetic radar testing facility on the Isle of Wight, UK. The testing is in advance of installation on the new Queen Elizabeth Class Aircraft Carriers (QEC) which are being assembled in Rosyth, Scotland. The aircraft carriers HMS Queen Elizabeth and HMS Prince of Wales are being delivered by the Aircraft Carrier Alliance, a unique partnering relationship between BAE Systems, Thales UK, Babcock and the UK Ministry of Defence. The first ship will begin sea trials in 2017.

AEM Inc. announced that it is a recipient of a 2012 Boeing Gold Performance Excellence Award. AEM maintained a Gold composite performance rating for quality and delivery for the twelve month period from October 1, 2011 to September 30, 2012. This year, Boeing recognized 594 suppliers who achieved either a Gold or Silver level Boeing Performance Excellence Award. AEM is one of only 153 suppliers to receive the Gold level of recognition achieving this status for four consecutive years.

CONTRACTS

Exelis has been awarded a foreign military sale contract valued at $115 million to provide an existing international customer with additional communications equip-

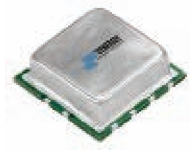
Product Hilites

Featured Products — HIGH PERFORMANCE POWER DIVIDERS

HIGH PERFORMANCE 16-WAY POWER DIVIDER

The DPK1100S is a low loss, 16-way power divider with multi-decade frequency coverage from 10 to 1000 MHz with typically less than 2 dB of insertion loss. This high performance model is available in a connectorized package with either SMA female or type N connectors (DPK1100N). Other typical features of this model are isolation better than 20 dB across the band, typical phase unbalance of 6 degrees and amplitude unbalance of 0.7 dB. When used as a splitter, power at the input port is a half watt maximum.

HIGH POWER 2-WAY POWER DIVIDER



The high power surface mount 2 Way Power Divider, Model CSB3550, covers the frequency BW of 350-500 MHz and is suitable for small space requirements while handling maximum input power of 20 Watts (CW). It features excellent insertion loss of 0.6 dB maximum and Isolation of 20 dB minimum. A tightly control amplitude unbalance of 0.2 dB Maximum and equally tight Phase Unbalance of just 2°. VSWR is 1.3:1 worst case. This performance comes in a very small surface mount package of 0.945” x 0.945” x 0.440 “.

WIDE BANDWIDTH 4-WAY POWER DIVIDER

The CSDK3100S is a 4-Way Power Divider/Combiner operating from 30 to 1000 MHz. This device is capable of handling 5 Watts when used as a divider. Product features include 0.7 dB (typ.) insertion loss, 0.2 dB (max.) amplitude unbalance, 20 dB (min.) isolation and 0.3° (typ.) phase unbalance over the temperature range of -40 to +85°C. This RoHS compliant, SMA connectorized package is ideal for moderate power signal splitting and low power combining.

HIGH PERFORMANCE 4-WAY POWER DIVIDER

The SPD-90-210 is a low insertion loss, 4-Way splitter, that spans the frequency band of 900 – 2100 MHz maintaining tight phase and amplitude tracking between outputs of typically 3 degrees and 0.2 dB of signal unbalances respectively. This product saves critical board space over the larger stripline splitters and is perfect for SATCOM applications. The compact splitter is packages in a small surface-mount RoHS compliant package, measuring 0.8x0.4x0.2 (LxWxH).

SYNSTRIP® HIGH POWER 2-WAY POWER DIVIDER

Model P2D100800, is an 8:1 frequency BW splitter/combiner covering the frequency range of 1 - 8 GHz. It offers an excellent Insertion Loss of 1.1 dB and Isolation of 22 dB or better and is unique to the industry. A tightly controlled Amplitude Unbalance is 0.2 dB Max. and typical Phase Unbalance of just 2 degree. Maximum input RF power is 5 watt CW. This performance comes in a very small surface mount SYNSTRIP® (Synergy’s Stripline technology) package of 0.8” x 0.50” x 0.05 “ suitable for applications requiring wide bandwidth, low height and small footprint.

HIGH PERFORMANCE POWER DIVIDER

The S5D1424 is a surface-mount, 5-Way signal splitter and low power signal combiner designed to operate from 1435 to 2395 MHz. It has excellent performance in the specified band with typical insertion loss of 0.5 dB, isolation of 15 dB minimum and VSWR of 1.4:1 maximum. The amplitude balance is less than 0.3 dB and the phase unbalance is 12 degrees maximum. The compact package measures 1.0 x 2.0 x 0.25 inches.

PRODUCTS

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- VCO’s
- Ultra-Low Noise Phase Locked Oscillators
- Oven Controlled Crystal Oscillators
- High Performance Crystal Oscillators
- Dielectric Resonator
- Oscillators
- SAW Oscillators
- Frequency Synthesizers
- Couplers
- Filters
- Hybrids
- Mixers
- Splitters/Combiners
- Transformers
- Attenuators/Switches
- Demodulators
- Fixed Attenuators
- Frequency Doublers
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- Phase Detectors
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Around the Circuit

ment, spare parts, ancillary devices and operator training. Communications equipment acquired under the contract includes the SpearNet radio system with accessories, the RT-1702 SINCGARS (Single Channel Ground and Airborne Radio System) in the VRC-90 System, and the VRC-92 Dual Long Range Radio System configurations with installation kits and spares to support both systems. Also included in the purchase are PRC-119 Manpack Radio Systems with GPS and Spearhead handheld radios systems with accessories.

Rockwell Collins has received a $2 million contract from the **Air Force Research Laboratory** (AFRL) to develop and demonstrate a secure software defined radio (SDR) Global Navigation Satellite System (GNSS) receiver capability. Hosted in a software defined radio, this AFRL program will develop the security architecture required for the receiver equipment certifications. The arrival of modernized GPS signals and other constellations is changing the way the U.S. military accomplishes GNSS-based positioning, navigation and timing.

Raytheon UK has taken its first order for a pre-production MiniGAS, the latest in GPS Anti-Jam technology, designed and manufactured by the company in the U.K. This contract, awarded by an undisclosed customer, requires Raytheon UK to produce demonstrator units for customer evaluation. As well as developing new products, Raytheon has also received an order for a further 100 of its Advanced Digital Antenna Production (ADAP) systems with the U.S. government.

Rohde & Schwarz UK Ltd. has been down selected after a 12 month competition process run by **BAE Systems** to be the preferred partner for the design phase of the integrated communications system for the future Royal Navy's Type 26 Global Combat Ship. The Rohde & Schwarz proposal for the Type 26 is at the forefront of technology and includes innovative systems to truly deliver a state of the art communications system.

Selex ES has been selected by **CELAB Communications AB**, which was contracted by the Swedish Defence Materiel Administration, FMV, to supply further communication systems to meet the battlefield needs of the Swedish Home Guard. Following a competitive tender, CELAB selected Selex ES to supply an extra 4,425 man-worn Enhanced Encrypted Personal Role Radio (EZPRR) systems, together with ancillaries and spares to meet FMV's requirements. These are additional to the 8,700 Selex ES EZPRR man-worn systems and around 50 vehicle systems supplied by CELAB to FMV in a recent phased programme.

PEOPLE

▲ *David Moorehouse*

TRAK Microwave announced the appointment of **David Moorehouse** as president and general manager. In his new role, Moorehouse will be leading the TRAK Microwave business, inclusive of the Lorch site in Salisbury, MD, and TRAK Microwave Ltd. in Dundee, Scotland, as well as his home facility in Tampa, FL. Moorehouse holds a Bachelor of Science in mechanical engineering from the Milwaukee School of Engineering, a Master of Science in mechanical engineering from Michigan State University, and an MBA from Saint Joseph's University in Philadelphia.

▲ *Purna C. Subedi*

Lark Engineering announces that **Purna C. Subedi** has joined the company as the new chief technology officer. Subedi comes to Lark with a wealth of experience in RF designs, product development and management. He was previously with Powerwave and Filtronic Comtek where he was instrumental in developing, implementing and launching many products including high power microwave cavity filters, diplexers and multiplexers. Subedi has over 18 years of business leadership experience as well as technical expertise.

▲ *Mike Beckett*

Tronser Inc. has appointed **Mike Beckett** as vice president and general manager of its U.S. Operations in Cazenovia, NY. He will be leading the company's strategic growth initiatives in North America including introducing the extensive Tronser product offerings into new markets and expanding the company's production and engineering capabilities. Beckett joins Tronser Inc. with over 30 years of broad financial, operational and executive leadership in electronics, plastics and service industries both domestically and internationally.

▲ *Lance Craft*

Dali Wireless Inc. announced the appointment of **Lance Craft** as vice president of sales, Americas, with the responsibility of leading and managing all sales activities at Dali Wireless throughout North and South America. Craft was employed by Powerwave Technologies Inc., from 2006 to 2013 where he most recently served as vice president of sales where he was responsible for activities related to strategic sales planning and forecasting, revenue attainment, customer satisfaction and business development.

Frank Haneman, the original founder and president of MITEQ Inc., has passed away. Haneman's career included engineering management positions at IBM, AIL and Fairchild after graduating from Columbia University. All who worked with Frank were impressed with the dedication and respect he showed to his engineering staff. Frank served in the Army Medical Corps. during World War II and the Korea conflict. His personal interests included reading books on Einstein, the American Legion, Knights of Columbus and church choir. He will be sorely missed by those who knew him.

Product	ε_r	Df @ 2.5GHz
RO4360G2™	6.15	0.0030
RO3006™	6.15	0.0018
RO3010™	10.2	0.0020

Around the Circuit

REP APPOINTMENTS

Aeroflex/Inmet announced a new distribution agreement with **Microwave Components Inc.**, headquartered in Stuart, FL. Microwave Components Inc. is a global RF and microwave distributor with a strong emphasis on coaxial and surface mount resistive components.

Coaxial Components Corp. has recently acquired new representation in three international markets. In Brazil, **Boreal Communications** will promote and sell the Coaxicom product line. **Globaltek International Ltd.**, headquartered in Hong Kong, will serve as Coaxicom's representative in People's Republic of China, Hong Kong and Macau SAR. In France, **Elhyte** will represent Coaxicom's inventory of high-performance connectors.

Custom MMIC announced the appointment of **Ultram Technologies Ltd.** as their technical sales representative in Israel. Ultram Technologies specializes in the sales design and support of electronics, RF, microwave devices and assemblies, and test equipment.

NuWaves Engineering announced that the company has added **Castle Microwave** as an authorized representative of its commercial off-the-shelf (COTS) products and design services for the United Kingdom and Ireland.

San-tron Inc. announced the hiring of a new sales representative, **Chesapeake Advanced Technologies**, to handle sales relationships in DE, MD, Southern NJ, Eastern PA, Washington, D.C., VA and WV.

XMA Corp. welcomes **G2 Sales** as its manufacturing representative for FL, GA, AL, NC, SC, TN and MS. G2 Sales has a vast amount of experience selling technical products in the RF, microwave, and millimeter-wave related industries.

PLACES

RFMD announced it has successfully completed a recently announced expansion of its test, tape and reel, and assembly facility, located in Beijing, China. In addition to newly qualified internal assembly capacity for power amplifiers, switch-based products, and antenna control solutions, RFMD is also qualifying advanced flip chip capabilities for its 2G, 3G and 4G LTE and TD-LTE products.

Tech-Inter recently opened an office in Kleve, Germany to be able to serve its growing German customer base more efficiently. Bas Klaver will be responsible for the German subsidiary. The German office will serve the German market, as well as the Swiss and Benelux markets.

NEW!

Ultra Low Profile LIMITERS

Block High Level RF Interference...
Protect Your Low Noise Receivers.

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Our ultra wideband CLM-83-2W+ limiter cuts overpowered inputs, as high as 2W, down to +11.5 dBm in just 2 ns! Full throughput is restored 8 ns later, with an IL of 0.5 dB typical. It adds up to excellent protection against a wide range of spikes and power surges—even in the harshest environments, where unwanted signals prevail. And a tiny 3 x 3 x 1.14 mm footprint makes it easy to fit on crowded PCBs!


Actual Size

The CLM has already qualified for tough MIL specs including gross and fine leak, acceleration, PIND, vibration, mechanical shock, and thermal shock, with an operating range from -55 to +100°C! For more details, go to minicircuits.com—it's even available on small-quantity reels! Order today, and you can get excellent protection for your sensitive applications in your hands as soon as tomorrow!

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MWJ REVIEW BOARD APPROVED

A Low Noise Oscillator Based on a Conventional Dielectric Resonator

This article describes a 4 GHz ultra low noise oscillator with a frequency-locked loop (FLL) that incorporates a frequency detector (FD) employing a conventional dielectric resonator having an unloaded quality factor (Q) of 8000. Its single sideband (SSB) phase noise spectral density of –153 dBc/Hz at 10 kHz frequency offset from the carrier is superior to the best traditional crystal oscillators scaled to the same output frequency. The oscillator was built using low-cost, commercially available off-the-shelf parts.

Modern high frequency synthesizers typically employ phase-lock-loop (PLL) architectures that rely on the phase noise characteristics of a lower frequency reference oscillator. A good example is the FSW-0010 synthesizer (a.k.a. QuickSyn) manufactured by Phase Matrix[1] that produces a signal with phase noise nearly equal to its multiplied internal reference with minimal added noise degradation. It is common to use a crystal oscillator as a reference, which provides the benefits of low phase noise and high frequency stability. Although performance varies from vendor to vendor, the single-side band (SSB) phase noise of the best state-of-the-art crystal oscillators is generally between –170 and –180 dBc/Hz at 10 kHz offset from a 100 MHz carrier. This scales to –130 to –140 dBc/Hz at 10 GHz.[2,3] Reference oscillators with lower phase noise can be built by employing higher frequency, higher Q, sapphire or metal cavity resonators.[4] Although they provide outstanding noise performance, these oscillators are limited in their application due to size and cost constraints. Alternatively, oscillator phase noise can be reduced using frequency-lock-loop (FLL) stabilization, which suppresses the phase noise generated by the oscillator components such as the loop amplifier and phase shifters.[5,6]

ANDREW GOREVOY
Micran, Tomsk, Russia

OSCILLATOR PHASE NOISE

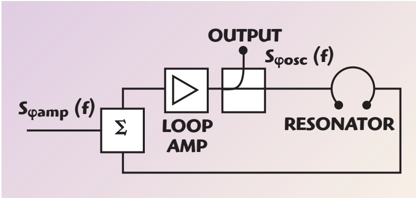
Oscillator phase noise at the output of the loop amplifier (see ***Figures 1*** and ***2***) is defined by Leeson's equation.[7-9]

$$S_{\varphi osc}(f) = S_{\varphi amp}(f)\left(1+\left(\frac{f_0}{2Q_L f}\right)^2\right) \quad (1)$$

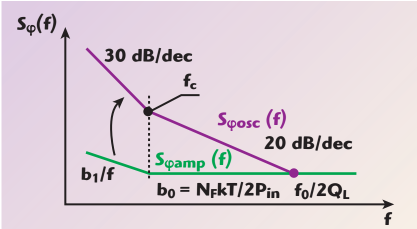
where f_0 is the oscillation frequency, Q_L is the resonator loaded quality factor and $S_{\varphi amp}(f)$ is the phase noise spectral density of the loop amplifier, which in most cases can be approximated by the following expression:

$$S_{\varphi amp}(f) = \frac{b_1}{f} + b_0 \quad (2)$$

where b_1 is the flicker constant (approximately $10^{-12}\ldots10^{-10}$) defining the flicker phase noise component[8] and b_0 is the relative level of the thermal



▲ *Fig. 1 Oscillator general block diagram.*



▲ *Fig. 2 Graphical representation of Leeson's equation.*

noise component at the output of the loop amplifier:[8,10]

$$b_0 = \frac{N_F kT}{2P_{in}} \quad (3)$$

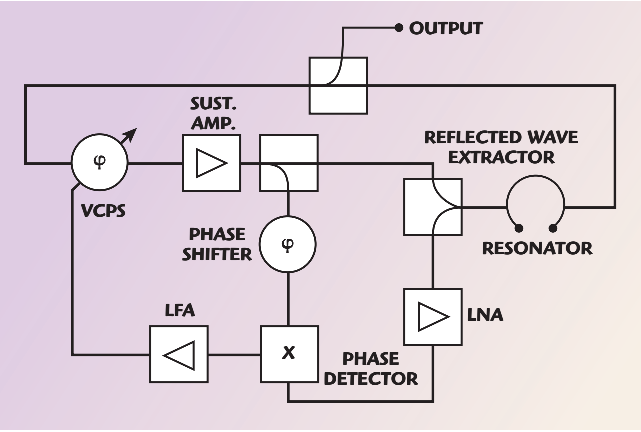
N_F is the noise figure of the saturated loop amplifier and P_{in} is the saturated power at the amplifier output divided by the feedback losses.

Equations 1 to 3 indicate simple methods for reducing phase noise:

1. Increase the power at resonator input.
2. Optimize the feedback losses.
3. Reduce the amplifier noise – thermal and flicker.
4. Increase the quality factor of resonator.

Unfortunately, these methods can work in opposition to each other. For example, increasing output power may (and normally will) result in its noise figure and flicker noise increase. Amplifier-induced noise can be reduced by keeping the amplifier out of compression, e.g., by inserting a limiter at the input;[9,10] however, this leads to a higher equivalent noise figure for the amplifier chain that limits overall noise improvement. A well-known practice is to simply use a low flicker-noise amplifier such as a BJT or HBT.[12]

Feedback losses are at least 6 dB due to resonator coupling factors, which are commonly set to 0.5 in order to fulfill the minimum phase noise condition.[13] In reality, however, feedback losses can easily exceed 9 to 10 dB due to additional losses in the coupling and phase balancing components. Effective methods for phase



▲ *Fig. 3 Oscillator with FLL.*

noise reduction are normally limited to the use of high-Q resonators, low noise amplifiers and optimum resonator coupling.[8,13]

PHASE NOISE OF AN FLL STABILIZED OSCILLATOR

The advantage of an FLL (see ***Figure 3***) is that it minimizes both the noise figure and flicker-noise while maintaining high power in front of the resonator.[5-9] The specific coupling with the resonator is important. The coupling coefficient at the resonator input must be set to $\beta in \approx 1$ in order to achieve minimum reflection and to assure a low signal level at the LNA input. The reflected signal is commonly extracted by the means of a directional coupler or a ferrite circulator. It is amplified and compared with the signal extracted directly from the oscillator loop using a conventional phase detector (PD). The low frequency PD output is used to reduce the phase noise arising in the oscillator loop.[5,6,8]

The minimum achievable phase noise level at frequency offsets smaller than the resonator's half-bandwidth is given by the following expression:[14,15]

$$S_{\varphi cfs}(f) = \frac{N_{FD}kT}{2P_{out}}\left(\frac{f_0}{Q_0 f}\right)^2 \qquad (4)$$

where N_{FD} is the FD noise figure equal to the LNA noise figure for high-gain amplifiers.[14] Comparing Equations 1 and 4, note that the last one is free of the limitations imposed by the resonator losses as well as by the loop amplifier phase noise.

A modification of the FLL approach employs a voltage controlled oscillator (VCO) stabilized by means of an external FD using a high-Q resonator. This enables further improvement and optimization of the main oscillator and the discriminator circuitry. A drawback of this technique is the possibility of FLL lock failure due to a frequency offset between the main oscillator and the external FD. This can be avoided with a narrowband (essentially fixed-frequency) main oscillator that is pretuned to the discriminator frequency.

THEORETICAL MODEL

The structure of the discriminator stabilized oscillator is shown in ***Figure 4***. Phase noise at the buffer output is defined by the following expression:

$$S_{\varphi cfs}(f) = \left(\frac{S_{vco}(f)}{\left|1+K_L(f)\right|^2} + S_{LNA}(f)\left|\frac{K_\varphi \frac{K_v}{2\pi jf}K_{LFA}}{1+K_L(f)}\right|^2\right)\cdot \left|T(f)\right|^2 + \frac{N_{FB}kTT_L L}{2P_{out}} \qquad (5)$$

where $S_{vco}(f)$ is the VCO phase noise, $S_{LNA}(f)$ is the LNA phase noise, K_V is the VCO tuning sensitivity, K_φ is the PD gain, K_{LFA} is the low frequency amplifier (LFA) gain, N_{FB} is the output buffer noise figure, T_L is the resonator transmission loss, L is the transmission loss from the loop amplifier output to the resonator input (4,5 dB) and $K_L(f)$ is the FLL transfer function given by:

$$K_L(f) = \left(1-B_r(f)\right)K_\varphi \frac{K_v}{2\pi jf}K_{LFA} \qquad (6)$$

where $B_r(f)$ and $T(f)$ are the resonator phase noise transfer coefficients given by:[8,14]

$$B_r(f) = \frac{1+CS\left(jf\frac{Q_L}{f_0}\right)}{1+\left(jf\frac{Q_L}{f_0}\right)} \qquad (7)$$

Here CS is the magnitude of carrier suppression at the LNA input equal to the resonator's reflection loss,

$$Q_L = \frac{Q_0}{1+\beta_{in}} \qquad (8)$$

where Q_0 is the resonator unloaded quality factor and βin is the input coupling coefficient.

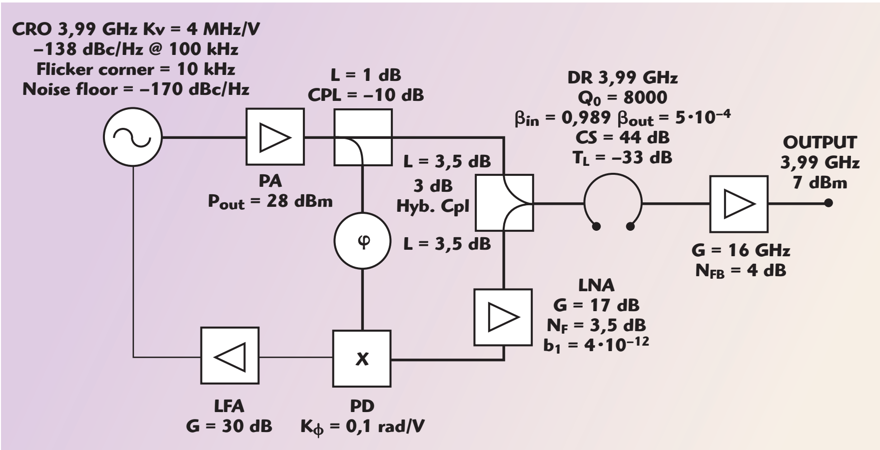
$$T(f) = \frac{1}{1+\left(jf\frac{Q_L}{f_0}\right)} \qquad (9)$$

In the case of a high-gain LNA, the $S_{LNA}(f)$ is defined by Equation 2 with

$$b_0 = \frac{N_{FLNA}kTL_bCS}{2P_{out}} \qquad (10)$$

where L_b is the additional loss introduced by the reflected wave extractor.

Unfortunately, flicker-noise parameters of the LNA and mixer are not necessarily specified by their manufacturers. Therefore, an accurate phase noise calculation is impossible without a preliminary characterization of the FD noise floor. This defines the overall noise introduced by the phase shifter, LNA and the mixer and en-



▲ *Fig. 4 Oscillator stabilized by a frequency discriminator.*

ables calculation of phase noise for the entire oscillator. The noise spectral density measured at the PD output is shown in ***Figure 5***.

Assuming the PD gain is 0.1 V/rad, the measured FD noise floor is –151 dBc/Hz at 10 kHz offset. On the other hand, considering that the LNA input power is –22 dBm and its NF is –3 to –3.5 dB,[16] then according to Equation 3, the calculated LNA phase noise is –151.5 to –152 dBc/Hz. This is in good agreement with the above measurements. Based on these results, the main source of FD phase noise is the LNA. The flicker constant (b1) is determined to be 4×10^{-12}.

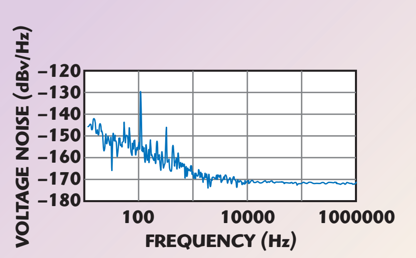
Equation 5 shows that system phase noise is proportional to the LNA-induced phase noise divided by the offset frequency at offsets within the resonator half-bandwidth; therefore, the flicker corner of the system phase noise will be the same as that at the flicker corner at the LNA output. As the CS value increases, the phase noise floor at the LNA output increases and the flicker corner decreases. Theoretically, the flicker corner of system phase noise can be infinitely small but it requires an infinitely high CS, which is difficult to achieve and hold. A CS of about 40 to 50 dB is a practically achievable number.

The total phase noise at different CS values and phase noise of some elements are shown in ***Figure 6***. This figure also includes the phase noise of the best crystal oscillators[17] multiplied to 4 GHz.

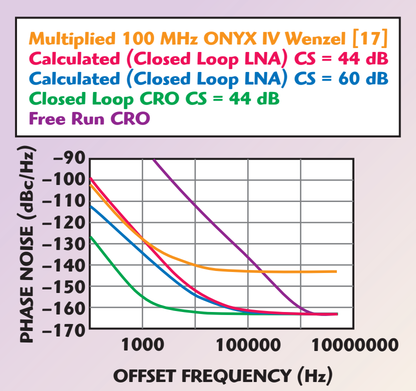
MEASUREMENT RESULTS

The oscillator is assembled on a round PCB placed on top of the dielectric resonator chamber as pictured in ***Figure 7***. It uses low cost, commercial off-the-shelf parts. Its diameter is 50 mm and is 40 mm high. For reliable frequency lock after power-on, a narrowband CRO is utilized. The CRO frequency is set with a DC-voltage offset applied to the feedback low-frequency amplifier to ensure frequency lock.

Two identical oscillators with a frequency difference of about 10 MHz were constructed to measure phase noise. The oscillator signals were mixed down in an external



▲ *Fig. 5 Voltage noise at the phase detector output.*



▲ *Fig. 6 Calculated phase noise.*

mixer and phase noise at the mixer IF output was measured. Assuming that both oscillators exhibit similar noise performance, phase noise at the IF output was corrected by 3 dB and is shown in ***Figure 8***. For comparison, calculated performance is also shown for a sapphire loaded cavity oscillator (SLCO)[14] and a dielectric resonator oscillator (DRO)[18] scaled to a carrier frequency of 4 GHz.

One can see that use of the discriminator with a dielectric resonator enables phase noise performance that is 15 to 18 dB lower than the simple DRO. The designed oscillator nevertheless has phase noise 10 dB higher than the SLCO because it is limited by the unloaded Q (Q_0=8000) of the DR.

CONCLUSION

A low noise oscillator based on a dielectric resonator frequency discriminator has been designed using low cost, commercial off-the-shelf components. Phase noise performance of the oscillator exceeds that of a multiplied crystal oscillator and is comparable to performance of more expensive and bulky sapphire and metal-cavity resonator oscillators. Further improvements are possible using dielectric resonators with higher Q-factors and by replacing the hybrid coupler with a ferrite circulator. Furthermore, frequency tuning can be implemented to compensate for thermal instability by applying an external reference signal as needed. The oscillator can be used as a low noise reference source in modern frequency synthesizers and other applications where low phase noise is a key specification. ■

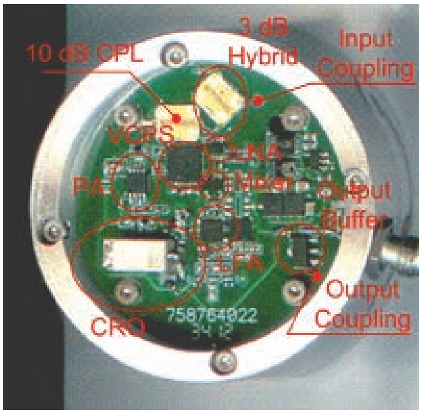


Fig. 7 Oscillator assembly.

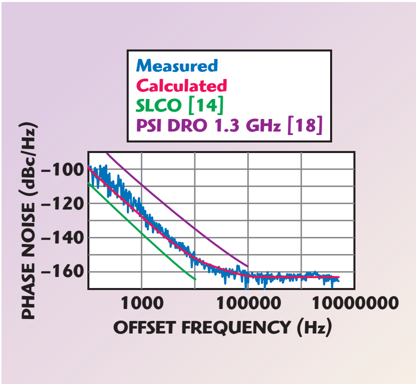


Fig. 8 Measured and calculated phase noise compared with a DRO and SLCO.

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Selecting Filters for Challenging Mobile Applications Worldwide

The global transition to 4G networks is driving a dramatic increase in the need for advanced filtering technologies in smartphones and other mobile devices. As a result, filter selection has become a key consideration for designers of these devices. As 4G LTE networks proliferate and WiFi becomes ubiquitous, smartphones must support an increasing number of RF bands. These bands must be isolated within each device to avoid interference, using filters.

While 3G networks used only about five bands, there are already over 20 4G LTE bands and this number could rise to more than 40 in the future. Though it's not practical to support all worldwide bands in a single smartphone, a feature-rich model for international use might need to filter transmit and receive paths for 2G, 3G and 4G in up to 15 bands, as well as WiFi, Bluetooth and GPS. Such a phone might require as many as 30 to 40 filters. The situation is likely to become even more complex in the future: next-generation high-end smartphones could include 50 or more filters.

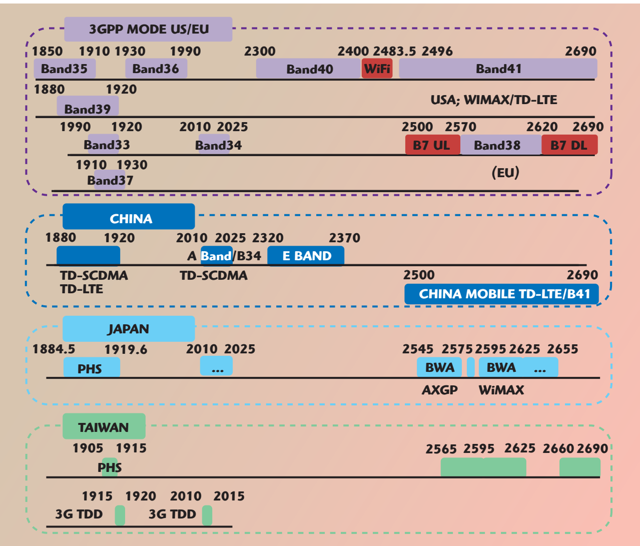

Fig. 1 LTE-WiFi coexistence issues worldwide.

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The filtering requirements differ in each region or country, due to local differences in spectrum allocation that are creating a worldwide patchwork of LTE bands. Adding to the challenges, many of these bands are very close together and therefore require highly selective filters. One reason is that the global demand for spectrum is leading governments around the world to re-farm existing spectrum; this often results in the allocation of new bandwidth that is adjacent to existing bands, often with minimal or even non-existent guard bands.

Some LTE bands are located next to the unlicensed international, industrial, scientific and medical (ISM) bands between 2.4 and 2.5 GHz, which are used to support existing standards including WiFi, Bluetooth and ZigBee, as shown in ***Figure 1***. These bands are crowded with signals from many devices, including PCs and cordless phones. Smartphones may therefore require advanced filters that support LTE-WiFi coexistence.

The complexity of filtering requirements will further increase due to carrier aggregation, a new 4G LTE-Advanced capability that enables carriers to aggregate multiple fragmented slivers of spectrum into a single wider channel to enable higher data rates.

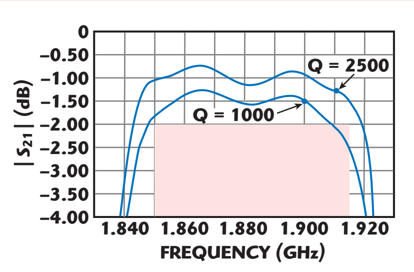
The combined effect of these trends is that mobile devices must isolate signals with bandpass filters that provide extremely high rejection of adjacent bands combined with low insertion loss. Advanced acoustic filters have these attributes, and are essential for addressing these challenges.

In this article, we'll discuss 4G filtering challenges with a focus on the regional differences that are unfolding in North America, Europe and Asia. We'll identify which filter technologies designers should consider as they seek to build devices for each market. Acoustic filter technologies continue to evolve to meet the growing challenges: advanced bulk-acoustic-wave (BAW) and temperature-compensated surface acoustic wave (TC-SAW) filters can solve some of the toughest mobile device filtering problems and are key enablers of the global 4G transition.

OVERVIEW OF FILTER TECHNOLOGIES

Several acoustic filter technologies exist, differing in their capabilities, cost and packaging technology. Today, the primary choices are surface acoustic wave (SAW) and BAW technologies. TC-SAW filters, which are much less sensitive to temperature changes, have also recently been developed. Each of these technologies can offer low insertion loss with good rejection

BAW Benefits: The Relationship between Low Insertion Loss, High Q and Sharper Corners



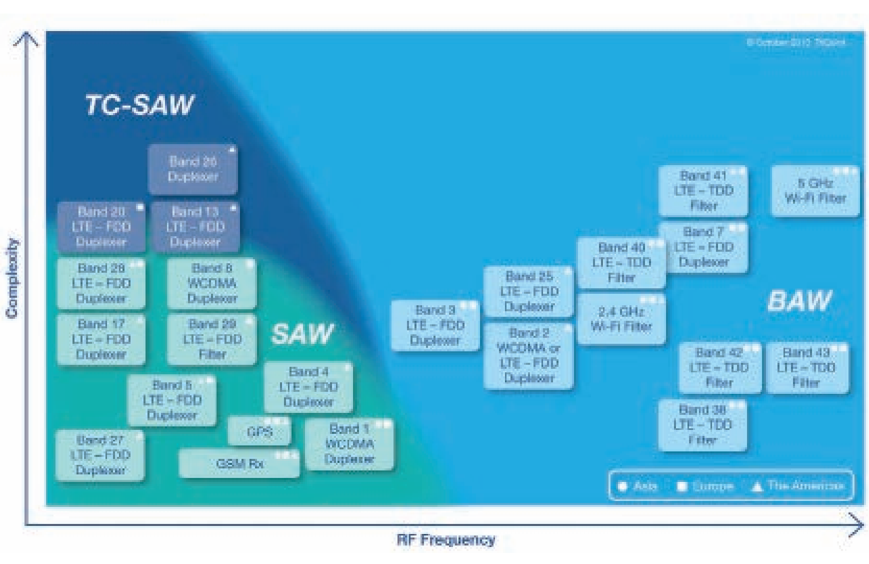
BAW filters offer lower loss and higher Q than SAW filters. These characteristics mean that for challenging applications, BAW filters are often a better choice – even for some frequency bands that are within the range of either filter technology. The diagram here compares the effectiveness of a higher-Q BAW filter (Q=2500) and a lower-Q SAW filter (Q=1000) for the same frequency band (Band 25 TX).

Clearly, the BAW filter offers lower insertion loss. But there is another important difference: the BAW filter's response curve has sharper corners, while the lower-Q SAW filter's curve has more rounded corners. Because of this, the difference in loss between the two filters increases at the corners. At 1.88 GHz, the center of the band, the difference in loss is about 0.5 dB. But at 1.85 GHz, the lower edge of the band, the difference is 0.8 dB, while at 1.915 GHz the difference increases to 1 dB. The rounder corners of the SAW filter's response curve impose the greatest penalty on the channels at the edge of the frequency band. Effectively, the passband of the lower-Q filter becomes narrower.

Narrow modulations such as GSM (200 kHz) and CDMA (1.25 MHz) will suffer the most sensitivity loss at the band edge due to this effect, while WCDMA will suffer less. LTE results depend on the system bandwidth, with narrower bandwidths more affected.

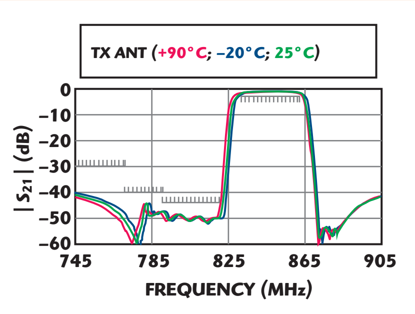
Drift due to temperature variation will make the problem worse, unless temperature-compensated processes are used. At higher temperatures, the SAW response drifts downward by as much as 4 MHz – nearly twice as much as BAW – resulting at an additional 1 dB difference in loss at the high end of the frequency band.

It might seem tempting to widen the lower-Q filter's response curve to improve the insertion loss problem. However, this will result in reduced selectivity to nearby interference. This selectivity degradation is not acceptable for many demanding filter applications.



▲ *Fig. 2 Matching filter technologies to applications.*

The Importance of Temperature-Compensated Filters



Temperature drift has become an important issue as spectrum becomes more crowded and high selectivity is required to minimize insertion loss and ensure rejection of adjacent bands.

The diagram illustrates a difficult Band 20 duplexer filtering problem that is solved by using a TC-SAW TX filter. The TC-SAW filter used in this design has a temperature drift that is roughly half that of a typical SAW filter. This duplexer must meet a critical specification for attenuation of the signal in the transmit path at the Band 20 receive frequencies. As shown in the diagram, the specification requires attenuation of at least –45 dB for the 791 to 821 MHz Band 20 RX frequencies.

At +25°C, the filter easily meets this requirement, achieving –45 dB attenuation across a frequency range that includes the RX frequencies and extends to an upper limit of 822.3 MHz. At +90°C, this attenuation point shifts down by 1.07 MHz, but the filter still achieves –45 dB attenuation at 821.23 MHz and below, including the entire Band 20 RX range, and therefore remains compliant with the specification. However, a SAW filter that is not temperature-compensated would drift by approximately twice as much — by –2.14 MHz at +90°C. With this drift, the –45 dB attenuation point would shift to 820.36 MHz and the filter would therefore violate the specification.

when used for suitable applications. Each technology is a good match for a specific range of applications, as shown in ***Figure 2*** and described in this article.

SAW

SAW is a mature technology widely used in 2G and 3G receiver front ends, duplexers and filters. SAW filters are well suited for frequencies up to about 1.9 GHz, including several standard GSM, CDMA and 3G bands.

A key advantage of a SAW filter is its low cost. In addition, techniques such as wafer-level packaging are being used to shrink SAW filters, allowing the integration of filters and duplexers for multiple bands onto a single chip. This is becoming increasingly important as smartphones incorporate more functions.

Limitations of SAW filters include frequency range and temperature sensitivity. Above about 1 GHz, selectivity declines; at about 2.5 GHz, the use of SAW is limited to applications with modest performance requirements. SAW is also very temperature-sensitive; a SAW filter's response may shift downward by as much as 4 MHz as temperature increases. This limitation has become more significant as guard bands become narrower and consumer devices are specified to operate across a wide temperature range (-35° to +85°C).

BAW

Compared to SAW, BAW filters generally offer superior performance (higher Q) with lower insertion loss. With BAW technology, it is possible to create narrowband filters with exceptionally steep filter skirts and excellent rejection. This makes BAW the technology of choice for many challenging interference problems.

BAW delivers these benefits at frequencies above 1.5 GHz, making it a complementary technology to SAW (which is most effective at lower frequencies). BAW can address frequencies up to 6 GHz and is used for many of the new LTE bands above 1.9 GHz. BAW is also highly effective for LTE-WiFi coexistence filters.

Because BAW filters offer low insertion loss, they help compensate for the higher losses associated with the need to support many bands in a single smartphone. Besides improving signal reception, lower loss also contributes to longer battery life. BAW excels in applications where the uplink and downlink separation is minimal and when attenuation is

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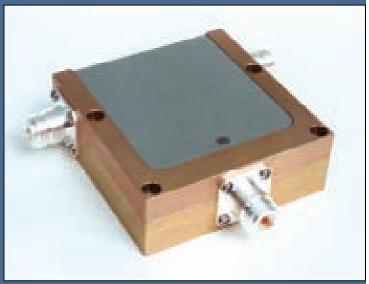

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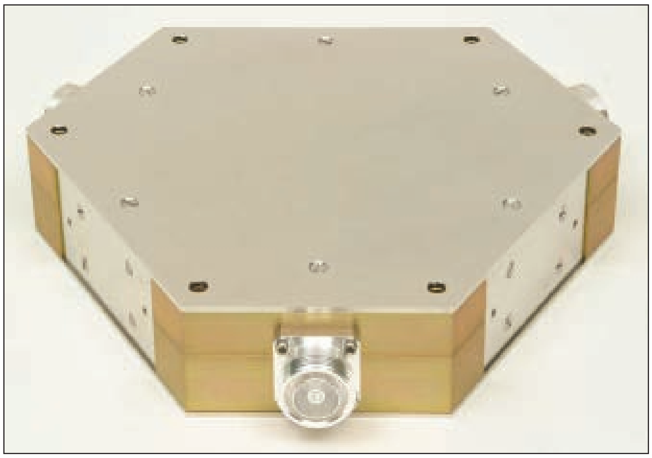

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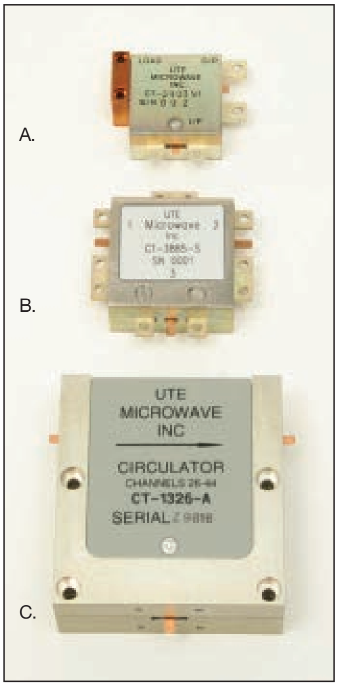

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CT-3877-S	2.5 Kw Pk 250 W Av	"Drop-in"	2.7–3.1 GHz
CT-3838-N	5 Kw Pk 500 W Av	N Conn.	2.7–3.1 GHz
CT-1645-N	250 W Satcom	N Conn.	240–320 MHz
CT-1739-D	20 Kw Pk 1 Kw Av	DIN 7/16	128 MHz Medical

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TC-SAW

For some challenging applications, reducing sensitivity to temperature changes is critical. This includes situations in which bands are located extremely close to one another. New TC-SAW technology enables the manufacture of highly selective filters that address these challenges. These filters have minimal or zero drift with changing temperatures, which is essential to ensure good rejection of adjacent bands and minimize insertion loss.

TC-SAW filters are effective within the same frequency range as SAW – up to about 1.9 GHz. The reduced sensitivity to temperature change makes TC-SAW a good choice for challenging specifications including some new 3G and 4G WCDMA duplexers and filters. For example, TriQuint uses TC-SAW to support Band 13, which is close to the U.S. public safety band, as well as Band 20 and Band 26 duplexers. The enhanced SAW process adds slightly to filter cost.

REGIONAL CONSIDERATIONS

Local differences in spectrum allocation, particularly the bands used for LTE, are creating a complex worldwide patchwork of frequency band assignments. Not too long ago, the picture was relatively simple. The primary four 3G bands were 1, 2, 5 and 8. Within the U.S., Bands 2 and 5 were the most commonly used; adding support for 1 and 8 allowed roaming in other countries.

With 4G networks, the situation is much more complicated; there are already significant differences in band allocations between regions and even between countries, and the situation will become more challenging as more LTE bands are allocated. Smartphones must of course also continue to support the primary 2G and 3G bands, as well as WiFi and Bluetooth. In some regions these bands are being refarmed for LTE, which may also change the filtering requirements; narrow 5 and 10 MHz 4G LTE bands require filters with sharper corners than 3G WCDMA, for example.

Adding to the filtering requirements, smartphones need multiple filters for each FDD-LTE and TDD-LTE band. For each FDD-LTE band, most smartphones require three filters: a duplexer for the primary TX and RX paths plus an additional filter for the secondary RX path. For each TDD-LTE band, smartphones will typically require at least two filters.

Because it is impractical to build a single phone that will work with all bands, manufacturers typically design smartphones for regional or country-specific use, or for a specific regional carrier's network. Phones also may include additional filters and other components to support roaming in other regions. Manufacturers may choose to include support for additional bands, where it is practical to do so, in order to be able to certify a single device for use in multiple countries. Because of the differences in local spectrum allocations, the challenges facing designers vary from region to region.

North America

The United States, along with Japan and Korea, is leading the worldwide transition to 4G networks; it is estimated that about half of the world's LTE devices have been sold in the U.S. The filters required in any specific model destined for the U.S. market will vary depending on factors such as whether the phone is designed for use with a specific carrier's network or for use on multiple networks.

In addition to Bands 2 and 5, major carriers are using a number of FDD-LTE bands across a broad range of frequencies, including Bands 4, 13, 17, 25 and 26. Of these, Bands 2 and 25 will require BAW filters.

WiFi coexistence will likely remain less challenging in the Americas than in other parts of the world. Most LTE bands used within the region are not immediately adjacent to the 2.4 GHz WiFi spectrum, and therefore most devices will not require high-performance filters to separate LTE and WiFi signals. An exception is the TDD-LTE Band 41, which will require a high-performance BAW filter. Other bands requiring highly selective filtering include Band 13, which is close to

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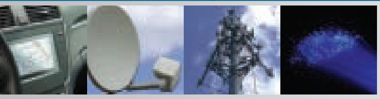

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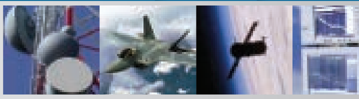

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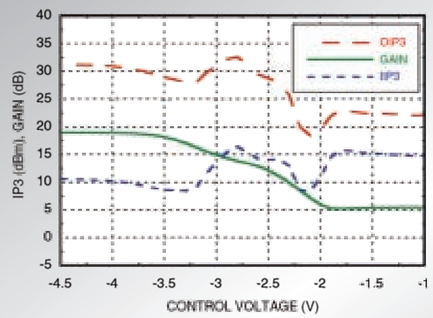
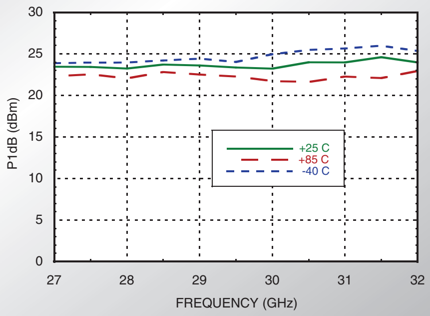


P1dB vs. Temperature, Vctrl= -4.5V



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2.3 - 2.5	Analog	-9 to +21	2.5	7	3	+3V @ 9mA	**HMC287MS8E**
5 - 12	Analog	+22	2	34	23	+5V @ 120mA	**HMC996LP4E**
6 - 17	Analog	+1 to +24	5	30	22	+5V @ 170mA	**HMC694**
6 - 17	Analog	0 to +23	6	30	22	+5V @ 175mA	**HMC694LP4**
17 - 27	Analog	+15 to +20	3.5	30	24	+5V @ 170mA	**HMC997LC4**
27 - 31.5	Analog	+13	4.5	31	24	+5V @ 230mA	**HMC6187LP4E**

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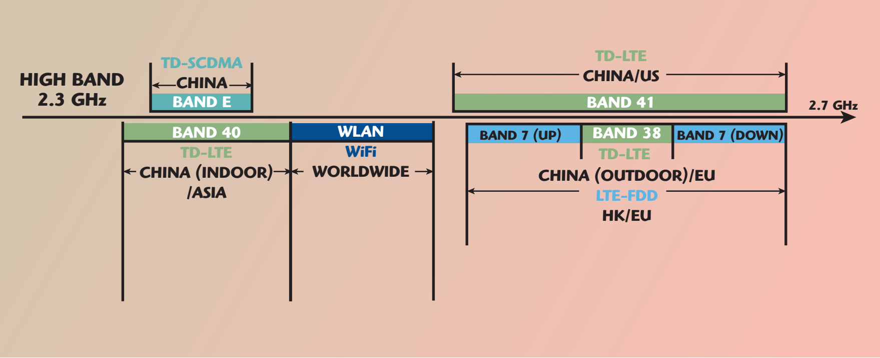


Fig. 3 Challenging WiFi coexistence issues in China.

the U.S. public safety band and will require a TC-SAW filter.

Europe

There are significant differences between the European market and North America. LTE adoption is proceeding more slowly, and there are differences in band allocation. Band 3 was originally used for GSM, the dominant 2G technology used in Europe, but is now being refarmed for LTE. In addition, two new "greenfield" frequency bands, 7 and 20, are being assigned for LTE use. It is likely that manufacturers building LTE phones designed for Europe will support all three bands to allow roaming.

The use of Band 7 introduces a challenging requirement for a high-performance BAW WiFi coexistence filter, since the Band 7 transmit path is only about 15 MHz from the 2.4 GHz WiFi band. Band 3 also requires BAW, while Band 20 may be best supported with TC-SAW.

Looking to the future, Europe is also auctioning Band 38 spectrum, which lies in the gap between the Band 7 transmit and receive bands. If a device needs to support both Band 7 and Band 38, a high-performance BAW filter may be required to allow coexistence.

Asia

The LTE picture in Asia is a complex map of regional band assignments with several distinct local markets. China is a huge potential market with unique requirements; other countries also have distinct needs, notably Japan and Korea, which, like the U.S., are the two nations that are most rapidly moving to LTE.

China

In China, the predominant LTE technology is TDD-LTE, as opposed to the FDD-LTE used in North America. Many of the LTE bands are at higher frequencies, including several that are adjacent to the WiFi band. This situation creates a strong requirement for BAW WiFi coexistence filters. For example, two of the TDD-LTE bands allocated are Bands 40 and 41. The WiFi frequencies are sandwiched between these two bands. As shown in ***Figure 3***, there is no gap between Band 40 and the lower end of the WiFi band, and only a minimal gap between Band 41 and the upper end of the WiFi band.

High-performance BAW coexistence filters will be needed; in addition, tradeoffs may be necessary depending on customer priorities. Supporting the full width of Band 40 may require giving up some of the lower WiFi channels. Alternatively, manufacturers may choose to give up part of Band 40 if supporting the full WiFi bandwidth is their top priority. The coexistence situation with Band 41 is slightly less challenging because of the minimal guard band between Band 41 and the WiFi spectrum. Within China, there is some local variation; for example Bands 7 and 38 replace Band 41 in Hong Kong.

Korea

Korea is particularly interesting because of its high smartphone use and rapid LTE adoption. About 26 million people — more than half the population — already have smartphones, and about 15 million of those are expected to be using LTE by the end of 2013.

Korea is refarming Bands 3 and 5 for LTE, and starting this year, every phone is expected to support Band 7. Band 26 has also been allocated and will require TC-SAW; though it overlaps with Band 5, Band 26 includes some frequencies that a Band 5 filter cannot cover. Bands 3 and 7 will require BAW filters; there is also a substantial need for WiFi coexistence filters.

Japan

The situation in Japan further adds to the regional complexity. Japan is unusual in its use of Bands 26, 11 and 21; Band 41 is also used, requiring a BAW WiFi coexistence filter.

Other Asia-Pacific Regional Challenges

Another interesting filtering challenge throughout the region is being created by the so-called digital dividend – the reallocation of 700 MHz spectrum freed up by the switch from analog to digital TV. Band 28, within this range, is uniquely designed so that it will require a pair of duplexers with overlapping frequency ranges.

Strategies for Asia

The question for manufacturers is whether to build phones for individual Asian countries or attempt to make phones that can be used throughout the entire region. China clearly is a large enough market to drive its own requirements; Korea, with its high percentage of LTE users, is another example of a market with its own identity. India is another huge potential market, although the high cost of smartphones relative to average personal income tends to restrict adoption; today most sales are of relatively low-end phones.

CARRIER AGGREGATION

Within each local market, fragmented spectrum presents a challenge for service providers trying to address the insatiable appetite for high-speed wireless data networks. Carrier Aggregation (CA) is a feature of 4G LTE-Advanced designed to allow service providers to offer higher data rates by bonding non-contiguous fragments of spectrum into a single wider channel of up to 100 MHz. CA is expected to become a major trend beginning in 2014; not surprisingly, markets leading in LTE deployment, such as the U.S., are expected to be the first to utilize CA. Initially, service providers are likely to focus on bonding widely separated bands, which may require only a diplexer; however, later implementations may present more challenging filtering problems that require high-performance filters.

PACKAGING AND INTEGRATION

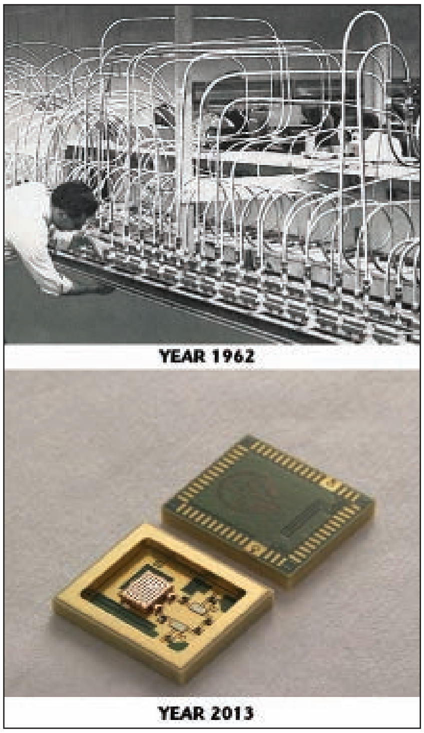
As smartphones support an increasing number of RF bands, combining multiple filters into a single package can free up valuable real estate. Some manufacturers organize filters in various combinations, from duplexer banks that consolidate several filters into a single module to two-in-one duplexers that permit the use of two-receiver operation simultaneously and independently. Wafer-level packaging (WLP) is a valuable technique for reducing size; it will increasingly be applied to BAW as well as SAW. Different filter technologies may be combined for specific applications. For some newer LTE bands, filters are more likely to be discrete simply because the bands are relatively new. This enables designers to simply add discrete LTE "satellite" components to existing layouts in order to offer regional 4G variants.

CONCLUSION

The worldwide transition to 4G networks is creating complex new challenges for designers of smartphones and other mobile devices. Fortunately, advanced acoustic filter technologies are becoming available to address these challenges. Each filter technology — SAW, BAW and TC-SAW — is suited to specific applications. With techniques such as WLP, it's also possible to combine multiple technologies into duplexers targeting specific applications. By careful selection of duplexers and individual filters, designers can meet the exacting requirements of each region worldwide. ■

High Performance 3D Micro-Coax Technology

The PolyStrata® fabrication process has been outlined in literature, including a 2008 article in *Microwave Journal*.[1] This process is exclusive to Nuvotronics but it is offered as a platform for commercial and military customers to design into next-generation systems. While the PolyStrata process defines a general 3D hardware micromanufacturing platform, the resulting air-dielectric micro-coax transmission line technology is in itself a significant new wave guiding medium worth understanding and exploring for many applications.



▲ *Fig. 1 Coaxial time delay unit miniaturization.*

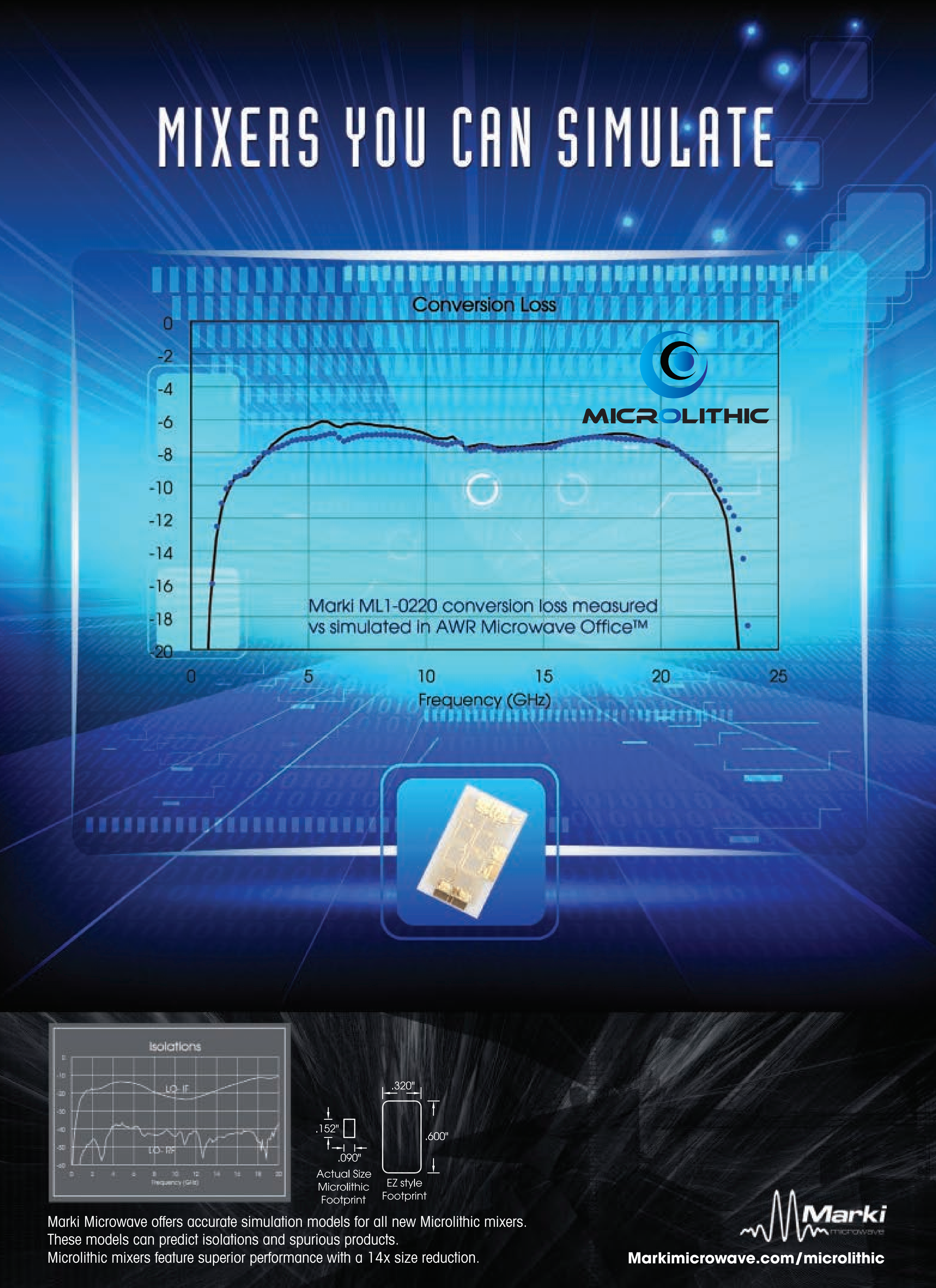
This article compares attenuation performance and other parameters of PolyStrata air-coax to other popular media. Linear behavioral models based on round coax are provided for two sizes. Attenuations of competing transmission line media are compared to PolyStrata coax with all relevant model parameters provided. While it is not possible to provide a comparison of every type of transmission line, this article provides a practical reference for engineers to analyze specific situations, weigh potential benefits that PolyStrata coax might hold for a given problem, and determine why and when it should matter to a particular design.

It goes without saying that attenuation of a transmission line is important, however, it takes on extreme importance in situations where long lines are required, as in feed networks and time delay networks. ***Figure 1*** compares a time delay unit from 1962 to what is possible today using Nuvotronics PolyStrata coax technology. The 2013 solution is no larger than the coax connectors that were used in the 1962 network.

TWO "STANDARD" COAX GEOMETRIES

Principally, there are two geometries for PolyStrata coax, which are shown in ***Figure 2***. The 700 and 500 µm pitch between adjacent conductors assumes shared vertical walls of 100 µm thickness, which are possible in most cases. Other dimensions and geometries are possible, but these two sizes have become the typical "standard dimensions" upon which a passive

Steve Huettner
Nuvotronics LLC, Radford, VA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-6
-8
-10
-12
-14
-16
-18
-20
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25
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device library has been constructed. In creating long delay lines, it is desirable to meander a delay line into a compact layout. Long meandered microstrip lines can cause problems due to coupling between adjacent segments. Grounded coplanar waveguide can solve the coupling issue when isolation vias are properly used but pitch between lines is several millimeters at best. The ability to share a 100 µm wide wall is an important consideration for this process, which can meander lines in three dimensions and maintain impedance control even in vertical transitions. When expressed in the time delay packing density figure of merit of nanoseconds/cubic centimeter, currently no other transmission line technology obtains the performance of PolyStrata coax:

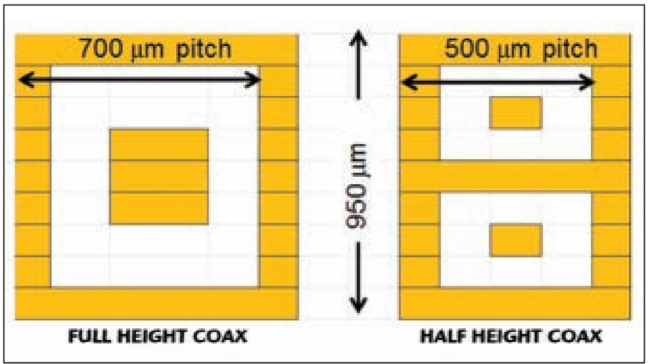
- Full height with shared walls: 5.2 ns/cubic centimeter (1.5 meters coax/cc)
- Half height with shared walls: 14.3 ns/cubic centimeter (4.2 meters coax/cc)

In practice, these figures of merit can be approached, but layout considerations such as input and output RF launches reduce what can be practically achieved.

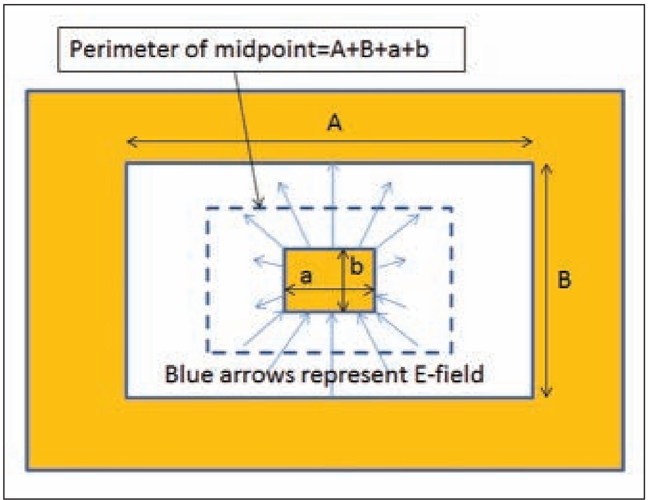
CUTOFF FREQUENCIES

Two slightly different undesirable TE11 modes are possible in rectangular coax,[2] but a very simple model of TE11 can estimate cutoff. TE11 for round coax cuts off when the midpoint between the conductors is approximately a wavelength in the chosen dielectric. TE11 can be approximated in rectax by the same calculation, as illustrated in ***Figure 3***.

A widely accepted engineering practice restricts operation to below 85 percent of calculated TE11 cutoff frequency. For full height and half height PolyStrata coax, critical geometries and estimated TE11 cutoff frequencies for fifty ohm lines are provided in ***Table 1***. Applying the 85 percent rule, PolyStrata half height fifty ohm lines can be used to 260 GHz, and full height to 130 GHz. Note that 1 mm air coax, which has become a standard in test and measurement systems, has a TE11 cutoff of ~129.5 GHz and is used to 110 GHz, following the 85 percent rule. The platform can also provide precision waveguide for millimeter and sub-millimeter-wave frequencies.



▲ *Fig. 2 Cross-sections of full and half height PolyStrata coax.*



▲ *Fig. 3 TE11 mode for rectangular coax.*

TABLE I

GEOMETRIES OF HALF AND FULL HEIGHT POLYSTRATA COAX

Type	A (mm)	B (mm)	a (mm)	b (mm)	Mid-point perimeter (mm)	TE11 FC (GHz)	85% rule (GHz)
Full height coax	0.7	0.7	0.255	0.3	1.955	153.4	130
Half height coax	0.4	0.3	0.176	0.1	0.976	307.4	260

PRACTICAL IMPEDANCE RANGES

Impedance ranges of PolyStrata coax are generally greater than what is available in other media. The following practical limits should be considered:

- 15 to 110 ohms (full height coax)
- 35 to 105 ohms (half height coax)

Impedance as low as 8 ohms has been demonstrated.

TRANSMISSION LINE ATTENUATION MECHANISMS

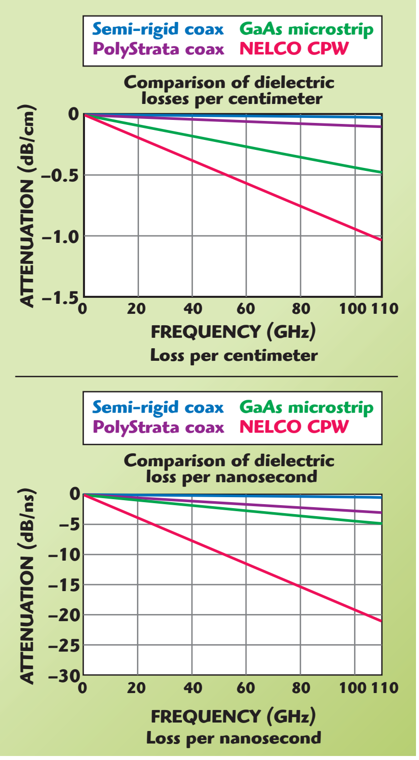
Attenuation in transmission lines includes losses due to metal conductivity, dielectric loss and radiation. In this article we consider losses due to metal and dielectric. We can ignore surface roughness (a component of metal loss) in the PolyStrata process as it has excellent surface finish inside and out. In ideal coax, attenuation due to radiation is zero; in this process, very small radiation occurs from "release holes" used to remove sacrificial photoresist. However, attenuation due to radiation is low enough so that it can be ignored compared to metal and dielectric losses, and it is an order of magnitude lower than radiation losses in CPW or microstrip transmission lines. In very large PolyStrata delay lines that are not packaged in shielded enclosures, release holes can be a minor source of electromagnetic interference that can be essentially eliminated using a coating system Nuvotronics has developed.

ATTENUATION DUE TO DIELECTRIC LOSS TANGENT (α_d)

Although PolyStrata structures are often referred to as "air coax," users should be aware that there is a non-zero dissipation factor (DF, a.k.a. loss tangent or tan(δ)) which would not be the case if the center-conductors were somehow magically suspended in air. Dielectric dissipation results from dielectric straps, which are used to position the center

conductor. Although they occupy just a few percent of the overall volume between center and outer conductors, the dielectric support material presents appreciable bulk loss. Overall a good composite number for the dissipation factor is 0.001. Efforts are underway to reduce dielectric attenuation while maintaining a robust transmission line.

In all transmission lines, dielectric attenuation (α_d) is known to be proportional to frequency, whereas attenuation due to metal conductivity (α_c) is proportional to $\sqrt{\text{frequency}}$. At increasing frequency, loss tangent eventually dominates attenuation of a transmission line compared to metal loss. Loss tangent attenuation is geometry dependent in that it only occurs where electric field is contained in the lossy material (i.e., dielectric loss of microstrip will be lower than stripline if they use the same dielectric material). In coax, 100 percent of the E-fields are in dielectric. In CPW, ~50 percent of E-fields can be considered within dielectric, while in microstrip, perhaps 70 percent are in dielectric. There is no size-scaling advantage for dielectric loss, fat coax will have the same dielectric loss as thinner coax provided they use the same dielectric fill.



▲ *Fig. 4 Loss tangent attenuation for various transmission lines.*

The equation for dielectric attenuation in TEM media is:

$$\alpha_d = \frac{27.3\sqrt{\varepsilon_R}\,\tan\delta}{\lambda}(\mathrm{dB/mm}) \qquad (1)$$

Note that lambda refers to free-space wavelength in the equation. Rearranging the equation, loss tangent attenuation is revealed to be directly proportional to frequency, SQRT(ε_R) and tan(δ):

$$\alpha_d = \frac{27.3\sqrt{\varepsilon_R}.f\,\tan\delta}{c}(\mathrm{dB/mm}) \qquad (2)$$

For quasi-TEM media such as CPW or microstrip, the "ε_R" term can be substituted with Keff (effective dielectric constant) with approximate results. Microstrip on 100 μm thick GaAs (ε_R=12.9, Keff~9), dielectric loss increases by a factor of three compared to media with ε_R close to unity (like PolyStrata), if they have the same loss tangent. Thus, higher ε_R leads to higher dielectric attenuation per length.

When expressed in dB/ns (as would be important in time delay), it is interesting to note that dielectric attenuation is no longer a function of ε_R but is still very much proportional to tan(δ) and frequency:

$$\alpha_d{}' = 27.3\times f_{GHz}\times\tan\delta\,(\mathrm{dB/ns}) \qquad (3)$$

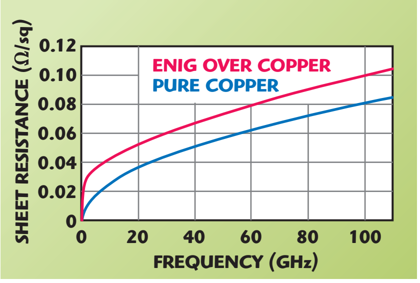
Thus, there is no dielectric attenuation disadvantage to having high ε_R in time delay systems, at least not directly. However, higher ε_R results in increased conductor losses, as conductor size shrinks to maintain required characteristic impedance.

Figure 4 shows modeled dielectric attenuation expressed both in dB/cm and dB/ns, for four transmission line media. Semi-rigid coax with PTFE dielectric has the most favorable dielectric loss, but PolyStrata coax is a close second. The "NELCO" CPW board has a tan(δ) of 0.007 so it is not a good choice for long networks. Microstrip on GaAs has almost 5× higher dielectric loss per unit length than PolyStrata coax, but when expressed in dB/ns, it is only 60 percent higher. Looking at dielectric loss alone is important in understanding relative performance of media, but metal conductivity loss must always be considered, and at lower frequencies metal conductivity is the dominant attenuation effect.

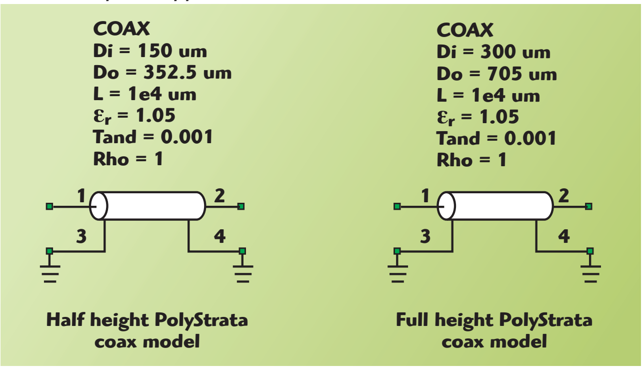
ATTENUATION DUE TO METAL CONDUCTIVITY (α_d)

Structures that use pure copper metallization are typically passivated

using electroless nickel/immersion gold (ENIG). One micron of gold provides a single skin depth at 6 GHz, at lower frequencies, much of the conduction that would have been possible in gold or copper is prevented by the nickel underplate. ***Figure 5*** compares surface resistivity of ENIG over copper to that of pure copper across frequency. To a first order, when ENIG is used to passivate copper, surface resistivity doubles at 5 GHz, and is 25 percent higher at 100 GHz (see RF sheet resistance spreadsheet of multimetal systems for calculating values[3]). Attenuation due to metal conductivity is not necessarily controlled by one surface resistivity value, because conductor surfaces are not always uniformly plated (in PWBs just the top surface of copper might be ENIG). Often, when a soldered joint is sought, the top gold is just a "flash" (<0.1 micron) which can increase loss substantially as more E-field penetrates to the lossy nickel layer. A coating system has been developed for PolyStrata coax that passivates copper with thin organic materials. This system preserves the conductivity of copper and offers a significant advantage over ENIG in the process.



▲ *Fig. 5 Comparison of surface resistivity for ENIG over copper (1 μm gold over 1 μm nickel) and pure copper.*

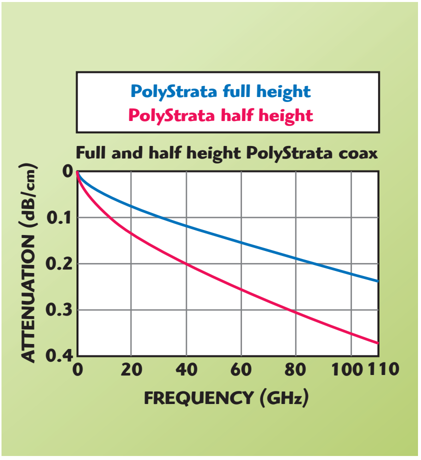


▲ *Fig. 6 Linear behavioral models for 50 Ω PolyStrata coax in AWR's Microwave Office.*

COAX BEHAVIORAL MODELS

Behavioral models for 50 ohm PolyStrata coax lines in AWR's Microwave Office (MWO) are shown in ***Figure 6***. "Rho=1" in MWO implies resistivity of copper, or 1.68E-9 ohm-m. Similar models can be employed in other EDA software using the values provided for ε_R and tan(δ). Note that different characteristic impedances can be modeled by changing center conductor diameter (leaving outer conductor diameter fixed), subject to the impedance limitations previously defined.

Figure 7 provides a plot of attenuation from DC to 110 GHz, of full and half height PolyStrata coax, predicted by Nuvotronics' behavioral model, for 50 ohm transmission lines. Here is where metal conductivity and dielectric loss tangent can be seen to have different effects depending on frequency band. At low frequency (10 GHz for example), half height coax has almost exactly double the loss of full height coax, which might be expected as its center conductor has exactly ½ the same cross-section perimeter and α_c is doubled. At increasing frequency, loss tangent attenuation α_d comes appreciably into play and is equal for both styles; thus at 110 GHz, half height coax's disadvantage is only



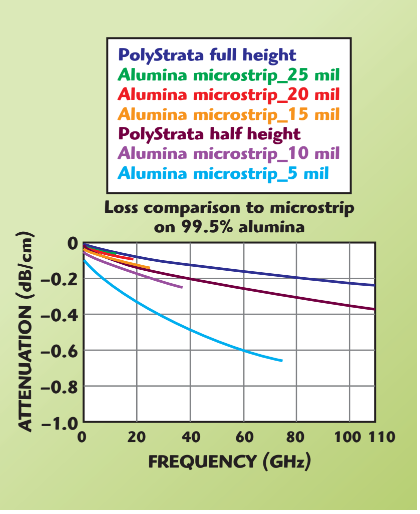
▲ *Fig. 7 Modeled attenuation of full and half height PolyStrata coax.*

~60 percent compared to full height.

COAX ATTENUATION COMPARISON

Here we have chosen several relevant transmission line media and plotted their attenuations compared to PolyStrata. Note that there is some controversy in the values of tan(δ) for many of the materials, reported values vary widely; the reader must be further warned that all material properties are functions of temperature, frequency, and manufacturing quality or purity.

The attenuation plots provided have different frequency stop points for different media. Generally accepted frequency limits of each media could be due to higher order modes, rules of thumb, or even MIL-standards, and are debatable. Although the plots all stop at 110 GHz, full height PolyStrata coax can operate to 130 GHz, while half height coax can operate to 260 GHz. In all cases, the potential effects of surface roughness were ignored. A complete list of material properties and geometries used to model all of the data in this report is available in the online version.



▲ *Fig. 8 Attenuation of PolyStrata vs. microstrip on Alumina.*

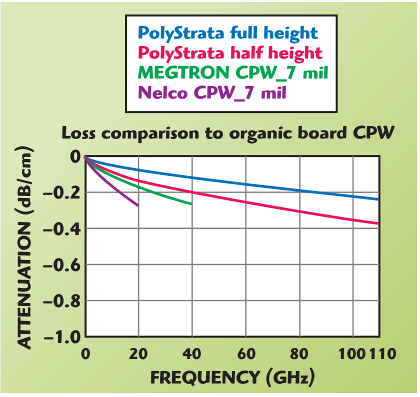
VERSUS ALUMINA MICROSTRIP

Alumina has been the go-to media of hermetic modules for forty years. Properties of alumina are dependent on purity and polishing; the comparison in ***Figure 8*** assumes 99.5 percent purity. Below X-Band, PolyStrata offers no loss advantage to alumina, provided the tallest alumina is used (20 or 25 mils). The frequency region where PolyStrata makes a big difference starts at 20 GHz, where the height of alumina must be reduced to 15 mils. Upper frequency bounds were determined to be where alumina microstrip height is 10 percent of a wavelength.

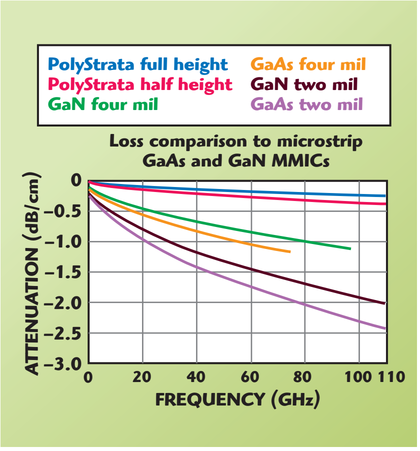
VERSUS CPW ON ORGANIC BOARDS

Organic boards are used successfully in many RF applications. One popular media is grounded CPW. Nelco N4000[4] and MEGTRON 6[5] are improved versions of the ubiquitous fire-retardant FR-4. FR-4 is almost never used for microwave networks as the loss tangent is as high as 0.01. Nelco N4000 material is a popular choice up to 12 GHz, MEGTRON 6 is a newer and more expensive material from Panasonic that can be used to 40 GHz. ***Figure 9*** compares each material to PolyStrata coax. In each case, the CPW media is sized at ~7 mil dielectric thickness, with line widths on the order of ~11 mils and gaps at ~4 mils which will perform without spurious mode problems beyond 20 GHz. Given the chosen geometries, PolyStrata has a substantial attenuation advantage over both technologies, at all frequencies.

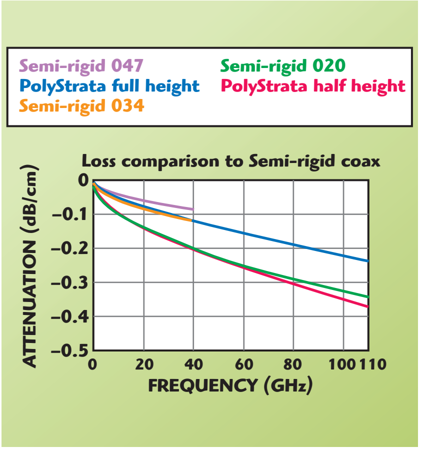
If the organic boards must support wirebonding, ENIG is used. We used conductivity of gold in the models that generated the loss plots, which may underestimate loss at low frequency. Dielectric loss due to solder stop can be considerable, and is ignored in the models, the reader is warned never to place solder stop over critical CPW runs on organic boards.



▲ *Fig. 9 Attenuation of PolyStrata coax vs. CPW-G on advanced organic materials.*



▲ *Fig. 10 Attenuation of PolyStrata coax vs. microstrip on GaAs and GaN.*



▲ *Fig. 11 Attenuation of PolyStrata coax vs. semi-rigid coax.*

VERSUS MICROSTRIP ON GaAs/GaN

One of the original claims for the DARPA 3D-MERFS program[6] was that PolyStrata coax is one-tenth the loss of MMIC transmission lines, but the exact ratio depends on the geometries of both media and the frequency that is being compared. In ***Figure 10***, four and two-mil GaAs and GaN MMIC microstrip are compared to PolyStrata coax. It is assumed that the GaN MMIC uses SiC substrate at $\varepsilon_R = 10$, versus GaAs at $\varepsilon_R = 12.9$. Many values of loss tangent have been reported for both materials. Frequency sweeps stop where four-mil microstrip media become 1/10 wavelength tall. As if GaN did not need another advantage over GaAs, attenuation is less because silicon carbide's lower ε_R results in wider microstrip traces.

Work on MMIC time delay networks has been reported, but printing delay lines greater than 50 ps on GaAs or GaN could be regarded as a misuse of expensive media.

VERSUS SEMI-RIGID COAX

Semi-rigid coax is often used for delay lines. It comes in many diameters, the closest diameters to PolyStrata coax are 020 (mils) and 034 which correspond to half and full height PolyStrata coax in terms of cross-section. However, the minimum bend radii of semi-rigid coax cannot compete with a system where a U-turn is possible on a 250 μm radius.

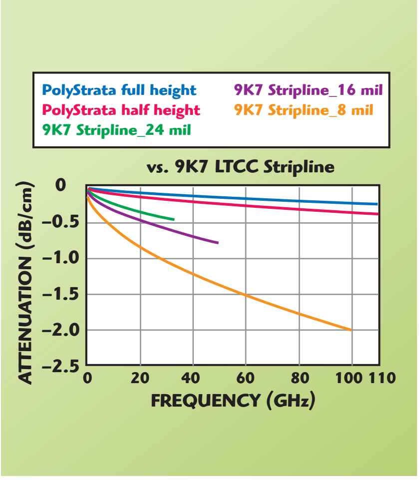
MIL-DTL-17 specifies semi-rigid cable, in diameters as low as 0.034 inches. Impedance tolerance is given at ±2 ohms, and max recommended frequency is 20 GHz, although these cables should support higher frequencies before TE11 occurs (see ***Table 2***). Delay accuracy of custom semi-rigid cables has been quoted at ±20 ps[7] and may change after temperature cycling due to dielectric expansion or relaxation. This is the equivalent of cutting cables with 4 mm accuracy in length. PolyStrata coax is formed with micron tolerances and will provide better time delay accuracy in all applications compared to semi-rigid delay lines.

Figure 11 compares attenuation of three sizes of semi-rigid coax to PolyStrata coax. The MIL-spec cables have been plotted to twice their specified frequency range (to 40 GHz) and the 020 semi-rigid is plotted over the full 110 GHz band. Semi-rigid 047

TABLE II

SEMI-RIGID COAX CUTOFF FREQUENCY CALCULATION AND MIL-SPECIFIED FREQUENCY RANGES

Semi-rigid type	Cut-off frequency for TE11 (GHz)	85% rule (GHz)	MIL Spec	MIL frequency range (GHz)
020	269.4	229	N/A	NA
034	154.8	132	MIL-DTL-17/154A	20
047	108.9	93	MIL-DTL-17/151A	20



▲ *Fig. 12 PolyStrata coax vs. stripline in LTCC.*

has a loss advantage but is significantly taller than full height PolyStrata coax; it can be seen that 020 semi-rigid has similar loss properties to half height PolyStrata coax, while 034 semi-rigid is similar to full height PolyStrata coax. In the comparison, the conductivity of copper for semi-rigid coax was used, although the center-conductor is copper-clad steel; at low frequencies, the full loss of semi-rigid cable may not be captured by the model. MIL-spec semi-rigid coax is specified to operate from -40° to 100°C. PolyStrata coax can operate over a much higher range of temperatures with less delay variation.

For geostationary space applications, every ounce of mass sent into orbit is worth its weight in gold. Each meter of semi-rigid 034 is specified at 4.17 grams. PolyStrata half height delay lines have been fabricated that weigh just 0.81 grams per meter, a 5× advantage. When expressed in grams/nanosecond delay (important in TDU applications), the advantage narrows but is still significant: semi-rigid 034 is 0.87 gr/ns, while half height PolyStrata coax has been demonstrated at just 0.24 gr/ns, an almost 4× advantage.

VERSUS STRIPLINE IN LTCC

LTCC has become a popular choice for products up to W-Band, owing to the evolution of materials such as Dupont's 9K7.[8] However, dielectric and metal losses are higher than PolyStrata (see ***Figure 12***). For delay lines or feed networks, LTCC is at a sizable disadvantage. The resistivity of metal that is printed as a thick film will never be as low as pure copper; in the case of 9K7, it is 3× higher. The loss tangent of 9K7 system is excellent at 0.001. Note that surface roughness was not considered in any of the media and reference data for the material properties and geometries of various interconnect systems used in this article are available online at www.mwjournal.com/polystratareference.

CONCLUSION

PolyStrata coax matters as a transmission line medium to applications where low RF loss is of paramount importance. Critical examples include power amplifier combiners and applications where long runs of low-loss transmission lines are needed (time delay units and feed networks). The attenuation advantage of the process depends on frequency and what other media are considered. Below X-Band, other solutions may hold advantages. PolyStrata coax also matters when volume and mass are design drivers, such as in time delay units or feed networks aboard satellites. Other trade advantages such as direct transitions to MMICs, thermal dissipation and 3D integration may be covered in future articles. ■

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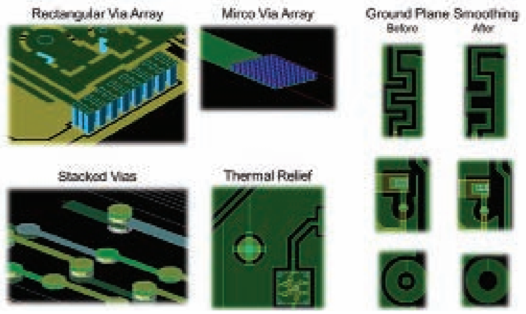
6. J. Evans, "3-D Micro Electro Magnetic Radio Frequency Systems (3-D MERFS) and other DARPA RF MEMS Programs," *Compound Semiconductor Integrated Circuit Symposium*, November 2006.
7. Microcoax app note, *Coaxial Delay Lines: Design Considerations*, created November 16, 2007.
8. Dupont 9K7 data sheet.



ADS 2014 Intelligent RF Layout Interconnect.

ADS 2014

Over the last few years, the needs of design engineers have undergone a significant shift. Designers now use newer high-power technologies like GaN in addition to LDMOS; are broadly adopting SiGe and CMOS for RF design and designing for more challenging 4G device specifications; and require more compact physical designs at the IC, module and PCB level. In addition, they are moving to concurrent team design and demanding interoperability between enterprise EDA platforms, as well as easier access to faster, more robust simulation technologies.

Anticipating these design challenges, for the last several years Agilent EEsof EDA has been investing in the ADS platform and its simulation technologies. As a result, ADS was re-architected for multi-technology design and was the first to offer integrated Finite Element Method (FEM) 3D Electromagnetic (EM) simulation and models for Amkor and Stats ChipPac QFN packages; a natively integrated electro-thermal simulator; a complete layout to manufacturing flow that includes GaAs, GaN, SiGe, and CMOS process development kits, as well as toolbars to improve designer productivity with native DRC/LVS as well as integrated support for Calibre and Assura; and support for design management and revision control tools like Cliosoft SOS.

ADS 2014 is the next major step in delivering more improvements, new capabilities and new technologies to further realize a long-term vision to improving design productivity and efficiency through design flow integration. Here is a closer look at some of the new capabilities available in ADS 2014.

LAYOUT INTERCONNECT DESIGN AND EDITING

Look at any of the teardowns for the latest consumer wireless products (e.g., iPhone or Galaxy, Droid or Kindle) and you will see RF components and modules designed by industry-leading companies using ADS not just for circuit simulation, but for EM analysis and MMIC and laminate layout as well.

With ADS 2014, Agilent has created new Intelligent RF Interconnect to dramatically improve RF layout physical design and editing. New, single and multilayer smart interconnect structures like traces, vias and ground/signal planes make pin-to-pin routing and modifying RF layout interconnect efficient, intuitive and easy.

Vias can now be used as layout interconnect objects, not components. This means they can be used more efficiently in routing, and automatically resized during trace width insertion. Additionally, support for pinless vias eliminates schematic clutter.

And new planes allow designers to create a layer of copper to carry a particular signal on a printed circuit board (PCB). A plane can be generated

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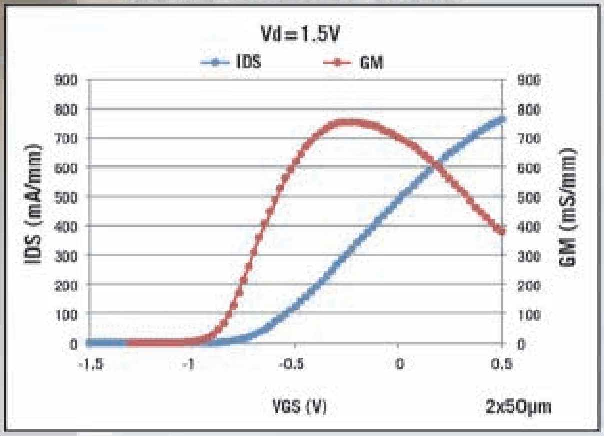

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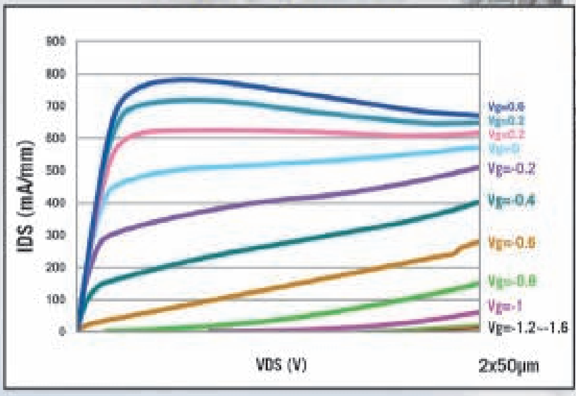

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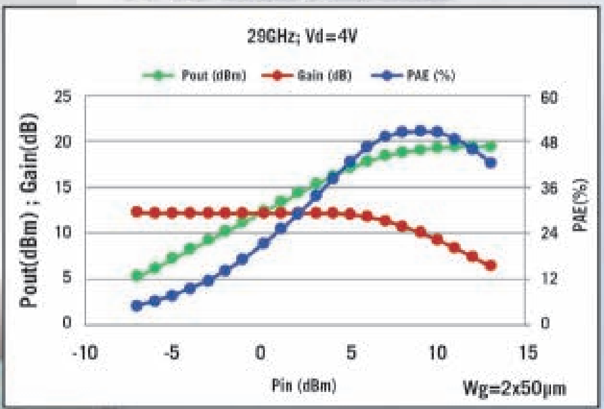

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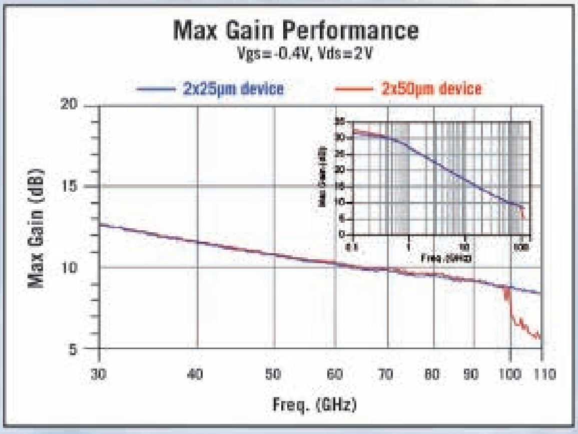

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as either a ground or signal plane using either an existing shape or by inserting or drawing a new polygon. The created planes support the following options:

- **Clearance** – Creates an appropriate clearance from shapes on different nets while connecting to shapes on the same net.
- **Thermal Relief** – Creates a thermal relief tie that helps take preventive action against overheating components.
- **Smoothing Options** – Enables you to smooth acute angles and remove notches.
- **Plane Regeneration** – Enables you to edit and regenerate the plane. For example, if you move the plane from one location to another, the shapes on the plane are automatically updated when the plane is regenerated.

AUTOMATED EM/CIRCUIT DESIGN PARTITIONING

One of the most well liked capabilities in today's ADS is the Layout Lookalike component. With this capability, the designer is able to set up a circuit/EM co-simulation where the schematic models (e.g., SMT parts or active IC devices) are connected to a "lookalike" representation of the layout—an especially great feature for smaller designs.

However, for cases where the device-count grows to dozens or even hundreds—a common occurrence for larger ICs and PCB or laminate multi-technology designs—ADS 2014 now offers a new automated EM/Circuit Simulation Setup capability. The capability takes final, or interim, layout designs and automates all of the manual steps to set up an EM/Circuit co-simulation by removing SMD and active devices from the layout, inserting ports and replacing the parts in the schematic. The result is substantial time savings and elimination of manual errors, while including all of the EM effects of traces, vias and grounds for unmatched EM/circuit simulation result accuracy.

WIRELESS VERIFICATION TEST BENCHES

Since ADS was first released, integrating standards-based modulated signal analysis has been a fundamental part of its architecture. Agilent Ptolemy with Wireless Libraries for Mobile Wireless (GSM, CDMA, 3GPP, LTE) and Wireless Networking (802.11, WiMAX) are the gold standard for verification of circuit designs to industry specifications.

The Wireless Verification Test Benches (VTB) in ADS 2014 provide circuit design verification solutions for the newest and most challenging multi-band, wide-bandwidth standards (LTE, LTE-A and 802.11ac) with a dramatically simplified user interface. These new VTBs and the underlying simulation technology are based on the Agilent EEsof SystemVue dataflow simulation technology and also allow system architects to develop custom VTBs for use by circuit designers in ADS.

The new simplified VTBs will be offered at a significantly lower cost than Agilent's Ptolemy-based Wireless Libraries. And current Agilent Ptolemy customers will get the VTB Engine as part of the upgrades and support for their Agilent Ptolemy license. The VTB Engine will also be available separately and offered in a new low-cost ADS Verification bundle.


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ADS BOARD LINK

RF and microwave designs are often combined with non-RF circuitry on larger PCB boards. ADS offers integrated PCB flow solutions for flows with Cadence, Intercept, Mentor Graphics, Zuken and other PCB tools, based on the Agilent Intermediate File Format (IFF), ADS DFI and Dynamic Access for Mentor products, as well as a variety of artwork translators. The new ADS Board Link (ABL) in ADS 2014 is the next-generation solution for ADS integration with Enterprise PCB tools.

The ABL is a bi-directional interface for layouts, schematics and libraries between ADS and enterprise PCB tools to be imported into ADS. ABL also supports the import and export of libraries and technology information (e.g., units, resolution, layers, purposes, and substrates), as well as design data.

ABL enables RF schematic and layout designs started in ADS to be easily transferred to the enterprise PCB environment for integration into a larger design for floor planning; modified to accommodate physical design constraints; and then returned to ADS for verification—all while maintaining complete design integrity. Additionally, to debug a design that failed on the bench or for high-speed digital applications, an enterprise PCB layout design can be imported into ADS via ABL to perform post-layout EM analysis in ADS with little to no need for layout pre-processing before EM simulation.

The ABL design transfer between tools is high-fidelity and preserves all data and original objects. ABL is also architected to have significantly improved speed and capacity. As a result, major enterprise PCB tool vendors are now working with Agilent EEsof to offer support for ABL as soon as early 2014 with support for most major enterprise PCB tools by the end of 2014.

And there's even more to look forward to in ADS 2014, including simulation support for the Agilent DynaFET Model, an advanced compact model of III-V FETs (GaAs and GaN) including electro-thermal and trapping effects; and simulation support for Agilent's Nonlinear Vector Network Analyzer-measured X-parameter* models with memory effects, electro-thermal simulator enhancements, new DRC and LVS capabilities and technologies, and Silicon RFIC schematic interoperability with Cadence Virtuoso designs. And, for the growing number of high-speed digital designers using ADS, there are new high-speed digital capabilities in ADS 2014 as well.

ADS 2014 is currently in Beta testing and is expected to ship in the first quarter of 2014. Agilent EEsof invites customers to join its Early Access Program and to download and provide feedback on the Beta release. If interested, please contact your local application or technical support engineer.

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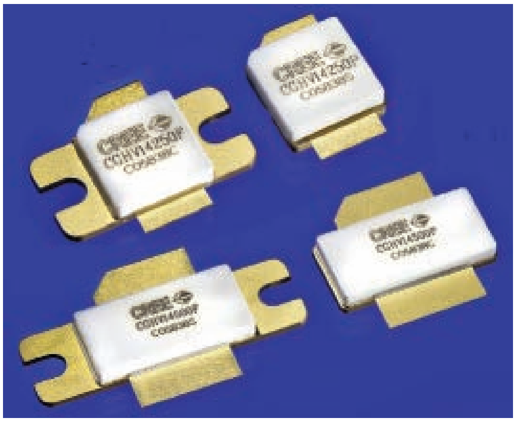

GaN Transistors for L-Band Commercial and Military Applications

The initial GaN high electron mobility transistors (HEMT) adoption started with ultra broadband applications and S-, C- and X-Band radar applications. In recent years, telecom applications have ramped up GaN HEMT production volumes. Cree recently reported that it has shipped more than 2 million transistors to the telecom market, which is accelerating the adoption of GaN HEMT technology. These increased volumes have enabled the GaN cost platform to be competitive with Si or GaAs solid-state FETs, independent of frequency.

PRODUCT DESCRIPTION

At L-Band frequencies, Cree has developed two new GaN HEMTs optimized for use in 1.2 to 1.4 GHz radar amplifier systems: the 250 W CGHV14250 and the 500 W CGHV14500. These L-Band high power transistors feature ultra-high efficiency performance (Class A/B operation in the 65 to 70 percent range), high power gain performance (20 dB range) and wide bandwidth capabilities. The new transistors are also input matched and unmatched on the output, allowing for utilization in HPA applications ranging from UHF to 1800 MHz, including tactical air navigation systems (TACAN), identification friend or foe (IFF) systems and other military telemetry systems.

Manufactured using Cree's latest generation 0.4 um, 50 V process, the CGHV14250 and CGHV14500 offer superior GaN HEMT performance, efficiency and bandwidth at an affordable price. Cree's GaN HEMT technology also delivers proven reliability of 2.5 million hours of MTTF life (285 years) at peak junction temperature of 225°C. Cree GaN processes are reliable, stable and proven, with a fielded FIT rate of less than 10. As one of the pioneers in commercializing GaN technology, Cree has demonstrated volume production and the reliability experiences to support pulsed, CW and modulated waveform applications.

UNIQUE BENEFITS

GaN's high efficiency and gain characteristics provide system designers with a number of advantages, including economies in heat sinks and thermal management. GaN high power density packages provide the potential benefits of smaller amplifier size/footprint and reduced drive power, resulting in lighter system weight, which can be important for mobile, outdoor and airborne applications. Further, GaN's efficiency advantage helps reduce load require-

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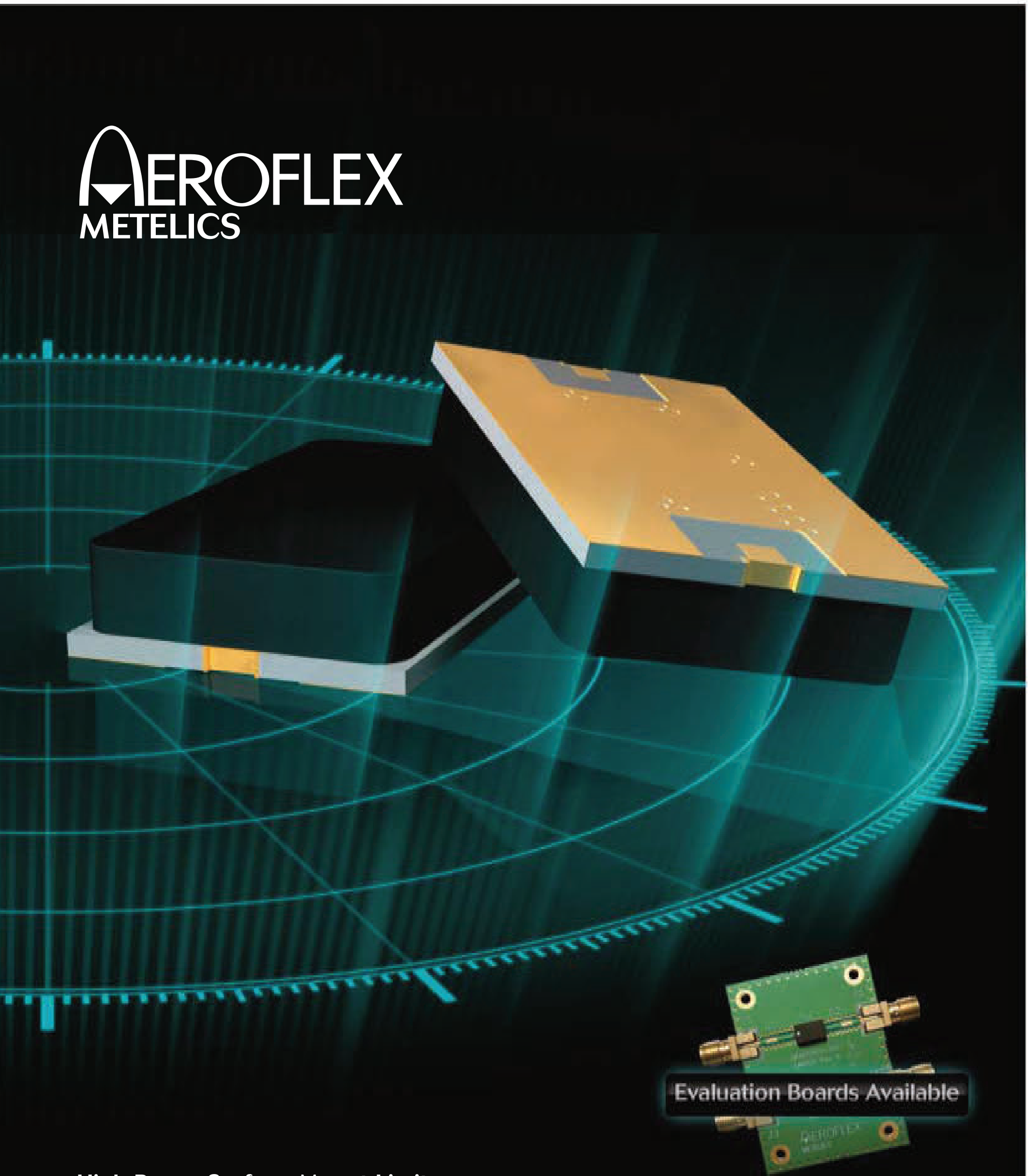

New high power surface mount limiters from Aeroflex / Metelics are making your receiver/ protector sections a whole lot easier to design. These drop-in devices include 11 completely integrated components that have been optimized for S and C band radar systems. In comparison to silicon and GaAs MMICs,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

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LM501202-L-C-300	Octave Band, Low Power	500-2000	0.4	5
LM501202-M-C-300	Octave Band, Medium Power	500-2000	0.4	30
LM202602-H-A-300	High Power	2000-6000	0.85	4
LM202602-H-C-300				
LM202802-L-C-300	Octave Band, Low Power	2000-8000	1.0	5
LM202802-M-C-300	Octave Band, Medium Power	2000-8000	1.2	30
LM401102-Q-B-301	Octave Band, High Power "Quasi-Active"	400-1000	0.3	125
LM401102-Q-C-301				
LM102202-H-C-301	Octave Band, High Power "Quasi-Active"	1000-2000	0.35	125
LM102202-Q-C-301				
LM202402-Q-C-301	Octave Band, High Power "Quasi-Active"	2000-4000	0.5	100
LM202402-Q-E-301	Octave Band, High Power "Quasi-Active"	2000-4000	0.5	125
LM202402-Q-F-301	Octave Band, High Power "Quasi-Active"	2000-4000	0.5	100
LM202802-Q-C-301	Octave Band, High Power "Quasi-Active"	2000-8000	1.1	125
LM2933-Q-B-301	High Power, Passive Two-stage Power Limiter	2900-3300	0.6	100

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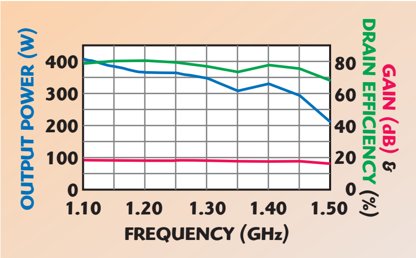
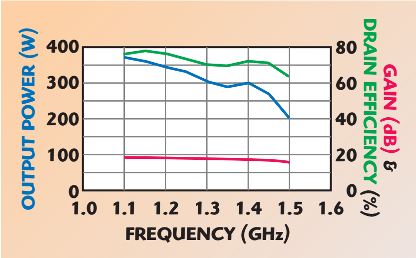
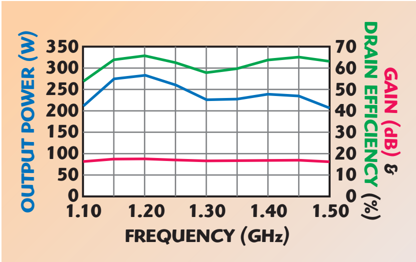


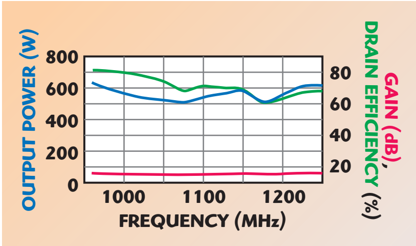
▲ *Fig. 1 CGHV14250 typical RF results (V_{dd} = 50 V, I_{dq} = 500 mA, P_{in} = 37 dBm, T_{case} = 25°C, Pulse Width = 500 us, Duty Cycle = 10%).*



▲ *Fig. 2 CGHV14250 typical RF results (V_{dd} = 50 V, I_{dq} = 500 mA, P_{in} = 37 dBm, T_{case} = 85°C, Pulse Width = 500 us, Duty Cycle = 10%).*



▲ *Fig. 3 CGHV14250F CW RF results (V_{dd} = 50 V, I_{dq} = 500 mA, P_{in} = 37 dBm, T_{case} = 65°C.)*



▲ *Fig. 4 CGHV14500F in applications circuit (V_{dd} = 50 V, I_{dq} = 500 mA, P_{in} = 41 dBm, T_{case} = 25°C, pulse width = 500 μs, duty cycle = 10%).*

ments for the power distribution system and the wider bandwidth potential offers system designers the option to employ a single antenna approach based on a multi-band high power amplifier (HPA) capability.

FULL SPECIFICATIONS AND FEATURES

Under typical operation at 25°C case temperature, the 250 W CGHV14250's output power reaches 330 W, 18 dB power gain with 77 percent typical drain efficiency (see ***Figure 1***). The 500 W CGHV14500 is rated for 500 W typical output power, 17 dB power gain, and 70 percent typical drain efficiency at 25°C. These specifications are measured at 500 μsec, 10 percent duty cycle operating conditions. For both the 250 and 500 W GaN HEMTs, the pulsed amplitude droop is < 0.3 dB.

Although the device part numbers indicate 250 and 500 W, a closer look at the data sheet reveals they are rated at a case temperature of 85°C (see ***Figure 2***). In examining Figures 1 and 2 to compare the devices' performance at 25° versus 85°C, note that the efficiency of the transistors remains above 70 percent from 25° up to 85°C. In demonstration of the robustness of the device, the power dissipation is also shown for running the parts in continuous wave (CW) mode (see ***Figure 3***).

TARGETED APPLICATIONS

Targeted applications for the new L-Band GaN HEMTs include TACAN, IFF systems and other military telemetry systems. Cree provides RF design engineers with Cree's industry-leading large signal models, now available for Agilent's ADS and AWR's Microwave Office simulators. S-parameter files are also available. The demonstrator circuits for the CGHV14250 and CGHV14500 were designed with their respective proprietary large signal models and achieved first-pass success for both the 1.2 to 1.4 GHz circuits and the 960 to 1250 MHz circuits (see ***Figure 4***).

Demonstration test fixtures for 1.2 to 1.4 GHz radar are available from Digi-Key, as well as directly from Cree. Additionally, an application circuit for IFF and TACAN performance will be available shortly.

Cree Inc.,
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(919) 407-5302,
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Product *Hilites*

Featured Products — **FREQUENCY SYNTHESIZERS**

HIGH PERFORMANCE SYNTHESIZER

Synergy's low phase noise synthesizer model LFSW170225-1M offers wide band coverage from +5 Volt supplies. The close-in phase noise is -102 dBc @ 1 KHz through 10 KHz offset and -123 dBc @ 100 KHz offset. It also provides buffered output power of +5 dBm (Min.), spurious suppression of 75 dB (Typ.), and harmonics of 25 dB (Typ.). The frequency is varied in 10 MHz steps. This great performance is packaged in a small 1.25" X 1.00" X 0.230" housing (RoHS compliant).

HIGH PERFORMANCE SYNTHESIZER

Low close-in phase noise L-Band synthesizer model LFSFN100200-100 provides typical phase noise of -102 dBc/Hz @ 1 kHz, -103 dBc/Hz @ 10 kHz, and -110 dBc/Hz @ 100 kHz offset. It also provides output power of +5 dBm (min.), spurious suppression of 70 dB (Min.), and harmonics of 10 dB (typ.). Operating with +5 volt supplies and is packaged in a small 1.25" X 1.00" X 0.230" housing (RoHS compliant).

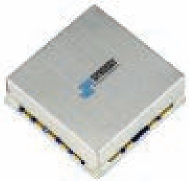
WIDEBAND LOW PHASE NOISE SYNTHESIZER

The LFSFN150320-50 is a new, wideband, low phase noise synthesizer covering 1500 MHz to 3200 MHz in 500 kHz step size when using a 10 MHz reference. Applications include microwave radio, radar, PCS and ISM communication links requiring low noise frequency generation. Phase noise at 1 kHz offset is -95 dBc/Hz and at 100 kHz offset is -108 dBc/Hz. Spurious products are suppressed by 65 dB and output power is +5 dBm, minimum. This surface mount package is 1.25 x 1.0 x 0.23 inches (L x W x H) and is powered by a single +5 volt supply drawing less than 200 mA of current. Other step sizes and reference frequency options are available by contacting Synergy directly.

PARALLEL ADDRESSABLE SYNTHESIZER

The LFCPH181254-10 synthesizer is ideal for designs that require spot frequencies across a particular frequency band. This device requires no external programming and can generate up to 16 selectable frequencies (pre-programmed at the factory) via a 4 bit binary address as specified in a supplied frequency look-up table in the frequency range of 1800 to 2540 MHz. The features include a minimum output power of +5 dBm, a typical harmonic suppression of 25 dB and a typical phase noise of -96 & -110 dBc/Hz at 10 KHz and 100 KHz offsets with an external 10 MHz reference. The operating temperature range is -40 to +85°C and is housed in a 1.0" x 1.25" RoHS surface mount package. This device is also available in a connectorized version as well as other frequency ranges.

PARALLEL ADDRESSABLE SYNTHESIZER



The FCPL65120-10 synthesizer requires no external programming and can generate up to 16 selectable frequencies (pre-programmed at the factory) via a 4 bit binary address as specified in a supplied frequency look-up table in the frequency range of 650 to 1200 MHz. This device features a minimum output power of +6 dBm with a typical harmonic suppression of 15 dB and a typical phase noise of -98 & -113 dBc/Hz at 10 kHz and 100 kHz offsets with an external 10 MHz reference. The operating temperature range is -40 to +85 deg. C and is housed in a 0.94" x 0.94" RoHS surface mount package. This device is also available in a connectorized version and is ideal for designs that require spot frequencies across a particular band. Other models with different selectable frequency ranges are available off the shelf.

PARALLEL ADDRESSABLE SYNTHESIZER

The MTS-200400-10 is a high resolution synthesizer that combines the latest in DDS and multi-loop synthesizer technologies with a high performance VCO to generate frequency signals from 2-4 GHz with as low as 1 Hz step size. It also provides ultra low phase noise, wide bandwidth performance and low spurious, while permitting for increased loop bandwidth, faster settling time and higher stability under vibration. Power consumption is less than 2.0 watts. This product is ideal for applications in imaging equipment such as RADAR and magnetic resonance, DVB transmitters, satellite ground station equipment, test equipment and control links for Unmanned Aerial Vehicles (UAV). This product is housed in a surface-mount package measuring 1.22 x 1.950 x 0.47 inches. Connectorized version is also available.

PRODUCTS

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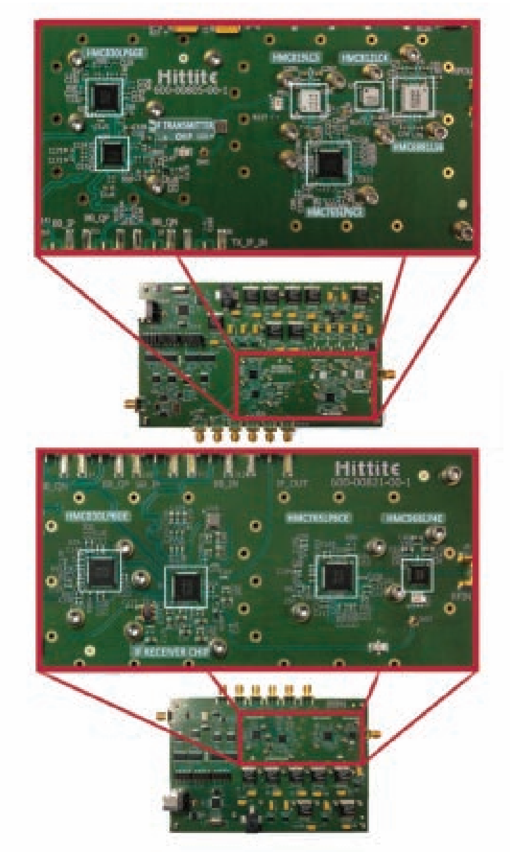


Microwave Radio Chipsets Cover 6 to 42 GHz Bands

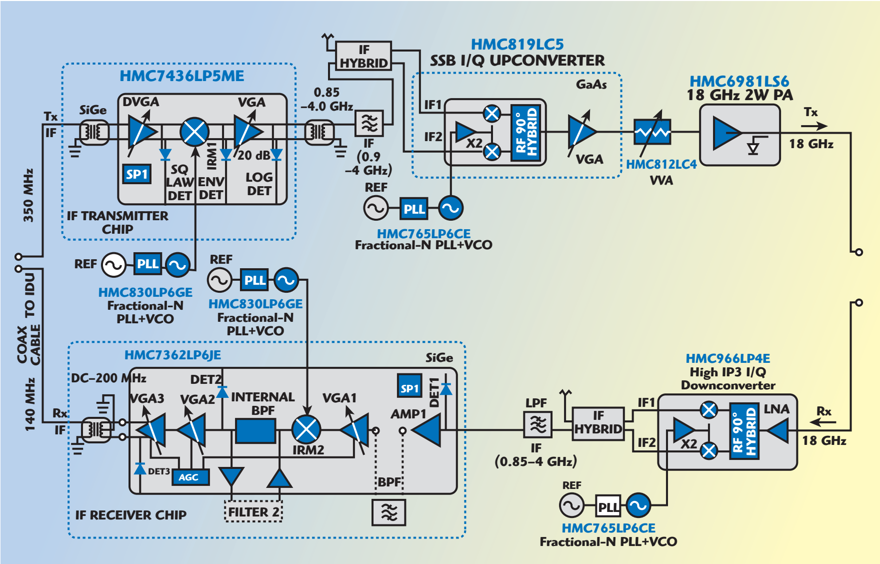
Hittite Microwave has developed a series of microwave radio IC chipsets that cover the 6 to 42 GHz frequency bands while dramatically reducing the size, complexity, production cost and power consumption of microwave radios. The chipsets offer complete upconversion and downconversion solutions that are designed to address the need for higher bandwidth and faster time-to-market in microwave split-mount outdoor units, and are equally applicable for direct modulation of full outdoor units (FODU). The chipsets simplify system manufacturing, deployment and inventory management, as the chipsets are highly integrated such that fewer individual ICs are required. Hittite's new chipsets also support high order modulation, up to 4096-QAM to meet the current and future requirements of high capacity microwave radios.

The functional diagram in ***Figure 1*** is an example of how Hittite's microwave chipsets can be used to realize a microwave radio transceiver solution for the licensed 18 GHz point-to-point radio band (17.7 to 19.7 GHz). The 18 GHz transmit chipset reference design converts the 350 MHz IF frequency from the indoor unit (IDU) to an 18 GHz transmit signal at the antenna.

At the heart of the transmit chipset is a highly integrated IF transmitter chip, HMC7436LP5ME. It is designed for high linearity operation, supports modulations up to 4096-QAM and is housed in a compact, 32-pin 5 × 5 mm standard QFN package. The HMC7436LP5ME IF transmitter chip, shown in ***Figure 2***, takes the industry standard 300 to 400 MHz IF input signal and converts it to a 0.85 to 4 GHz single-ended RF signal at its output. The IF input power range is from –28 dBm to +3 dBm. To equalize for input signal cable losses, HMC7436LP5ME provides 32 dB of digital gain control in 1 dB steps, while an analog VGA controls the transmit output power continuously from –20 dBm to 0 dBm.

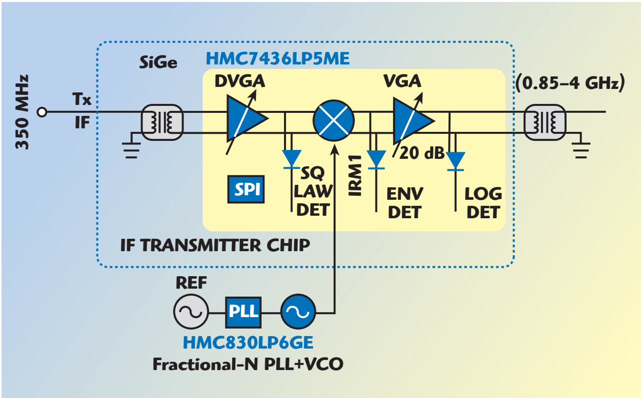
The HMC7436LP5ME also features three integrated power detectors. A square law detector after the DVGA is used to set the power level into the mixer, the envelope detector af-

Hittite Microwave Corp.
Chelmsford, MA



▲ *Fig. 1 Complete 18 GHz transmit/receive chipset reference design.*

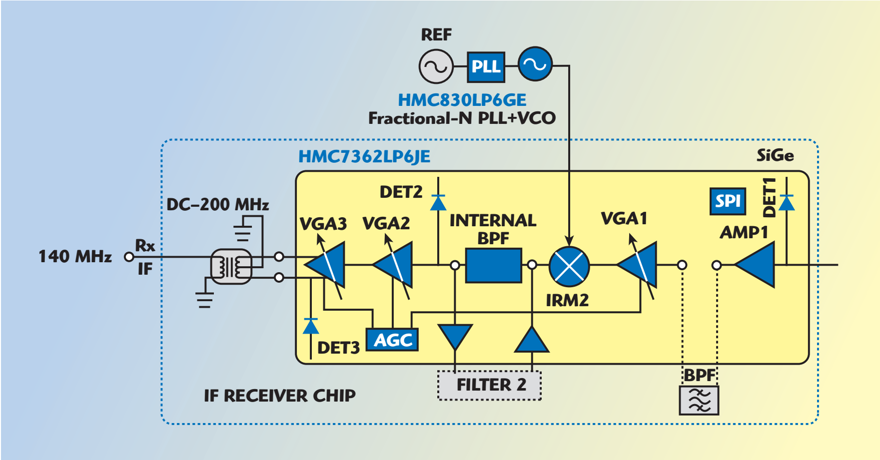
ter the mixer can be used for calibration, and the log detector is for fine output power adjustment through the analog VGA. Analog baseband IQ interfaces (not shown) are also provided to support FODU direct modulation configurations. In this baseband configuration, the HMC7436LP5ME includes four integrated and configurable lowpass reconstruction filters covering channel bandwidths of 14, 28, 56 and 112 MHz with bandwidth calibration. The IF transmitter chip is configured via a three-wire SPI interface.



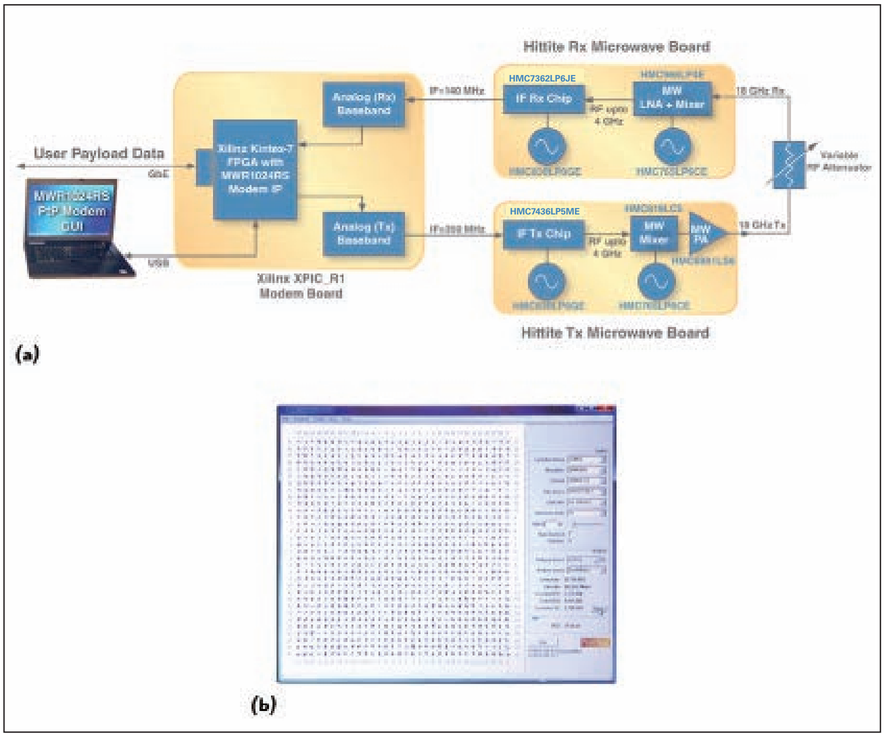
▲ *Fig. 2 HMC7436LP5ME IF transmitter chip block diagram.*

The LO for the IF transmitter chip can be taken from the HMC830LP6GE wideband fractional synthesizer, which covers 25 to 3000 MHz, or the HMC833LP6GE, which covers up to 6000 MHz.

The HMC819LC5 in the transmit chain is a sub-harmonically pumped I/Q transmitter that incorporates a frequency doubler in the LO path, a pair of double balanced mixer cells, and a single-ended driver output amplifier. This high linearity I/Q transmitter is rated for microwave frequencies from 17.7 to 23.6 GHz, and provides 15 dB conversion gain and 35 dB of sideband rejection. The HMC819LC5 I/Q transmitter is followed by the HMC812LC4 voltage variable attenuator (VVA), which is used to set the output power level of the transmit chain. The HMC812LC4 is rated from 5 to 30 GHz and provides a continuously variable attenuation range from 0 to 30 dB. Implementing a VVA in this section enables the radio to dynamically adjust its output power depending upon the environmental conditions. Following the VVA, the HMC6981LS6 power amplifier delivers 2 W of output power, representing one of Hittite's best-in-class microwave radio linear power amplifiers. The HMC6981LS6 covers the 15 to 20 GHz frequency band and delivers 26 dB of gain, +33.5 dBm output P1dB and +43.5 dBm output IP3. The amplifier also features an integrated, temperature-compensated power detector, which may be used in a closed loop circuit to maintain constant output power over temperature variations.



▲ *Fig. 3 HMC7362LP6JE IF receiver chip block diagram.*



▲ *Fig. 4 18 GHz microwave link demonstration setup (a) and constellation view (1024-QAM).*

The LO for the HMC819LC5 I/Q transmitter is provided by the HMC765LP6CE fractional PLL/VCO, which covers 7.8 to 8.8 GHz with closed loop phase noise of –101 dBc/Hz at 10 kHz offset. Hittite Microwave offers the widest portfolio of fully integrated PLL-based microwave frequency synthesizers and VCOs with best-in-class phase noise and spurious performance.

In the receiver section, the HMC966LP4E shown in ***Figure 3*** is a sub-harmonically-pumped low noise downconverter (LNC) that is rated for input frequencies from 17 to 20 GHz, and incorporates a low noise amplifier and frequency doubler in the LO path and an image reject mixer. The HMC966LP4E accepts a sub-harmonic LO input between 7.5 and 11.75 GHz, supports an IF of DC to 3.5 GHz, and achieves 40 dBc image rejection and a low 2.5 dB noise figure. Following the LNC is the highly integrated IF receiver chip HMC7362LP6JE, which converts the downconverted receive signal to a 140 MHz IF that is fed back to the IDU. As shown in Figure 3, it includes three VGAs to achieve 80 dB of analog gain control, three power detectors, a programmable AGC block, as well as selectable integrated

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Join us for the 9th annual IEEE Radio Wireless Week (RWW) in Newport Beach, California from 19- 22 January 2014. This exciting week includes the IEEE Radio and Wireless Symposium (RWS) and the IEEE Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems (SiRF). Join us to learn about the latest in the wireless technologies and networks with colleagues while enjoying the beautiful ocean view of southern California.

RWW: ***IEEE Radio Wireless Week***
RWS: ***IEEE Radio and Wireless Symposium***
PAWR: ***IEEE Topical Meeting on Power Amplifiers for Wireless and Radio Applications***
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Highlights

Technical Oral Sessions - Mon/Wed, 20-22 Jan., 2014
Interactive Poster Sessions - Mon/Wed, 20-22 Jan., 2014
Student Paper Competition Finals - Mon, 20 Jan., 2014
Demo Session - Tue, 21 Jan., 2014
Plenary Talk - "THz imaging for Biomedical Applications"
Workshops
Power Amplifier, Radar Systems/Biomedical Radar, RF Energy Harvesting, etc.
Panel Sessions
Future of Wireless Communications, Emerging PA Breakthrough, THz Wireless Communications, etc.
Distinguished Lecturer Talks
Monday morning Distinguished Lecturer session featuring four prominent speakers. For more information, Advance Program will be available at http://www.radiowirelessweek.org/

Exhibits and Sponsorship Opportunity

This year's Exhibit will offer tabletops and full 10×10 exhibits. The exhibition will operate on Monday and Tuseday, with a special offer for Sunday Set-ups. WirelessApps talks and Demo Sessions will also be held in the Exhibition area. Rental fees for 2014 are $1200 per tabletop booth space and $1500 per 10×10 booth space. Sponsors at the $3000 level and above will be offered one free 10×10 booth space. In 2011, 2012 and 2013 the exhibition was SOLD OUT so please book early in order to insure premium exhibit space. For more about exhibits and sponsorship, visit http://www.radiowirelessweek.org/exhibits/

bandpass filters (14, 28 or 56 MHz bandwidth). The filters can also be bypassed to allow for off-chip filtering of other user-defined bandwidths.

The HMC7362LP6JE IF receiver chip is designed for high linearity operation, supporting modulations of up to 4096-QAM and bandwidths up to 112 MHz. It supports an RF input range from 0.8 to 4 GHz and is housed in a compact, 40-pin 6 × 6 mm standard QFN package. The HMC7362LP6JE also supports baseband IQ interfaces after the mixer so that the chips can be used for direct modulation in the FODU configuration.

For all other microwave radio bands, designers can select chipsets to realize all of the licensed microwave radio bands from 6 to 42 GHz. Hittite has a large selection of components available for microwave radio applications. The IF transmitter and receiver chips HMC7436LP5ME and HMC7362LP6JE support all of the standard microwave frequency bands from 6 to 42 GHz.

18 GHz PtP MICROWAVE 1024-QAM LINK DEMO

To validate the performance of the Tx and Rx chipsets, an 18 GHz point-to-point (PtP) microwave radio demonstration link was set up. Hittite Microwave and Xilinx worked together to develop the demonstration setup shown in ***Figure 4***. The demonstration setup combines the Xilinx XPIC_R1 modem with 18 GHz microwave Tx and Rx sections configured on PCBs using Hittite's chipsets. The connections between the Xilinx and Hittite boards are the conventional 140 MHz Rx IF and 350 MHz Tx IF. The Xilinx XPIC_R1 is running the complete PtP modem IP, named MWR1024RS, on a Kintex-7 FPGA. This full-featured, high-performance modem IP from Xilinx is capable of up to 1.0 Gbps raw data throughput with 1024-QAM modulation. The user data payload is streamed over a Gigabit Ethernet link in the end system. The demonstration platform relied on the Xilinx MWR1024RS PtP Modem GUI to control the boards and display the received signal constellation and key link statistics (see Figure 4b). More information on the MWR1024RS PtP modem IP is available from Xilinx.

The Hittite synthesizer and IF chips were programmed using a three-wire SPI port. The synthesizers were programmed for an IF frequency of 1740 MHz for Tx and 1840 MHz for Rx, while the IF chips were programmed for channel bandwidth, gain and interface type (IF). The Tx modem was configured to transmit a 1024-QAM modulated signal in a 30 MHz channel, and the transmitter chip gains were set to achieve +20 dBm RF signal output power. A variable RF attenuator was connected between the transmit and receive RF ports to simulate the link path loss that would be realized in a deployed microwave radio link. As the RF attenuator was varied, the AGC in the Rx IF chip maintained the appropriate IF output power to the modem to maintain optimal link performance. The modem was able to measure a Bit Error Rate (BER) of better than 10^{-9} over a wide range of attenuation settings. The digital modem can demodulate even lower signal levels as it supports modulation orders down to QPSK – which may be changed on-the-fly.

Hittite Microwave continues to provide innovative, high performance, Antenna-to-Bits microwave radio solutions covering all bands from 6 to 42 GHz, while supporting both split-mount and full ODU style microwave radios. The IF transmitter and IF receiver chips HMC7436LP5ME and HMC7362LP6JE provide a very high level of integration, support all of the standard microwave frequency bands from 6 to 42 GHz, and form the core of these compact, high performance microwave radio chipsets.

Hittite Microwave and Xilinx have successfully demonstrated a complete modem with 1024-QAM modulation in a 30 MHz channel over an 18 GHz microwave link. The BER of the complete modem was better than 10^{-9} over a wide range of attenuation settings. The IF transmitter and IF receiver chips are also capable of supporting modulations of 2048 and 4096-QAM.

VENDORVIEW

Hittite Microwave Corp.,
Chelmsford, MA,
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The IEEE Microwave Theory and Techniques Society's 2014 International Microwave Symposium (IMS2014) will be held 1 - 6 June 2014 in Tampa, Florida as the centerpiece of Microwave Week 2014. IMS2014 offers technical sessions, interactive forums, plenary and panel sessions, workshops, short courses, industrial exhibits, application seminars, historical exhibits, and a wide variety of other technical and social activities, including a guest program. As usual, the Microwave Week technical program also comprises the RFIC Symposium (www.rfic2014.org) and the ARFTG conference (www.arftg.org). Unique to Microwave Week 2014, Florida's own WAMICON (www.wamicon.org) will be held jointly with ARFTG for this year. With over 9,000 participants and 600 industrial exhibits of state-of-the-art microwave products, Microwave Week is the world's largest gathering of Radio Frequency (RF) and microwave professionals and the most important forum for the latest research advances in the field.

PAPER SUBMISSION: Authors are invited to submit technical papers describing original work on radio-frequency, microwave, millimeter-wave, and terahertz (THz) theory and techniques. The deadline for submission is 9 December 2013. Paper submissions should be three pages in length (PDF format), and should not exceed one megabyte in file size. Hardcopy and email submissions will not be accepted. Please refer to the IMS2014 website (www.ims2014.mtt.org) for detailed instructions concerning paper submission. Authors must adhere to the format provided in the conference paper template available on the symposium's website. It is the authors' responsibility to obtain all required company and government clearances prior to submission. Please don't wait until the last day to start using the paper submission process. Those unfamiliar with the process may encounter paper formatting or clearance issues that may take time to resolve.

A double blind review process will be used. Papers will be evaluated on the basis of originality, content, clarity, and relevance to the symposium. For accepted papers, the electronic submission of a final manuscript along with a copyright assignment to the IEEE will be required no later than 3 March 2014. Symposium proceedings will be recorded on electronic media and archived in IEEE-Xplore. Authors of accepted papers should consider submitting an extended version of their symposium paper for possible publication in the IEEE Transactions on Microwave Theory and Techniques.

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IMS2014 enthusiastically invites submission of papers that report state-of-the-art progress in technical areas that are outside the scope of those specifically listed in this Call for Papers, or that may be new to the symposium, but are of interest to our attendees.

STUDENT PAPER AND STUDENT DESIGN COMPETITIONS:

Eligible students are encouraged to submit papers for the student paper competition. The papers will be evaluated using the same standards as all contributed papers. In addition, eligible students or student teams are invited to consider taking part in student design competitions during the IMS2014, which are organized and sponsored by various Technical Committees (TC) of the MTT-S Technical Coordination Committee (TCC). Please visit the IMS2014 website for full details.

MICROAPPS:

The Microwave Application Seminars serve as a forum for exhibitors at the IMS to present the technology behind their commercial products and their special capabilities. The presentations are open to all conference and exhibit attendees.

Electronic Submission Deadline:
9 December 2013
All submissions must be made through email:
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Broadband High Dynamic Range Active Mixer

Linear Technology has developed an ultra-high dynamic range RF down-converting mixer for applications that demand the very best in performance. The LTC5551 offers very high linearity of +36 dBm IIP3 and low 9.7 dB noise figure comparable to the highest IIP3 passive mixers available. Unlike passive mixers which typically have 7 to 9 dB of conversion loss, the LTC5551 actually has 2.4 dB of conversion gain, substantially improving receiver dynamic range. The device also has broad RF frequency range capability, operating from 300 MHz to 3.5 GHz.

Additionally, passive mixers require high LO drive to reach their claimed IIP3. The LTC5551 has an integrated LO buffer requiring only 0 dBm drive level, hence external circuitry and costs are minimized. And with the elimination of a high power LO signal in the users' receiver, it substantially reduces a potential source of undesirable radiation, thus simplifying filtering and RF shielding requirements.

The LTC5551 ensures robust radio performance with its high 1 dB compression point of +18 dBm. Both the RF and LO inputs have integrated balun transformers, further reducing cost and external components while simplifying the design task. The mixer is powered from a single 3.3 V supply with current consumption of 204 mA, delivering its high performance with exceptionally low power. If needed, the mixer also has a low power mode controlled via the ISEL pin. In this mode, current consumption drops by 30 percent to 142 mA, trading off the IIP3 to +29.3 dBm. The mixer's minimum external circuits and its 16-lead, 4 × 4 mm QFN package provide a highly compact solution footprint.

The superior performance of this mixer is ideally suited for a wide range of mission-critical, high performance applications that are exposed to strong interference sources such as multi-carrier GSM, 4G LTE and LTE-Advanced multimode base stations, point-to-point backhauls, military communications, wireless repeaters, public safety radios, VHF/UHF/white-space broadcast receivers, radar and avionics.

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Linear Technology,
Milpitas, CA,
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500 W, Broadband HPAs in a 3U Chassis

Empower RF Systems continues to leverage next generation hardware and software architecture and is proud to introduce the next series in the "size matters" portfolio – 500 W in a 3U chassis. This new PA family operates in the frequency ranges of 20 to 500 MHz (Model 2173), 500 to 1000 MHz (Model 2174) and 20 to 1000 MHz (Model 2175) with the output power guaranteed over full bandwidth and temperature. These products offer a unique combination of size, weight, RF power delivery and control features embedded into 500 W units.

All of the features of the 1 kW next generation platforms are designed into the 500 W family and size is reduced further to a 3U chassis. Also similar to Empower's 1 kW units, the 500 W solid state amplifiers utilize high power LDMOS devices that provide wide frequency response, high gain, high peak power capability and low intermodulation distortion. Advanced broadband RF matching networks and low-loss combining techniques are critical to performance as well.

Empower's control and user interface software, now standard on the "size matters" platforms, has an embedded web server and feature rich menu which includes not only the software update process, but also real-time monitoring, protection and control, sensor driven dynamic adjustments to the amplifier while in operation, remote user access and a selection of communications protocols that can be enabled by the end user during system set up.

Consider the possibilities – the smaller size, easier system integration and higher efficiency of the "size matters" HPAs significantly broadens the application capabilities within the test and measurement, electronic warfare, radar and digital communications markets. Additionally, GaN-based 1 kW in a 5U chassis with 1 to 3 GHz coverage will be available later in Q1 2014 (Empower model 2170).

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Empower RF Systems,
Inglewood, CA
(310) 412-8100,
www.empowerrf.com.

Software and Mobile Apps

FieldFox Mobile App

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The FieldFox handheld analyzer handles everything from routine maintenance and in-depth troubleshooting wherever you go, but at times it would be more convenient to operate it remotely. Now you can monitor and control your FieldFox using any iOS device, including iPhones and iPads, with the new FieldFox remote control capability, Option 030 and the new FieldFox Remote Viewer iOS app. The app is available on iTunes. For a limited time, get the FieldFox remote control option for free.

Agilent Technologies Inc.,
www.agilent.com.

CISPR Test Configurations

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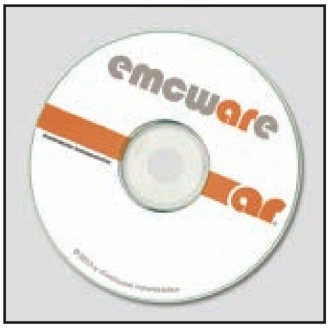
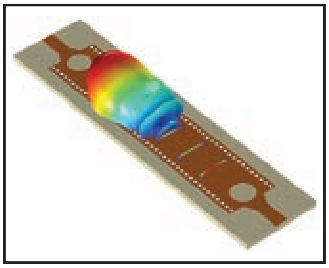


AR RF/Microwave Instrumentation emcware's latest release expands on an already great platform with the addition of CISPR custom test configurations. Enhancements include predefined receiver setups and report generation to standards such as: CISPR 11, 13, 22, 15 and 32. emcware also retains a user friendly environment with all of its previous functionality allowing users maximum flexibility to create their own test configurations or modify existing ones. Download the free software at www.arworld.us/html/IRC_software_details.asp?swid=23.

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

Analysis Software



COMSOL Multiphysics provides analysis tools for engineers working in RF and microwave engineering, in addition to application-specific modules in the electrical, mechanical, fluid and chemical disciplines. With six specially designed modules for simulating such diverse applications as the propagation of waves in and around structures, to analyzing microwave devices and antennas, COMSOL provides an interface for modeling any physics. Paramount among its strengths is COMSOL's ability to combine all physics effects, such as RF heating, mechanical stress and deformation effects – all crucial to electrical applications.

COMSOL Inc.,
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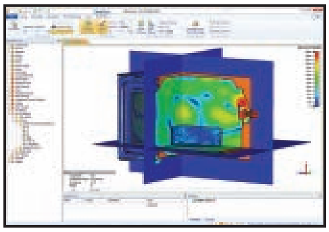

CST STUDIO SUITE®, a package of simulation tools, is used by researchers and engineers to design, model and optimize electromagnetic (EM) systems. CST STUDIO SUITE 2014 further improves usability and performance with new modeling features and CAD tools to streamline workflows. Particular attention has been paid to model setup, meshing and System Assembly and Modeling (SAM) as well as multiphysics and PCB simulation. Official release is scheduled for March 2014.

CST of America Inc.,
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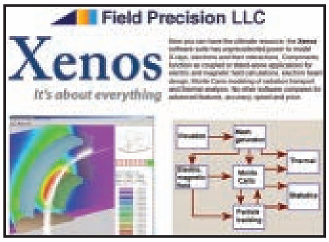
X-Ray Simulation and Source Design



Field Precision released GDE, an enhancement to the Xenos suite for Windows. Xenos models X-ray and electron interactions. Coupled components address electric/magnetic fields, electron beams, Monte Carlo radiation transport and thermal transport. Applications include X-ray imaging, dose distributions and the design of X-ray equipment. GDE is an extension for researchers who run massive Monte Carlo simulations. The program makes it possible to split calculations between any number of worker computers. Simulations may be apportioned over local networks or the Internet.

Field Precision LLC,
www.fieldp.com.

Hittite Mobile App

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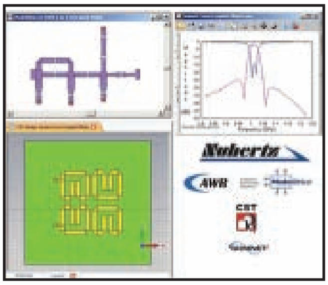
Download Hittite's new mobile app and view the latest products on your iPad or iPhone from the App Store. Hittite's selection guide, Off-the-Shelf newsletter and product solution brochures are available in e-Book and pdf formats for your mobile device or request your copy of the new selection guide at the company's website by selecting "Submit Inquiry" in the left hand navigation. New product data sheets can also be found online.

Hittite Microwave Corp.,
www.hittite.com.

Software and Mobile Apps

Filter Synthesis and Analysis

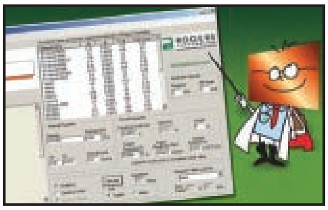


Nuhertz Technologies has established leadership in filter synthesis and analysis with its flagship program, FilterSolutions®. Nuhertz has developed numerous synthesis algorithms, unparalleled in industry and academia, delivering a superior level of filter design automation and productivity improvements. As a leader in the synthesis of electronic filter design, FilterSolutions provides direct integration with the tools of its partners: AWR, CST, Modelithics and Sonnet Software. These partnerships allow the achievement of improved modeling accuracies.

Nuhertz Technologies,
www.nuhertz.com.

Transmission-Line Modeling Tool

VENDORVIEW



Free software can be invaluable, especially a tool such as the Microwave Impedance Calculator from Rogers Corp. This simple-to-use, transmission-line modeling tool calculates key parameters for most RF/microwave transmission lines, including microstrip, stripline and even coplanar-waveguide (CPW) transmission lines. The calculator can be used to predict such parameters as impedance and insertion loss based on different circuit materials and their dielectric properties. The Microwave Impedance Calculator runs on personal computers (PC) and portable electronic devices.

Rogers Corp.,
www.rogerscorp.com.

SkyOne Semiconductor Solution

VENDORVIEW

SkyOne™ is the world's first semiconductor solution to integrate all the RF and analog content between the transceiver and antenna, combining multiband power amplifiers, high throw switches, filtering, duplexing and control functionality into a package that is less than half the area of the industry's most advanced approach. This groundbreaking solution delivers the best linearity and power added efficiency, providing smartphone, tablet and ultrabook manufacturers with a device that is easy to implement and scalable as bands increasingly proliferate worldwide.

Skyworks Solutions Inc.,
www.skyworksinc.com.

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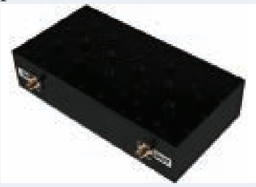
Bandpass Filter

The AB897B599 cavity bandpass filter has a passband of 890 to 905 MHz, low insertion loss of 0.75 dB, and high rejection of 70 dB from 935 to 955 MHz. Passband ripple is less than 0.2 dB and return loss is at least 18 dB. The filter measures 88 × 167.4 × 46 mm and uses SMA female connectors.

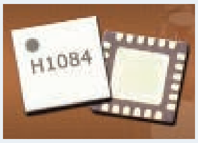


VENDORVIEW

Anatech Electronics,
www.anatechelectronics.com.

Reflective Switch

The HMC1084LC4 is a broadband reflective GaAs MESFET SP4T switch that provides frequency coverage from 23 to 30 GHz, and is controlled with 0/-3V logic. The HMC1084LC4 SP4T switch exhibits fast switching speed of 15 ns (rise and fall times) and consumes much less DC current than PIN diode based solutions. With an input signal of 30 GHz, the HMC1084LC4 exhibits 11 dB return loss, 26 dB isolation and only 2.8 dB insertion loss.



VENDORVIEW

Hittite Microwave Corp.,
www.hittite.com.

Directional Coupler

KRYTAR announced a new directional coupler operating in the frequency range of 4 to 20 GHz offering nominal coupling of 30 dB in an extremely compact package. Model 104020030 delivers frequency sensitivity of ±0.7 dB. Directivity is >15 dB. The coupler exhibits insertion loss of < 0.60 dB across the full frequency range including coupled power. Maximum VSWR at any port is 1.35, input power rating is 20 W average and 3 KW peak. Operating temperature is -54° to +85°C.

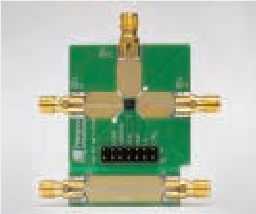
KRYTAR Inc.,
www.krytar.com.

Broadband Capacitor

The PPI 0201BB104KW160 is a 100 nF capacitor and offers resonance-free, low loss operation from 16 KHz (-3 dB point) to > 50 GHz at 16 V with an insertion loss of <1 dB. The applications for which these parts are intended require small, surface-mountable (SMT) devices with low insertion losses and reflections across RF frequencies extending from the tens of KHz to the tens of GHz, and temperatures typically ranging from –55° to +125°C.

Passive Plus Inc.,
www.passiveplus.com.

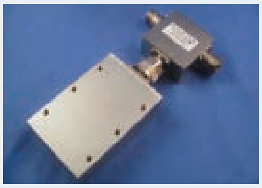
SPDT RF Switch



Peregrine Semiconductor introduced the industry's first SPDT RF switch to offer Gigabit Wi-Fi access-point designers 50 times more isolation (41 dB at 6 GHz) and 10 times better linearity (65 dBm IIP3) than other solutions. Based on UltraCMOS® technology, the new PE42423 exceeds stringent 802.11ac standards and delivers equally high performance at either 3.3 or 5 V. The switch helps networking vendors meet carrier-grade Wi-Fi data-rate and capacity demands while improving the signal quality and performance of access points.

Peregrine Semiconductor,
www.psemi.com

Isolators and Circulators



Raditek's Octave Band isolators and circulators are a cost effective solution for wideband frequency applications. This model covers 4 to 8 GHz with 150 W of reverse power and 150 W of forward power. Power options available are: 110, 150, 200 and 250 W. Typical specifications: 0.4 dB insertion loss, 18 dB isolation and VSWR 1.3:1. Operating temp. range from –30° to +70°C. Dimensions: 83 (W) × 55.2 (L) × 21.5 (H) mm. These units are proven in the field and are fully RoHS compliant.

Raditek Inc.,
www.raditek.com.

Waveguide Mount Relay

Relcomm is offering a new 18 GHz microstrip/co-planer waveguide mount relay in a 1P2T configuration. This "pin out" device provides greater layout and packaging density measuring just 0.900" Sq. × 0.550" high. The relay provides exceptional RF performance to 18 GHz (1.50:1 VSWR max, 0.50 IL max & 60 dB min ISOL). Typical uses include standby applications, input/output swapping and developing switch matrices. It can be configured with a failsafe or latching actuator and is available in 12 and 28 V DC operation.

Relcomm Technologies,
www.relcommtech.com.

Directional Couplers

RLC Electronics' high power directional couplers offer accurate coupling, low insertion loss and high directivity in a compact package. The standard units are optimized for 2 octave bandwidths and are available with a choice of coupling values. These units are ideal for sampling forward and reflected power with a negligible effect on the transmission line and very low intermodulation products. The couplers offer 2 to 40 GHz, single and dual directional; up to and beyond 500 W average; and various connector options.

RLC Electronics,
www.rlcelectronics.com.

Attenuators

SV Microwave has officially been approved by DLA as the only QPL source for qualified M3933/30 (DC-32 GHz) attenuators. SV's line has the precision, quality and performance using 2.92mm connectors for the frequency range DC through 32 GHz. The company's dB values range from 0.5 to 30 dB with low VSWR and flat attenuation. SV also offers screened and non-screened versions, so please visit its website or email marketing@svmicro.com for more information.

SV Microwave,
www.svmicro.com.

180 Degree Hybrid

The 3 port 180 degree hybrid, model DJK-2120, covers a wide frequency range of 20 to 1200 MHz (BW 60:1) with excellent performance. It is built in a rugged coaxial SMA RoHS package, with excellent insertion loss of 1.8 dB (max.) and isolation of 20 dB minimum. Outputs are matched for amplitude unbalance (0.4 dB max.) and phase unbalance (4 degree max.). Maximum RF power is 1 W. It measures 1.25" × 1.25" × 0.75".

Synergy Microwave Corp.,
www.synergymwave.com.

SPDT Switch

The TriQuint TQP4M0008 is a packaged GaAs FET single-pole, double-throw (SPDT) switch. It is a low loss reflective switch that provides 0.1 to 6 GHz broadband performance. The TQP4M0008 is operated using a DC supply for control signals operating from 1.8 to 5 V. It is packaged in a RoHS-compliant, compact 2 × 2 mm surface-mount leadless package. This SPDT switch can be used in wireless infrastructure, test and measurement, or can be used for any general purpose wireless application.

TriQuint Semiconductor,
www.triquint.com.

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AMPLIFIERS

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Model (*with heat sink/fan**)	Frequency (MHz)	Gain (dB)	Pout @ Comp. 1 dB (W)	3 dB (W)	$ Price (Qty. 1-9) ***with*** *heat sink*	***without**** *heat sink*
LZY-22+	0.1-200	43	16	32	1495	1470
ZHL-5W-1	5-500	44	8	11	995	970
• ZHL-100W-GAN+	20-500	42	79	100	2395	2320
• ZHL-50W-52	50-500	50	40	63	1395	1320
• ZHL-100W-52	50-500	50	63	79	1995	1920
LZY-1+	20-512	43	37	50	1995	1895
• ZHL-20W-13+	20-1000	50	13	20	1395	1320
• ZHL-20W-13SW+	20-1000	50	13	20	1445	1370
LZY-2+	500-1000	46	32	38	1995	1895
NEW ZHL-100W-13+	800-1000	50	79	100	2195	2095
ZHL-5W-2G+	800-2000	45	5	6	995	945
ZHL-10W-2G	800-2000	43	10	13	1295	1220
ZHL-30W-252+	700-2500	50	25	40	2995	2920
ZHL-30W-262+	2300-2550	50	20	32	1995	1920
ZHL-16W-43+	1800-4000	45	13	16	1595	1545
ZVE-3W-83+	2000-8000	36	2	3	1295	1220
ZVE-3W-183+	5900-18000	35	2	3	1295	1220

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

** To order **without** heat sink, add **X** suffix to model number (example: LZY-22X+).*

• Protected under U.S. Patent 7,348,854

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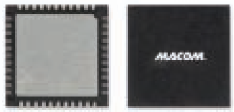
Components

HCMOS Crystal Clock Oscillator

Model 680 offers many key features for applications requiring the performance and long term reliability of a crystal clock oscillator. The hermetically sealed 5 × 7 mm surface mount package protects the component from rugged environmental conditions. It operates at a frequency range between 20 kHz to 100 MHz. It features excellent stability (±50 ppm over –55° to +180°C temperature range), low phase noise (-170 dBc/Hz at noise floor) and ultra-low jitter (<80fsec).

CTS Electronic Components Inc.,
www.ctsvalpey.com.

X-Band Core Chip



MACOM announced the industry's first integrated core chip for the 8 to 11 GHz frequency range. Containing 6 bits of phase control, 6 bits of attenuation control and 26 dB of gain, MACOM's core chip is an easy to use serial/parallel interface in a surface mount QFN package. Ideal for commercial radar applications, this integrated MMIC enables radar systems in early detection and warning for severe impending weather.

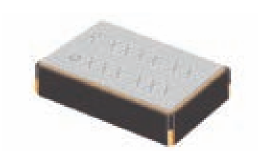
VENDORVIEW
MACOM,
www.macomtech.com.

Frequency Mixer

Mini-Circuits' ceramic surface mount wideband frequency mixer features wide bandwidth, 7.3 to 19 GHz; low conversion loss, 6.2 dB typ.; high L-R isolation, 33 dB typ.; excellent IF BW, DC to 7.5 GHz; LTCC double balanced mixer; tiny size, low profile, 0.08"; useable as up and down converter; aqueous washable; and it is protected under US Patent 7,027,795. Applications include fixed satellite, mobile and radio location.

VENDORVIEW
Mini-Circuits,
www.minicircuits.com.

Miniature TCXO



Rakon pioneered the world's first 0.5 ppm TCXO for GPS applications and announced the extension of its product offering to include the RIT2016C model TCXO. The RIT2016C minimizes power consumption in portable devices to extend the battery life. Operating at a 1.2 V supply voltage, the RIT2016C reduces power consumption even further with the additional benefit of the enable-disable mode to deliver better power management. The RIT2016C is available in the small form factor 2.0 × 1.6 mm.

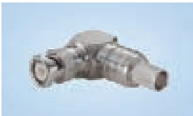
Rakon Ltd.,
www.rakon.com.

Iso-Adapter

Renaissance has developed a new X-Band iso-adapter that is designed for High Rel applications requiring waveguide to coaxial transition. Operating between 8.2 and 12.4 GHz, the iso-adapter provides 0.5 dB of loss and 18 dB of reverse isolation. The output is WR90 for the waveguide interface with UG135/U flange. Input is a type N-Female connector.

VENDORVIEW
Renaissance Electronics & Communications LLC/HXI LLC,
www.rec-usa.com.

No-Solder Connectors



Times Microwave Systems has recently announced the availability of the EZ-400-BM-X BNC no-solder male (plug) straight connector and EZ-400-BM-RA-X BNC no-solder, male (plug) right angle connector for LMR-400 low loss coaxial cable. The new crimp-style connectors do not require soldering of the center conductor into the contact making these connectors perfect for field installations and do not require braid trimming. They are also compatible with the CST-400 cable prep tool and either the CT-400/300 or HX-4 (with Y1719 dies) crimp tools.

Times Microwave Systems,
www.timesmicro.com.

Fixed Frequency Synthesizer

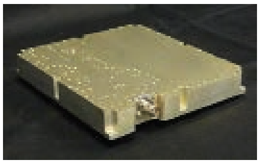
Z-Communications announced a new RoHS compliant fixed frequency synthesizer model SFS10000C-LF in X-Band. The SFS10000C-LF is a single frequency synthesizer that operates at 10 GHz. This synthesizer features a typical phase noise of -100 dBc/Hz @ 10 KHz offset and typical sideband spurs of -70 dBc. This fixed frequency synthesizer features typical 2nd harmonic suppression of -30 dBc and comes in Z-Comm's standard SFS-L1 package measuring 1" × 1" × 0.22".

Z-Communications Inc.,
www.zcomm.com.

Amplifiers

High Power SSPA

Aethercomm has recently completed a high power X-Band SSPA using a GaN with a frequency range covering 8,600 to 10,200 MHz, Aethercomm part number SSPA 8.6-10.2-100. This amplifier offers high power with ex-



cellent power added efficiency. This high power SSPA produces 100 W across the band. The amplifier design includes an external DC blanking command that enables and disables the module in less than 10 uSec and is housed in an 7.0"(w) × 8.7"(l) × 1.1"(h) module.

Aethercomm Inc., www.aethercomm.com.

Millimeter-Wave Amplifier

API Technologies introduced a standard 44 GHz millimeter-wave (MMW) amplifier to its family of products. It features an ultra-high frequency, two-stage design for high gain and medium power, and is enclosed in a rugged laser welded SMA-connectorized housing. BXHF1075 offers both high efficiency and extreme stability with 13 dB of return loss, all while generating 30 dB of gain and +17 dBm of output power off a +15 V supply. It also incorporates an internal voltage regulator to accommodate either +12 or +15 V.

API Technologies Corp., www.apitech.com.

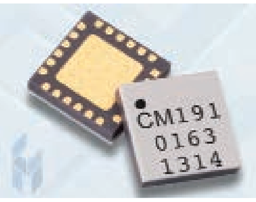
Hybrid Amplifier Module

AR's new hybrid power module (HPM) is a broadband Class A power amplifier, which operates from a single DC voltage with 42 dB small signal gain and excellent gain flatness, load tolerance and harmonics. The HPM has a built-in over voltage protection and is also available in Class AB when efficiency and higher power is required.

VENDORVIEW

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

Driver Amplifier



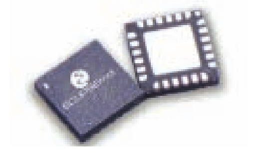
Custom MMIC introduced the CMD191C4 to its growing MMIC library of standard products. The CMD191C4 is a GaAs MMIC driver amplifier housed in a leadless, RoHs compliant, 4 × 4 mm surface mount package. It offers high output power and low current consumption. Ideally suited for complex communications systems where small size and high linearity are needed, the device operates from 4 to 10 GHz and delivers 20 dB of gain with a corresponding output 1 dB compression point of greater than +21 dBm.

VENDORVIEW

Custom MMIC, www.custommmic.com.

Low Noise Amplifier

Eclipse Microdevices' EMD1715 is a GaAs MMIC PHEMPT distributed general purpose



LNA. It has a small signal gain of 14 dB with noise figure less than 1.8 dB at 6 GHz. This device is ideal for applications that require a typical P1dB output power of +20 dBm up to 12 GHz, while requiring only 103 mA from a +5 V supply. The EMD1715 comes in a small RoHS compliant 4 mm QFN leadless package and this package has excellent RF and thermal properties.

Eclipse Microdevices, www.eclipsemicrowave.com.

Wideband PA

Electro-Photonics LLC announced the availability of a wideband power amplifier operating from 0.7 to 4.2 GHz. Its new EPA-0742P1-SF uses the latest GaN technology to achieve a gain of 46 dB and an exceptional gain flatness of ±1 dB. This amplifier provides 30 dBm output power in a very small package (6.49" × 2.87" × 1.89").

Electro-Photonics LLC, www.electro-photonics.com.

L-Band HPA

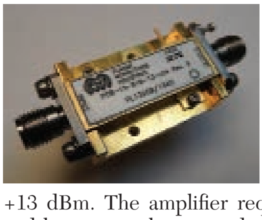
This recent and unique SATCOM solution delivers 2 kW P1dB (CW, digital modulated signal) in L-Band and a companion product delivers 800 W P1dB (CW, digital modulated signal) in S-Band.The 2 kW L-Band HPA is a GaN based design and housed in an amazingly small 5U chassis. The amplifier control and power supply unit is based separately in a 3U chassis. The 800 W S-Band unit is also a GaN based design and self-contained (with power supply) in a 5U chassis.

VENDORVIEW

Empower RF Systems Inc., www.empowerrf.com.

Low Noise Amplifier

PMI Model No. POB-15-818-13-LCA Rev.B is an 8 to 18 GHz, low noise amplifier that provides 15 dB of gain while maintaining a gain



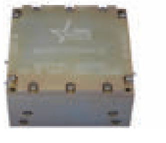
flatness of ±1.5 dB typically over the operating frequency. The noise figure is 3 dB typical and offers a typical OP1dB of +13 dBm. The amplifier requires +12 V DC and has a typical current draw of 75 mA. The unit is supplied with removable SMA(F) connectors in PMI's standard PE2 housing.

VENDORVIEW

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

Wideband Amplifier

QuinStar Technologies Inc. introduced the QPW-71803014-S1 E-Band power amplifiers. The QPW model of E-Band amplifiers come



with some of the widest industry frequency ranges, such as 71 to 86 GHz, a gain of 30 dB and output power available up to +30 dBm depending on the frequency range and bandwidth. The wide bandwidth of these amplifiers makes them ideally suited for broadband MMW communications systems and other broad spectrum systems applications.

QuinStar Technologies Inc., www.quinstar.com.

Low Noise Amplifiers

Richardson RFPD introduced three new LNAs from WanTcom. The WHM0913R LNA operates from 900 to 1250 MHz, is fully-matched

to 50 ohms and is designed to meet rugged MIL-STD-883 standards. The WBA0010A LNA operates from 10 to 1000 MHz, offers high linearity and exceptional gain flatness, is fully-matched to 50 ohms, has standard SMA-connectorized, WP-11 gold plated housing, and is designed to meet MIL-STD-202. The WMA32C 32.19 MHz low noise pre-amplifier features 3.0 ohm input impedance and built-in ESD protection.

VENDORVIEW

WanTcom, distributed by Richardson RFPD Inc., www.wantcominc.com.

E-Band LNA

Model SBL-7438433060-1212-S1 is an E-Band low noise amplifier with center frequency at 79 GHz with ± 5 GHz operation bandwidth. The

amplifier is designed and fabricated for emerging automotive ACC radar industry applications. The amplifier exhibits more than 30 dB small signal gain with ±2 dB gain flatness and around 6 dB noise figure. The output P1dB of the amplifier is +5 dBm typical and it draws 200 mA current from a single DC power supply in the range of +8 to +15 V.

VENDORVIEW

SAGE Millimeter Inc., www.sagemillimeter.com.

Antenna

Log Periodic

Signal Antenna Systems' (SAS) SA LP700-1 log periodic can be used for transmit/rcv and covers 0.7 to 2.7 GHz. It comes with a positioning handle, which allows the user to manually aim the antenna and vary the polarization. It is designed for field use/surveillance and covers all cellular bands.

Signal Antenna Systems' (SAS), www.signalantenna.com.

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(3) Paid Distribution Outside the Mails Including Sales Through Dealers and Carriers, Street Vendors, Counter Sales, and Other Paid Distribution Outside USPS®	6272	6074
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f. Total Distribution (Sum of 15c and 15 e)	39,503	42,281
g. Copies not Distributed (See Instructions to Publishers #4 (page #3))	36	70
h. Total (Sum of 15f and g)	39,539	42,351
i. Percent Paid (15c divided by 15f times 100)	92.72%	89.79%

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✓ If the publication is a general publication, publication of this statement is required. Will be printed in the November, 2013 issue of this publication. ☐ Publication not required.

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Carl S. Sheffres, Publisher	September 30, 2013

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

Materials

High-Speed Materials

Isola Group S.a.r.l. announced its new low loss, low skew, high-speed material, GigaSync™. This product has been engineered to eliminate skew issues in high-speed designs that use differential pairs to create a balanced transmission system able to carry differential (equal and opposite) signals across a printed circuit board. The company will immediately begin alpha site testing of GigaSync and expects field validation using industry-standard Test Vehicles (TV) to be completed by November 2013.

Isola Group S.a.r.l.,
www.isola-group.com.

Flux Coating

Indium Corp. introduced a new, high-reliability, low-voiding flux coating for solder preforms. LV1000 reduces false failures while increasing productivity, throughput yields, and component performance. This new halide-free (ROL0) material is especially suited for assembly processes in which the components don't allow for proper outgassing of volatized flux. LV1000 provides a durable, level, clear coating that does not clog pick and place equipment, even in automated assembly processes. It offers complete coverage, even with a weight percentage as low as 0.5 percent.

Indium Corp.,
www.indium.com.

Processing Equipment

Wire Bonder

Model 7KE Series, a flexible manual wire bonder, bonds Au, Al and Cu in Wedge-Wedge mode at 45 degree feed of the wire and 90 degree feed of the wire for deep access. Ribbon bonding is performed in the 90 degree mode. Ball-Wedge bonding Au wire is performed in deep access as well. This machine is available in both 64 and 110 kHz ultrasonics. The Gantry style ESD protected chassis allows for unlimited part size, orthogonal X-Y-Z axis and its patented X-Y-Z 8/1 Ration Micromanipulator.

West•Bond Inc.,
www.westbond.com.

Test Equipment

Digital Subsystem

EADS North America Test and Service launched its second generation Talon Instruments™ high-speed digital testing system for both legacy replacement and new test stations. The T940 digital subsystem, a single-wide, VXI 4.0-compatible module, provides a complete state-of-the-art digital solution at either a subsystem level or at a fully integrated system level. The T940 digital resource module (DRM) features dual sequencers that can function independently or synchronously for timing, memory, and control of the two front end modules automatically.

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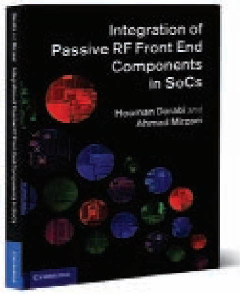

Integration of Passive RF Front End Components in SoCs

Hooman Darabi and Ahmad Mirzaei

Designing less expensive RF wireless transceivers that can operate effectively and efficiently in the crowded wireless spectrum is a major challenge that must be met by today's designers. External components such as filters and their matching components, which are typically bulky and expensive, must be integrated on the chip to the greatest extent possible. This book describes and evaluates both active and passive solutions for on-chip high-Q filtering, and explores M-phase filters in depth. A step-by-step approach is used to introduce everything an RF designer needs to know about these filters, including their various forms, principles of operation and performance against implementation-related imperfections. Real-world examples are described and mathematical analyses demonstrate the practical quantification of relevant circuit parameters.

For future software defined radio applications, designers need to find highly linear and low-noise filtering solutions with center frequencies that can be controlled. This book discusses techniques that can be used to design and implement SAW-less broadband receivers with sharp on-chip filters, the center frequencies of which are precisely controlled by a clock frequency.

This book is highly focused on integrated and tunable RF receiver front ends so it is very appropriate for engineers and academics interested in this topic. However, it would not be very relevant for those outside of this area of focus.

To order this book, contact:

Cambridge University Press
32 Avenue of the Americas
New York, NY 10013-2473
(212) 924-3900
www.cambridge.org

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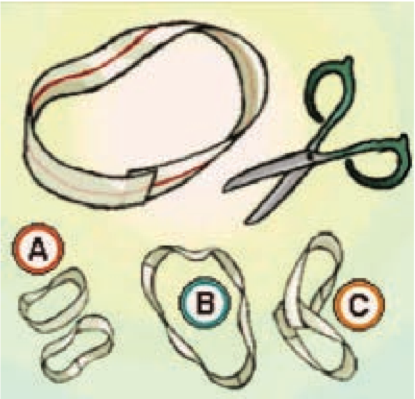


Puzzle

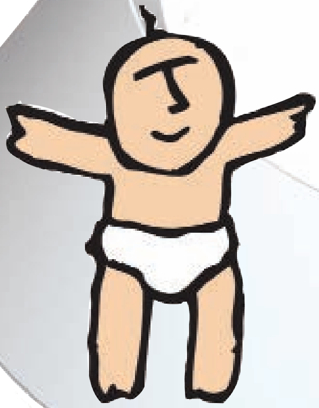
By twisting a thin ribbon of paper once and forming a ring with it, you can make a ring with one continuous surface. If you started to draw a line on one side, it would eventually cover both sides and join back up with itself. This is the famous Möbius strip. It is now possible to go from one side of the paper to the opposite side of the paper without crossing the edge simply by following the circuit of the loop. One circuit around the loop will end you exactly opposite your starting point, and another circuit around will land you back where you began.

Now, if you cut along this line with a pair of scissors, which shape would the paper make – A, B or C?

The Joke Shop Version of the Möbius Strip Is an Index Card That Has a Riddle Printed on It:

"How do you keep a fool occupied all day? (Over)"

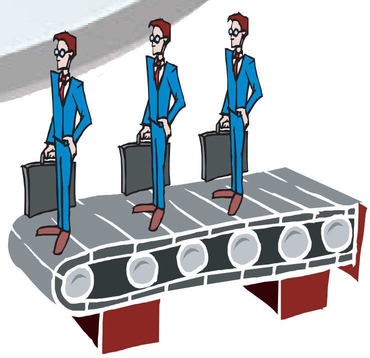
The same text is printed on the reverse of the card so as to complete the effect. That's the basic structure of a Möbius puzzle: self-referencing, self-reversing.



A New Solution to an Old Problem

by Eleanor Ninestein

The Topologist's child was quite hyper
'Til she wore a Möbius diaper.
The mess on the inside
Was thus on the outside
And it was easy for someone to wipe her.



Möbius Trivius

- Giant Möbius strips have been used as conveyor belts (to make them last longer, since each "side" gets the same amount of wear) and as continuous-loop recording tapes (to double the playing time).
- In the 1960s, Sandia Laboratories used Möbius strips in the design of versatile electronic resistors.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MOBILE COMMUNICATIONS 2013

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BPA WORLDWIDE

Cover Feature
Invited Paper

The Economics of GaAs and CMOS PAs: Crunch Time

The Qualcomm RF360 envelope tracking power supply hit production during the past couple of months, in the Samsung Galaxy Note 3. The funny part was that it is not attached to the Qualcomm CMOS power amplifier. Instead, the Qualcomm Power Management IC drives a GaAs PA supplied by Avago.

To old radio guys like me, the rise of CMOS power amplifiers brings back memories of the first integrated CMOS transceivers for mobile handsets. Back in the 1980s, with AMPS cellular systems, the handset used discrete components in the transceiver. By the 1990s, when 2G systems were starting to ramp up, baseband modem suppliers suggested a migration to CMOS transceivers.

In 1993, many RF engineers laughed at the idea of an integrated CMOS transceiver. Comments like "You're going to sacrifice sensitivity" or "You won't get enough linearity in your front end" were common. But here we are. Twenty years later, it is impossible to find a discrete handset transceiver anywhere in the world.

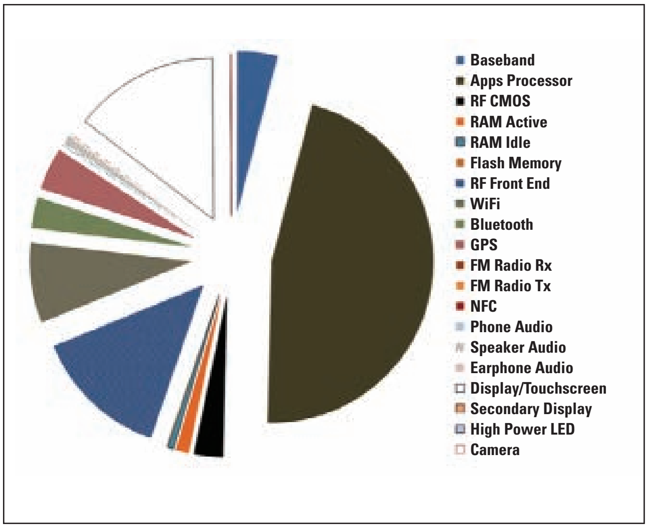
It is true that the systems engineers sacrificed noise figure and linearity and a few other metrics to achieve the flexibility and low cost of CMOS transceivers. But the benefits of 2G standards (coding gain for CDMA, or wider FM bandwidth for GSM) made up for these sacrifices and it worked out okay.

We will see the sequel to this movie with CMOS power amplifiers. We have seen CMOS PAs take over the constant-envelope GSM market, at price levels that GaAs products will not match. A few 3G handsets now include CMOS PAs, and the battle has begun.

TECHNICAL COMPARISON

There's no doubt that GaAs performs better. As Peter Gammel illustrated in the August issue of *Microwave Journal*, GaAs has a performance advantage in both efficiency and linearity, resulting in roughly 10 percentage points better efficiency with other factors held constant. Especially for waveforms with a high peak-to-average ratio, the combination of power, linearity and efficiency is inherently better due to physical attributes of the semiconductor material.

Joe Madden
Mobile Experts, Campbell, CA



▲ *Fig. 1 Breakdown of power consumption in a typical LTE smartphone, urban case, business user.*

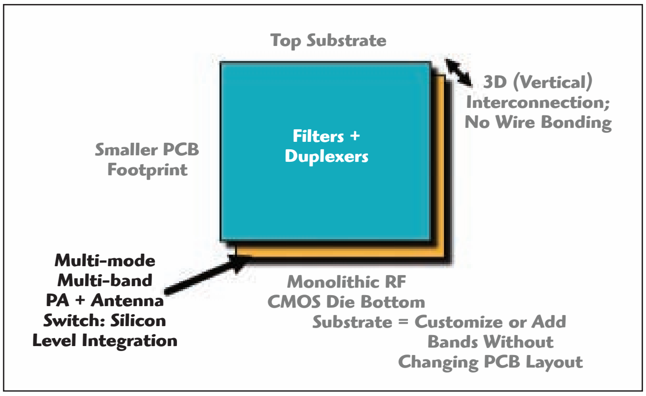
Recently, mobile terminals have started to use multi-mode, multi-band power amplifiers (MMPA) which cover a much wider operating bandwidth than single-band PAs. This is just one more design constraint that limits efficiency/linearity improvement for both CMOS and GaAs.

To continue the improvement, almost all PA suppliers and handset OEMs are investigating envelope tracking (ET). Put simply, ET involves a fast power supply that ramps the voltage rail for the amplifier along with the modulated waveform. As peak power requirements spike up, the supply voltage ramps up. The idea here is to only provide the power that is necessary at any instant in time. CMOS amplifiers are now emerging that use ET to achieve performance roughly on par with non-ET GaAs amplifiers. At the same time, GaAs amplifiers with ET provide excellent efficiency performance. The Samsung Galaxy Note 3, launched during September, uses a Qualcomm ET power supply, with a GaAs PA from Avago in order to achieve a longer battery life.

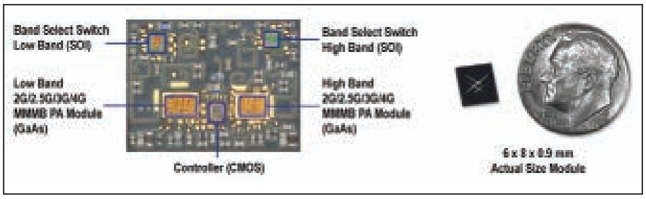
PERFORMANCE THAT IS "GOOD ENOUGH"

Better performance is always desirable. But at some point, performance for a PA can be "good enough" for a segment of the market. We have seen that already for the GSM market, where CMOS has taken over despite performance tradeoffs. With the arrival of ET, several modem suppliers are betting that CMOS is now "good enough" for some 3G and LTE applications.

From a cost point of view, CMOS PAs are generally perceived as lower cost. Are they? This question has been largely theoretical for several years, but during the past six months, the idea has been subjected to a real-world test. RFMD acquired Amalfi Semiconductor in November 2012 and found that initially the manufacturing cost was too high. However, with a redesign of the CMOS PA to utilize RFMD's streamlined assembly and test facilities, the RFMD CMOS PA will achieve a cost far lower than previous GaAs products. Extending this to 3G and 4G products will take more work, but one initial proof-of-concept is now established.



▲ *Fig. 2 Qualcomm RF360 CMOS RF front end module.*



▲ *Fig. 3 Skyworks SkyOne™ system in package.*

HOW IMPORTANT IS A 10 PERCENT ADVANTAGE IN PA EFFICIENCY?

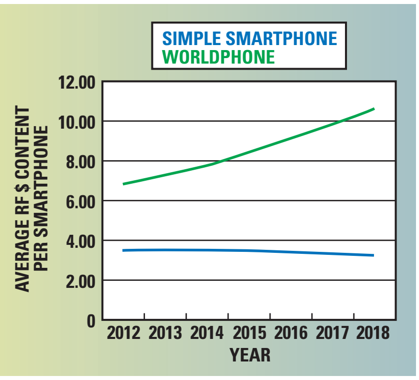
Battery life is important to mobile operators, but as multi-core apps processors and large displays have taken over the smartphone market, the RF section of the handset consumes less of the total power. In the Mobile Experts Battery Life Model, the RF front end represents between 14 and 20 percent of the power consumed in a smartphone, accounting for the typical distribution of LTE transmit power levels in an urban network and the losses of a complex multi-band RF front end (see ***Figure 1***). That means that 10 percentage points in PA efficiency results in about four percent longer battery lifetime for a heavy smartphone user, or about half an hour.

In the high-end smartphone market, half an hour is still a worthwhile level of differentiation, so Mobile Experts forecasts that these markets will use GaAs for quite some time. With simpler 3G handsets in cost-sensitive markets, the cost/benefit decision is not yet clear.

RF INTEGRATION

A Complete Front End (CFE) – like Qualcomm's RF360 (see ***Figure 2***) or the Skyworks SkyOne product line (see ***Figure 3***) – represents a single module which addresses all of the RF devices between the transceiver and the antenna. The power amplifiers, filters and duplexers, switches, and antenna mismatch tuning can all be included in the module. This makes life easy for the customer, and in some cases the CFE can save space in the handset. As a result, the CFE is likely to capture a significant portion of the handset market.

On the other hand, the high end of the market is unlikely to benefit much from the CFE. The latest iPhone 5s and the Galaxy S4 are very complex, customized products. Integrating everything into a single module (and concentrating production with a single vendor) increases risk and time to market for the major smartphone vendors.



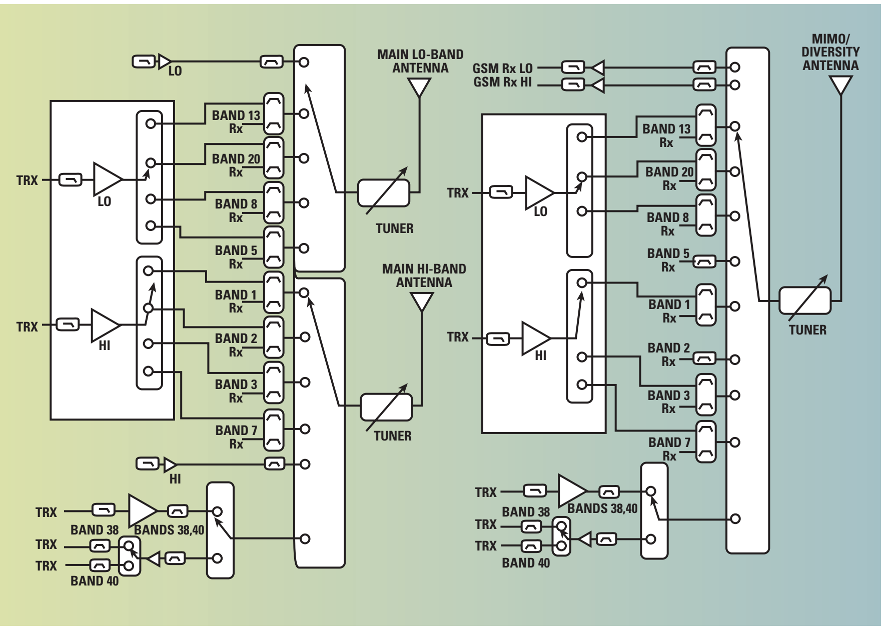
▲ *Fig. 4 Average dollar content for RF per smartphone.*

From an RF vendor's point of view, the investment of R&D resources into any RF project is a bet that the resulting product will be useful. A multidisciplinary CFE project can cost $10M or more in R&D expense. No single handset product achieves enough volume to make the R&D cost worthwhile. Because of the straightforward economics of return on investment, any semiconductor vendor will focus CFE development on the most common mainstream applications. The ROI decision can be illustrated with two case studies:

Economics of an Entry Level 3G Smartphone

A CMOS-based CFE with integrated duplexers and filters, covering quad-band GSM and a single 3G band would be useful in at least 40 different handset models. This kind of simple CFE could reach a volume of 100 million units per year, with a long product life cycle. The R&D investment of about $10M would be amortized over 300 million units, reducing the cost burden to three cents per unit.

Of the 2.2 billion handsets produced this year, 1.7 billion are feature phones, simple smartphones with three data bands or fewer, PC dongles, tablets or M2M modems. Most of the industry focus falls on the high-end smartphones, because smartphones with four or more data bands (worldphones) are the most complex and challenging applications. Today, 84 percent of handsets have three or fewer data bands. CMOS-based CFEs are targeted at this market (don't listen to all the hype to the contrary). Mobile Experts predicts that the RF dollar content in an entry-level smartphone will decline over the next few years (see ***Figure 4***).



▲ *Fig. 5 An example of the level of customization in a multi-band "worldphone."*

Economics of a Single-SKU "Worldphone"

A CFE covering 12 different data bands (plus quad-band GSM) represents a much higher level of R&D investment, with a complex filter bank and a multi-mode multi-band amplifier in addition to switching and possible antenna tuning (see ***Figure 5***). Creating this kind of CFE module could cost $40M or more in R&D expense. Then, the production run would last for about 12 to 18 months before the product would be replaced by something else. Even with a successful run of 100 million units, the R&D cost represents 40 cents per unit, not three cents.

Another issue comes from time-to-market. Our hypothetical single-SKU super-module would be difficult to develop in the right bands, power levels and form factor within the R&D cycle. Samsung and Apple do not know exactly what they need two years from now.

In general, handset OEMs do not pay premium prices for integration. A PA/duplexer module does not sell for a higher price than the discrete PA and duplexer separately. While the CFE saves R&D cost for the OEM, our estimated 40 cents in R&D cost cannot be passed along to the OEM as a higher price.

Looking at the worldphone market, the growth is clear. The iPhone's entry into China will result in big growth for worldphones. By 2018, 42 percent of the handsets produced worldwide will include four or more data bands. With far higher dollar content than entry-level smartphones for RF devices, there is still major growth in the high end of the RF front end market.

MARKET SEGMENTATION

When Henry Ford built cars and trucks in the 1910s, he put the same transmission into both vehicles. The early automotive market fit this model of commonality, and mass-producing a single transmission drove improvements in quality and cost that made vehicles affordable for everyone. Eventually, the market grew large enough that investment in different transmissions for lighter cars and heavy trucks made economic sense.

The mobile terminal market has finished that early phase of market development, where the same modular strategy was used for every application. At $5B in market size, the mobile RF front end ecosystem can support different product strategies for different tiers of the market. The CFE approach is most viable for the RF suppliers at the low end of the market, where R&D investment is lower and volumes are higher. A modem supplier like Intel or Qualcomm can offer a CFE for low end smartphones and capture a sizable chunk of market revenue. At the high end of the market, separate modules used in more flexible combinations are a better solution.

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IT'S ABOUT THE PROCESSORS

While the PA engineers arm wrestle over which wafer to use, another fight is taking place in the modem. Qualcomm has lost significant market share to MediaTek and Spreadtrum in China, and it wants it back. One way to do that is to offer a simpler product line, with a chipset that takes care of everything: applications processor, modem, transceiver and RF all the way to the antenna. A handset OEM does not need deep RF expertise with this approach. Enter Qualcomm's RF360 product, which includes the ET power supply, PA, filters and antenna tuning. For entry-level smartphones, this addition to the Qualcomm product line could make it easier to sell modems.

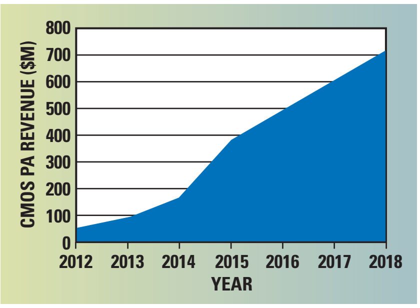
Intel, MediaTek, Broadcom, Nvidia, Spreadtrum and Marvell are all working on ET programs, indicating that there is some merit to this strategy for processors. At this moment, there is only one modem supplier with an ET/PA product – but as time passes, multiple competitors will take part and the modem/transceiver/ET/PA relationships will become very important in the market. Some of these vendors plan to use CMOS PAs, and others have GaAs partners.

By themselves, Qualcomm will not compete aggressively for PA business. (A great example is the Galaxy Note 3, where Qualcomm is happy to support a GaAs PA). Things will change when Qualcomm, Intel and MediaTek begin to compete head-to-head with solutions that include RF. Fighting for the bigger modem business, the price erosion in PAs may be severe. These companies may need to defend their modem business with low prices for PAs. It is never healthy to add a few new competitors into a market which is below about 10 percent growth.

MARKET IMPACT

For GaAs vendors, the main question comes down to this: How much market share will CMOS take? Will the GaAs fabs be fully utilized? Will price erosion become a problem?

The market for GaAs power amplifiers was already slowing, as multimode, multi-band PAs take hold and limit market growth by reducing the need for additional PAs in new bands. In the Mobile Experts forecast "RF Front Ends for Mobile Terminals 2013," overall RF front end market revenue will grow by 15 percent annually for the next five years, but the PA segment growth will be much weaker, at six percent or possibly lower due to a combination of MMPA adoption and price erosion.



▲ *Fig. 6 CMOS PA revenue projection.*

In the 1990s, the battle between discretes and CMOS transceivers was short and decisive. The sequel will not end the same way. In the PA world, changing peak-to-average requirements play directly into the strengths of GaAs. Fragmented frequency bands mean that most worldphones will need to be highly customized for years to come. There is no clear path for CMOS to enter the high end of the market, where performance matters.

Emerging CMOS products will gobble up the low end of the market, growing to more than $700M by 2018, or roughly 25 percent of the total PA market value (see ***Figure 6***). GaAs PAs will continue to dominate the high end. In the end, the CMOS PA growth will rob the GaAs PA suppliers of the opportunity for market growth, and the "cash cow" business at companies such as RFMD and Skyworks will be impaired. A few GaAs suppliers will continue to succeed, but they will compete for a flat GaAs market in a highly fragmented LTE landscape. Nobody ever promised that life would be easy. ■

Joe Madden *founded Mobile Experts in 2002, and serves as the company's primary expert in semiconductors for handsets and infrastructure. A Silicon Valley veteran, Madden has 24 years of experience in wireless hardware, supplying amplifiers and filters into both base station and handset applications. He survived two startups, including successful IPOs and LBOs along the way. He holds a degree, cum laude, in Physics from UCLA.*

Design and Test Challenges for Next-Generation 802.11ac, ad WLAN Standards

Equipment based on the 802.11 wireless LAN standards (first IEEE 802.11a and b, 802.11g in 2003 and 802.11n in 2009) has moved firmly into the home and home office environment. Now, whether at work or play, we have multiple devices that need to be connected together: computers, smartphones, tablets, printers, game consoles, media servers, scanners and more. Beyond what we do now, proposed usage models requiring even higher data throughput to support tomorrow's home and office applications are driving the most recent versions of wireless LAN standards.

In addition to the 2.4 and 5 GHz wireless LAN standards currently used, there are active proposals within the standards organization for vehicular applications (802.11p), TV white space frequencies (802.11af) and sub-1 GHz to support extended range applications (802.11ah), though there is no commercial activity yet in these areas.

802.11ac

IEEE Working Group TGac has specified 802.11ac as an extension of 802.11n, providing a minimum of 500 Mbit/s single link and 1 Gbps overall throughput, running in the 5 GHz band. The physical layer is an extension of the existing 802.11n standard, and bearing in mind the huge number of existing client devices, backward compatibility with existing standards using the same frequency range is a must. ***Table 1*** shows the physical layer features of 802.11ac and highlights the mandatory extensions from 802.11n. Companies are already shipping commercial products based on the current draft of the standard.

The new wider channel bandwidths are shown in ***Figure 1***. While 160 MHz and 80+80 MHz modes are both included as optional features in the 802.11ac standard, it is likely that first devices will have a maximum of 80 MHz bandwidth, and no more than the maximum four spatial streams specified in 802.11n.

Even though the first 802.11ac consumer devices might be limited to an 80 MHz channel with four spatial streams, 160 MHz and 80+80 MHz modes are both included as optional features and will be a focus for chip and device development. New simulation, signal generation and analysis tools must include scenarios of non-contiguous frequency blocks, as well as being able to cope with the need for 160 MHz modulation bandwidth at 5 GHz. Previous RF wireless communications standards have required much narrower channel bandwidths, and test equipment development has followed those needs. For transmitter design and development, today's vector signal analyzer (VSA)

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TABLE I

IEEE 802.11ac KEY SPECIFICATIONS

Feature	Mandatory	Optional
Channel bandwidth	20, 40 and 80 MHz	160 MHz, 80+80 MHz
FFT size	64, 128, 256	512
Data subcarriers/ pilots	52/4, 108/6, 234/8	468/16
Modulation types	BPSK, QPSK, 16QAM, 64QAM	256QAM
MCS supported	0 to 7	8 and 9
Spatial streams and MIMO	1	2 to 8 Tx beamforming, STBC Multi-user MIMO (MU-MIMO)
Operating mode/ PPDU format	Very high throughput/VHT	

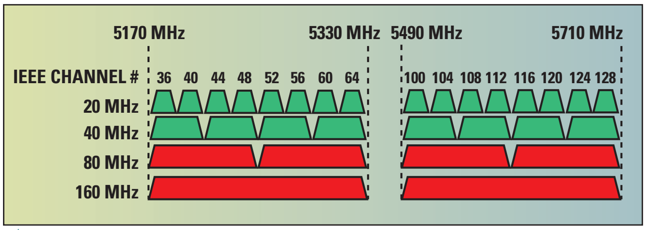


Fig. 1 IEEE 802.11ac frequency allocation for Europe/Japan/ global regions.

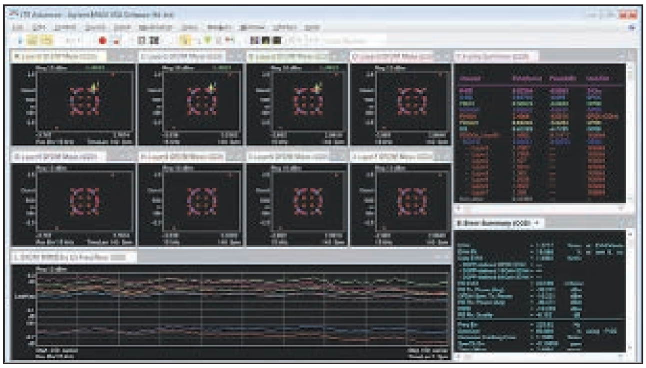


Fig. 2 Example of 8x8 MIMO demodulation with Agilent VSA.

must be able to cope with the correct demodulation, analysis and display of a wireless signal that uses two frequency blocks, OFDM modulation and may comprise up to the eight MIMO data streams allowed in the standard. ***Figure 2*** is an example display, showing each of the eight MIMO transmit streams and a summary table of the results.

The receiver must recover multiple simultaneous signals and adequately demodulate and decode them. The signal generation equipment needed for receiver design and development has the same overall frequency, bandwidth and multiple data stream requirements as the transmitter. In addition, it must provide a wide range of stress-test conditions – including repeatable and deterministic dynamic fading of each MIMO path as well as interference scenarios to ensure the receiver is designed to cope with the worst real world conditions. Up to eight separate signal generators may be needed to produce the required MIMO channel, along with additional generators to provide interference. Both modular and desktop product configurations are available, each having its own benefits and providing choices depending on specific test requirements. ***Figure 3*** shows one example.

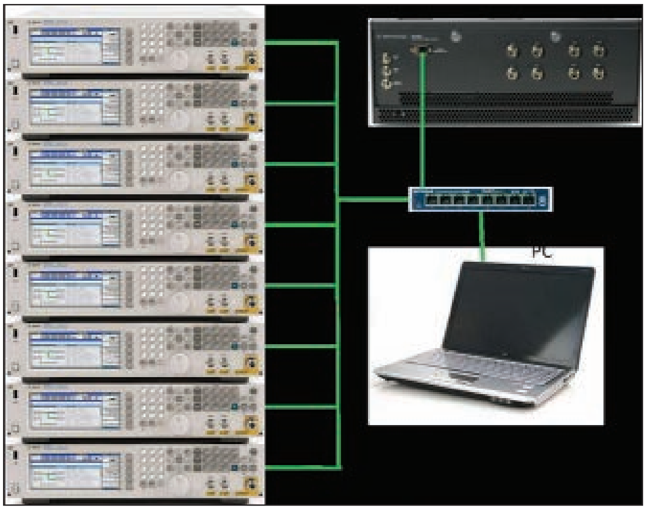


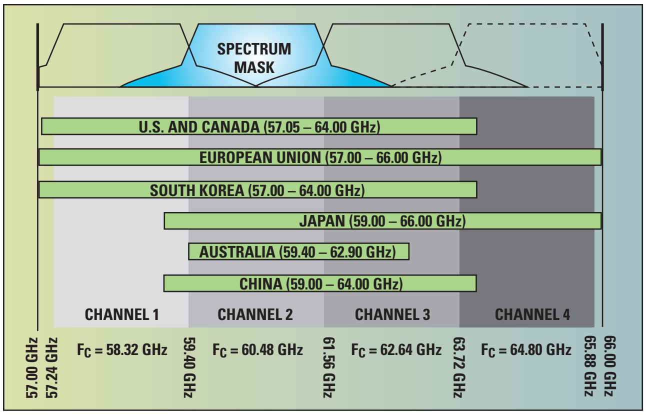
Fig. 3 Signal generator configuration for MIMO receiver test.

802.11ad

While 802.11ac is an extension of the existing 802.11n specification, 802.11ad represents a completely new paradigm. Extreme data capacity requires a large spectrum allocation. Data capacity is ultimately tied to modulation order and bandwidth. Simplicity of design demands such bandwidth be a smaller percentage of the transmission frequency (Q) and the practical reality is such bandwidth is only available at higher frequencies. 802.11ad has been specified by Working Group TGad, in partnership with the Wireless Gigabit Alliance, and operates over a short range in an established global unlicensed 60 GHz band. It is designed to provide the multi-gigabit data rates required for uncompressed high-definition multimedia transmissions, including known futures such as 2048×1080 and 4096×2160 digital cinema and 3D video streaming.

The unlicensed frequency allocations at around 60 GHz in each region do not match exactly, but there is substantial overlap; at least 3.5 GHz of contiguous spectrum is available in all regions that have allocated spectrum. The ITU-R recommended channelization comprises four channels, each 2.16 GHz wide, centered on 58.32, 60.48, 62.64 and 64.80 GHz respectively. As ***Figure 4*** illustrates, not all channels are available in all countries. Channel 2, which is globally available, is therefore the default channel for equipment operating in this frequency band. In November 2011, this channelization and the corresponding spectrum mask for the occupying signal were approved by ITU-R WP 5A for global standardization.

The 802.11ad specification defines a backward-compatible extension to the IEEE 802.11-2007 specification that extends the MAC and physical layer (PHY) definitions as necessary to support short-range (1 to 10m) wireless interchange of data between devices over an ad-hoc network at data rates up to approximately 6.75 Gbps in the 60 GHz unlicensed band. It also supports session switching between the 2.4, 5 and 60 GHz bands.



▲ *Fig. 4 60 GHz band channel plan and frequency allocations by region.*

802.11ad uses RF burst transmissions that start with a synchronization preamble (common to all modes) followed by header and payload data. The preamble is always single-carrier modulation, the header and data may use single-carrier (SC) or OFDM modulation depending on the target bit rate.

The 802.11ad PHY supports three distinct modulation methods:

- Control Modulation; the Control PHY.
- Single Carrier (SC) Modulation; the Single Carrier PHY and the Low Power Single Carrier PHY.
- Orthogonal Frequency Division Multiplex (OFDM) Modulation; the OFDM PHY.

Each PHY type has a distinct purpose and packet structure, but care has been taken to align the packet structures, and in particular the preambles, to simplify signal acquisition, processing and PHY type identification in the receiver. The three packet types share an essentially common preamble structure comprising a Short Training Field (STF) followed by a Channel Estimation Field (CEF). These fields are constructed from π/2-BPSK modulated repeating Golay sequences.

Golay complementary sequences are sequences of bipolar symbols (±1) that have been mathematically constructed to have very specific autocorrelation properties. The 'a' and 'b' indicate that the "G_a128" and "G_b128" sequences form a complementary pair and the suffix indicates the sequence length.

The mathematics behind the sequence constructions is beyond the scope of this article, but important attributes of these sequences are:

1. The autocorrelation of each sequence has low side lobes and low DC content under π/2 rotation.
2. The sum of the very good but imperfect autocorrelation functions of the G_a and G_b sequences is perfect (the side lobes cancel exactly).

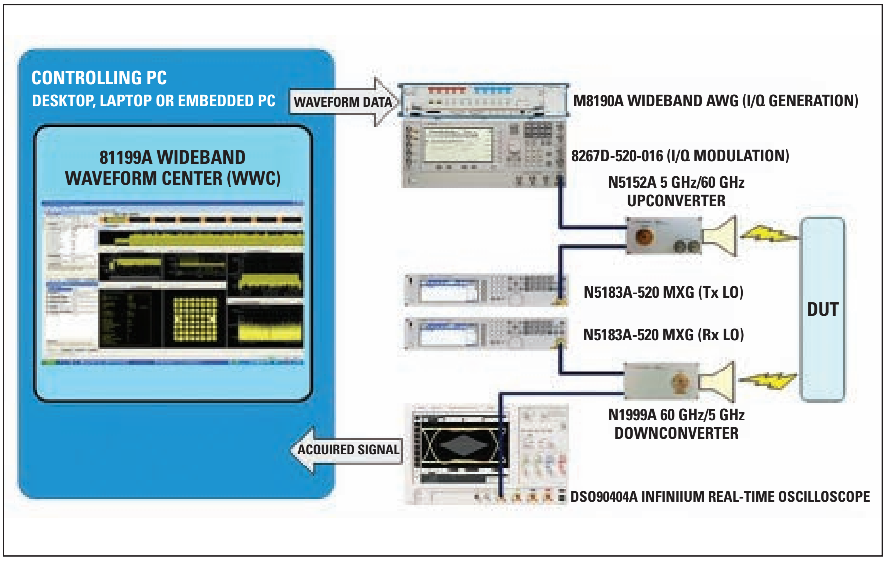
Multiple-antenna configurations using beam steering are an optional feature of the specifications. Beam steering can be employed to circumnavigate minor obstacles, such as people moving around a room or a piece of furniture blocking line-of-sight transmission.

Component and system design and test at 60 GHz is a well-understood and established science, but its application to high-volume, low-cost devices for the consumer market is new. Two major differences are the much wider modulation bandwidth than other wireless communications systems, and the physical construction of the devices which may not allow direct connection.

The system shown in ***Figure 5*** combines all the equipment needed for transmitter and receiver design and development in one software-controlled package, providing signal generation and analysis capability tailored to high-bandwidth applications running in the 60 GHz band. It allows the use of calibrated horn antennae, since in many complete devices, the antenna is bonded directly to the RF components and a direct metallic connection is not possible. The system can also be used in conjunction with software (Agilent's SystemVue design libraries) to analyze and compare real-world measurements with those predicted by design simulations.

CONCLUSION

802.11ac and 802.11ad both aim to provide significantly higher data throughput than previous wireless LAN systems and are complementary. 802.11ac is an evolution of the 802.11 WLAN capability. It gives the "unwired office" the ability to compete directly with gigabit wired systems, while offering much better office layout and connection flexibility. 802.11ad is an extension of the 802.11 family providing ad-hoc connectivity to deliver extreme data rates between devices over short distances. Both standards pose new challenges in design, development and test: 802.11ac due to the somewhat wider bandwidths used and 802.11ad due to the even wider bandwidth and to the new application of 60 GHz technology to consumer devices. In each case, proving design integrity during product development is critical. Manufacturing test must be minimal enough to preserve cost, while being sufficient enough to ensure product and process control. ■



▲ *Fig. 5 802.11ad physical layer signal generation and analysis solution.*

CoMP: The Most Challenging Technology Component in LTE-Advanced 3GPP Release 11

LTE has become a global phenomenon: By August 2013, a total of 204 LTE networks in 77 countries were commercially operated. With only four years of real-life deployment, however, the technology is still in its infancy compared with 2G/3G technologies. But time in mobile communications moves quickly, and significant improvements were added to the initial LTE technology as specified in 3GPP Release 8.

In LTE 3GPP Release 9, the main improvements are support for multimedia broadcast multicast services (eMBMS), positioning and, last but certainly not least, optimizations such as semi-persistent scheduling (SPS) and transmission time interval (TTI) bundling in order to more efficiently support voice services. 3GPP Release 10 – the start of LTE-Advanced – added technology components that are even more significant. The one that is most in demand is carrier aggregation, which is already in commercial use and allows more efficient utilization of the fragmented spectrum available to an individual operator.

The next set of improvements was added in 3GPP Release 11. For this release, the core network and radio access protocols were finalized in December 2012 and June 2013, respectively. Defining test specifications, of course, takes additional time. This article introduces coordinated multipoint operation (CoMP), an enhancement that was initially discussed in the 3GPP Release 10 time frame. CoMP is widely talked about and applicable to the cellular industry. This article also examines the impact on testing both base station and end-user devices that support CoMP.

CoMP AND LTE-ADVANCED

CoMP for LTE is one of the most important technical improvements with respect to heterogeneous network (HetNet) deployment strategies, but also for the traditional homogeneous network topology. In brief, HetNets aim

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to improve spectral efficiency per unit area using a mixture of macrocell, picocell and femtocell base stations and/or remote radio heads (RRH).

In contrast, homogeneous network topologies comprise cells of about equal size, usually the macro layer. Nevertheless, with both network deployment strategies, cell edge users can experience intercell interference. This type of interference is caused by the downlink transmissions from two (or more) different base stations (cells). In a frequency reuse 1 system like LTE, when the same frequency is used in all cells, this affects in particular user devices at the cell edge. The goal of CoMP is to further minimize intercell interference for cells that are operating on the same frequency. With HetNets, this intercell interference becomes even more significant due to unbalanced output powers used in the macrocell and picocell/femtocell layer.

As the name implies, CoMP will make it possible to coordinate the optimization of transmission and reception from multiple distribution points, which could be either multiple cells or RRHs. CoMP will enable joint transmission and/or reception to mobile devices. It will also have a positive effect on power consumption as well as overall throughput and thus system capacity. Plus, it will allow load balancing between cells that are coordinated.

3GPP standardization is based on four different CoMP scenarios (see ***Figure 1***). The first two scenarios focus on homogeneous network deployments, one with a single eNodeB serving multiple sectors (scenario 1) and the other with multiple high-transmit-power RRHs (scenario 2). The remaining two scenarios target HetNets, where macrocells and small(er) cells are jointly deployed using different cell identities (ID), as shown in scenario 3, or the same cell ID, as shown in scenario 4.

Due to its complexity, CoMP has been separated during the standardization process into two independent work items for downlink and uplink. Both link directions benefit from the two major schemes being used in CoMP: joint processing (JP), which includes joint transmission (JT, downlink) and joint reception (JR, uplink) as well as coordinated scheduling/beamforming.

WHAT'S IMPORTANT TO KNOW ABOUT CoMP?

Performance gains from CoMP result from managing the interference at cell boundaries, specifically in the HetNet scenario. To understand the details behind downlink and uplink CoMP, it is essential to know the terminology used: CoMP cooperating set, CoMP measurement set and CoMP resource management.

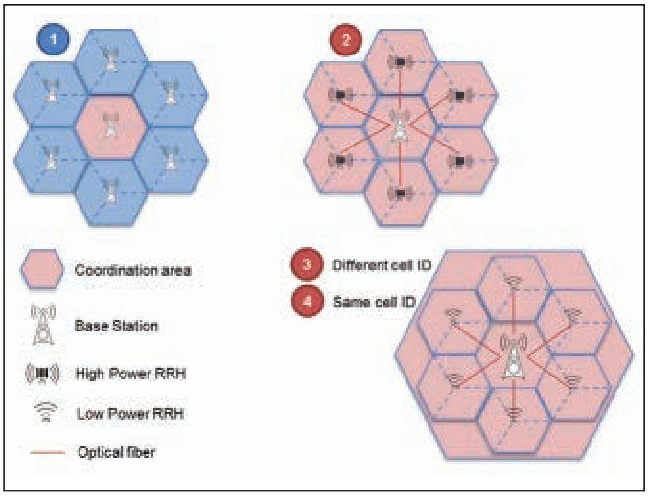


Fig. 1 Coordinated multipoint operation (CoMP) scenarios.

CoMP cooperating set: The CoMP cooperating set is determined by higher layers. It is a set of geographically separated distribution points that are directly or indirectly involved in data transmission to a device in a time-frequency resource. Within a cooperating set, there are CoMP points. With regard to the CoMP schemes, the set could contain multiple points at each subframe (e.g., joint transmission) or a single point at each subframe (e.g., coordinated scheduling/beamforming).

CoMP measurement set: The CoMP measurement set is a set of points about which channel state information (CSI) or statistical data related to their link to the mobile device is measured and/or reported. This set is determined by higher layers. A mobile device is enabled to down-select the points for which the actual feedback is reported.

CoMP resource management: The CoMP resource management is a set of CSI reference signal (CSI-RS) resources for which CSI-RS-based reference signal received power (RSRP) measurements can be made and reported.

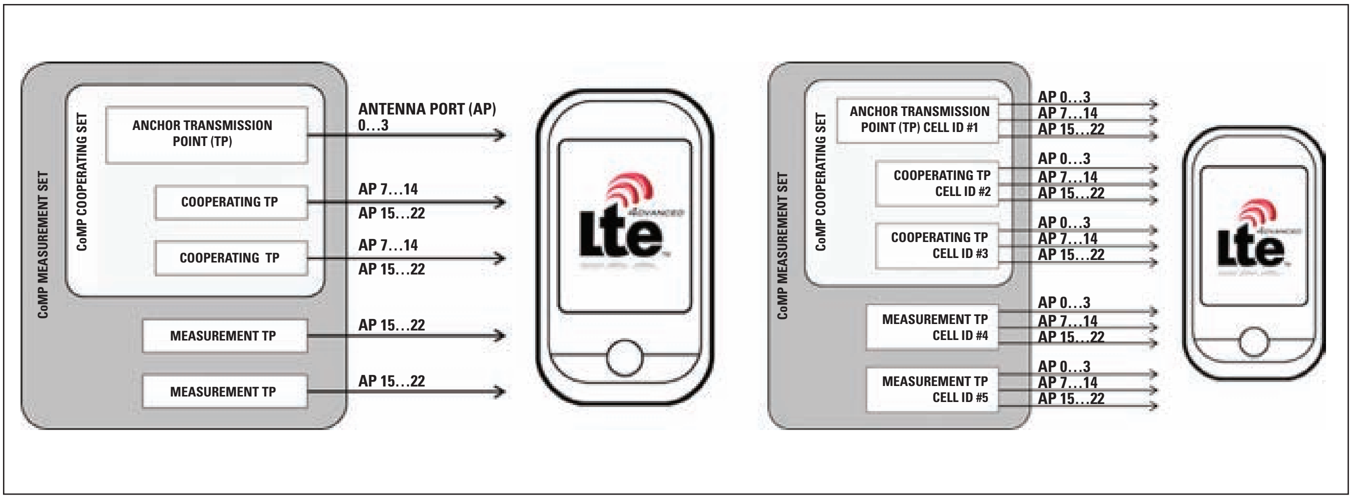
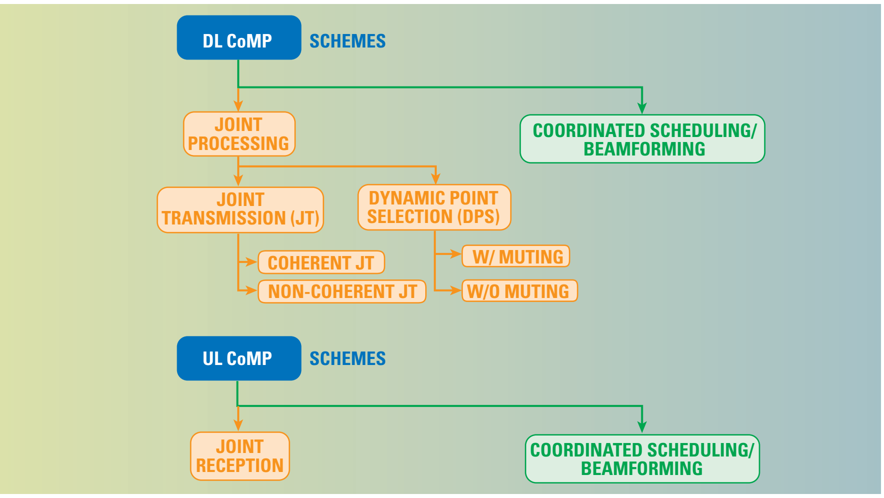


Fig. 2 Downlink CoMP cooperating and measurement set for cells using the same (left) or different (right) cell identity/identities.



▲ *Fig. 3 Overview of downlink (DL) and uplink (UL) CoMP schemes.*

Figure 2 shows the CoMP cooperating set and the CoMP measurement set for the two cases defined: Either all cells use different physical cell identities, or multiple cells have the same cell identity. In the latter case, the concept of virtual cell identities (VCID) can be applied. VCIDs are assigned by higher layers.

CoMP SCHEMES

Figure 3 provides an overview of the CoMP schemes used in the downlink and uplink. In the downlink, joint transmission enables simultaneous data transmission from multiple points to a single UE or even multiple UEs. This implies that the UE data is available at multiple points, belonging to the CoMP cooperating set, throughout the network. The goal is to increase signal quality at the receiver and thus the average throughput. The coherency of JT refers to the ability to form precoders that exploit the phase and possibly amplitude relations between channels associated with different transmission points.

In other words, in coherent JT the signal from multiple transmission points is jointly precoded. In noncoherent JT, the UE would receive multiple signals individually precoded by each transmission point. In general, JT requires a low latency between the transmission points, high-bandwidth backhaul and low mobility UEs. Also for dynamic point selection (DPS), the physical downlink shared channel (PDSCH) data has to be available at multiple points. However, in contrast to JT, data is only transmitted from one point at any given time. For coordinated scheduling/beamforming, the data is only present at one transmission point.

Furthermore, with the coordination of frequency allocations and used precoding schemes (beamforming) at the various transmission points, performance can be increased and interference mitigated. The CoMP schemes implemented for the uplink are similar. For joint reception, the physical uplink shared channel (PUSCH) data transmitted by the UE is received jointly at multiple points (part of or entire CoMP cooperating set) simultaneously to improve the received signal quality.

With regard to coordinated scheduling and beamforming in the uplink, the scheduling and precoding selection decisions are made with coordination among points corresponding to the CoMP cooperating set. But the PUSCH data is intended for one point only. A fundamental change due to CoMP in the LTE uplink is the introduction of virtual cell IDs. As of 3GPP Release 8, the generation of the demodulation reference signal (DMRS) embedded in two defined single carrier frequency division multiple access (SC-FDMA) symbols in an uplink subframe is dependent on the physical cell identity (PCI). The PCI is derived from the downlink.

For future HetNet deployment scenarios, where a macro cell provides the coverage and several small cells are used for capacity, there is higher uplink interference at the cell boundaries. This is especially true for when macrocells and small cells are using the same cell identities. The VCID concept makes it possible to signal a dedicated cell ID via radio resource control (RRC) signaling to be used by the UE for uplink transmission, which allows the UE signal to be received by different reception points.

TESTING CoMP

LTE-Advanced CoMP is a complex and powerful technology enhancement. The various downlink and uplink CoMP schemes permitted increase both base station and mobile device complexity. With respect to uplink CoMP, the burden appears on the base station receiver end. More precisely, UE data needs to be transferred between multiple reception points and jointly processed. For intra-eNodeB (intrasector) CoMP, this becomes purely implementation-dependent without impact on testing, since the combining takes place in a single entity.

Simulating multiple UEs for testing the base station receiver is a standard test case used since the beginning of LTE (as well as other cellular technologies). Transferring user data between multiple reception points places latency requirements on the inter-eNodeB interface, which in the best case can be satisfied with fiber connections. Therefore, today's method for testing a single eNodeB will evolve into testing a distributed base station architecture comprising multiple baseband units (BBU), sometimes also called digital units (DU), in combination with high-power or low-power RRHs (as shown in Figure 1, scenarios 2 to 4).

However, this will not change the testing principle, because the input signal from multiple UEs needs to be provided in the same way as it is today. There also remains the need to verify the signaling information exchange between UE(s) and BBUs combined with RRHs. A new test scenario will likely be added in order to verify the VCID concept. In the downlink, i.e., testing the UE implementation, CoMP requires redesign in the receiver chain because multiple signals from multiple transmission points – potentially on multiple frequencies – need to be successfully combined. In order to allow any CoMP algorithm to schedule the best possible resource from the best possible transmission

AMPS
WiFi
TX
DCS
WLL
MMDS
VHF
UHF
CDMA
GSM
Wireless
Microcell
&
Reactel, Incorporated
Mobile
EGSM
UMTS
RX
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point, it is essential to have good knowledge of the channel conditions of a particular UE toward the cooperating transmission points.

Consequently, UE measurements on the various reference symbols (cell and channel state information reference symbols [CSI-RS] and interference measurement resources [IMR]) need to be verified. This requires a mobile communications tester to establish multiple scenarios in an easy and efficient way. In contrast to traditional LTE operation, signals from multiple transmission points may expose frequency and time shifts.

Since reporting channel quality information (CQI) is so important, frequency and timing correction measures at the UE end need to be tested extensively as well. The responsible working group (RAN5) in 3GPP has just started drafting the test case details based on initial agreements made in 3GPP RAN4, the group that defines the performance requirements.

Finally, any efficient CoMP algorithm in the network may be applicable to a large number of cells in a certain network area, if not in the complete network. This means that it may be possible to verify whether the implementation-dependent CoMP algorithm is delivering its capacity gain promise by monitoring KPIs in the core network (e.g., overall data throughput per cell). In case of errors, it will be necessary to conduct dedicated drive testing in order to identify the root of a problem.

CoMP is a key technology component in LTE-Advanced 3GPP Release 11 for further increasing system capacity. The advent of continuously increased data consumption specifically on smartphones, along with the anticipated, exponentially growing number of machine-type communications devices such as sensors, makes CoMP the technology of choice for network operators for satisfying capacity needs.

The major design challenge is on the network end, since if coordination is done across multiple cells, high capacity and low latency interfaces between BBUs are required. Additionally, precise knowledge of propagation conditions at the end user position is essential. This requires comprehensive verification of UE reporting behavior under various conditions. ■

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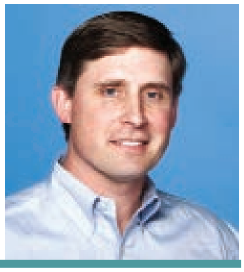
The Road to 5G FAQs



James Kimery, Director of Marketing, National Instruments

WHAT IS 5G AND WHY IS IT NEEDED?

Since the cell phone was first introduced many years ago, cellular infrastructure has undergone many transformations. The first generation cellular networks were based on “analog” technology such as Advanced Mobile Phone Service (AMPS). The second generation (2G) systems featured digital technology utilizing standards such as Global System Mobile (GSM). In terms of capability, 2G added basic SMS (texting) to voice with limited wireless data capability. Web browsing on a 2G mobile device was limited. Wireless data was driven by texting, email and static photo transfers.

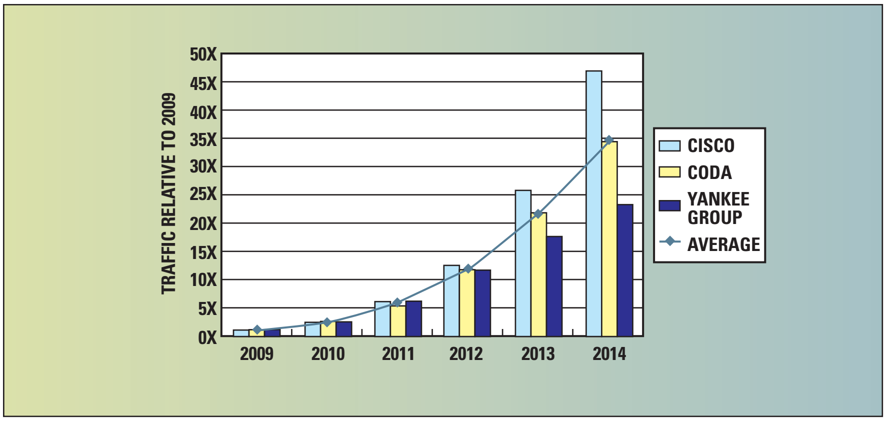
TABLE I

DATA SPEEDS

Network Generation	Down Link (Mbps)	Up Link (Mbps)
4G	300	150
3G	14.4	<<14.4

3G, or third generation networks, added a higher speed data capability where limited video could be transferred using Wideband Code Division Multiple Access (W-CDMA). Later evolutions of 3G included HSPA and HSPA+ (the equivalent of 3.5G) and delivered an enhanced user experience. However, big data applications such as streaming video were slow compared to WiFi or Wireless LAN speeds, which most consumers used as a comparison benchmark.

Today, network service providers are rolling out fourth generation (4G) networks based on Long Term Evolution (LTE). LTE offers significant upgrades over 3G in terms of data throughput with up to five to six times faster peak rates (see ***Table 1***). Most service providers plan to transition to LTE-Advanced, or 4.5G, which is expected to double the available bandwidth from LTE. With LTE and LTE-Advanced, wireless data consumers now have a communication technology that rivals current WiFi in terms of user experience.



▲ *Fig. 1 Industry forecasts of mobile data traffic (From* Mobile Broadband: The Benefits of Additional Spectrum*, FCC Report 10/2010).*

On the surface, future wireless data capabilities along the LTE trajectory appear to approach parity with WiFi from a user experience perspective, ostensibly reducing or mitigating the need for quantum leaps in increased bandwidth. However, with the rapid adoption of smart devices such as smartphones, tablets and even fablets, network capacity and bandwidth are being consumed at accelerated rates. In fact, industry analysts predict that wireless data demand will exceed 2009 levels by over 35× in 2014 (see ***Figure 1***), and this growth rate is not expected to subside any time soon. Capacity is, in effect, a function of bandwidth. More bits transmitted faster free up spectrum for other users and their data demands. Doubling the data rate effectively increases the capacity by 2×. Therefore, the primary motivation for investments in 5G research is to increase network capacity via increased bandwidth and to avoid a capacity shortage.

ARE LTE AND LTE-ADVANCED NOT SUFFICIENT TO ADDRESS CONSUMER DEMAND?

Considering the rate at which wireless users are consuming data, there is genuine concern across the industry that network capacity may become constrained in the not too distant future without significant technology upgrades. Let's take, for example, current LTE quoted rates, 300 Mbps in the downlink and 150 Mbps in the uplink. These rates are about four to five times faster than 3G and 3.5G technologies. LTE-Advanced may essentially further double to quadruple data rates. So, in a span of 10 to 15 years, the world's cellular operators increased capacity by 20×. In that same time frame, "demand" increased by more than 100×. It's clear that LTE-Advanced is necessary and that a new fifth generation network is critical. Wireless infrastructure companies and other members of the 3GPP standardization body, in fact, have set out a challenge to increase capacity by "1000× by 2020" (www.cvt-dallas.org/MBB-Nov11.pdf).

HOW WILL 5G ADDRESS THE "BANDWIDTH/CAPACITY" CRUNCH?

First of all there is much discussion regarding 5G – what it will be or what it will not be. We do know that 5G will have to be much faster than today's 4G networks and the eventual LTE-Advanced (sometimes referred to as 4.5G). The real question is how we achieve faster performance and high capacity with the current infrastructure including existing equipment, available spectrum and so on. The 3GPP standardization body is establishing an investigative group to explore the next generation wireless question, which will hopefully be kicked off early next year. The consensus is that there is no "silver bullet" or one technology that will lead to the necessary bandwidth expansion, but a combination of advancements such as heterogeneous networks encompassing small cells and coordinated multipoint, reallocation of spectrum, and other advanced techniques such as self-organizing networks (SON).

WHAT TECHNOLOGIES ARE BEING INVESTIGATED TO SUPPORT A POTENTIAL 5G STANDARD?

Several technologies are being researched today to increase spectrum efficiency and lower the intercell interference such as heterogeneous networks, small cells, relays and coordinated multi-point. Essentially the motivation behind these research vectors is to lower the load per base station by increasing the density, which in turn increases spectrum efficiency to users in a smaller geographic area. All of these options focus on deploying more infrastructure equipment and further increasing utilization by employing "smart" techniques (i.e., coordinated multi-point, beamforming and so on). Fundamentally, by sharing network information at the base station level, load and coverage per user can be optimized to more effectively use the existing spectrum.

A more difficult challenge is the availability of spectrum. The transition from 3G to 4G introduced new technologies for increased data throughput and reliability, but what is often overlooked is that new spectrum was introduced in conjunction with the LTE rollouts. For example, in the United States, the 700 MHz spectrum was auctioned specifically as a vehicle to deploy LTE.

This scenario also played out similarly with W-CDMA and the 3G rollout as 2G networks were pervasive and successful. 3GPP offered new coding and modulation techniques but these new technologies were largely (if not exclusively) deployed on new spectrum earmarked for those deployments.

With 5G, the answer is not so simple. Unless industry, government and associated spectrum regulating entities can agree on how and when to reallocate spectrum, there is essentially no spectrum available below 6 GHz. Reallocating spectrum is not an easy task since many service operators paid billions of dollars to acquire the spectrum already in use, and transitions are not easy or cheap.

Of particular note is the research that Dr. Ted Rappaport is doing at NYU Wireless. Dr. Rappaport has been characterizing the spectrum at 28, 38 and 60 GHz plus E-Band that covers frequencies from 71 to 76 GHz in New York City – which is a very challenging environment. These measurements show that wireless outdoor communication is possible at those frequencies although significant investment is required to make communication at these frequencies feasible.

IS 28 GHz TO mmWAVE E-BAND A CHALLENGING DESIGN TASK?

None of the options proposed to address the wireless data crunch will be simple or easy. The industry has to challenge conventional thought, which includes the design process. mmWave frequencies in particular were widely considered not suitable for cellular data and a network based on this spectrum unfeasible. Dr. Rappaport's work has essentially challenged this thinking. He has proven that reliable transmission and reception at these frequencies is possible but there is much work to do. Essentially, all the paradigms associated with communication below 6 GHz must change, creating research opportunities in RF front end design and antennas, beamforming, physical layer design and even new protocols.

What's encouraging is that while many of these technologies are new and have yet to be developed, there is history of rolling out new data capabilities overlaying the existing infrastructure. Even if you consider all of the research below 6 GHz in terms of physical layer, small cells, and RF front ends (MIMO), the network is still limited by the Shannon theory – a communication channel is limited by the bandwidth and noise. Heterogeneous networks will improve capacity but it is not clear that this alone will achieve 1000× capacity in 2020. If there is no available bandwidth, then new spectrum must be found somewhere.

YOU MENTIONED A NEW DESIGN APPROACH. CAN YOU ELABORATE ON THIS POINT?

A typical "design" approach has been to come up with an idea, simulate it and then prototype. Usually there are several iterations in the design and simulation stage before prototyping because of the large expense required to develop a working prototype. If there is a fundamental problem in the theory, then it is back to the beginning to start over again. Therefore heavy simulations are typically required before a prototype is even planned. With conventional methods, transitioning from concept to simulation to prototype takes a very long time and consumes many resources. In other words, it is very expensive. The most important goal of the design process is to deliver a working prototype sooner rather than later so that the real world conditions and system issues can be accounted for early in the design.

Most of today's simulations mostly use additive white Gaussian noise or AWGN to model the channel. As network operators will tell you, this is simply not a realistic scenario – perhaps a good start but far from realistic. With the new technologies being investigated for 5G, conventional channel models are not good proxies for the real world. System engineers and network designers must also consider the processing requirements and the feasibility of actually deploying a new algorithm/protocol on a platform that is both cost effective and low power (to conserve battery life). Getting to a prototype sooner rather than later is very important.

WHERE DOES NATIONAL INSTRUMENTS FIT INTO THIS 5G REVOLUTION?

National Instruments has been working with wireless researchers for a number of years through the RF/Communications Lead User program. Through this program, NI has been working directly with top researchers, such as Dr. Rappaport at NYU Wireless and also Dr. Gerhard Fettweis at TU Dresden, to explore a new approach to communications system design.

We already discussed Dr. Rappaport's work on mmWave, but also of significance is Dr. Fettweis' work on new physical layers for 5G. He is already prototyping a new physical layer called GFDM or General Frequency Division Multiplexing that addresses some of the shortcomings of OFDM – the standard in today's 4G communications. Through this work, Dr. Fettweis has gone from simulation to prototype in a matter months.

The Lead User program was the idea of National Instruments' CEO and founder, Dr. James Truchard. Dr. Truchard believes that a new design paradigm is needed for research not just in wireless but across many different areas. The tools used in research to transition from design to simulation to prototype have not really evolved over the last 20 years like so many technologies that have improved our everyday life. In particular, National Instruments focuses on a graphical system design approach to accelerate the process from design to simulation to prototype. The combination of this approach with tight hardware and software integration enables researchers to focus on their area of expertise rather than having to struggle with disparate tools and technologies that can take months and years to integrate into a working prototype.

Through the RF/Communications Lead User program, we are also working with leading researchers at commercial companies but I am not at liberty to disclose these relationships as they are confidential. However, I can say that you should stay tuned for some exciting demonstrations using NI tools and technologies on the 5G front. ■

James Kimery *is the director of marketing for RF, communications, and software defined radio (SDR) initiatives at National Instruments. In this role, Kimery is responsible for the company's communication system design and SDR strategies. He also manages NI's advanced research RF/Communications Lead User program. Prior to joining NI, Kimery was the director of marketing for Silicon Laboratories' wireless division, which later became a subsidiary of ST-Ericsson. With Kimery as director, the wireless division grew revenues from $5 million to over $250 million. The division also produced several industry innovations including the first integrated CMOS RF synthesizer and transceiver for cellular communications, the first digitally controlled crystal oscillator, and the first integrated single-chip phone (AeroFONE). The IEEE voted AeroFONE one of the top 40 innovative ICs ever developed. He also worked at NI before transitioning to Silicon Labs and led many successful programs, including the concept and launch of the PXI platform. Kimery was a founding member of the VXIplug&play Systems Alliance, the Virtual Instrument Software Architecture (VISA) working group, and the PXI Systems Alliance. He has authored over 26 technical papers and articles covering a variety of wireless and test and measurement topics. He earned a master's degree in business administration from the University of Texas at Austin and a bachelor's degree in electrical engineering from Texas A&M University.*

kAelus

Improving Wireless Networks is Not Just a Tag Line...

It's what we do - from testing to optimization, Kaelus is your one-stop shop!

Kaelus designs and manufactures a wide range of innovative RF and microwave solutions for the wireless Telecommunications sector. Kaelus' experience and understanding of the radio environment enables it to excel by developing technically differentiated offerings that improve network performance. Kaelus' industry-leading portfolio of products support the testing and optimization of cell site performance. New products offered by TESSCO include:

In-Building DAS Power Management Solutions:

Solutions include a range of products which provide the interface between the radio source and the fiber head-end of the Distributed Antenna System (DAS).

Site Optimization Solutions:

Products include a wide range of Interference Filters, Combiners and Tower Mounted Amplifiers (TMAs) that enhance radio system performance, reduce OPEX and increase operator revenue.

Industry-Leading PIM Test Solutions:

Kaelus is the industry leader in portable PIM test solutions. Since 2005, Kaelus has delivered thousands of IEC compliant high power, highly reliable, portable PIM test sets to network operators and installation teams around the world to support field testing. The iPA comes with a five-year warranty which includes the screen.

Kaelus Recognized with the 2012 Frost & Sullivan Global Market Leadership Award in Passive Intermodulation Test Equipment

smiths microwave

www.kaelus.com

Smarter Antenna Front End Modules

Once in a while, a technology has the numbers to back up the buzz it's generating, and that's the case with LTE. By the end of this year, ABI Research predicts that LTE subscriptions will hit 183 million worldwide. In the first two years it was commercially available – Q4 2010 to Q3 2012 – LTE racked up far more customers than W-CDMA did in that technology's first two years.

For OEMs of smartphones, tablets, laptops and other devices, the message is clear: an LTE strategy including innovative devices is critical to stay ahead of the competition and remain relevant. But less obvious are the challenges, costs and competitive risks of choosing the wrong LTE RF solution. Mistakes are easy to make because LTE has fundamentally different requirements and considerations than those of 3G and 2G:

- **Highly fragmented spectrum.** LTE is designed for use in more than 40 bands between 450 MHz and 2.7 GHz. Roughly half of those are already in commercial use. To enable regional or global roaming on par with what 3G provides, or single-SKU products, OEMs currently must build support for a dozen bands into their devices. That increases cost, complexity and development time, all of which increases further when those bands are widely spaced. LTE-Advanced introduces carrier aggregation, which makes fragmentation even more challenging when the aggregated frequencies are far apart.
- **Operators prefer lower bands.** Many mobile operators prefer to use low frequency bands, 700 MHz, for LTE because lower frequencies require fewer base stations, thus reducing their CapEx and OpEx. But lower frequencies require electrically larger antennas, which are literally a bad fit for the trend toward thinner devices. In smartphones, for example, the amount of space available for antennas and other RF components is shrinking 25 percent annually to make room for bigger batteries while enabling increasingly thin, sleek form factors. Although M2M devices such as vending machines, smart meters, and telemedicine monitors appear to have ample room for large antennas, they are actually often as space-constrained as smartphones and tablets.
- **MIMO (Multiple Input, Multiple Output) is required.** MIMO increases the number of cellular antennas. The two antennas must have enough separation between them to benefit from the differences in signal conditions. That amount and spacing increase the challenge of finding enough room as devices become thinner.

Jeff Shamblin
Ethertronics, San Diego, CA

- **Multi-technology support is a must-have.** Although 193 LTE networks have launched and another 123 will debut over the next two years (according to ABI Research), the technology will not have ubiquitous coverage in most countries until late this decade. So in that interim, many LTE devices still need the ability to use other wireless technologies, such as 2G/3G fallback in places where LTE is not yet available, or WiFi when it's more cost-effective. GPS is another common requirement. Each additional technology increases the challenge of finding enough room for antennas and other RF components.

Device OEMs must overcome all of these challenges. If they do not, their products will not deliver the high performance and fast speeds that consumers and business users expect from 4G. Sub-standard performance would directly affect their competitive position and ultimately revenue. OEMs that rely on mobile operators for distribution also risk losing their sales channels if customers inundate operators with complaints about poor performance, or if those devices create problems that sap network capacity. To overcome these challenges, device OEMs need to focus on two things: the trend toward active antenna systems and where each RF vendor's products fit into that trend.

ACTIVE ANTENNA SYSTEMS

Active antenna systems are not just the future of LTE – they are also the present. An active antenna system went into production in August of 2011 in a medical device monitoring critical medication dispensing and inventories. Several months later, the Galaxy S II LTE SC-03D phone, using an active antenna system with active impedance matching techniques, launched on the DOCOMO network. Most recently, an ultrabook from a tier one OEM utilized band aperture techniques to provide global 3G and 4G coverage. Active antenna systems are gaining traction in the marketplace to help OEMs solve LTE's toughest challenges.

Unlike passive antennas, active systems can be dynamically tuned to cover significantly wider bandwidths, achieve smaller physical volumes, and provide more degrees of freedom in the design process. This flexibility reduces the cost, complexity and lead time of developing antenna systems capable of meeting unique device or application requirements, such as an LTE M2M module mounted inside a metal box or in an underground vault, or a smartphone that needs to be ultra-thin and capable of global roaming on LTE. This flexibility also increases the likelihood that a device will pass operator certification on the first try, which means faster time-to-market and faster time-to-revenue for the OEM.

Active antenna systems also enable single-SKU products, reducing the OEM's development and support costs while expanding those products' addressable market to the world rather than just a single region or country. For example, a single active antenna system can support multiple LTE bands, plus the bands for 3G and 2.5G fallback, ISM, WiFi, Bluetooth and ZigBee. Covering all of those bands with multiple passive antennas is somewhere between difficult and impossible, depending on both the amount of space available in the device and the requirements for cost and performance.

Unlike passive antennas, active antenna systems can seamlessly adjust the antenna's characteristics to compensate – all in real time – for frequency shifts due to environmental changes such as the position of the user's head and hand, or a large truck parked over an underground utility vault. Active antenna systems also can make those adjustments to overcome challenging installations, such as when an M2M module is mounted on a metal surface that would wreak havoc with a passive antenna.

The ability to mitigate detuning effects directly affects an LTE device's market potential and support costs, as well as its OEM's brand reputation. Active antenna systems enable those devices to provide data speeds, video performance and call quality that are noticeably superior to what's available from LTE products that try to make do with passive antennas.

Quality of Service (QoS) and reliability also affect mobile operators' cost of delivering service. For example, when M2M modules use active antenna systems to maintain connectivity even under difficult, changing environmental conditions, the mobile operator is under less pressure to increase its cell site density. The CapEx and OpEx of dozens, hundreds or thousands of additional cell sites would make it difficult for the operator to price its M2M services competitively, yet profitably.

WHAT MAKES AN IDEAL ACTIVE ANTENNA SYSTEM?

Not all active antennas, or tunable antennas, provide equal performance and integration benefits. That is a key point for OEMs, systems designers and others to keep in mind because many vendors are now talking about tunable antenna products. It is important to understand the key differences between them.

For starters, the ideal active antenna system for many applications is an all-in-one module that device OEMs can quickly and cost-effectively integrate into their products instead of spending weeks or months on custom designs with components from multiple vendors. The plug-and-play approach has obvious benefits, such as reduced development costs and faster time-to-market. A less obvious benefit is that OEMs now do not need to hire staff to create an RF engineering team to handle integration in house. That benefit is particularly valuable for M2M and consumer electronics OEMs, which typically have limited or no RF experience.

The turnkey plug-and-play module approach includes being able to dynamically sense and optimize the antenna system without external control signals from the device. That is possible by using advanced antenna architecture, tunable capacitors and adaptive algorithms designed and integrated in conjunction with a microprocessor.

To achieve the highest performance and ease integration, an active antenna system needs to perform dynamic impedance matching at the feedpoint rather than farther back in the system, such as in the transceiver chipset. The feedpoint approach maximizes performance because the tuning is focused entirely on the antenna. When tuning is done farther back in the signal chain, the process can be undermined by the transmission line's electrical delay and losses.

Band switching is another important feature to look for. Also known as active aperture, this technique dynamically changes the electrical length of the antenna element to shift its frequency response. An alternative method is active matching, where a tuning circuit at the feedpoint changes the antenna's impedance. The main difference between the two methods is that active aperture/band switching is a coarse tuning of the antenna element followed by active impedance matching for a fine tuning of the frequency response at the feedpoint. This allows the device to quickly tune across the required frequency bands in the smallest antenna volume.

OEMs used to have to choose between the two techniques because of the cost of implementing multiple components. Impedance matching requires tunable capacitors, while band switching requires a switch. OEMs are always looking for ways to reduce costs given the competitive nature of the wireless industry.

The latest active antenna solutions minimize the cost factor by combining a four-port switch and multiple tunable capacitors in a single RFIC. These products combine the active aperture/band switching technique to quickly tune across frequencies and then use the active impedance matching function to fine tune the impedance to the desired frequency for the best performance.

Many of LTE's biggest RF challenges occur below 1 GHz because above that, antennas do not have to get larger to the point that they're difficult to integrate inside space-constrained devices. That is why these next-gen active antenna system solutions focus on impedance matching at the lower frequencies.

Device OEMs have been asking RF vendors to provide single-RFIC active antenna systems to maximize performance benefits without significant cost increases, so it is a milestone that they are now commercially available. They also do not come with many tradeoffs. For example, multiport switches and tunable capacitors typically have low current consumption – well under 200 micro amps – so the performance and reliability that they enable do not come at the expense of battery life.

Even so, not all RFIC active components are equally effective. The reason is the heritage of the companies that produce them. For example, some RFIC vendors know chips but not antennas, so they are developing products that are unnecessarily expensive because they conduct tuning at higher frequencies.

By comparison, a chipset vendor with extensive antenna experience knows that all the tunable components in the world will not compensate for a poorly designed, inefficient antenna. An experienced antenna vendor also knows that a systems approach is a key to performance: the antenna, chips and algorithms need to be designed together in order to deliver the easiest integration, best performance and the lowest cost. By comparison, a chip vendor will design an RFIC that will attempt to work with as many bands, antenna types and impedances, which inevitably translates into compromises in performance and higher cost.

Single-RFIC chips and active antenna systems are an idea whose time has come because they solve a variety of unique challenges created by the arrival of LTE. They're also the first in a wave of next-gen active antenna solutions, which will feature even more complexity to enable higher performance and lower costs. ■

Broadband LDMOS FETs for Land Mobile Radios

Handheld and vehicle-mounted transceivers used by public safety and other agencies may look much like their predecessors, but peering inside reveals a profound difference, thanks to the "digitization" of functions formerly performed by analog components. Nevertheless, although the transmit section (and some receive components) remain the last bastion of RF technology within these increasingly digital products, advancements are being made in performance and functional integration as well as size reduction and power consumption. Two additions to Freescale® Semiconductor's Airfast™ RF power solutions family have been designed to address these challenges by reducing amplification stages and covering multiple frequency allocations with a single device.

The AFT09MS007 and AFT05MP075 are broadband LDMOS FETs that can be optimized for operation over wide bandwidths between 136 to 941 MHz and 136 to 520 MHz, respectively. The AFT09MS007 operates from a supply voltage of 7.5 VDC making it compatible with handheld radio power supplies. The AFT05MP075 delivers 70 W or more and operates from a 12.5 to 13.6 VDC supply, typically a vehicle battery.

Both devices can operate into a VSWR greater than 65:1 without degradation, even when driven with twice their rated input power from a supply voltage of 10.5 (AFT09MS007N) and 17 VDC (AFT05MP075). They have built-in protection against electrostatic discharge, are housed in Freescale's over-molded plastic packages, and are available in tape and reel.

The ability of both devices to cover more than one frequency allocation (such as 136 to 174 MHz or 350 to 520 MHz) provides significant benefits for manufacturers as they can rely on a single device to serve all or most of their entire product line. The manufacturer's portfolio will typically have a lower bill of materials, fewer circuit designs, and lower cost than if different devices were used. It also allows manufacturers to address the need of agencies that operate at frequencies other than the standard public safety bands, whether they require small or large quantities of radios.

It is obviously advantageous for radio manufacturers to use as few different RF power transistors as possible throughout their product lines. This is often not the case, as transceiver manufacturers typically use different RF power transistors over a specific band or split bands such as 350 to 520 MHz into two or even three parts to optimize for efficiency or another parameter. The Airfast devices eliminate this requirement. The devices achieve their performance without use of internal matching, so rather than being optimized to operate over a relatively narrow, fixed band they can, through external matching, be optimized over any bandwidth within their specified range of operating frequencies.

Figure 1 shows the performance of the two devices in typical mobile radio broadband circuits. The AFT05MS075 shows excellent performance characteristics across VHF frequencies from 136 to 174 MHz. At 12.5 V operation, the device has typical gain of 18.8 dB, producing 84 W nominal with 1.1 W of input drive. Efficiency under these conditions is typically 76 percent. The AFT05MS075 is also characterized for 13.6 V operation. When operated at the higher voltage, power gain increases approximately 0.5 dB and output power increases to 94 W nominal when tested with

Freescale Semiconductor
Tempe, AZ

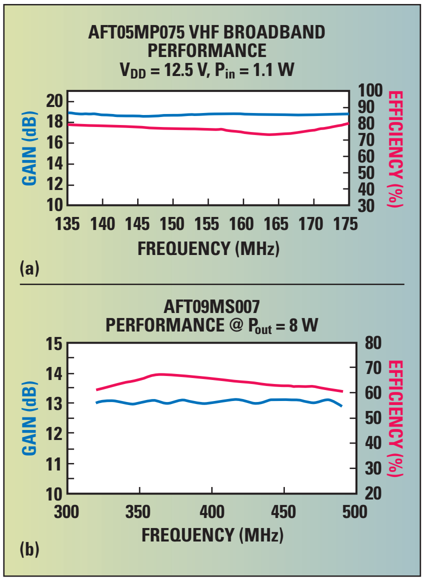


Fig. 1 Only an inexpensive driver and the AFT09MS007 are required to provide the 7 W required for handheld radios or the AFT05MP075 to produce a 55 W+ amplifier for vehicle-mounted radios.

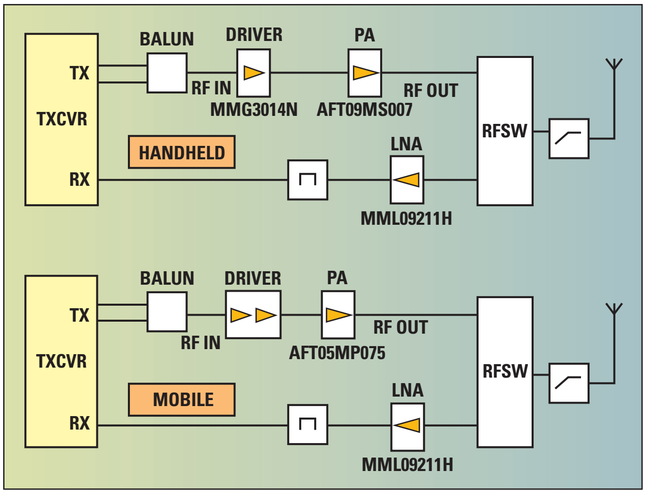


Fig. 2 Typical circuits for handheld and vehicle-mounted radios using these new devices.

the same 1.1 W input. Efficiency is similar at the higher power condition.

The AFT09MS007 is shown operating into a single broadband UHF fixture. The fixture shown is tuned for 350 to 490 MHz. At a power output of 8 W, the device exhibits typical gain of 13 dB and efficiency of greater than 60 percent across the band. For lower power operation, the device has also been tested at a power output level of 6 W. Under this condition, the device shows typical gain of 11.8 dB and typical efficiency of 63 percent.

In addition, as the devices have high gain and efficiency, the rated output power of the end product can be satisfied using fewer amplifier stages, further building on the previously mentioned advantages of reduced parts count, board space and cost. Both the AFT09MS007 and AFT05MP075 employed as the final amplifier in a handheld and vehicle-mounted transceiver (respectively) can deliver their rated power when driven by a single, inexpensive driver amplifier.

Figure 2 illustrates typical circuits for handheld and vehicle-mounted radios using these devices. In the handheld circuit, Freescale's MMG3014 directly drives the AFT9MS007 in the transmit path and Freescale's MML09211H low-noise amplifier is employed in the receive path. In the vehicle-mounted radio diagram, a broadband general-purpose amplifier directly drives the AFT05MP075. In both cases, rated output is achieved using only two devices (see ***Table 1*** for key device parameters).

Both Airfast devices also have integrated stability enhancement circuitry, which is particularly desirable for the AFT05MP075 as it draws its DC power from a vehicle battery. Although vehicle power supplies are regulated, their voltage can vary dramatically from 12 VDC to as low as 10 VDC and as high as 17 VDC depending on environmental and other conditions. Transceivers typically have power monitoring circuits that maintain stable RF performance under varying power supply voltages, but when voltage drops, the circuit boosts the RF input power to driver amplifier to compensate. The stability enhancement circuits within the devices compensate for the effects of these conditions, so they remain stable in severe under- and over-voltage conditions produced by idling, a faulty regulator or battery, hot underhood temperatures, as well as varying ambient temperatures encountered throughout the seasons.

The two new devices join a growing family of Airfast LDMOS and GaN RF power transistors for land mobile radio applications as well as "MRF" series LDMOS FETs that operate from 7.5 to 12 VDC. The AFT09MS007N and AFT05MP075 are available now and are supported by reference designs, evaluation boards, and other designer resources.

TABLE I

KEY AIRFAST DEVICE SPECIFICATIONS

	AFT09MS007N	AFT9MP075	MMG3014 (driver)
Frequency range (MHz)	136 to 941	136 to 520	40 to 4000
RF output power (W)	7.3	57	0.3
Gain (dB)	14.6 to 15	14.6 to 21	10 to 19.5
Drain efficiency (%)	71	68	19.5
Maximum RF input power	200 mW	1.5 W	316 mW
Load/mismatch ruggedness with no signal degradation, CW input signal	More than 65:1 input VSWR at all phase angles, 3 dB overdrive, 10.8 VDC (AFT9MS007) or 17 VDC (AFT9MP075)		
Matching	External	External	Internal
Power supply (VDC)	7.5	12.5 to 13.6	3 to 5
Other features	ESD protection, Internal stability enhancement		Active bias control
Plastic package	PLD-1.5	TO-270WB-4 or TO-270WB-4 gull	SOT-89

Freescale Semiconductor,
Tempe, AZ
(800) 521-6274,
www.freescale.com/rfpower.

Battery Powered PIM Tester

Beginning in 1996, Kaelus, formerly Summitek Instruments, has focused on providing test solutions for passive intermodulation (PIM). The Kaelus PIM test instruments defined a global standard in manufacturing and field test. As technology evolved toward remote radio heads and installation at the top of the tower, a new instrument architecture was required in the interest of personnel safety and test convenience.

Kaelus seized this opportunity to start with a blank sheet of paper and designed a solution built for purpose and that capitalized on all of the lessons learned in delivering more than 4000 PIM solutions for field use over the last five years. The resultant product, named the iPA, is uniquely suited for top-of-tower test as well as the more traditional applications of bottom of tower, rooftop and in-building. The obvious configuration change needed was to get smaller and lighter without sacrificing functionality. This meant higher levels of integration and creative mechanical layout.

MECHANICAL: ROBUST, RUGGED, WEATHERIZED

To withstand the abusive environment of field testing and hoisting units to the top of the tower, Kaelus focused on creating a toughened design. This is immediately evident upon first glance. The rubberized enclosure, the solid metal enclosure, the shatter resistant display and the strategically located dual handles assure long term survivability. It is so tough, you can even drive a vehicle over it.

There are no open portals to allow water penetration and no fans, as it is passively cooled. And, for good measure, the iPA includes four integrated lifting hooks eliminating the need for special packaging to get it to the top of the tower.

SAFETY AND CONVENIENCE

Testing at the top of the tower is dangerous; particularly, if the test personnel are simultaneously trying to run the test equipment, observe the results and dynamically stress the RF path (flexing cables, tapping on connectors, tapping on the back of the antenna, etc.). To minimize the demand on personnel at the top of the tower, Kaelus integrated in a WiFi wireless access point and provides a WiFi-enabled tablet to accommodate remote control of the test by ground personnel. The remote control is a great convenience on rooftops where the PIM tester is connected back at the BTS and the test operator is remotely located near the antenna doing dynamic testing.

KAELUS (A SMITHS COMPANY)
Centennial, CO

TEST EFFICIENCY

Test site certification can be a time-consuming and costly exercise that must be performed with precision and the results accurately communicated to the customer – most often the wireless network operator. The iPA requires no time-consuming calibration process prior to use and the operator interface is simplified to minimize opportunities for taking errant data or misinterpreting the results. The Kaelus industry leading reporting developed for the iQA has been incorporated and enhanced in the iPA.

LOW COST OF OWNERSHIP

A key aspect of any test instrument is availability. The iPA builds on the experience of the industry stalwart of field PIM test equipment, the Kaelus iQA. The iPA's robust mechanical design has already been described. Complementing this is the high reliability of the electronics as well as the focus on serviceability and low cost to repair.

RF PERFORMANCE THAT MATTERS

The IEC specification for PIM test methods guides the design and the performance capability of nearly all PIM test solutions. Kaelus/Summitek has been active with the IEC committee on PIM for more than 15 years and helped define the test standard. Whereas the IEC recommends the test methods (two test tones at 20 watts per tone and measurement of IM3), for making a PIM measurement, it does not recommend what is an acceptable performance standard. This is left to the customer and the manufacturers.

Typical PIM specifications for manufacturing test are –107 dBm (–150 dBc) or better. For field testing, this is typically relaxed to –97 dBm (–140 dBc). This sets the performance requirements of the PIM tester. To keep measurement uncertainty to acceptable levels, the noise floor of the test instrument must be at least 10 dB better than the level being verified. It is important to note that the measurement noise floor is set by the thermal noise floor of the receiver, or the residual PIM (the PIM generated by the test setup), whichever is greater.

Implementing a high performance receiver subsystem with a noise floor better than –107 dBm is relatively straightforward. The iPA specification is significantly better than this at –128 dBm. The challenge is providing low residual PIM – not just at time of manufacture, but with a design that maintains this performance despite the abuse the unit will absorb as a field test tool. This is where the Kaelus PIM test solution excels. The Site Solutions division of Kaelus is known for designing, manufacturing and delivering high performance, low PIM. These same engineers provide the technology used in the PIM test equipment. The residual PIM is conservatively specified at –117 dBm (–160 dBc), but is typically better than –125 dBm (–168 dBc).

The Kaelus iPA family of battery powered PIM test equipment builds on the legacy and experience of more than 15 years addressing this measurement application. The iPA is a superior solution providing the very best in ruggedness, reliability, performance and utility.

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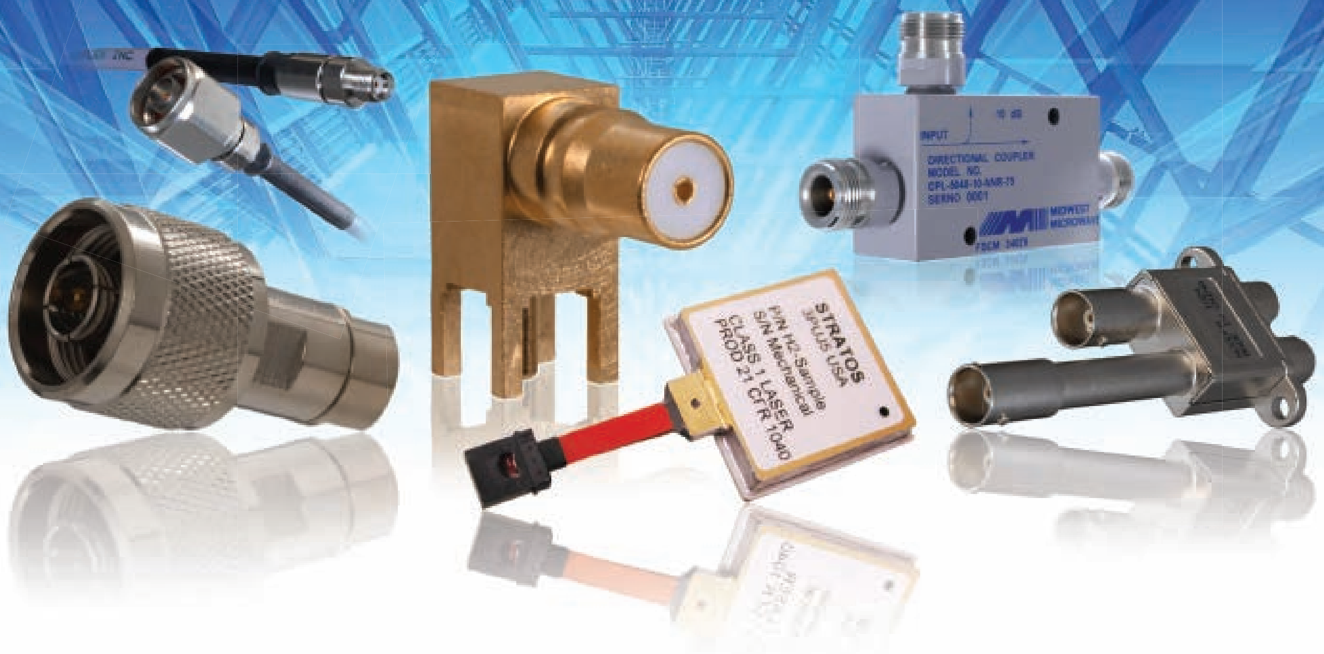
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Connector System for Mobile Communications Market

The newly developed 4.3-10 connector system is designed to make the deployment of mobile communications infrastructure easier, more reliable and more powerful. The new connector system has been developed from scratch with the increasing demands of the modern communications market in mind. In comparison with previous connector systems that have been developed for other purposes, this brand-new system has several advantages.

With the new 4.3-10 connector family, the industry is responding to the changing demands for modern mobile communications infrastructure and addressing the fact that as base stations and antennas become more compact, the large size of existing connectors can be a restricting factor. In particular, as more and more frequencies are released for mobile communication carriers, the problem of passive intermodulation (PIM) is increasing. And in the field, the connectors that would normally be used often resulted in problems if they were not mated with the correct torque.

SMALLER & LIGHTER

When designing the new connector, the most important requirement was to decrease size and weight compared to the 7-16 connectors used previously but without losing the possibility of feeding the signals of several mobile carriers over a single line. With a maximum 500 W CW transmission power at 2 GHz, the 4.3-10 connector system has more than enough power capability for today's and even future demands. An inner diameter of 4.3 mm combined with a 10 mm outer conductor are more than adequate for this kind of power. Furthermore, the footprint of the fixed socket has been reduced from 1.26 × 1.26 inch in the 7-16 system to 1 × 1 inch, and the weight reduced by 60 percent.

A totally new connector design was required because of the well-known PIM problems of existing connectors. The PIM performance of all currently used systems relies on the torque applied to the coupling nut. If the nut is acci-

SPINNER GmbH
Munich, Germany

Fig. 1 *The three coupling mechanisms include the existing screw type and two new ones: a hand screw version and a push-pull type.*

dentally not tightened correctly, poor intermodulation values are the result – a nightmare in today's multi-carrier and multi-frequency mobile networks.

SPRING LOADED RADIAL BUSHING

The 4.3-10 connector system separates the mechanical and electrical reference planes, which was not the case in previous systems. Instead of a direct contact dependant on the torque of the coupling nut, a spring loaded radial bushing is used for the outer conductor. This means that no additional coupling force is needed and the connector is immune to PIM. PIM is excellent even when mechanical force is applied to the connection, which is also a requirement of IEC 62037.

The concept of the separated mechanical and electrical reference planes has some other advantages too. Since mechanical pressure was no longer an issue, besides the existing screw type, it was possible to design two new coupling mechanisms that do not require any installation tools: one hand screw and a push-pull type. All three (shown in ***Figure 1***) have excellent PIM performance even under mechanical stress, allow for a very high packaging density of one inch and use the same universal socket.

With these characteristics, the new connector system is very versatile and allows for installation in confined conditions where tools cannot be used. In effect, the 4.3-10 connector system opens the door for a new and more compact generation of mobile communication components.

ALL STANDARDS COVERED

The 4.3-10 connector system is designed for frequencies up to 6 GHz, which covers all the current mobile communication standards. All contacts and seals are protected against mechanical damage, which gives the system excellent mechanical properties and ensures its role as a modern alternative to the established connector systems in mobile communications.

The new system is currently in the standardization process at DKE (German Commission for Electrical, Electronic & Information Technologies of DIN and VDE) and the International Electrotechnical Commission (IEC). Connectors, test and measurement equipment as well as jumpers will be available by the end of 2013.

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See the big picture quickly in one design environment with VSS. Zoom in to make circuit tweaks. Then zoom out to see the system impact. VSS does system budget analysis and identifies sources of IM products, harmonics, and noise directly on your Microwave Office circuits. VSS's powerful simulator defines complex systems — radio and circuit designs, baseband signal processing, algorithmic development, and digital fixed-point implementations too. Grab a test copy at awrcorp.com/VSS.
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VSS SYSTEM SIMULATOR

High Isolation, Carrier-Grade Wi-Fi Switch

Peregrine Semiconductor has developed one of the highest performance carrier-grade Wi-Fi switches on the market. With the very high isolation, Peregrine's switch also sets a high bar in linearity, which makes it ideally suited for the fast-growing market of 802.11ac Wi-Fi access points. Based on Peregrine's UltraCMOS® technology, the PE42423 is the first in its class to offer 41 dB of port-to-port isolation at 6 GHz. This best-in-class isolation enables multi-radio access points to perform at peak levels without interference between the radios. Exceeding the stringent 802.11ac standard, Peregrine's switch also offers 65 dBm of linearity to achieve higher data rates.

In addition, UltraCMOS technology delivers equally high performance at either 3.3 or 5 V, unlike GaAs switches that experience performance degradation below 5 V. Peregrine's switch gives networking-product designers the flexibility to operate at lower power supplies and reduce energy consumption.

Peregrine's PE42423 is a single-pole double throw (SPDT) RF switch featuring low insertion loss (0.8 dB at 2.4 GHz, 0.95 dB at 5.8 GHz), fast switching time (500 ns) and high ESD ratings (3.0 kV HBM on all RF pins). It operates over a wide frequency range from 100 MHz to 6 GHz and supports 802.11 a/b/g/n/ac. In addition, it has high power handling of 38.5 dBm at 2.4 GHz and 37.0 dBm at 6.0 GHz. The switch supports +1.8 V standard logic control. It provides stable and consistent RF performance over a power supply range between 2.3 and 5.5 V. The packaging is RoHS compliant, 16-lead QFN and measures 3 × 3 mm. Peregrine is committed to meeting the Wi-Fi data-rate and capacity demands of the future, and it is already helping networking vendors achieve unprecedented performance using this switch in their Gigabit Wi-Fi access points.

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

Space Saving Components

Aeroflex / Weinschel is a leading manufacturer of high power attenuators and terminations, covering 25 to 1000 W. Although these are good as free standing units for a lab environment, they are not suitable for system integration with package density constraints. To meet that demand, Aeroflex / Weinschel has introduced a new series of slim, low profile (flat pack) conduction cooled coaxial fixed attenuators and terminations to be utilized by cellular carriers and defense integrators who find the need to deploy broadband high power, high performance RF components needed at a system level.

Aeroflex / Weinschel's newer flat pack design provides the end user the capability to design smaller form factor solutions for tightly confined telephone closets, cable end heads, DAS cellular repeater stations and tactical RF transmission systems. Optimized for use in the most common communications bands, these new designs offer DC to 6 GHz frequency range coverage in 50, 100, 250, 400 and 550 W average power handling and 10 kW peak, conduction cooled configurations with a choice of Type N or SMK (2.92mm) male or female connector options. Attenuators are available in values of 6, 10, 20, 30 and 40 dB.

Other key features include:

- Low IM distortion option
- Precision connectors with high temperature support beads
- Designed to meet the environmental requirements of MIL-DTL-3933
- Rugged construction
- Custom configurations available.

VENDORVIEW

Aeroflex / Weinschel,
Frederick, MD,
weinschel-sales@aeroflex.com,
www.aeroflex.com/weinschel.

COMPANY SHOWCASE

Pulse Measurement

VENDORVIEW

Agilent Technologies Inc. introduced a pulse measurement option for its FieldFox handheld analyzers that is designed to further simplify radar field testing. Testing radar in the field can be challenging due to the multitude of instruments engineers and technicians are required to carry. With the new pulse-measurement option, Agilent's FieldFox analyzers allow users to carry a single instrument into the field to verify and measure radar pulse characteristics, S-parameters, spectrum analysis and transmitter power.

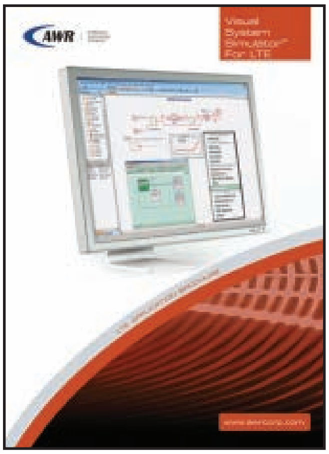
Agilent Technologies Inc.,
www.agilent.com.

RF and Microwave Technology

VENDORVIEW

Anaren Inc. is a Syracuse-based, global leader in RF and microwave technology used by in wireless infrastructure, satellite, defense and consumer-electronics applications. The company has approximately 1000 employees and five state-of-the-art facilities worldwide. Product lines include: standard passive components (e.g., couplers, power dividers, baluns, resistors, attenuators, terminations), RF multichip modules, high-reliability softboard and ceramic PCBs, and complex assemblies (e.g., switching, beamformers, antenna feed networks, DRFMs, IMAs).

Anaren Inc.,
www.anaren.com.

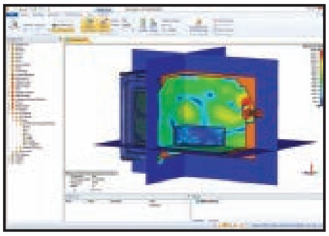


Visual System Simulator Software

VENDORVIEW

The new AWR Visual System Simulator™ for LTE brochure provides information for RF/analog engineers on effortlessly evaluating and providing the best performance possible for today's demanding LTE communication systems. The capabilities in VSS for LTE help designers cut system costs by ensuring that components are not over-specified and needlessly expensive and reduce time-to-market by eliminating iterations and rework. Learn more about VSS for LTE online and download the brochure at www.awrcorp.com/VSS.

AWR Corp.,
www.awrcorp.com.

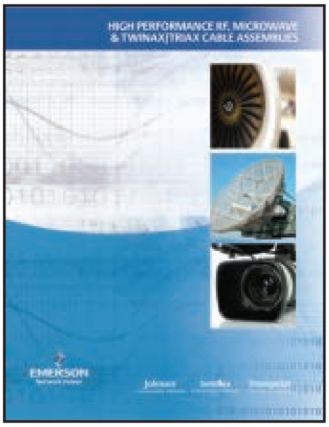


EM Simulation for Mobile Communications

VENDORVIEW

As mobile communication devices become thinner, smaller and more complex with every generation, designs need to meet new standards of performance. Using electromagnetic (EM) simulation, engineers can not only design and optimize the antenna of mobile devices, but also test its performance within the handset, for example, by evaluating coupling effects and the impact of dielectric materials, and investigating the influence of the human body on performance. Find out more about CST STUDIO SUITE®, an EM simulation tool, at the company's website.

CST, Computer Simulation Technology AG,
www.cst.com.



Cable Assemblies Catalog

Emerson Network Power Connectivity Solutions has a wide range of cable assemblies suited for RF and microwave signal transmission. Emerson Connectivity Solutions is a vertically integrated supplier of custom, fixed length and semi rigid cable assemblies from DC to 50 GHz. The company can create custom cable assemblies to satisfy your specific application requirements, also with manufacturing in the United States, United Kingdom and China; it has a cable assembly to meet any price requirement.

Emerson Network Power Connectivity Solutions,
www.emersonnetworkpower.com.

4.3-10 Connectors

HUBER+SUHNER 4.3-10 connectors offer very low PIM performance together with weight and compactness advantages. A key feature of this connector is the separation of the electrical and mechanical plane, which results in a lower coupling torque and the possibility of offering the connector with screw, hand-screw and quick-lock design, thus simplifying the installation effort and offering for all mechanisms a very high electrical performance. The 4.3-10 connector system is designed to meet the rising performance needs of mobile network equipment while also reducing its size.

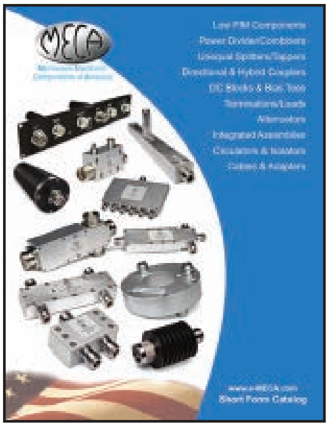
Huber + Suhner,
www.hubersuhner.com.

COMPANY SHOWCASE

Passive Intermodulation Testing

The iPA is the first battery powered PIM test analyzer versatile enough to support multiple test scenarios such as testing at the top of the tower, base of tower, roof top and in-building for DAS systems. Designed for purpose, the iPA features a rugged design and robust software to assure the product is available when you need it, performs as expected and provides reliable results. And the integrated wireless access point makes remote control easy to configure and use.

Kaelus,
www.kaelus.com.



Components Catalog

VENDORVIEW

Celebrating its 52nd anniversary, MECA (Microwave Electronic Components of America) designs and manufactures an array of RF/microwave components with industry leading performance, most recently low PIM products. MECA is recognized worldwide as a primary source of supply for rugged and reliable components to commercial and military OEMs, service providers and installers by only providing products made in the USA. Download the company's components catalog at www.e-meca.com/pdfs/MECA_Short_Catalog2013.pdf.

MECA Electronics Inc.,
www.e-MECA.com.

Filters, Multiplexers and Multifunction Assemblies

VENDORVIEW

Reactel offers a variety of filters, multiplexers and multifunction assemblies for the mobile communication industry. Reactel's experienced engineers can come up with a creative solution for all of your Tx, Rx or Co-site requirements. Reactel has designed a broad range of filters from high power units operating to 5 kW and beyond to extremely small ceramic units that are suitable for handheld or portable applications. The company's product line includes bandpass, lowpass, highpass and notch filters as well as multiplexers and multi-passband filters. Offering fast turnaround, competitive pricing and high quality, Reactel can satisfy most any requirement you may have.

Reactel Inc.,
www.reactel.com.

Communications, Power Conversion and Renewable Energy Products

VENDORVIEW

Richardson RFPD Inc., an Arrow Electronics company, is a global leader in the RF and wireless communications, power conversion and renewable energy markets. Relationships with the industry's top component suppliers enable Richardson RFPD to meet the total engineering needs of each customer. Whether it's designing components or engineering complete solutions, Richardson RFPD's worldwide design centers and technical sales team provide support for all aspects of customers' go-to-market strategy, from prototype to production. More information is available online.

Richardson RFPD Inc.,
www.richardsonrfpd.com

Switch Matrix

VENDORVIEW

Mini-Circuits has introduced the USB-1SP4T-A18 switch matrix to its growing lineup of switch matrix test equipment. This new unit covers a wide frequency band from DC to 18 GHz and is useable for most test lab applications. A durable RF switch promises exceptional longevity of 100 million cycles and typical switching time of 25 milliseconds. Extremely low insertion loss (0.2 dB typical) and high on/off isolation (85 dB typical) make the USB-1SP4T-A18 a versatile, high-performing, and economical solution for a wide variety of RF applications.

The USB-1SP4T-A18 is packaged in a rugged metal casing small enough to fit in a brief case with room to spare. It is configured with five SMA(F) connectors (COM, 1, 2, 3 and 4), a 2.1 mm DC socket and a USB type B control port. Switch position is clearly indicated both on the control screen with a simple schematic and on the device itself with green light "on-position" indicator located on the front panel adjacent to each of the output ports. Like all Mini-Circuits portable test tools, the USB-1SP4T-A18 is supplied with easy-to-install, easy-to-use GUI software with an API DLL com object. USB-1SP4T-A18 switch matrices are available off-the-shelf for immediate delivery at an outstanding value.

Mini-Circuits,
www.minicircuits.com.

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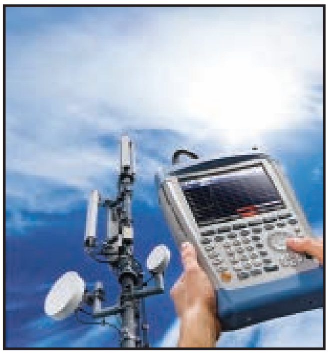
COMPANY SHOWCASE

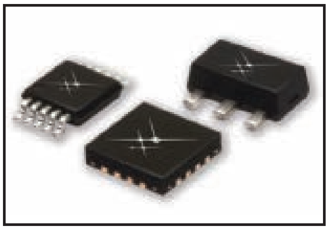


Test Solutions

VENDORVIEW

Rohde & Schwarz is the only test equipment vendor to provide solutions for the entire lifecycle of a mobile network; from planning and installation to optimization and operation. This approach enables operators to ensure the performance of their network. At Mobile World Congress 2014 Rohde & Schwarz and its subsidiaries SwissQual and ipoque will be exhibiting solutions for all network phases. Visit booth B50 in hall 6 to learn more about this integrated set of test solutions.

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



Discrete and Integrated RF Solutions

VENDORVIEW

Skyworks Solutions Inc. is an innovator of high performance analog semiconductors. Leveraging core technologies, Skyworks supports automotive, broadband, cellular infrastructure, energy management, GPS, industrial, medical, military, wireless networking, smartphone and tablet applications. Visit the company at GSMA Mobile World Congress to learn more about its broad product portfolio of highly integrated front end solutions as well as discrete components for mobile platforms including smartphones, tablets, data cards and GPS systems.

Skyworks Inc.,
www.skyworks.com.

Mobile Communication Portfolio

SPINNER is a global leader in developing and manufacturing state-of-the-art RF components. The company's mobile communication portfolio, which includes jumper cables, surge protectors, and diplexers, supports all major communications networks worldwide, such as LTE, WiMAX, UMTS, GSM, GSM-R, TETRA. It provides all passive components between base station and antenna. The portfolio delivers innovative solutions and systems for multiple uses by outdoor and indoor antennas and is internationally registered with all major system houses and network operators.

SPINNER GmbH,
www.spinner-group.com.

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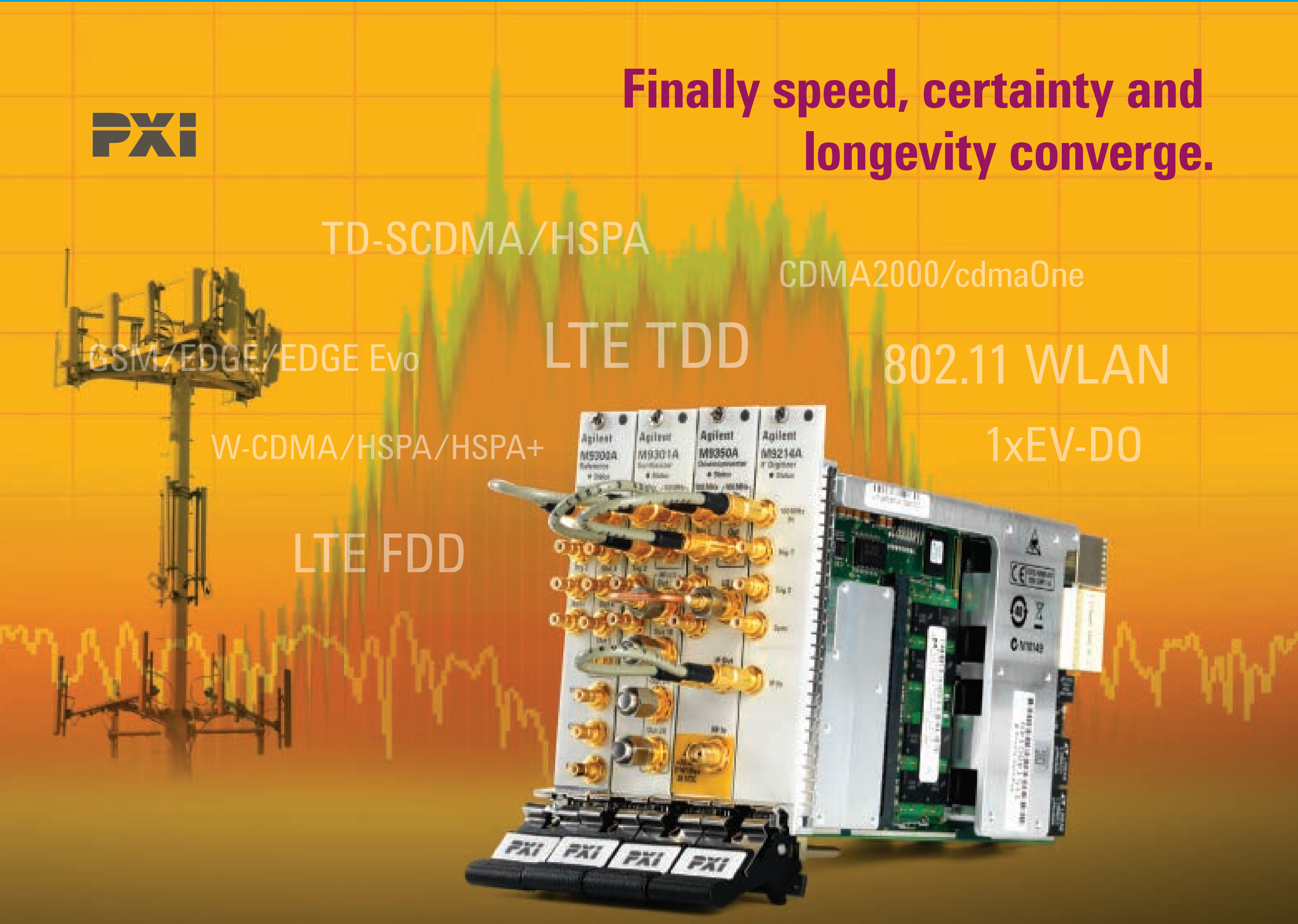

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