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November 2011

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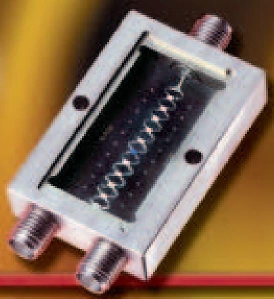

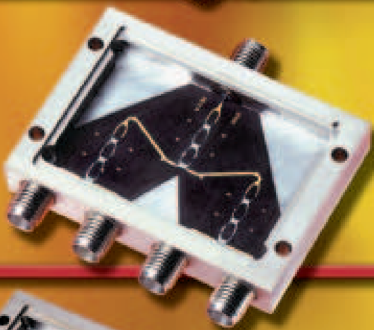

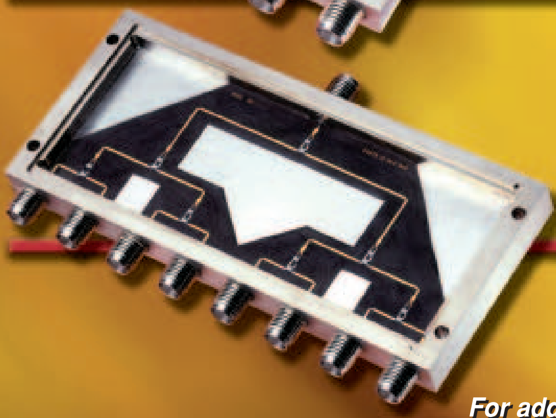

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Output VSWR	Ratio		1.7
Phase unbalance	Degrees		±5.0
Amplitude balance	dB		±0.5
4 Way Power Divider - Model PD04-18004000			
RF frequency range	GHz	18	40
Insertion loss	dB		2.5
Isolation	dB	17	
Input VSWR	Ratio		1.8
Output VSWR	Ratio		1.7
Phase unbalance	Degrees		±5.0
Amplitude balance	dB		±0.5
8 Way Power Divider - Model PD08-18004000			
RF frequency range	GHz	18	40
Insertion loss	dB		3.5
Isolation	dB	17	
Input VSWR	Ratio		1.8
Output VSWR	Ratio		1.7
Phase unbalance	Degrees		±5.0
Amplitude balance	dB		±0.5

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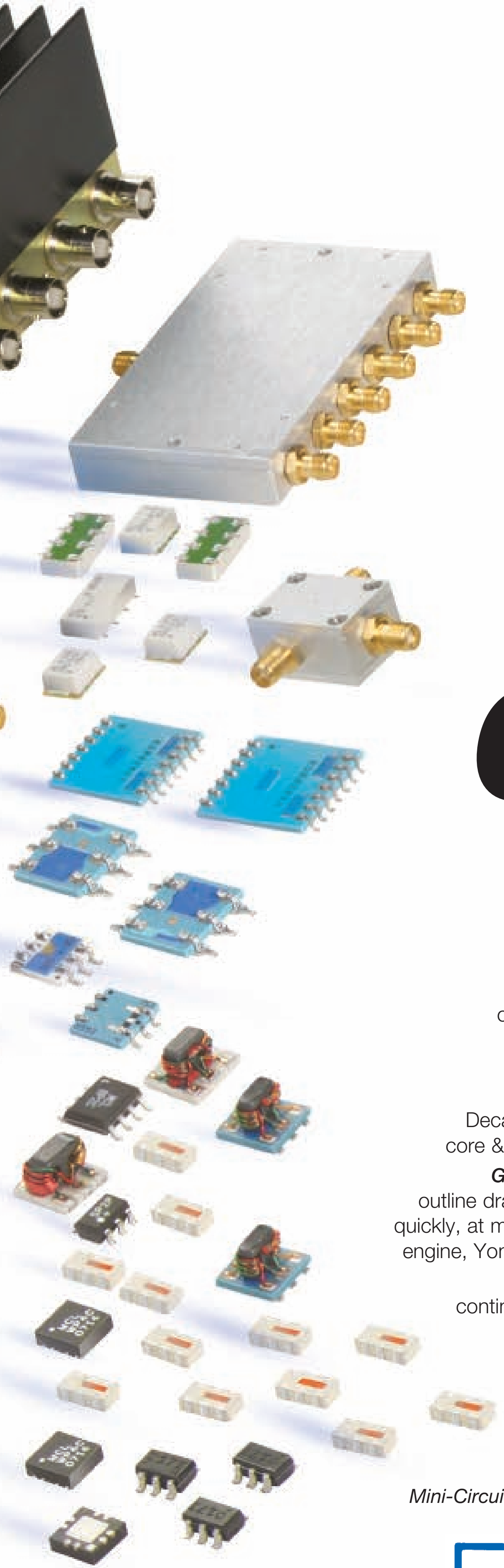


NOVEMBER 2011 VOL. 54 • NO. 11

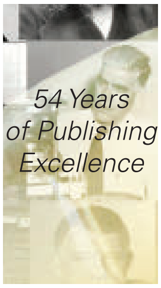
FEATURES

COVER FEATURE

MVP

PERSPECTIVE

TECHNICAL FEATURES



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Choosing the Right RF Switches for Smart Mobile Device Applications
White Paper, Skyworks

Dual Phononic and Photonic Band Gaps in a Periodic Array of Pillars Deposited on a Membrane
Presented by COMSOL

RFID Objects Monitoring in Space Bounded by Metallic Walls
White Paper, Scientific and Technical Center

Addressing Traffic and Channel Power Distributions in 3G Networks
White Paper, ISCO

Executive Interview

Wolfgang Damm, Director of Product Marketing at **Wireless Telecom**, the parent company of the Noisecom, Boonton Electronics and Microlab, talks about the military and commercial test markets and the direction of his company's product development.

Event Coverage

Pat Hindle, Technical Editor, *Microwave Journal*, will be reporting live from the MILCOM and AOC events, with blogs, Twitter and online news.

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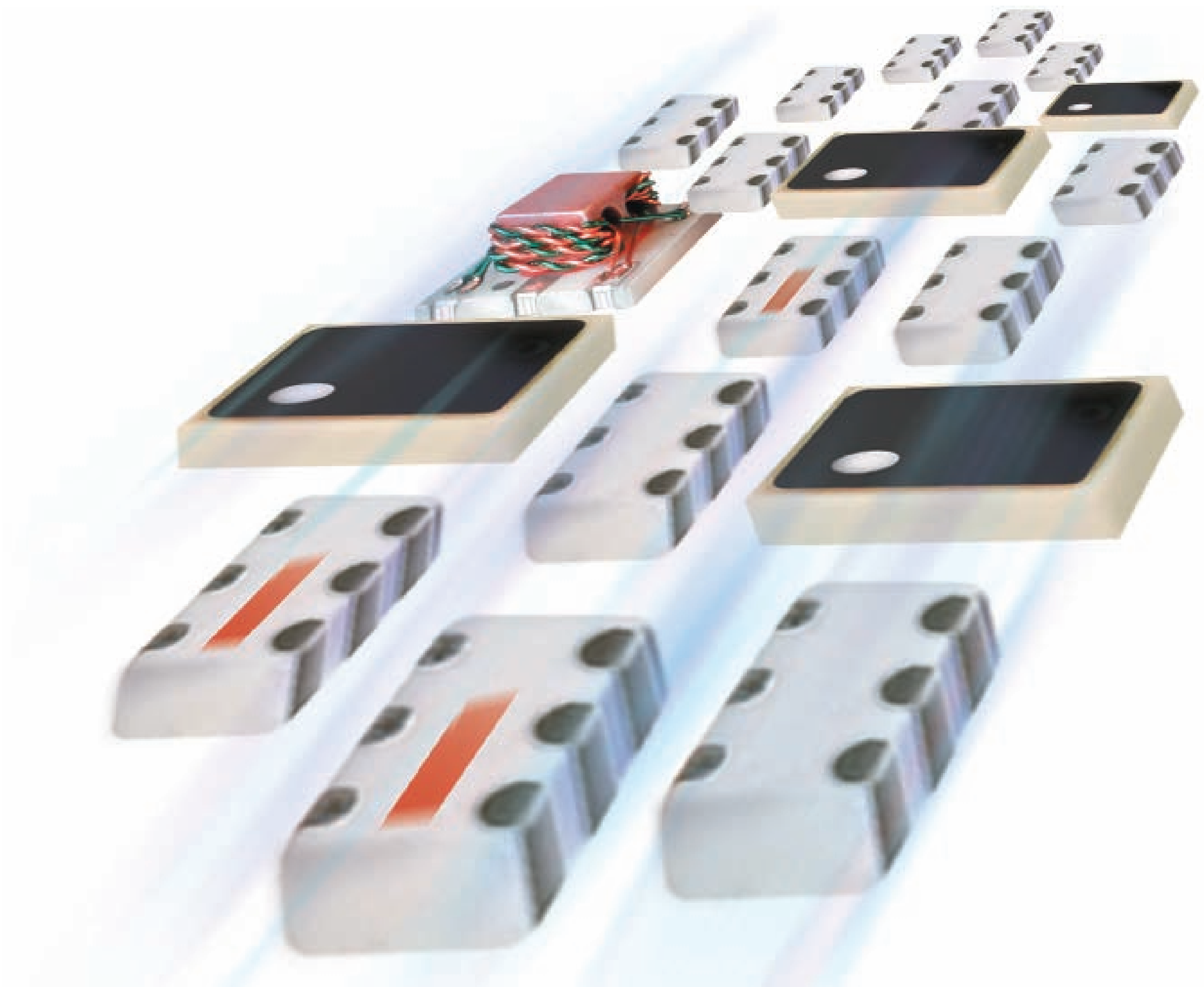

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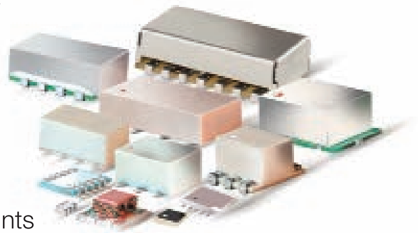

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DECEMBER 2011

Divine Innovations

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
27	28	29	30	1 **Webinar: PCB and Package Co/design and Co/optimization** (CST)	2	3
4	5 **Call for Papers Deadline** (International Microwave Symposium)	6 The Asia Pacific MICROWAVE CONFERENCE, APMC 2011 Melbourne, Melbourne, 5 - 8 December, 2011	7	8	9	10
11	12	13	14	15	16	17
18	19	20 **MWJ Besser Webinar: Radio Communications** Sponsored by AWR, Tektronix	21	22	23	24
25	26	27	28	29	30	31 **Call for Papers Deadline** (ARFTG)

Next month: Radio Wireless Week
January 15-19, 2012
Santa Clara, CA

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IMS 2012
Deadline: December 5, 2011
ARFTG 2012
Deadline: December 31, 2011
WAMICON 2012
Deadline: January 9, 2012
ICMMT 2012
Deadline: January 10, 2012

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NOVEMBER

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48th Annual AOC International Symposium and Convention
November 13–16, 2011 • Washington, DC
www.crows.org

ARMMS RF and Microwave Conference
November 21–22, 2011
Corby, Northamptonshire, UK
www.armms.org

78th ARFTG Microwave Measurement Conference
November 29–December 2, 2011 • Tempe, AZ
www.arftg.org

1st WIMA NFC USA
November 30–December 1, 2011
San Francisco, CA
www.wima.mc/2011usa

DECEMBER

APMC 2011
Asia Pacific Microwave Conference
December 5–8, 2011 • Melbourne, Australia
www.apmc2011.com

JANUARY

IEEE RWS 2012
Radio and Wireless Symposium
January 15–19, 2012 • Santa Clara, CA
www.rawcon.org

IEEE MEMS 2012
International Conference on Micro Electro Mechanical Systems
January 29–February 2, 2012 • Paris, France
www.mems2012.org

FEBRUARY

NATE 2012 Conference & Exposition
National Association of Tower Erectors
February 6–9, 2012 • San Antonio, TX
www.natehome.com

ISSCC 2012
IEEE International Solid-State Circuits
February 19–23, 2012 • San Francisco, CA
www.isscc.org

IWCE 2012
International Wireless Communications Expo
February 20–24, 2012 • Las Vegas, NV
www.iwceexpo.com

MWC 2012
Mobile World Congress
February 27–March 1, 2012
Barcelona, Spain
www.mobileworldcongress.com

MARCH

SATELLITE 2012
March 12–15, 2012 • Washington, DC
www.satellitetoday.com/satellite2012/

ISQED Symposium 2012
13th Annual International Symposium on Quality Electronic Design
March 19–20, 2012 • Santa Clara, CA
www.isqed.org

APRIL

ACES 2012
28th Annual International Review of Progress in Applied Computational Electromagnetics
April 10–14, 2012 • Columbus, OH
http://aces.ee.olemiss.edu/

WAMICON 2012
IEEE Wireless and Microwave Technology Conference
April 16–17, 2012 • Cocoa Beach, FL
www.wamicon.org

MAY

ICMMT 2012
International Conference on Microwave and Millimeter wave Technology
MWIE 2012
Microwave Wireless Industry exhibition In China
May 5–8, 2012 • Shenzhen, China
www.cnmw.org

CTIA WIRELESS 2012
May 8–10, 2012 • New Orleans, LA
www.ctiawireless.com

JUNE

IMS 2012
IEEE MTT-S International Microwave Symposium
June 17–22, 2012 • Montreal, Canada
www.ims2012.org

RFIC 2012
IEEE Radio Frequency Integrated Circuits Symposium
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www.rfic2012.org

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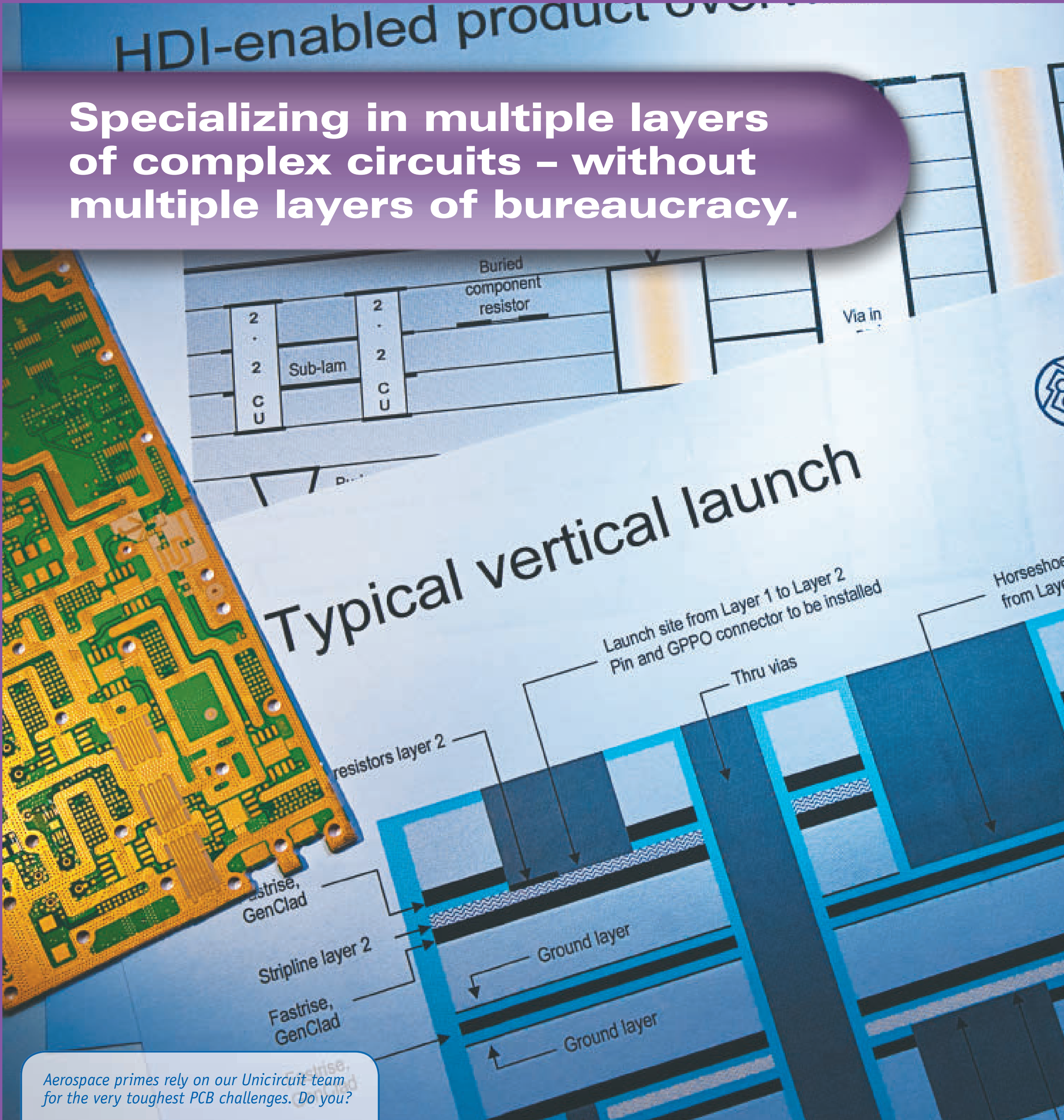

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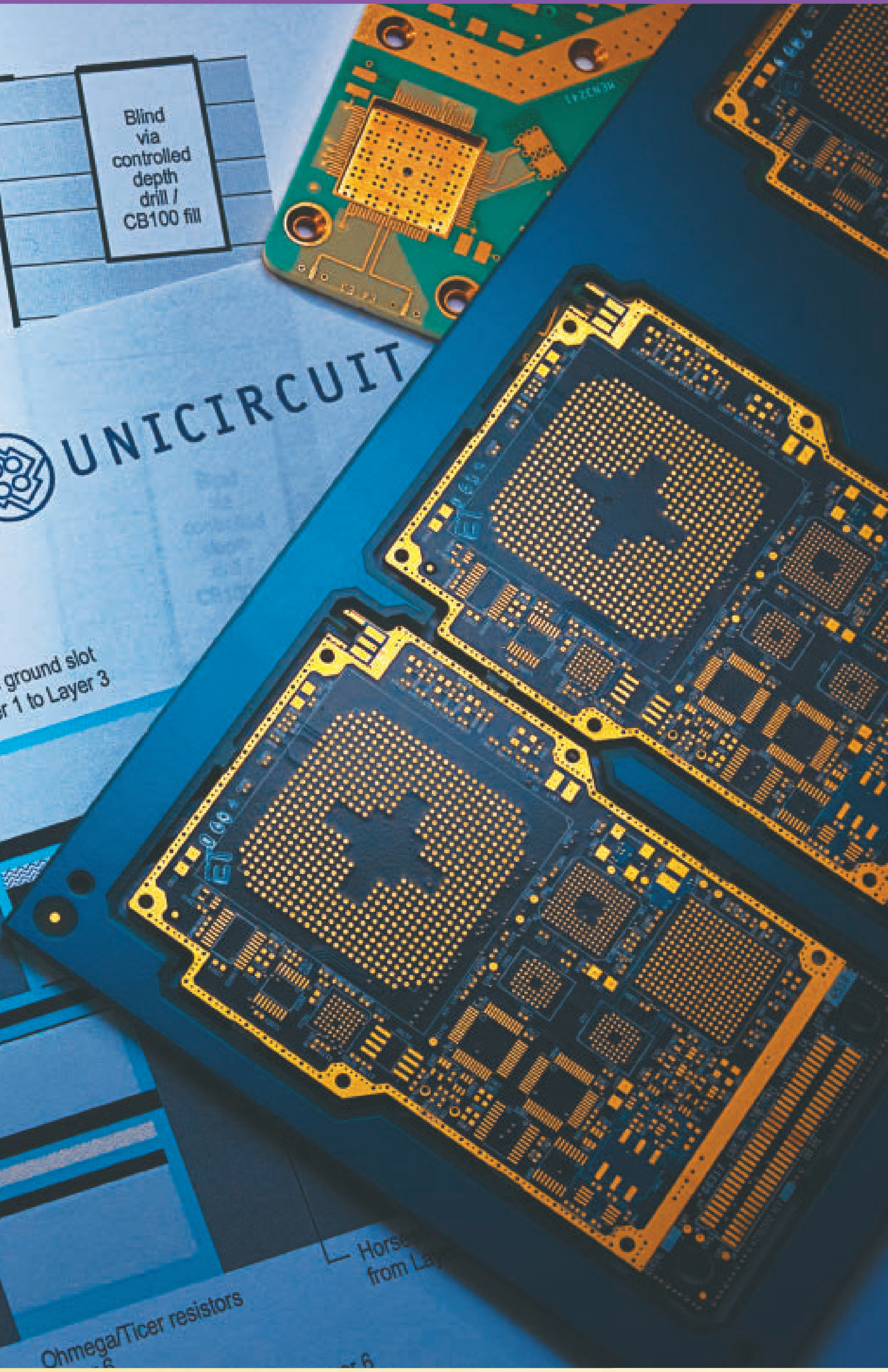

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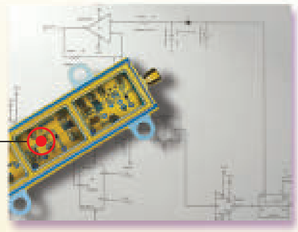

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Cover Feature

Divine Innovation: 10 Technologies Changing the Future of Passive and Control Components

In "The Innovator's Dilemma" (1997), Clayton Christensen, Professor of Business Administration at the Harvard Business School, coined the term "disruptive technology" to describe innovation that changes the fundamentals of an existing market and related value network through displacement of an entrenched technology. Although the phrase connotes an abrupt transition, the innovation itself often takes years to develop and be adopted.

Christensen described a process by which a product or service initially took root in simple applications at the bottom of a market and then relentlessly moved "up market," eventually displacing established competitors. In contrast, he defined "sustaining innovation" as a continuous evolution of an existing technology by the established market leaders to remain competitive. This type of innovation does not necessarily create new markets, but does have the ability to transform the market with better products and services. Yet it is the disruptive technology that drastically lowers prices, enables new functionality or alters product efficiency, desirability or competitive advantage to the extent that the market is changed forever.

Established companies in technology-driven markets recognize the need for continual technology development; yet many remain vulnerable to unforeseen market innovations. Unfortunately, in today's current business climate many companies are unwilling to redirect their scarce resources away from immediately profitable ventures for fear that they cannot afford to invest their R&D beyond sustaining innovations, such as those needed to compete against current competition. And yet, market leaders need to be on the alert for innovations occurring elsewhere in their industry, lest a game changing technology transforms the market and leaves them behind.

In "The HP Phenomenon" (2009), Charles House and Raymond Price tell the story of how Hewlett-Packard innovated and transformed itself six times. Continually prevailing over each challenge, the company came across along the way. Early on, David Packard observed that "change and conflict are the only real constants." As a result, HP developed internal philosophies, practices and organizational principles that led to a sequence of innovations and transformations, made possible through the company's customer-centered, contribution-driven, and growth-focused approach.

The "HP Way," with its emphasis on bottom-up innovation and the flexibility to see results brought to the marketplace, is a classic example of what is required to develop disruptive technologies. Perhaps HP's most drastic game

David Vye
Microwave Journal *Editor*

changer took place in the 1960s when the company was the start-up risk taker. During that time, test equipment utilizing HP's semiconductor technology was able to displace the tube-based test equipment manufactured by then-market leader General Radio (GenRad). From there, test equipment became highly automated through computer control and the market never looked back.

According to Christensen, a firm's existing value network(s) often places insufficient value on pursuing disruptive innovations. In contrast, start-up companies have a different set of value networks and operating costs, which allow them to take more risks and follow an alternative path of innovation, one that is not tied to an established method.

This risk taking approach to R&D was glorified in the "Think Different" advertising campaign from Apple Computer, coincidently in the same year "The Innovator's Dilemma" was published.

THE CRAZY ONES – APPLE'S "THINK DIFFERENT" AD CAMPAIGN

"Here's to the crazy ones. The misfits. The rebels. The troublemakers. The round pegs in the square holes.

The ones who see things differently. They're not fond of rules. And they have no respect for the status quo. You can quote them, disagree with them, glorify or vilify them.

About the only thing you can't do is ignore them. Because they change things. They invent. They imagine. They heal. They explore. They create. They inspire. They push the human race forward.

Maybe they have to be crazy.

How else can you stare at an empty canvas and see a work of art? Or sit in silence and hear a song that's never been written? Or gaze at a red planet and see a laboratory on wheels?

We make tools for these kinds of people.

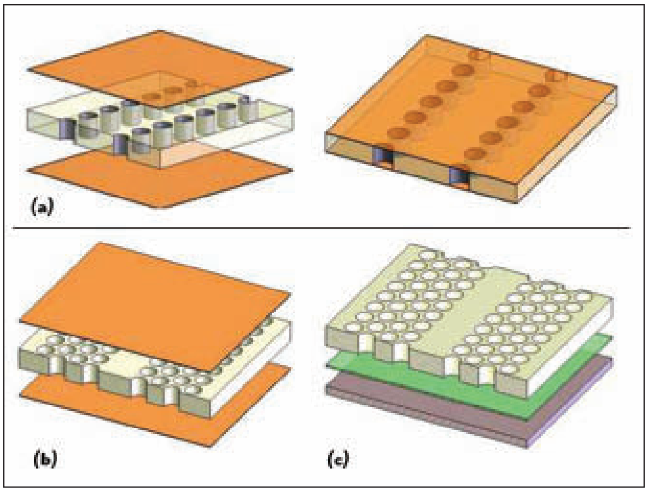
While some see them as the crazy ones, we see genius. Because the people who are crazy enough to think they can change the world, are the ones who do."

More than a decade later, Apple's iPhone played a significant role in establishing the Smartphone category and transforming the slumping mobile phone market (22 percent decline in US sales in 2008) into one of high growth and profitability. In this case, the disruptive technology was the phone itself - with its ergonomic and user-friendly look and feel, not to mention the cool factor. But the microwave technologists designing components for these handsets also needed to innovate to enable the multi-mode, multi-band radios inside these products.

For microwave companies building the passive and control components found in RF/mW front-ends, mobile devices and infrastructure, test equipment or Radar/EW systems, sustaining innovation is about improving insertion loss, filter selectivity, switching speeds, reliability, etc. in order to outperform their competitors. Additionally, the market demands manufacturers build smaller passive components with more integrated functionality. Miniaturization leads to greater circuit density, which in turn leads to an increase in parasitics and poorer electrical performance at high frequencies. To overcome this degradation, researchers are focusing their attention on new materials and novel structures. These research efforts target both printed circuit boards and semiconductors.

If Christensen is right, one could expect to find disruptive innovation coming from little known start-ups with a tolerance for risk or from radical larger firms, such as Apple and early HP – companies that have institutionalized a process for breaking the rules. Still, even Apple and HP innovations were initially linked to research from places such as Stanford, UC Berkeley and Xerox PARC.

Given the "bottom up" nature of disruptive technologies, anyone scanning the horizon for such developments needs to keep a close eye on published research and watch for its evolution toward productization. The following technologies are in different states of making this transformation. Whether any of them has the potential to disrupt the market remains to be seen.



▲ *Fig. 1 Examples of SIW construction showing metal (top/bottom) and dielectric layers along with via side walls.*

SUBSTRATE INTEGRATED WAVEGUIDES FOR GREATER POWER HANDLING AND LOWER LOSS

Substrate integrated waveguide (SIW) structures also known as laminated waveguide or post-wall waveguide have received some attention over the past several years. The construction offers easy fabrication while sharing comparable electrical and mechanical performances with conventional rectangular waveguide. This new family of transmission line and distributed planar waveguide component is formed by a dielectric substrate and densely arrayed metalized posts or via-holes that form side-walls connecting upper and lower metal plates, which sandwich the substrate material. The metal layers along with the array of metalized via-holes define the waveguide walls as shown in ***Figure 1***.

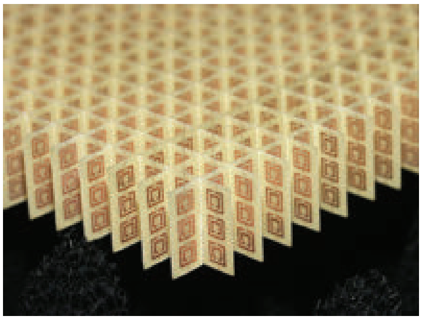
Developments in SIW technology target both multi-layer PCB and CMOS substrates and can be easily fabricated with through-hole techniques for low cost and mass-production. The post-wall waveguide is known to have similar guided wave and mode characteristics to conventional rectangular waveguide with equivalent guided wavelength. The resulting power handling capability and low loss performance of the SIW are much better than conventional transmission planar lines.

In the February *Microwave Journal* cover story, R. Holtzman of Elisra Electronic Systems (Israel) wrote that "one current area of research is substrate integrated waveguide (SIW) components. Using this technique, some of the alumina filters may be replaced by SIW filters." In a *Microwave Journal* article appearing last December, Y. Yun employed a periodically arrayed grounded-strip structure (PAGS) on silicon substrate to create an ultra-wideband, multi-section transformer using a Chebyshev polynomials design technique. At 0.026 m^2 on a silicon substrate, the resulting transformer was more than 90 percent smaller than the one fabricated using conventional coplanar waveguide and showed good RF performance over an ultra broadband from 8 to 49.5 GHz.[1]

High precision PCB manufacturing techniques including LTCC should support passive component design using SIW structures to extend up to the 100 GHz range while advanced micro-fabrication techniques, such as photo-imaging, micromachining, CMOS process, and others, have the potential to push design of substrate integrated structures up to the hundreds GHz and THz range.[2]

METAMATERIALS: MATERIALS UNBOUNDED OR WEIRD SCIENCE

Metamaterials are synthetic materials constructed from periodically



▲ *Fig. 2 Metamaterial formed by an array of complementary split ring resonators.*

arranged, resonant conductive sub-wavelength elements with specific inductive and capacitive characteristics (see ***Figure 2***). These structures manipulate the flow of electromagnetic energy in ways that cannot be achieved with naturally occurring substances. At microwave frequencies, they have demonstrated great promise in high performance beam steerers, modulators, bandpass filters, lenses, couplers and antenna systems. Planar metamaterials and metamaterial resonators are easily incorporated into microwave circuits and support passive component size reduction and the high integration densities required by mass-market wireless communications.

Metamaterials' greatest potential lies in its ability to create a structure with a negative refractive index. Most materials, whether they are a conductor or insulator, have positive permittivity and permeability values, resulting in an ordinary index of refraction. Metamaterials, however, are able to exhibit a state where both permittivity and permeability are negative, resulting in an extraordinary index of negative refraction. For plane waves propagating in electromagnetic metamaterials, the electric field, magnetic field and wave vector follow a left-hand rule.

In 2000, microwave frequency metamaterials from horizontal stacking of periodically placed split-ring resonators and thin wire structures was first demonstrated. In 2002, a method was developed to realize negative index metamaterials using artificial lumped-element loaded transmission lines in microstrip technology.[3] By 2006, metamaterials advanced the state of stealth technology when the first real invisibility cloak at microwave frequencies was realized.[4]

This past May, G. Jang and S. Kahng presented a metamaterial bandpass filter in *Microwave Journal*. In the design, an intermediate gap was used to provide capacitive coupling between neighboring zero-order resonators formed by half circular, mushroom-shaped cells. Along with an improvement in the stopband performance, a size reduction of more than half that of a conventional filter (based upon half-wavelength resonators) was achieved.

NANOTECHNOLOGY: THE PATH TO HIGHER CIRCUIT DENSITIES

Nanotechnology is expected to be an enabling technology for many of the new electronic devices and circuits, including those for communication, sensors, imaging and advanced medical applications. Nanoelectronic materials and devices, such as carbon nanotubes, graphene, spin-flip electronic devices and superconducting quantum interference devices, are expected to offer higher integration densities and substantially improved microwave properties. The field of nanotechnology is quite broad.

For instance, with its high carrier mobility and saturation velocity, attention is being focused on the development of graphene-based transistors for RF applications. Synthesis of large-scale graphene sheets of high quality and low cost has been demonstrated using chemical vapor deposition (CVD). Using this manufacturing technology, Scientists at IBM have managed to create a graphene transistor that operates at 155 GHz. The carbon-based graphene transistor was developed together with DARPA to be used in radio frequency technology and reach extreme clock frequencies through its molecular characteristics where the hexagonal pattern makes it possible for electrons to move at incredible speeds.

At the University of Southern Florida, magneto-dielectric polymer nanocomposites are being investigat-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ed as a new class of functional materials for use in RF and microwave applications. Magnetite (FE_3O_4) nanoparticles homogeneously dispersed in a polymer matrix were shown to exhibit low loss at microwave frequencies. The mono-dispersion of the magnetic nanoparticles, with sub-10 nm diameters and tight size distribution, enhanced the microwave properties of the engineered composite material by increasing the relative permeability and relative permittivity. Moreover, complex permeability and permittivity of the nanocomposite material can be tuned by an externally applied DC magnetic field.

HIGH PERMEABILITY FERROMAGNETIC THIN-FILMS TO SUPPRESS SKIN EFFECT IN ON-CHIP CONDUCTORS

At the EuMIC conference, researchers from Japan and Germany presented an overview of RF high permeability ferromagnetic thin films applied to a new ferromagnetic/conductive multi-layer to suppress skin effect in RF on-chip conductors. The combined multi-layer structure has certain properties that are attractive for designing inductive passive components.

At sufficiently high frequencies, the negative permeability of the ferromagnetic films effectively compensates the positive permeability of the nonmagnetic metal layers, leading to an overall suppression of the skin effect. Addressing the increased resistance due to skin effects, researchers believe the multi-layered structure of metal/magnetic thin film will improve the performance of any on-chip conductor, including transmission lines, integrated inductors and antennas in order to realize high-Q and energy-saving systems. Available in various forms, including sputter-deposited metallic alloy, traditional oxides and nano-composites, application trials are ongoing for CMOS integrated inductors, one-chip DC-DC converters and on-chip noise suppression for LTE-era RFIC receivers.

DESIGNING HIGH Q PASSIVES IN LIQUID CRYSTAL POLYMERS

Liquid Crystal Polymer (LCP) is a fairly new thermoplastic organic material that offers both low loss and dielectric stability (2.9 at 5.8 GHz) from DC to 110 GHz. LCP has a permittivity value that is particularly well suited for antenna systems because the material naturally prohibits the excitation of surface waves. LCP is also conformal (in thin film form, it is as flexible as paper), so it can be rolled into a cylindrical shape, packed into a rocket payload and launched into space or deployed as an antenna array on the battlefield. Multi-layer LCP devices can be made with a low melting temperature, which gives it a key advantage over other packaging materials. When the footprint size must be minimized, a multi-layer LCP can be used as a combination substrate and packaging material, making it a useful medium for System-on-package and embedded designs.[5]

LCP is excellent material for designing high Q spiral inductors with quality factors as high as 90 at X-Band for inductance values ranging from 2 to 5 nH. Presentations on high-Q, miniaturized LCP-based passive components and filter design for SoP applications and high-Q multi-layer LCP were presented at this year's European Microwave Week.

In addition, research at UC Davis has recently focused on the development of sealing techniques of LCP onto LCP and LCP onto semiconductor materials to form near hermetic cavities for housing MEMS and MMICs. Using the newly developed sealing techniques, LCP wafer-level packages, surface-mount packages and multi-chip modules to 40 GHz have been realized.

These surface-mount packages were designed with novel feed-through interconnects that achieved a measured insertion loss of ~0.2 to 0.4 dB up to 40 GHz and included embedded filters. Reliability evaluation of the LCP packages included environmental testing at 1000 hours of 85°C and 85 percent humidity as well as temperature cycling and thermal shock testing.[6]

wireless infrastructure markets such as point-to-point radio

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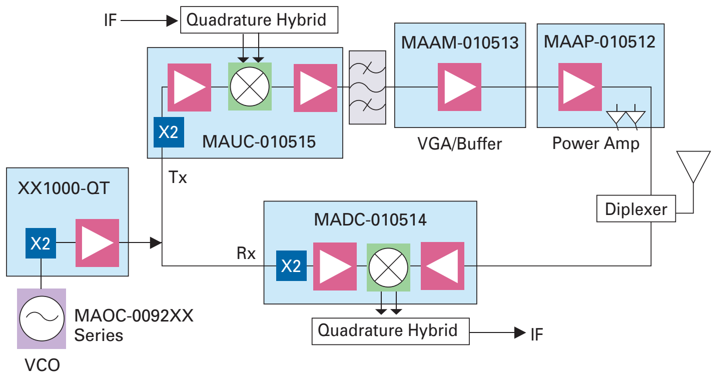

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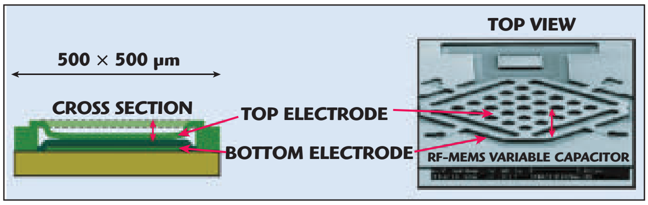
ANTENNA TUNING WITH ADAPTIVE IMPEDANCE RF MEMS MODULES

Disruption is all well and good when a company is creating a new smartphone category, but Apple had a problem on its hands when its iPhone's antenna reception experienced disruption in the hands of its customers. The output power and radiation efficiency of a mobile phone with a compact narrow-band antenna can be greatly degraded by large mismatches resulting from the user's hand position. Phone manufacturers study the impact using over-the-air testing with the actual phone placed in various positions against hand and head models. Testing all possible hand/head positions is not practical, so over-the-air testing is limited in its ability to detect potential failures. Since multi-mode, multiband phones with densely packed radios and future MIMO antennas will only make next generation designs even more problematic, antennas need to be less sensitive to their environment.



▲ *Fig. 3 A single capacitive RF MEMS switch with quality factor of 250 at 1 GHz.*

Microwave Journal Technical Editor Pat Hindle discussed recent work with adaptive antenna tuners in "MEMS Tuner Modules Could Solve Handset Reception Problems" (January 2011). These modules dynamically change antenna impedance using a feedback controller so it is always tuned for maximum efficiency. In these modules, a detector measures the transmitted RF signal and an algorithm derives the mismatch information from the phase of the matched input impedance and calculates any necessary changes for the adaptive matching circuit.

A simple series-connected LC matching network compensates the complex component in the antenna impedance variations. A DC-DC controller forces the change in the impedance matching by varying the voltages applied to a varactor in the LC network. This process is repeated until the desired impedance has been reached. TDK-EPC and WiSpry are two companies developing this technology using tunable RF MEMS devices to switch the loading circuit between different valued capacitors in an array.

The module from TDK-EPC uses a binary weighted 5 bit RF MEMS array of electro-statically variable capacitive RF MEMS switches is shown in **Figure 3**. A high voltage driver generates the MEMS bias voltages. It supports all common frequency bands

from 824 to 2170 MHz in a module size of 5 × 5 × 1 mm. RF MEMS offer several distinct advantages over competing varactor technologies, especially linearity and power stability. A single capacitive RF MEMS switch has a Q factor of up to 250 at 1 GHz – three to five times greater than competing technologies – as well as a large tuning range of 10:1.

Earlier this year, WiSpry announced a partnership with IBM to develop single-chip tunable RF front-ends for mobile handsets, which the company has begun marketing to tier-one original equipment manufacturers. WiSpry's tunable RF MEMS technology, shown in ***Figure 4***, also uses arrays of capacitive devices that can provide more than 3 dB of link resiliency. WiSpry reports similar results as TDK-EPC, including a broadband tuning range of 10:1, +3 to +6 dB of transducer gain and overall efficiency gains of 30 percent or more, depending on the implementation within the handset. WiSpry's standard RF CMOS manufacturing process through the IBM foundry supports integration of RF MEMS devices on active CMOS, setting the stage for future tunable SoCs.

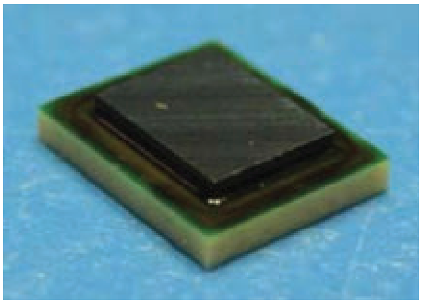
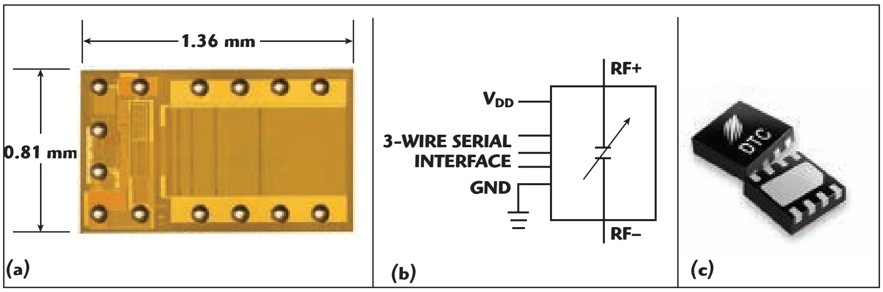


Fig. 4 WiSpry's fully integrated tunable impedance matching (TIM) solution (3.5 × 4.0 mm).

MOSFET SWITCHED CAPACITOR IMPEDANCE TUNING

The downside of tunable impedance networks based on voltage variable capacitors and MEMs switched capacitor banks is that both of these options require 30 to 40 V for operation, which is difficult to produce in a handset. Peregrine Semiconductor is now offering an alternative solution based on MOSFET switched capacitors that permit higher frequency operation, faster switching and higher Q. The company's DuNE technology has yielded a digitally tunable capacitor (DTC) chip that contains five capacitors switched by MOSFETs operating from a serial input bus with a 5-bit code providing 32 possible capacitor values.

Making a big debut at this year's MTT-S IMS, Peregrine's DuNE chips offer capacitor values ranging from 0.5 to 10 pF with typical tuning ratios of 3:1 to 6:1, or 10:1 in some cases. Typical switching speed is less than 5 µs. Capacitor Qs greater than 100 are possible. The frequency range is up to 3 GHz, and power handling is up to 40 dBm. The chip operates with a supply voltage of 2.4 to 3 V with current consumption in the 20 to 100 µA range (see ***Figure 5***).



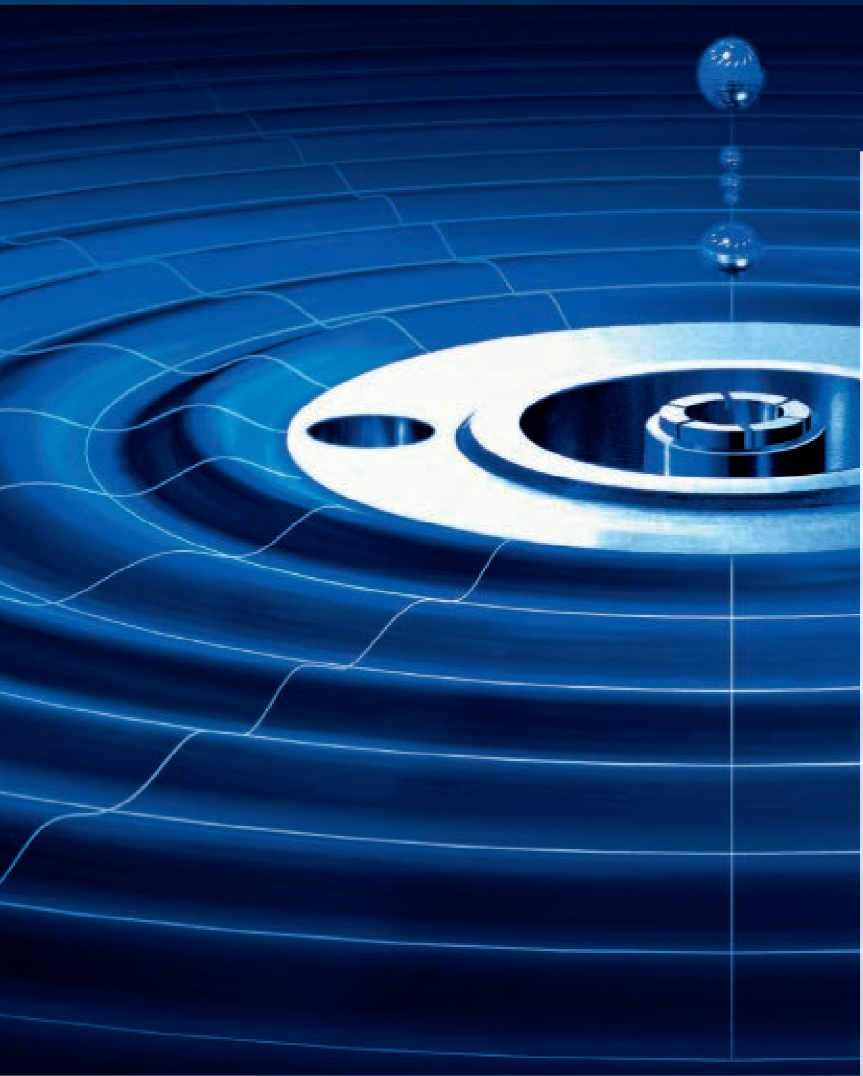
▲ *Fig. 5 View of chip (a) component schematic (b) and packaged Digitally Tunable Capacitors from Peregrine Semiconductor (c).*

One or more of the devices can be used in an L, T, or π network for matching purposes. The chip can be used in an open-loop fashion with input control from a lookup table or in a closed-loop adaptive tuning network. The closed-loop system uses a directional coupler to sense forward and reflective power. A tuning algorithm is implemented to provide automatic adjustment to bring the VSWR to its lowest possible value. Among the potential applications, Peregrine is promoting the technology for use in mobile TV receivers that must operate over wide frequency ranges. For example, the European DVB-H and Japanese ISDB-T mobile TV systems commonly operate in the 470 to 862 MHz range, creating a massive detuning problem with channel selection.

SWITCHING HIGH POWER RF APPLICATION WITH GaN

PIN diodes and GaAs FETs are two widely used technologies in RF switching applications. While FETs offer low insertion loss and high switching speed with minimal DC-bias power requirements, the short source-drain separation required for operating at microwave frequencies leads to the low breakdown voltages, which, in turn, limits their power-handling capability, typically in the range of a few watts. While switches based on PIN diodes have a much higher power handling capability, they consume more DC power and typically require a larger circuit footprint area to incorporate the passive components and multiple diodes that make up their non-integrated design.

GaN switches on the other hand, offer high electric field strength for significantly improved power handling capability along with the size and cost benefits that come with integration into standard MMIC architectures. A couple of GaN suppliers have started to release switch products to the market. TriQuint has developed three broadband GaN on SiC MMIC



switches to cover frequency ranges of DC to 6, DC to 12 and DC to 18 GHz. These devices have maximum insertion loss of 0.7, 1.0 and less than 1.5 dB, and demonstrate 40, 20 and 10 W RF power handling, respectively, for 6, 12 and 18 GHz designs. Switching speeds are below 25 ns and the isolation is greater than 30 or 35 dB depending on the device (for more information, see TriQuint's product feature article in this issue, page 132).

TriQuint's GaN process yields a breakdown voltage of 70 V DC compared to about 13 V DC for GaAs and can handle current of more than 1 A/mm of device area versus 650 mA/mm for GaAs. The high thermal conductivity of the insulating SiC substrate reduces leakage caused by high RF voltage swing while also improving heat transfer to the back of the device, which is useful in radar, EW and high power communication systems.

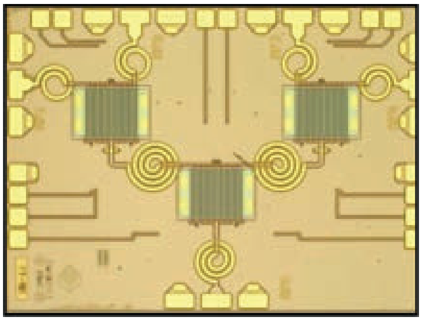


Fig. 6 SPDT GaN switch from Cree.

At this year's Compound Semiconductor Manufacturing Conference (CS Mantech), Cree presented results for a 25 W, 0.1 to 3 GHz SPDT GaN MMIC switch featuring less than 0.7 dB insertion loss, 15 ns switching speed, over 30 dB isolation and a TOI over 60 dBm, see ***Figure 6***. And at EuMW, researchers from Fujitsu in collaboration with the Japan Ministry of Defense, presented a 200 W+ high isolation GaN switch for L-Band Radar, indicating that GaN switches are well poised for adoption into numerous applications calling for high power switches with lower current consumption.

MULTI-MODE RF FILTERS SAVE SPACE

High selectivity, group delay flatness, power handling, insertion loss, weight and volume constraints are among the stringent requirements for today's microwave filter. As a result, many technologies and physical configurations have been introduced to satisfy various performance criteria over a range of applications. New filter configurations, such as single and dual-mode filters with elliptic function responses, have been developed. Combined with new high dielectric constant materials with a high quality factor and low temperature coefficient, these filters have the advantages of low loss, smaller size and superior temperature stability.

With the deployment of micro base stations, including remote radio head (RRH) systems, and the overlay of multiple frequency bands for multiple

standards on a single cellular site, the space available for the RF hardware is decreasing. RF filters typically occupy a significant fraction of the base station volume, so base station manufacturers are looking for filter technologies that offer size and cost reduction, while still meeting the stringent base station RF specifications of insertion loss, rejection and power handling.

One such example is the "Black Hole Filter (BHF)" from KMW, which claims to be the first commercialized use of "Triple-Mode" technology, providing high stopband attenuation with low passband insertion loss in a relatively small package. The company's innovative approach to "Triple-Mode" technology enables three distinctive resonances with only one resonant cavity, utilizing a dielectric resonator with high Q value inside the single pocket. Compared to conventional dielectric resonator filters, the triple mode "Black Hole Filter" offers very low insertion loss and high attenuation with a significant size reduction. Inside the pocket, waves can travel without bending and distortion, achieving the highest possible Q and steepest band-edge skirts seen in a single-pocket filter.

Whereas conventional single-mode filters may provide only a single resonance mode in the single pocket, the triple-mode filter generates three distinctive resonances using the same TE$_{01\delta}$ mode as the single-mode filter. It also enables two additional TE$_{01\delta}$ modes allowing the single cavity to function as three cavities, which improves the performance and lowers the manufacturing cost. The single-mode filter with eight resonators can be replaced by the triple-mode filter comprised of only two resonators while achieving the same performance, occupying less than a third of the size of the conventional cavity filter.

VERY-HIGH-Q SOLENOID RF INDUCTORS OFFER BETTER PERFORMANCE ON A VARIETY OF SUBSTRATES

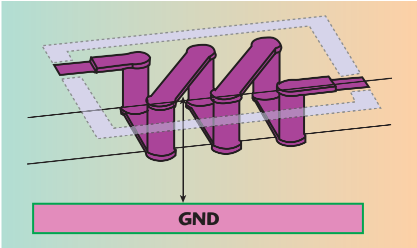
Inductors and resonators are essential passive components used in the design of most RF circuits, especially oscillators and filters. As such, they have a great impact on the performance and physical size of these circuits. Distributed components require considerable real-estate and, like planar spiral inductors, they may limit circuit performance with a low quality factor. A number of research efforts have focused on redefining the structure and shape of the RF inductor using via interconnects to synthesize solenoids that offer high Q and can be manufactured on many different substrates.

At IMS in Baltimore, researchers from École de Technologie Supérieure in Montréal and Robert Aigner, Director of R&D Acoustic Technologies at TriQuint, presented their work on very-high Q solenoid RF inductors. Targeting SiP LTCC integration, this team produced a compact high-Q three-dimensional inductor topology that achieved a quality factor of 75

and high self-resonance frequency (SRF 4.5 GHz) with inductance-values ranging from 2 to 7 nH at 2 GHz. In the same workshop, a team from University of Alabama in Huntsville presented a high Q tuned resonator based on a two-turn solenoid and embedded capacitor fabricated on RT/Duroid 5880, shown in ***Figure 7***. Measured results showed a quality factor over 300 at 12.25 GHz.

These structures are not restricted to LTCC or multi-layer PCBs. In 2001, Georgia Institute of Technology researchers first reported a fabrication process for high Q solenoid inductors on top of 0.24 μm CMOS technology using surface micro-machined, epoxy-embedded electroplated structures. The six-turn inductor yielded a peak Q-factor of 20.5 at 4.5 GHz and an inductance of 2.6 nH.[7] By 2007, a low temperature, two step copper-plating process fully compatible with CMOS technology was used to fabricate solenoid inductors with Q-factors as high as 87 at 14.5 GHz and 35 at 6.4 GHz.[8]

The increased number of metal layers available in today's CMOS processes will support the development of compact, high quality on-chip vertical solenoid inductors that will continuously reduce the inductor area while increasing the Q and self-resonant frequency (SRF). At this year's RFIC conference at IMS, researchers from Renesas Electronics reported very small on-chip vertically coiled solenoid inductors (V-solenoid) with measured self-resonance frequencies higher than 40 GHz using 90 nm CMOS multilevel interconnect technology.



▲ *Fig. 7 HFSS model of high Q resonator constructed with planar solenoid inductor with embedded capacitor.*

Are any of these 10 technologies the next big thing for drastically enhancing the performance of passive and control components? Some technologies tend to linger as a perennial favorite of researchers, never quite making it outside the R&D lab. Others slowly work their way into the next generation of products. Modest innovation will only buy so much time in the effort to stay ahead of competition. Eventually, new technologies will disrupt the status quo. Want to really get ahead of the pack? Think different, go crazy.

In Memory of Steve Jobs, 1955-2011 ■

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Frequency Range (MHz)	*Small Signal Gain (dB)*	*Output IP3 (dBm)*	*P1dB (dBm)*	*Noise Figure (dB)*	*V_{CC} (V)*	*I_{CCQ} (mA)*	*Package*	*Part Number*
150 to 960	18.0	49.0	36.7	5.0	7	650	SOIC-8	RFPA3800
700 to 2700	23.5	50.0	33.5	4.0	5	880	QFN	RFPA3806
400 to 2700	15.8	43.0	25.0	3.5	5	90	SOIC-8	RFPA3807
400 to 2700	17.0	49.0	29.0	3.9	5	275	SOIC-8	RFPA3809
400 to 2700	19.5	43.0	27.5	2.8	5	155	SOT-89	RFPA2189
400 to 2700	16.3	43.0	25.0	3.0	5	100	DFN	RFPA1012
400 to 2700	15.7	41.5	27.0	3.8	5	165	QFN	RFPA2013

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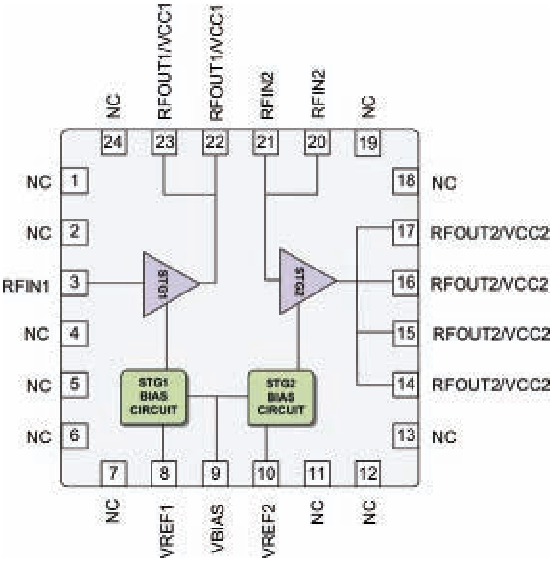

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The new, innovative internal architecture of the analyzer is claimed to deliver RF performance not previously possible in high end analyzers. For example, the first intermediate frequency (IF) of about 9 GHz allows image suppression up to 8 GHz without a YIG preselector. Traditionally, this frequency limit has been 3 to 4 GHz. The advantage is a very flat, stable, reproducible frequency response up to 8 GHz, which results in an absolute level accuracy of < 0.4 dB. This is especially significant for wireless applications in the 5 GHz bands, e.g. WLAN IEEE 802.11a/n/ac.

In addition, the R&S FSW uses different signal paths depending on the RF frequency. From 2 Hz to 30 or 40 MHz (depending on the resolution bandwidth used), the input signal is directly digitized by the 200 MHz, 16 bit A/D converter. Excellent sensitivity and a dynamic range down to the lowest frequency are the result.

The frequency range up to 1 GHz uses 1.31 GHz as the first IF. Due to the low first IF, a low frequency local oscillator and low frequency mixer with a very high dynamic range can be used. This results in a high third order intercept point of 30 dBm and very low phase noise. This makes the analyzer very powerful for this frequency band, which is of interest for many applications, such as professional and private mobile communications.

MICROWAVE FREQUENCIES

In the frequency range up to 8 GHz or the microwave range up to 26.5 GHz, where a YIG preselector is used, the R&S FSW offers a very high dynamic range up to microwave frequencies. At 20 GHz, with preamplifier, for example, the result is a displayed average noise level (DANL) of -166 dBm (1 Hz). With noise compensation, it nearly reaches the thermal noise floor with -173 dBm (1 Hz). The instrument not only delivers very good sensitivity, it also handles high signal levels. For example, an adjacent channel leakage ratio (ACLR) of -88 dB for a 3G signal at 2 GHz says a lot about its dynamic range. This is especially important for manufacturers of mobile radio base stations.

The R&S FSW is believed to be the first analyzer to provide switched lowpass and bandpass filters in the RF frequency range for the measurement of harmonics. This is the most critical range, i.e. when measuring harmonics of mobile radio base stations or handsets. A second harmonic

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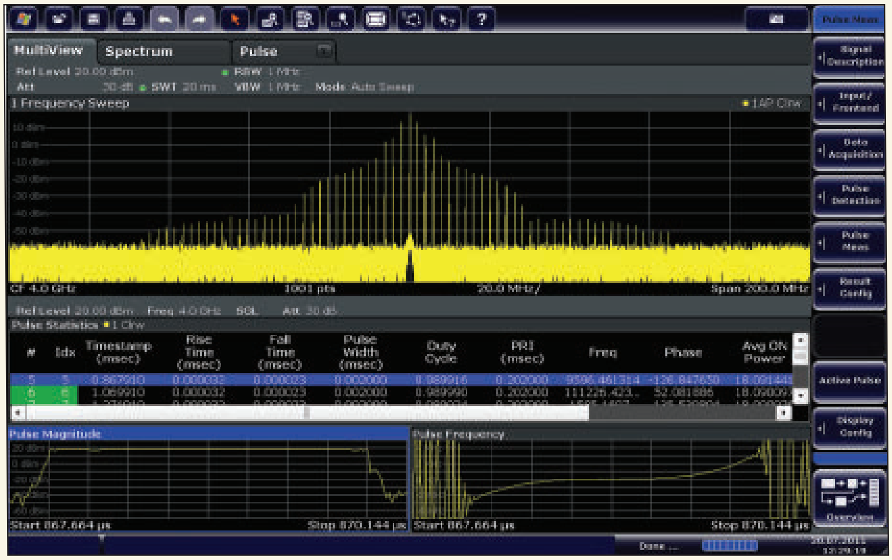
▲ *Fig. 1 A Flat menu structure and block diagrams make measurement setup an easy task.*



▲ *Fig. 2 Multiple measurements, such as spectrum analysis and special analysis of pulsed signals, can be displayed at the same time.*

intercept of 70 dBm eliminates the need for external filters with switch matrixes. The R&S FSW reduces cost and the customer no longer has to calibrate the setup with external signal paths.

Developers of oscillators, synthesizers and transmit systems benefit from the analyzer's excellent dynamic range when performing phase noise measurements. Thanks to the in-house YIG technology and the custom R&S synthesizer ASICs, the R&S FSW achieves a phase noise of -137 dBc (1 Hz) at 10 kHz offset from the carrier (for a 1 GHz carrier). With this performance, the instrument detects signals close to the carrier that previously could not be seen with a spectrum analyzer. It also delivers a previously unattainable dynamic range for adjacent channel power measurements in narrow bandwidth applications such as public mobile radio.

WIDEBAND AND MULTI-STANDARD APPLICATIONS

The R&S FSW offers up to 160 MHz analysis bandwidth for measuring wideband-modulated signals such as future 4G, WLAN IEEE 802.11ac and frequency-agile signals. Furthermore, the RF signal path can handle up to 500 MHz bandwidth in anticipation of future wider bandwidth requirements. The 500 MHz bandwidth is available at the IF output and can be used to connect an R&S RTO scope for wideband analysis, for example.

When designing the R&S FSW, the engineers introduced a new feature for signal analyzers. Currently, signal and spectrum analyzers measure different standards (GSM, CDMA, W-CDMA and LTE) separately. The new instrument takes analysis to the next level, providing the capability to measure multiple standards simultaneously with the multi-standard radio analyzer (MSRA) function. This feature is interesting both for the design and production of multi-standard base stations as well as for testing interactions between radar signals and mobile radio communications.

EASE OF USE

As well as the RF performance it offers and the fact that it covers future wideband application requirements, the R&S FSW also provides a new level of usability and ease of operation. Similar to a smartphone, it features a touchscreen user interface and a flat menu structure (shown in ***Figure 1***) so deep menu trees are no longer needed. The result is a straightforward, clear presentation.

The analyzer displays various measurements simultaneously in separate windows on its large 12.1-inch screen, which greatly facilitates result interpretation (see ***Figure 2***). Users can quickly switch between different setups because settings are kept in the memory and do not have to be reloaded from disk. In addition to practically delay-free switching between instrument setups, the R&S FSW also features outstanding measurement speed such as 1000 sweeps/s in remote operation.

Currently, three models of the R&S FSW are available, covering the frequency ranges of 2 Hz to 8/13.6/26.5 GHz. With an initial focus on A&D applications, the R&S FSW comes with application firmware for measuring phase noise, noise figure and gain and pulsed signals. The most frequently requested measurement applications for mobile radio, such as analysis of LTE and 3G signals, are also available. Other measurement applications and frequency enhancements will be introduced step-by-step to cover the full application range of the well-known R&S FSU/Q spectrum and signal analyzers.

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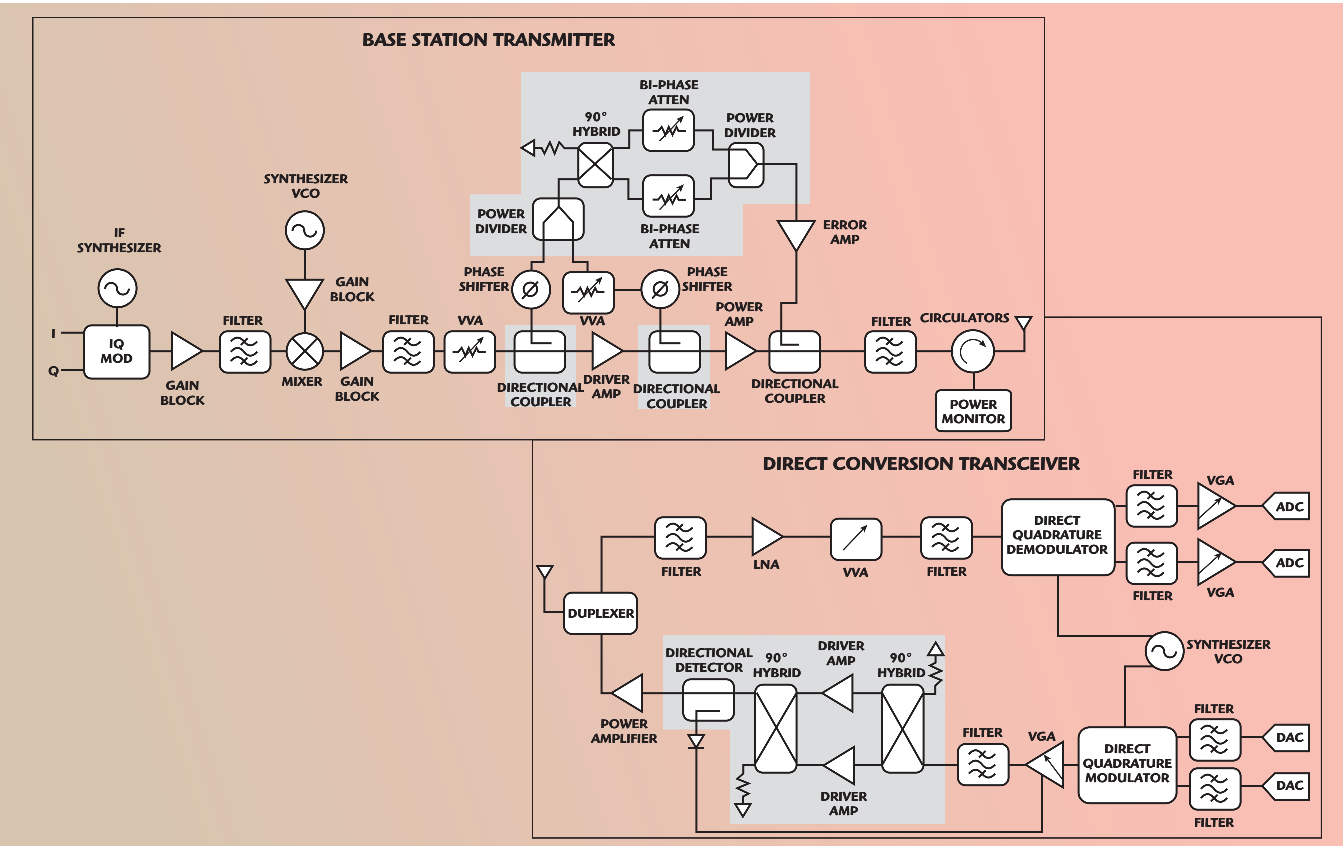
RF INTEGRATED PASSIVE DEVICES: THE NEXT BIG, SMALL THING

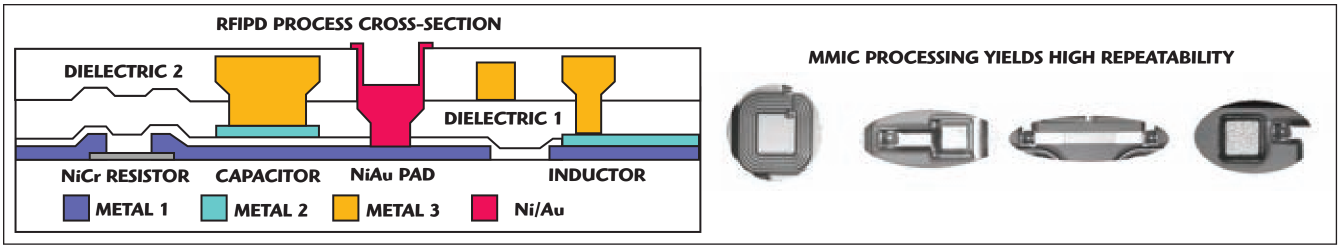
THOMAS ARTHUR, *Valpey Fisher Microwave Products Group, Hopkinton, MA*

RF front-end designers have always been in need of passive devices that serve in many functional blocks in their radio designs. These devices include 90 degree hybrids, power dividers and directional couplers, to state a few. There are many others that can also be considered. Key challenges for the suppliers of these parts have been to maintain high RF performance while continuing to make them smaller and drive out cost. Also, the ability for these devices to have a high degree of repeatability and be easily integrated into higher level functions is certainly desirable. These high performance passives are used in wireless infrastructure, point-to-point radio, RFID readers, repeaters, instrumentation and many other ISM band applications. An example might be a direct conversion transceiver or base station transceiver where they might be responsible for dividing and combining the signals in a balanced amplifier or coupling a signal for error correction in a linear power amplifier (see ***Figure 1***).

For any of these applications, the behavior of the individual passive component will play a serious role in the overall RF front-end performance. Lying in the critical path of RF signals, hybrids, directional couplers and n-way dividers are all required to have low insertion loss and VSWR as well as sufficient power handling capability. In addition, hybrids and power dividers need high isolation along with excellent phase and amplitude balance, while directional couplers need to



▲ *Fig. 1 Highlighted passive components in a block diagram of direct conversion transceiver and base station transmitter.*



▲ *Fig. 2 IC passive elements and IC cross-section of RFIPD.*

maintain high directivity. Clearly, performance is not something that can be sacrificed for the sake of size and cost.

At Valpey Fisher, we recently established a Microwave Products Group to focus on developing and bringing these high performance passives and integrated modules to market. The approach chosen is a semiconductor-based monolithic design.

At the core of these microwave devices is a state-of-the-art foundry, capable of producing highly repeatable structures on high resistivity silicon wafers. This technology is known as our RF Integrated Passive Device (RFIPD) platform (see ***Figure 2***). It offers a significant advantage compared with alternative-technologies – miniaturization, performance and reduced cost. The processes have been optimized to achieve high quality factors inductors with Qs of greater than 30 at 1 GHz and capacitors with ESD ratings greater than 250 V human body model. In addition, the power handling of these devices is quite adequate for a majority of applications as, depending on the specific product type, handling 4 W CW has been demonstrated. In addition, lower thermal resistance packaging containing an exposed lead frame paddle could potentially allow for higher powers.

The combination of the material sets chosen, innovative modeling software as well as utilizing a standard MMIC process provide a higher performance device with excellent repeatability at a lower cost. Some additional advantages are the ability to realize a series of devices across a broad frequency range while maintaining a small package form factor. This is a challenge for LTCC or stripline as the sizes of these devices change more drastically with frequency. Also, being a semiconductor die allows for higher levels of integration utilizing existing multi-chip module (MCM) manufacturing capability. Some examples of these functions can include components such as voltage variable attenuators, phase shifters and vector modulators.

This process has been implemented to realize a series of products that fall

into two main categories, namely single function discrete monolithic passives and higher functionality multi-chip module components. The first category includes devices such as 90 degree hybrids, two-way power dividers, directional couplers and fixed attenuators. These devices can all fit in a miniature 1.5 × 2.0 mm plastic leadless package. Also a four-way power divider has been demonstrated in a 3 × 3 mm package form factor. The frequency of operation ranges from as low as 500 MHz to as high as 8 GHz depending on the specific device type. Taking a look at just a few typical examples of RF performance, the 90 degree hybrids consistently provide 1.1:1 VSWR, isolation between 28 and 33 dB and a phase balance of 1 degree. Fixed attenuators have been shown to operate from DC to 8 GHz with an extremely flat attenuation response and low reflection. Two-way power dividers have amplitude and phase balances of ± 0.1 dB and ±1.0 degrees, respectively, a 1.1:1 VSWR while also maintaining low loss and very good isolation. These performances demonstrate some significant improvements over other types of solutions. Some other key advantages to the monolithic approach is the small form factor and the ability for these devices to have the same inputs and outputs within a specific product type across a broad frequency range. With today's multi-band requirements, this provides the designer with flexibility during implementation.

Another category of solutions utilizes a Multichip Module or MCM process. Here, the monolithic passive devices can be integrated with various other semiconductors to create higher-level multi-function devices. In this case, one can leverage the high performance of the monolithic passive with a controlled manufacturing approach to realize components with increased performance and reduced variability. A good example is a highly repeatable, low distortion voltage variable attenuator where the 90 degree hybrid is combined with PIN diodes and all the additional bias and decoupling components to provide a fully integrated solution. This provides the designer with an easy drop in solution, which requires just a single 0 to 5 V control line to fully operate the device. In addition, the manufacturing approach enables the ability to apply tight controls on all of the elements that cause the greatest variability. This results in at least a 2× improvement in the attenuation profile repeatability. At the nominal 20 dB point the maximum variation in the attenuation is ±1 dB. Other RF performance characteristics of note due to this approach are the IIP3 of +45 dBm due to the PIN diode implementation and the low VSWR and insertion loss, which can be directly attributed to the monolithic 90 degree hybrid.

The monolithic approach of RFIPDs, whether discrete functions or integrated into higher level MCM components, are a very good choice for many applications. They are a cost-effective alternative that offers smaller size and extreme repeatability while maintaining high RF performance.

VENDORVIEW

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Lockheed Martin On Pace to Deliver the First GPS III Satellite for Launch in 2014

The Lockheed Martin team developing the US Air Force's next generation Global Positioning System has turned on initial power to the program's pathfinder spacecraft, known as the GPS III Non Flight Satellite Testbed (GNST). The milestone gives the team high confidence in meeting the scheduled launch of the first GPS III satellite in 2014.

The GPS III program is the lowest risk solution to constellation sustainment and the most affordable path to meet the needs of military, commercial and civilian users worldwide. GPS III will improve position, navigation and timing services and provide advanced anti-jam capabilities yielding superior system security, accuracy and reliability. With a focus on affordability, the GPS III team is first developing the GNST, a full-sized prototype of the GPS III spacecraft used to identify and solve issues prior to the first space vehicle. This approach significantly reduces risk, improves production predictability, increases mission assurance and lowers overall program costs. The GNST, populated with fully functional non-flight boxes, provides space vehicle design level validation, early verification of ground, support, and test equipment and early confirmation and rehearsal of transportation operations.

"Turning initial power on for the GNST is a major milestone for the GPS III team demonstrating we are well on track to deliver the first satellite for launch in 2014," said Lt. Col. Don Frew, the US Air Force's GPS III Program Manager. "Our joint government and industry team is committed to delivering GPS III on schedule to sustain and modernize the GPS constellation for users worldwide."

> *"Turning initial power on for the GNST is a major milestone for the GPS III team…"*

The GPS III team has installed power subsystem components, harnesses and tracking, telemetry and control hardware on the GNST structure to support phased checkout of the integrated design. Flight software versions have also been delivered for all of the spacecraft and payload computer processors. In parallel, GPS III teammate ITT is integrating the GNST Navigation Payload at its facility in Clifton, NJ. Successfully powering on the GNST demonstrates initial mechanical integration, validates the GNST's interfaces and leads the way for electrical and integrated hardware-software testing. The GNST will be shipped to Lockheed Martin's GPS III Processing Facility in Denver late this year to demonstrate assembly, integration and test procedures. It will then be delivered to Cape Canaveral Air Force Station in the summer for 2012 for pathfinding activities at the launch site.

"Together with the Air Force, we continue to meet major program milestones on or ahead of schedule and we are committed to delivering GPS III spacecraft affordably and efficiently," said Keoki Jackson, Lockheed Martin's GPS III Program Director. "Our progress on the GNST is already saving the program money, eliminating risk early and providing highly reliable mission assurance for GPS constellation sustainment."

Building on lessons learned from previous GPS space programs, the US Air Force's GPS III acquisition approach is considered by many to be the model for future space acquisition. The program has reinstated rigorous technical specifications and standards, and placed a strong emphasis on systems engineering with a robust mission assurance process. These actions provide the basis for verifying the quality of the technical work and ensuring issues are surfaced and corrected earlier in the program. For GPS III, Lockheed Martin is building on its proven record of delivering highly reliable GPS spacecraft. The fleet of Lockheed Martin-built GPS IIR and IIR-M satellites makes up the majority of the operational GPS constellation. The satellites have exceeded 140 cumulative operational years on-orbit with a reliability record of better than 99.9 percent. Lockheed Martin heritage also dates back to the production of the Oscar and Nova satellites, the programs that paved the way to the current GPS system.

Northrop Grumman Demonstrates HAMMR 'On-the-Move' Radar at Yuma

Northrop Grumman Corp. successfully demonstrated the Highly Adaptable Multi-Mission Radar (HAMMR), which is a derivative of the Defense Department's Ground Based Fighter Radar (GBFR), a multi-mission ground tactical radar designed to provide the US Army with counter-rocket, artillery and mortar (C-RAM) as well as air defense capabilities while "on-the-move." The GBFR contract was awarded to Northrop Grumman in 2009 by the US Army Aviation and Missile Research, Development and Engineering Center at Redstone Arsenal, AL. HAMMR features a compact, lightweight ground configuration that employs active electronically scanned array (AESA) antenna technology from airborne fighter aircraft. In this configuration, the radar provides 360-degree coverage while mounted and moving on a vehicle and is easily deployable from a variety of expeditionary platforms, providing the rapid transport capability required by today's warfighter. The testing took place at the Army's Yuma Proving Grounds.

> *"HAMMR's on-the-move capacity… will provide the US ground forces with critical capabilities that ensure mission success in today's irregular warfare environment."*

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"HAMMR's on-the-move capacity, as demonstrated at Yuma, will provide the US ground forces with critical capabilities that ensure mission success in today's irregular warfare environment," said John Jadik, Vice President of Weapons and Sensors for Northrop Grumman's Land and Self Protection Systems Division. "This demonstration further positions Northrop Grumman as a leader in AESA technologies."

The heart of the HAMMR system, the AESA, is composed of more than a thousand programmable transmit/receive modules that enable HAMMR to successfully detect, track and engage numerous target types, at multiple positions and in varying paths and trajectories. The flexibility of HAMMR's AESA architecture enables growth to address new threats without redesigning the system, a major benefit compared to existing radar systems.

US Army to Procure 56 Sentinel Battlefield Radars from Thales-Raytheon Systems

Thales-Raytheon Systems announced that the US Army will procure 56 Improved Sentinel Battlefield Air Defense AN/MPQ-64 Radars. Thales-Raytheon Systems has already delivered more than 220 radars to customers worldwide. The company is working with several allied nations to leverage the current production to meet their sensing requirements. The AN/MPQ-64 Sentinel radar is a three-dimensional, phased-array radar system that operates in the X-Band frequency range. The primary mission is to automatically detect, track, identify and report airborne threats, including aircraft, cruise missiles and unmanned aerial vehicles. The Sentinel radar capabilities are suited for a wide range of missions, including air defense and missile systems coordination, and homeland defense, as well as infrastructure, asset and special event protection.

"…the Sentinel radar is one of the most cost-effective and reliable radar systems available to our armed forces."

"The Sentinel battlefield radar not only meets the needs of today's soldier, but will grow and evolve as requirements, threats and the mission changes," said Kim Kerry, Chief Executive Officer, Thales-Raytheon Systems, US Operations. "With a low-risk modernization roadmap, the Sentinel radar is one of the most cost-effective and reliable radar systems available to our armed forces."

Thales-Raytheon Systems' radar capabilities span short-, medium- and long-range systems. The ground-based radars are capable of detecting both conventional and unconventional threats for homeland and tactical air defense, counter-battery and weapons system coordination.


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Richard Mumford, International Editor

£50 M UK Hub to Commercialise Graphene

The UK Department for Business, Innovation and Skills has announced the formation of £50 M Global Research and Technology Hub that will connect UK researchers and businesses working to commercialise the Nobel Prize winning super strong material graphene.

The UK's Universities and Science Minister, David Willetts said, "One year ago, scientists working in Manchester won the Nobel Prize for their discovery of graphene – the Global Hub will ensure we win the race to develop commercial uses for it as well. The Hub will keep world-beating research into graphene in this country. It brings researchers and the companies seeking to exploit its incredible commercial potential together. This is an excellent example of leading-edge British science being harnessed to drive economic growth and the creation of high tech jobs."

Graphene, discovered by Manchester University scientists Professor Andre Geim and Dr. Konstantin Novoselov, is an exceptionally good conductor and the strongest and thinnest material ever measured. The UK government, through the Engineering and Physical Sciences Research Council (EPSRC), supported the early research that led to the discovery of graphene.

The UK has particular strength in graphene research with centres of excellence at leading universities. There are graphene centres of research excellence at Manchester, Cambridge, Lancaster, Exeter, Bath, Oxford and Durham universities and Imperial College London. UK researchers are in a worldwide race to develop commercial uses for graphene. The Hub will ensure leading researchers stay in Britain, leverage private-sector investment and help develop a home-grown, high tech industry.

Nobel Laureate Addressed EuMW

Those who attended the Opening Session at European Microwave Week 2011 in October witnessed first-hand Professor Konstantin S. Novoselov FRS, Nobel Laureate 2010, deliver a presentation titled, Graphene: Materials in the Flatland. He outlined the material's discovery and the properties that make it a promising candidate for future electronic applications.

Satellite Industry Addresses Signal Interference in Asia-Pacific

Interference prevention and mitigation are to be addressed in the Asia-Pacific region through closer collaboration between national, regional and global satellite industry groups. The quality-assurance plans were announced during an Interference-Prevention Summit co-organised by the Interference Reduction Group (IRG), Global VSAT Forum (GVF) and Indonesian Satellite Industry Association (ASSI) in conjunction with the Asia Pacific Satellite Communications Council (APSCC).

The plans, which have already begun to be implemented in several Asian nations, arise from a broader global collaboration of the satellite industry with the World Broadcasting Unions – International Satellite Operations Group (WBU-ISOG) and the Radio Frequency Interference – End User Initiative.

"…it is time for the industry to provide even higher assurances of quality of service…"

Through the plans, four parallel initiatives are under way: training, product quality assurance, spectrum management and carrier ID. The first three facets of the plan are designed to help prevent interference, while the fourth aims to help industry more effectively respond when interference incidents occur.

"Asian demand for satellite communications services is escalating exponentially, and it is time for the industry to provide even higher assurances of quality of service," said a joint statement of APSCC, ASSI, GVF and IRG. "Strengthening skills, product performance, spectrum management, and satellite operator's ability to react to interference incidents will enable the industry to continue to provide the high level of service that users have come to expect."

PPP Between ESA and Astrium Advances Plans for European Data Relay System

A public–private partnership (PPP) contract signed with Astrium means that the European Space Agency (ESA) is moving ahead with an independent, European satellite system that will speed up the transmission of large quantities of data beginning in 2014. The PPP for the European Data Relay System (EDRS) demonstrates ESA's capability to pull together resources and knowhow from several partners under an efficient and operational scheme.

The PPP approach allows industry to take on a greater risk in order for Europe to reap the benefits of advanced satellite technology. Under the terms of the agreement, the partners will jointly finance the EDRS with ESA's contract with Astrium amounting to €275 M.

The PPP approach allows industry to take on a greater risk…

Astrium has the overall responsibility for designing and developing the complete space and ground infrastructure. The company will then acquire ownership of EDRS and is committed to its operation for the next 15 years. Initial users for EDRS will be the Sentinel 1 and Sentinel 2 satellites of the GMES Global Monitoring for Environment and Security programme, the EU's ambitious Earth obser-

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vation programme, headed by the European Commission in partnership with ESA and the European Environment Agency.

The EDRS system will consist of two payloads carried by satellites in geostationary orbit. User data will be transmitted via dedicated terminals from satellites in lower orbits to either of the EDRS nodes and then relayed to the ground. The first of the two EDRS nodes will be launched in late 2014. The second will be launched in late 2015 on a dedicated satellite built by OHB (DE) that will use the Small GEO platform.

"The EDRS programme is another prime example of a public–private partnership," said Magali Vaissiere, ESA Director of Telecommunications and Integrated Applications. "EDRS is a big step forward in how low-orbit satellites and future unmanned aerial vehicles can be used, to the benefit of Europe's citizens and economy."

ZigBee® Alliance and Energy@home Collaborate on European Platform

The ZigBee® Alliance and Energy@home will cooperate on the creation of an integrated residential energy services platform for Europe by leveraging four ZigBee standards. Under a liaison agreement, the groups will focus on blending the strengths of ZigBee Home Automation™, ZigBee Smart Energy™, ZigBee Telecom Services™ and ZigBee Gateway™ to create the platform.

"…improving the use of energy is a global issue."

The platform will offer control of consumer smart appliances, communication with broadband networks, and communication with Automatic Meter Management systems. The platform will create value-added services designed to help European consumers better manage energy use in their homes. These energy services will also give Europeans the ability to lead the way in the global energy efficiency challenge.

"Energy@home is focused on increasing consumers' awareness of their energy consumption, while also providing them with new tools to better control their energy use wherever they might be and at any time at all times," said Fabio Bellifemine, a member of the Steering Committee of Energy@home. "The ZigBee Alliance has done groundbreaking work by developing a variety of standards that will play an integral role in our proposed platform."

"The collaboration with Energy@home will increase the scope and value of ZigBee Home Automation," said Bob Heile, Chairman of the ZigBee Alliance. "Energy@home recognizes the tremendous value of the growing family of standards developed by the ZigBee Alliance and we look forward to helping Energy@home seize the numerous time-to-market advantages our standards offer because improving the use of energy is a global issue."

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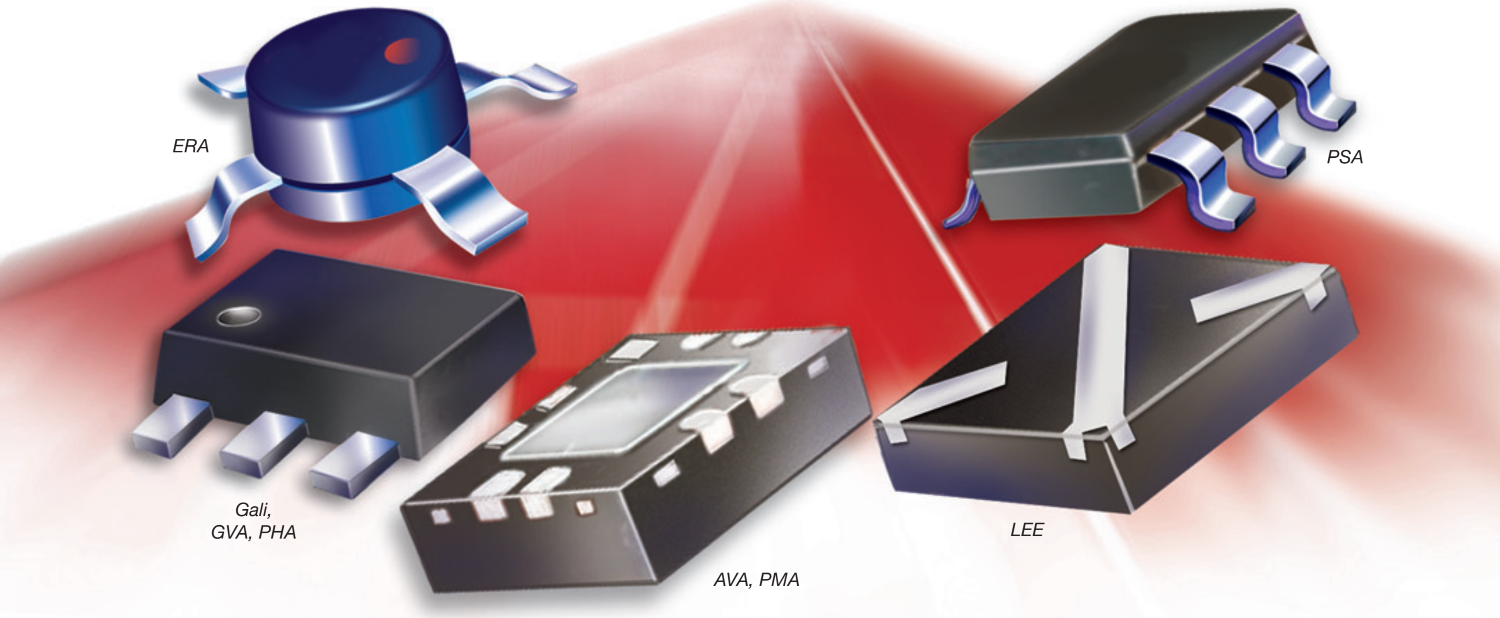

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IF/RF MICROWAVE COMPONENTS

Dan Massé, Associate Technical Editor

M2M Module Market Declines 16 Percent from 2009 to 2010 Due to Price Erosion

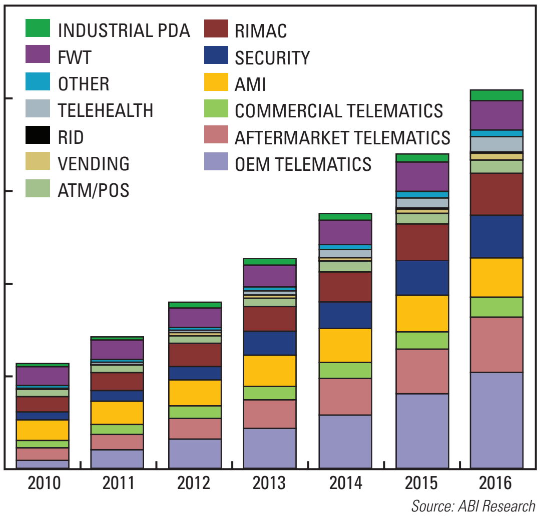
The cellular M2M embedded module market experienced a more difficult than expected year in 2010, according to ABI Research. Although total unit volumes continued to rise, reaching nearly 34 million units shipped in 2010, total industry revenue fell from roughly $996 M in 2009 to about $841 M in 2010, reversing the upward momentum in revenue seen in 2009 as the market rebounded from its 2008 lows.

"Although total unit volume continued to grow in 2010, average selling pricings (ASP) fell at a faster rate, leading to an overall decline in revenue," says Sam Lucero, Practice Director, M2M connectivity. "The sharp decline in ASPs is continuing in 2011 and is indicative of the fierce competition in the market, competition that has led to industry consolidation, such as Gemalto's acquisition of Cinterion and Novatel Wireless' acquisition of Enfora, both in 2010."

While module makers are challenged by both competition and an overall trend toward commoditization, the resulting declines in ASPs are broadening the addressable market for cellular M2M connectivity. As module prices decline, it becomes more feasible to embed cellular modules into a growing array of applications ranging from smart utility meters, to automobiles, to remote healthcare related devices, such as cardiac monitors.

"Ultimately, lower prices, combined with other factors that facilitate M2M application development, will lead to overall unit shipment volumes growing faster than prices are declining, and we will see overall module industry revenue grow significantly by 2016," says Lucero. "Consequently, falling ASPs are, in essence, benefiting module vendors as a whole, although individual vendors may not be able to survive the fiercely challenging market environment."

Total Cellular M2M Module Shipments by Application



Current Market for RF Components in BTS

Strategy Analytics has just published a new report examining the state of the base station component market, Radio Access Network RF Power Device Trends & Forecast: 2011 – 2015. This latest Strategy Analytics report provides an in-depth view of the current market for RF components in BTS, the most important recent developments in this field, and a global forecast for how the market will come to develop in the medium-term, out to 2015. The key message from the report is that the BTS market is currently in the process of changing more than it has done at any other point in its history. The report finds that conditions are favourable for continuing growth, particularly in emerging markets, with the market for BTS components set to top $5.4 B worldwide by 2015. Resonating strongly through the report is a warning that advances in technology are opening up the market for a host of new players, posing a substantial threat to the more established semi firms and subsystem equipment vendors who have dominated this space for so long. New materials and signalling technologies could potentially be the Trojan Horses that allow new players to enter the BTS market and undermine the current market leaders. For more information about this report, go to www.mwjournal.com/SAreportBTS.

2011 Base Station Shipments Up; Prognosis Is Good for 2012 and Beyond

The world economy may be teetering on the brink of a double-dip recession, but business is booming for wireless infrastructure vendors. According to Jake Saunders, Vice President of Forecasting for ABI Research, "Base station installations in 2011 will total at least 10 percent more than anyone expected just one year ago and we also see increases in planned orders for 2012 and beyond."

There are a number of factors contributing to the increase in base station shipments, but two countries in particular are significant to growth. Operators in China will more than double their number of 3G subscribers by the end of 2011, with low cost smartphones becoming popular there. Meanwhile, US operators are investing large amounts of CAPEX in 4G. Reports indicate that Verizon has installed or upgraded 20,000 to 30,000 base stations over the past 16 months, AT&T is starting to launch LTE services in major cities around the country, and Sprint's Network Vision will see most of its existing infrastructure replaced by multi-mode base stations that can support 2G, 3G and 4G simultaneously.

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The major motivation for mobile operators to expand their networks comes from the continuing growth in mobile broadband data traffic, driven by increasing penetration of smartphones (and, to a lesser extent, tablets). "Existing networks are struggling to cope with the surge in data traffic, so operators are forced to increase capacity," says Jim Eller, Principal Analyst for wireless infrastructure. "However, operators are finding new revenue opportunities with mobile data, which more than compensate for decreasing voice revenues, so they are expecting good returns on this investment."

Moving 2G subscribers to 3G, and 3G to 4G, results in more efficiencies for operators and allows operators to offer more data services.

Go Long Wireless Baltimore Pilot Introduces Hyper Broadband with MVDDS

A pioneering new broadband wireless technology is now on display in Baltimore, providing 50+ Mbps downstream capability. Go Long Wireless has launched the Baltimore MVDDS pilot to demonstrate how this new "wireless FTTH" broadband option can bring both a next generation triple play bundle to consumers and robust mission-critical broadband connectivity to the small, medium, and enterprise business communities.

"MVDDS is about broadband options. With this new wireless approach to broadband, we are demonstrating how communities all over the country can introduce broadband competition, bring broadband to the unserved and underserved and significantly reduce the cost of broadband facilities construction," said Bruce Fox, CEO of Go Long Wireless. "We're bringing an unrivaled wireless broadband pipe, Hyper Broadband, into the home or business, on par with what any wireline broadband technology can do, at a fraction of the typical wireline deployment cost."

"We're bringing an unrivaled wireless broadband pipe, Hyper Broadband, into the home or business."

MVDDS is a fixed wireless broadband technology, which uses 500 MHz of protected licensed spectrum in the 12.2 to 12.7 GHz band, capable of delivering high speed broadband, HD video and voice services. The Go Long Wireless Baltimore pilot uses a transmission antenna at the World Trade Center in downtown Baltimore and a receive antenna at the Emerging Technology Center in the Canton area. The pilot is currently delivering up to 50 Mbps in downstream broadband (3+ Mbps in upstream broadband), multichannel 1080p HD video, and voice services. The pilot is available for demonstration.

Kerri Germani, Staff Editor

INDUSTRY NEWS

Atmel® Corp. announced that it has signed a definitive agreement to acquire **Advanced Digital Design S.A.** (ADD Semiconductor), a privately held company based in Zaragoza, Spain, that develops power line communication solutions. ADD Semiconductor, a founding member of the PRIME Alliance, specializes in the design of system-on-chip solutions that allow for narrow-band data communication across existing electric power lines. With ADD Semiconductor, Atmel will acquire a portfolio of innovative products and a team of technical experts focused on signal processing and power line communications.

Cobham plc announced that it has agreed to acquire US-based **Trivec-Avant Corp.**, a supplier of UHF satellite communication (SATCOM) antenna systems. Trivec's SATCOM technology, product range and customer base are complementary to Cobham's Antenna Systems' strategic business unit. The acquisition is in line with Cobham's strategy to build scale in its target markets and deepen its investment in highly differentiated technology. Cobham will acquire the entire share capital of privately owned Trivec for a cash consideration of $126 M, payable on completion, on a debt and cash free basis. An additional cash consideration of up to $18 M is payable between 2013 and 2014, contingent on future performance.

Spreadtrum Communications Inc., a fabless semiconductor provider in China with advanced technology in both 2G and 3G wireless communications standards, announced that it has completed a majority acquisition of W-CDMA solutions provider **MobilePeak Holdings Ltd.** The acquisition of MobilePeak allows Spreadtrum to enter the global 3G and LTE markets with W-CDMA/HSPA+ technology. MobilePeak's 3G technology combined with Spreadtrum's advanced 40 nm baseband platform will enable Spreadtrum to deliver low cost, high performance W-CDMA solutions for the global market and serve as a foundation for the company's next-generation multi-mode 3G/4G solutions. Spreadtrum increased its equity ownership in MobilePeak to approximately 85 percent as a result of the acquisition. Spreadtrum expects to purchase the remaining outstanding shares by year end. Spreadtrum expects the total cash consideration for the ordinary shares, including shares purchased on September 30, 2011, and shares that remain to be purchased, to be approximately US $5 M.

Aviat Networks Inc. has sold its WiMAX business to **EION Networks Inc.**, a privately owned Canadian company headquartered in Ottawa, Ontario. As a result of the sale, the WiMAX business will be consolidated into a division of the company, EION Wireless, which plans to extend its broadband wireless solutions portfolio through the purchase. Aviat Networks acquired the WiMAX business in 2009 to expand its technology portfolio and capabilities to address opportunities in the wireless broadband and mobility markets. In May 2011, as part of a company restructuring aimed at reducing costs, streamlining operations, and optimizing the company's business model, Aviat Networks announced its intentions to sell the WiMAX business for an undisclosed amount.

Thales has acquired 100 percent of the capital of **Omnisys**, a Brazilian company headquartered in São Bernardo do Campo, near São Paulo. The company has been majority-owned by Thales since 2005 and already designs, develops and manufactures long-range L-Band radars under a successful industrial cooperation agreement, producing more than 26 TRAC L-Band radars since 2008. The Brazilian company serves key market segments, including air traffic control radars, weather forecasting radars, weapon locating radars, electronic warfare and naval missile systems, and is progressively expanding its activities into other sectors. In March 2011, Thales announced its decision to manufacture the Ground Master 400 (GM 400) air defence radars in São Bernardo, bringing the Brazilian company access to the world's most advanced and complex radar technologies.

Aeroflex Ltd. and **Lancaster University**, UK, have inaugurated the **Aeroflex Wireless Broadband Laboratory** in the University's School of Computing and Communications at InfoLab21, Lancaster's world-class center of excellence for research in information and communication technologies. The new laboratory is equipped with $1.4 M worth of test equipment donated by Aeroflex, a leading US-headquartered technology company with a large R&D and manufacturing facility in Stevenage, UK. The laboratory will enable Lancaster University to play a leading role in the development of the next generation of wireless broadband networks and user equipment.

Maxim Integrated Products Inc. is introducing a new Obsolescence Mitigation (OM) Program to minimize the impact of integrated circuit (IC) device obsolescence on long-term military/aerospace programs. The new program requires a collaborative effort between the customer and Maxim's Mil/Aero Group. Maxim will work with the customer to set aside wafers to support the obsolescence of any COTS plastic part. Any customer who needs that part for a long-life program should contact the Maxim Mil/Aero Group.

Texas Instruments Inc. (TI), a Promoter member of the ZigBee® Alliance, announced that it achieved ZigBee Certified status for its ZigBee Smart Energy™ 1.1 standard implementation, recently introduced by the ZigBee Alliance. TI announced the availability of its new Z-Stack™ 2.5.0 with support for ZigBee Smart Energy 1.1, geared toward home area networks (HAN).

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

HIGH POWER PRODUCTS

POWER DIVIDERS

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

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

HYBRIDS

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

◊ In excess of theoretical coupling loss of 3.0 dB

COUPLERS

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

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

Unless noted, products are RoHS compliant.

SYNERGY® MICROWAVE CORPORATION

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

Scintera Networks Inc., a leading provider of mixed signal semiconductors for wireless communications, announced it has received the ISO 9001:2008 certification for its Quality Management System. This certification acknowledges Scintera's commitment to meet the globally recognized management system requirements and regulations for the design and sale of semiconductors.

Florida RF Labs is the recipient of a 2011 Florida Governor's Business Innovation Award, one of the categories in a statewide program that recognizes Florida companies in emerging and high technology industries for their contributions to Florida's economic growth. Florida RF Labs was recognized in the Business Innovation category for both design and manufacturing technology for its Diamond Rf® Resistives family of products. The technology was released in 2010 after four years of development and is used in products that make our troops overseas significantly safer, which enhance our domestic security.

Agilent Technologies Inc. announced that its M8190A arbitrary waveform generator received the Frost & Sullivan Global Arbitrary Waveform Generators Enabling Technology Award. The M8190 AWG was singled out because it simultaneously provides high bandwidth and high resolution to allow engineers to perform testing that is as close as possible to real-world conditions.

Auriga Microwave has moved its headquarters, design center, labs and assembly operations to a state-of-the-art facility located at Two Executive Drive, Suite 305, Chelmsford, MA 01824. The new telephone number is (978) 452-7700. The new fax number is (978) 452-7715. Email addresses and website (www.aurigamicrowave.com) remain the same.

Plessey Semiconductors announced the opening of a new office in Futian, the heart of the Shenzhen Central Business District, Shenzhen, China, which is the first stage in an aggressive expansion plan for the company. The new offices begin with a full-time staff of two – Eden Ho, Plessey Semiconductors' Regional Sales Manager for China, and Mark Chen, Technical Sales & Applications Manager – and the company plans to increase the headcount rapidly. Plessey's operations are also supported by two Chinese distributors – Chieftech and AMOD.

Linear Technology Corp., Milpitas, CA, is commemorating three decades of innovation in analog integrated circuits. Founded in September 1981, at the dawn of the digital revolution, some questioned the wisdom of founding a company focused purely on analog technology. Over these 30 years, the worldwide analog market has grown from $2 B to more than $40 B today, and Linear has prospered with that growth.

CONTRACTS

Dynamics Research Corp., a provider of management consulting, science, engineering and technology solutions to federal and state governments, announced that it has established a five-year, blanket purchase agreement with an estimated value of $1.5 M with the General Services Administration (GSA) Office of General Supplies and Services' Supply Operations through the GSA Mobis contract vehicle. The first task order, having a one-year period of performance, has been awarded in the amount of $717,000.

API Technologies Corp., a provider of electronic systems, subsystems, RF, and secure solutions for the defense, aerospace, and commercial industries, announced that its RF Solutions/Spectrum Control division has received a new $1.9 M order from a Fortune 500 aerospace and defense contractor for a microelectronic solution to be used in the Heads Up Display (HUD) on a major US military fighter aircraft.

Wireless Telecom Group has been awarded a five-year supply agreement by Robin Warner Air Force Base for Boonton 4542 high performance RF power analyzers. These RF power analyzers are used to service and maintain radar and control systems for the Global Hawk unmanned aerial vehicle (UAV). Global Hawk UAVs are equipped with Synthetic-Aperture Radars (SAR) that can provide details of target areas with resolutions of less than 10 cm. SAR use relative motion between the radar antenna and the target. This radar system repeatedly transmits high power pulses of various frequencies ("chirps") to a target and receives multiple echo waveforms that are stored. Post-processing of the received information creates images revealing the most subtle details.

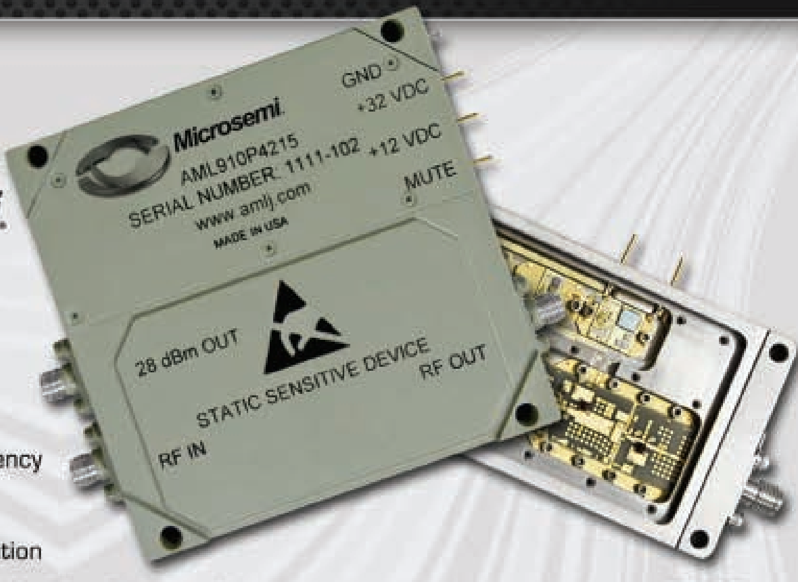
Defense and security company Saab and its American subsidiary **Saab Sensis Corp.** has been awarded contracts to supply the Sea Giraffe Agile Multi-Beam (AMB) multi-role naval surveillance radar as part of the US Navy's Littoral Combat Ship Program. The Sea Giraffe AMB 3D naval surveillance radar provides medium-range, multi-mission capability, including 3D surveillance of simultaneous air and surface targets and weapons. It also provides the proven, mature capabilities for periscope detection and splash spotting.

COM DEV USA LLC announced that it has been awarded a contract to supply equipment for a military communications satellite. Valued in excess of $5 M, the contract is a follow-on order for an additional flight set of equipment on a satellite program for which the company is an incumbent supplier. COM DEV USA will be providing filters, diplexers, ferrite devices and switches for the satellite. Work on the contract will be carried out at the company's facility in El Segundo, CA, with completion expected by the end of fiscal 2012.

NEW MARKET ENTRY

RF Micro Devices Inc. (RFMD) announced a strategic initiative to extend RFMD's industry leadership in compound semiconductor technologies into a broad array of adjacent non-RF growth markets. The strategic initiative includes the formation of a new business group, the Compound Semiconductor Group (CSG), which will operate alongside RFMD's Cellular Products Group (CPG) and RFMD's Multi-Market Products Group (MPG). RFMD's Compound Semiconductor Group will create innovative new high pow-

AML is now Microsemi.



Our Gallium Nitride (GaN) amplifier products employ the latest semiconductor technologies and present the very best performance to our customers. Gallium Nitride (GaN) technology, coupled with our chip and wire die level expertise maximize power added efficiency and high power density characteristics of GaN in small convenient packages. Multi-octave amplifiers and application specific narrow band amplifiers cover frequencies to 18 GHz. GaN amplifiers operate with voltages between +28VDC to +50VDC (design dependent). Catalog designs offer power levels up to 100 Watts; custom designs to 200 Watts are available.

GaN Power Amplifiers

Model Number	Frequency (GHz)	Gain (dB min)	Psat (dBm min)	Psat (dBm typ)	Psat (Watts typ)	Voltage (V) Current (A)	PAE	ECCN
AML056P4013	0.5 - 6.0	40	35	36	4	28V, 0.75A	22%	EAR99
AML056P4014	0.5 - 6.0	40	37	38	6	28V, 1.0A	20%	EAR99
AML056P4511	0.5 - 6.0	45	39	40	10	28V, 1.3A	25%	EAR99
AML056P4512	0.5 - 6.0	45	43	44	25	40V, 2.7A	23%	EAR99
AML13P5013	1.0 - 3.0	50	46	47	50	28V, 4.8A	25%	EAR99
AML26P4011	2.0 - 6.0	40	40	41	12	28V, 1.5A	30%	EAR99
AML26P4012	2.0 - 6.0	45	43	44	25	28V, 3.0A	30%	EAR99
AML26P4013	2.0 - 6.0	50	46	47	50	28V, 6.0A	30%	EAR99
AML59P4512	5.5 - 9.0	45	45	46	40	28V, 4.0A	35%	3A001.b.4.b
AML59P4513	5.5 - 9.0	45	48	49	80	28V, 8.0A	35%	3A001.b.4.b
AML910P4213	9.9 - 10.7	43	37	38	6	32V, 0.5A	30%	EAR99
AML910P4214	9.9 - 10.7	43	39	40	10	32V, 0.8A	30%	EAR99
AML910P4215	9.9 - 10.7	46	41.5	42	15	32V, 1.3A	30%	EAR99
AML910P4216	9.9 - 10.7	46	42	43	20	32V, 1.3A	30%	3A001.b.4.b
AML811P5011	7.8 - 11.0	45	43	44	25	28V, 2.8A	30%	3A001.b.4.b
AML811P5012	7.8 - 11.0	50	46	47	50	28V, 5.5A	30%	3A001.b.4.b
AML811P5013	7.8 - 11.0	50	48	49	80	28V, 11.5A	25%	3A001.b.4.b
AML1416P4511	14.0 - 16.0	45	42	43	20	35V, 3.2A	18%	ITAR
AML1416P4512	14.0 - 16.0	45	45	46	40	35V, 6.2A	18%	ITAR
AML618P4014	6.0 - 18.0	40	39	40	10	32V, 2.8A	12%	ITAR
AML618P4015	6.0 - 18.0	40	42	43	20	32V, 4.9A	12%	ITAR
AML218P4012	2.0 - 18.0	35	37	38	6	32V, 1.5A	13%	ITAR
AML218P4011	2.0 - 18.0	40	39	40	10	32V, 2.8A	12%	ITAR
AML218P4013	2.0 - 18.0	38	42	43	20	32V, 4.9A	12%	ITAR

Features: Fast TTL On/Off (Rise/Fall < 100ns);
Wide operating temperature range: -54° to +85°C (hermetically sealed)

Microsemi Corp. - RFIS, Camarillo, CA (formerly AML Communications)
Tel: 805-388-1345 | Fax: 805-484-2191 | Email: sales@amlj.com | www.amlj.com

er and high performance products utilizing the company's industry-leading gallium nitride (GaN) and gallium arsenide (GaAs) process technologies. Bob Van Buskirk, President of RFMD's Multi-Market Products Group, will lead RFMD's Compound Semiconductor Group.

PERSONNEL

▲ *Peter Staeker*

Peter Staeker has been elected President of **IEEE**, according to unofficial election results. Staeker is a *Microwave Journal* Contributing Editor and IEEE fellow. The results will not be confirmed until the IEEE Board of Directors meets November 20. IEEE is an association designed to serve professionals in the electrical, electronic and computing fields.

▲ *Bruce D. Hoechner*

Rogers Corp. announced that its Board of Directors has elected a new President and Chief Executive Officer, **Bruce D. Hoechner**. He also became a member of the company's Board of Directors. Hoechner, 51, succeeds Robert D. Wachob, 64, who will become Chairman of the Board of Directors. For the past five years, Hoechner was based in Shanghai, China, first with Rohm and Haas Co., for whom he worked for 28 years, and then moving to Dow Chemical upon its acquisition of Rohm and Haas in 2009.

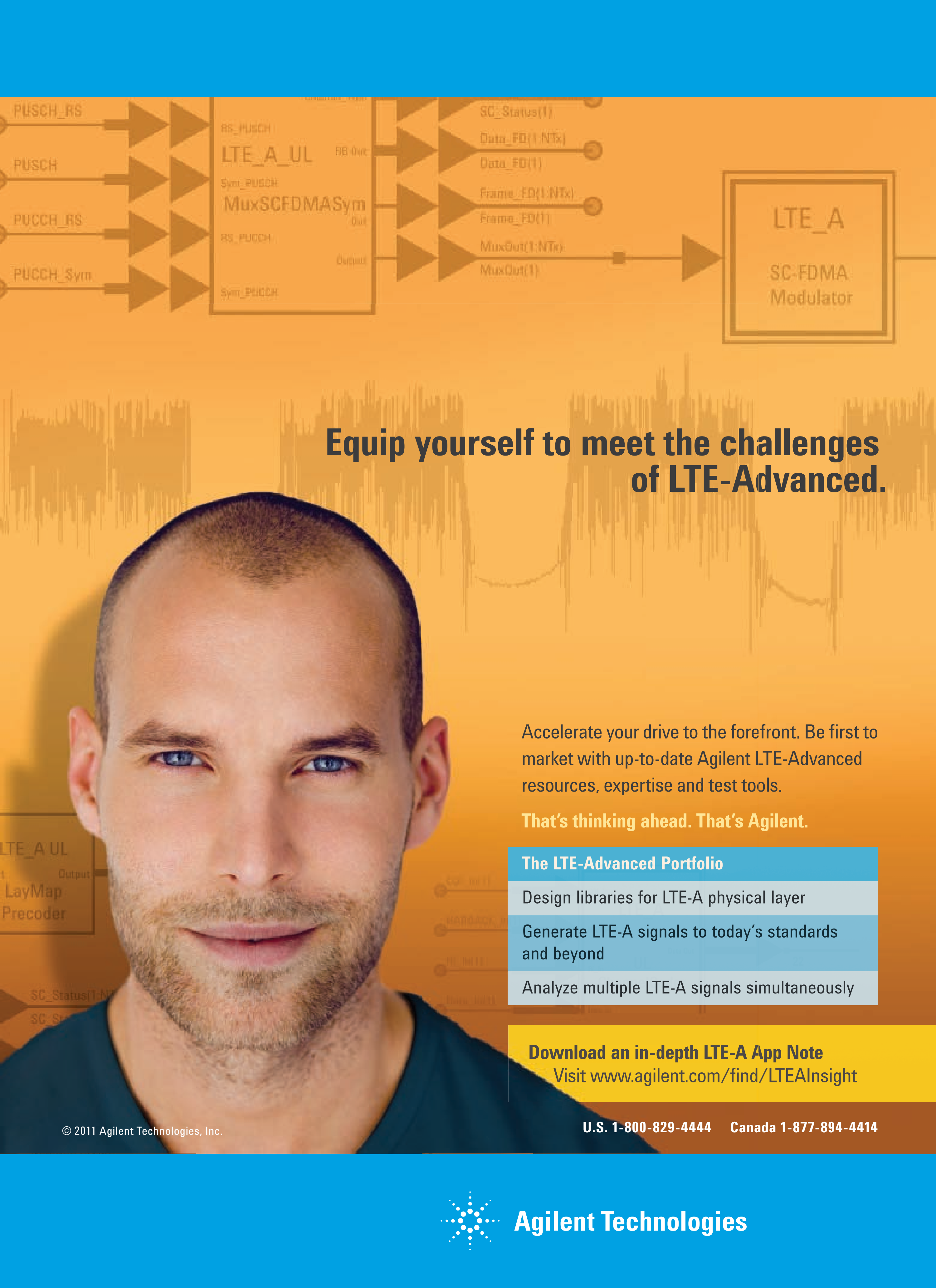
Passive Plus, a manufacturer of passive components, has appointed **Sidney Arnow** as the new Regional Sales Manager for the Western US. After 25 years developing microwave components and antennas for Wheeler Labs, Dorne & Margolin, Arnow moved into sales serving as Regional Sales Manager for Narda Microwave East. He later founded US Technical Marketing (USTM), a NY metropolitan area microwave rep firm.

▲ *William L. Pappani*

Park Electrochemical Corp. announced the appointment of **William L. Pappani** as Vice President of Business Development and Planning for the company. Pappani will report to Brian Shore, Park's President and Chief Executive Officer. Prior to joining Park Electrochemical Corp., Pappani was Vice President of Finance and Chief Financial Officer of Maskless Lithography Inc.

REP APPOINTMENTS

Siklu, a pioneer in the wireless backhaul market, has signed a distribution agreement with **Connectronics**, a leading wireless product distributor, for Siklu's millimeter-wave radio systems, which deliver unparalleled price-performance



Equip yourself to meet the challenges of LTE-Advanced.
Accelerate your drive to the forefront. Be first to market with up-to-date Agilent LTE-Advanced resources, expertise and test tools.
That's thinking ahead. That's Agilent.
The LTE-Advanced Portfolio
Design libraries for LTE-A physical layer
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value. The agreement is the latest for Siklu, which recently established a presence in North America and has begun offering in that market its carrier-grade millimeter-wave Gigabit Ethernet radio solutions. Under the agreement, Connectronics will offer Siklu's EtherHaul millimeter-wave E-Band system to its network of value added resellers, system integrators and Internet service providers.

L-com Inc., a global leader in the manufacture of wired and wireless connectivity products, has partnered with **PIDSO** from Vienna, Austria. The partnership allows L-com greater distribution of both wired and wireless products in central Europe.

International Manufacturing Services Inc., a manufacturer and supplier of high quality thick and thin film resistors, terminations, attenuators, planar dividers, planar filters and thermal management devices to the electronics industry, announces the appointment of **Spantech Microwave Technology S.A.** as its representative to Spain and Portugal. Spantech is headquartered in Malaga, Spain, and has been serving the electronics industry with superior service, technical knowledge and efficiency since 1992. More about Spantech may be found at www.spantech.es.

MITEQ Inc. announced the appointment of **Omarim Technologies Ltd.** as the company's exclusive sales representative in Turkey and **Sanetronic Co. Ltd.** as the company's exclusive sales representative in China and Hong Kong. Omarim and Sanetronic will represent MITEQ's Component division of products. Omarim can be contacted at 011-90-216-340-8832. Sanetronic can be contacted at 011-86-755-2518-1122.

WEBSITES

American Technical Ceramics (ATC), a manufacturer of microwave, millimeter-wave and RF passive components, has launched a new website, www.atceramics.com. ATC's newly redesigned website features many valuable additions and enhancements in navigation, searching and e-commerce that afford easy access to all ATC product information.

Empower RF Systems, a leading manufacturer of solid-state power amplifiers and amplifier-based solutions has launched a web-linked and inventory backed program with **Richardson RFPD** to offer faster availability on a specific selection of standard, building block products in its most requested frequency bands and power levels. The teamed approach between Empower and Richardson RFPD offers RF designers an attractive array of power amplifier solutions on a "quick turn" basis to support lab test requirements, prototype developments, and assurance of supply on COTS products. Visit Empower's website, www.empowerrf.com, and look for the "Buy Now" tab included with descriptions of specific products in this program. The Richardson RFPD website, www.richardsonrfpd.com, also features an Empower "storefront" and application based, interactive selection guides with specific listings of Empower products in inventory.

HI-REL LIMITERS

BLOCK HIGH LEVEL RF INTERFERENCE... PROTECT YOUR LOW NOISE RECEIVERS.

10 MHz to 7 GHz from $9.95 10-49

Need to protect a low-noise receiver that will be operating in a hostile environment? These limiters offer excellent protection against ESD, power surges and unwanted high-level signals--without the tradeoff of high insertion loss. And these limiters react nearly instantaneously (2 ns response time, 10 ns recovery time) and work over a very broad band.

With an insertion loss of only 0.23 dB typical, these hi-rel, wide-band limiters provide protection against high level signals from +12 dBm to +30 dBm input. The power out of the limiter is +11.5 dBm, typical. Thus protecting the sensitive devices connected to the limiter output. *The surface mount RLM series* is housed in a miniature plastic case, 0.25" x 0.31" x 0.17". While the *VLM SMA connectorized series* is housed in a rugged, patented unibody package for easy connection to sensitive devices following the limiter.

Data sheets, performance curves, measurement data, and environmental specifications are available on our website, *minicircuits.com.* So why wait, order on our website and get delivery as quickly as the next day.

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U.S. Patents 7739260, 7761442

IF/RF MICROWAVE COMPONENTS

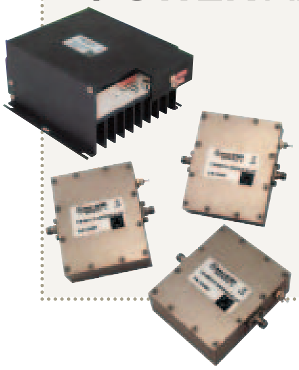
MITEQ® Your Amplifier **Source**

The largest and broadest Standard Amplifier product line available today!

Narrowband to Multi-Octave, ranging from 1 kHz to 65 GHz, with noise figures and power levels only dreamed about.

GaN

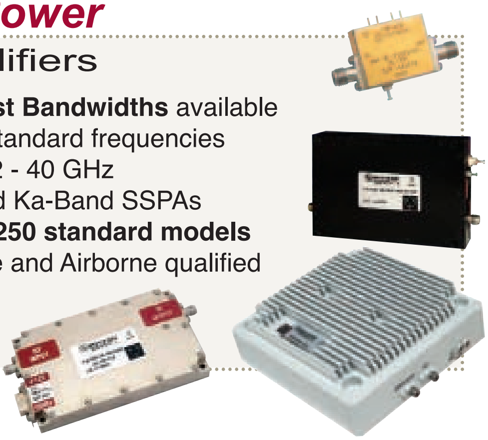
POWER Amplifiers



- **Frequencies in excess of 10 Octaves**
- Models from 30 MHz to 4 GHz
- **3 to 10 W**
- Single bias, 30V

High Power

Amplifiers



- **Widest Bandwidths** available with standard frequencies from 2 - 40 GHz
- X- and Ka-Band SSPAs
- Over **250 standard models**
- Space and Airborne qualified

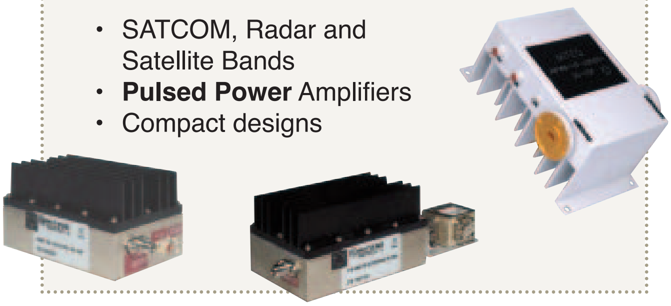
Broad and *Ultra-Broadband*

Amplifiers

- **0.1 - 40 GHz**
- Standard models covering all standard Communication, SATCOM and Military Bands
- Over **2,500 standard models**

SATCOM and *Radar*

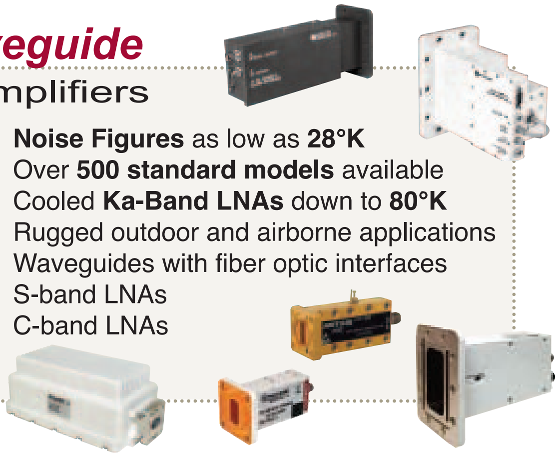
High-Performance Amplifiers



- SATCOM, Radar and Satellite Bands
- **Pulsed Power** Amplifiers
- Compact designs

Waveguide

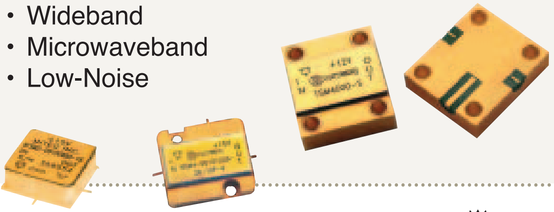
Amplifiers



- **Noise Figures** as low as **28°K**
- Over **500 standard models** available
- Cooled **Ka-Band LNAs** down to **80°K**
- Rugged outdoor and airborne applications
- Waveguides with fiber optic interfaces
- S-band LNAs
- C-band LNAs

Surface Mount

Amplifiers



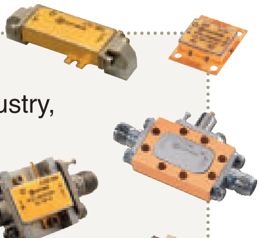
- **True Surface Mount** Amplifiers with frequencies **up to 40 GHz**
- Ultra High Frequencies
- Wideband
- Microwaveband
- Low-Noise

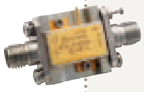
Quality RF/Microwave Prducts For Over 40 Years

3 YEAR WARRANTY

Low Noise

Amplifiers .001 MHz to 75 GHz





- **Lowest guaranteed noise figures** in the industry, ie: 0.3 dB in L-band and 2 dB in K-band
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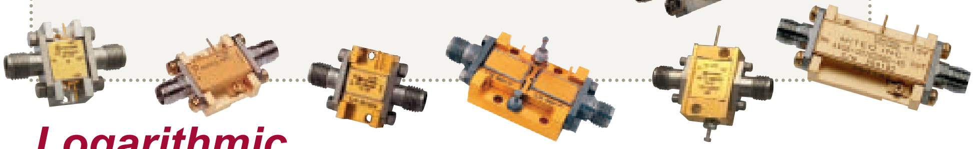

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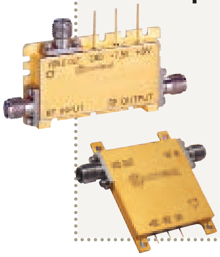

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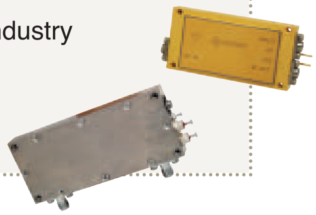

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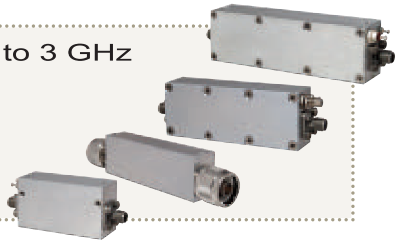

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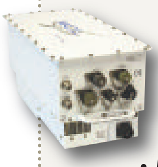

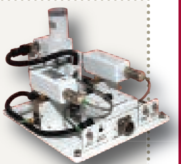

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Design and Fabrication of Monolithic High Quality Factor RF-Solenoids Using Dielectric Substrate

In this article, the design, simulation and fabrication of novel off-chip solenoid inductors with high quality factor are reported. The minimum feature size of standard PCB fabrication has been used to make embedded solenoids in Duroid substrate with a relative permittivity of 2.2. A solenoid turn includes two imbedded copper via of 125 µm radius and two surface conductors 250 µm wide to shape a rectangular coil. Different pitch sizes, conductor lengths, solenoid heights and numbers of turns were simulated and fabricated. The maximum quality factor obtained was 160.3 for a 500 µm pitch size and 1 mm conductor length in a substrate 380 µm thick. In addition to the very high Q-factor, the inductor benefits from a facilitated design and ease of fabrication. The analytical design has been investigated, using a lumped circuit model and electromagnetic simulation. The S-parameter measurements are in close agreement with the circuit design. The micro-solenoids have a higher quality factor, compared to other counterparts.

Radio frequency micro-structured inductors are currently being developed to optimize the transmission and filtering features for microwave applications like RFIDs, radars, satellite communications and medical sensors. This technology is also of interest for the next generation wireless communication devices and biomedical instruments. To fulfill these requirements, different design techniques have been developed for the miniaturization of inductors.[1-3] This article proposes a new method for the design and fabrication of high quality factor micro-solenoids.

On-chip inductors such as micro-spirals,[4-6] micro-solenoids[7-10] and micro-toroidals,[11] have been extensively studied. Among the circuit parameters related to micro-inductors is the parasitic capacitance between the coil and the ground, which has a significant effect on the resonance frequency and the quality factor of the actual inductor. For example, on-chip micro-spirals have large parasitic capacitance between the coil and the substrate. However, several design techniques, including ground shielding, suspended micro-coils and isolation layers, have been developed to decrease this capacitance. Nevertheless, the on-chip micro-spirals are not able to provide Q-factors greater than 100.[12-14] Alternatively, to over-

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UAHuntsville, Huntsville, AL

come the parasitic capacitance, different on-chip micro-solenoid structure schemes have been made but they require complex fabrication. For example, to make a suspended micro-solenoid with low parasitic capacitance, one needs five layers of photolithographic patterning. Regardless of the improvements in their Q, these coils are currently unreliable as commercial devices.[15]

A few approaches have been proposed to enhance quality factor by the making of off-chip micro-inductors. New substrates were used for the sake of lower parasitic capacitance. Soh et al. used a high resistivity silicon wafer to build the micro-solenoid using vias through the wafer.[16] Nevertheless, this method had an uncommon process and did not offer Q-factors higher than 18.5. Yoon et al. and Lu et al. have used Pyrex glass as the substrate, which decreased the capacitive coupling and substrate loss in the fabrication of micro-solenoids.[17,18] However, the resulting quality factor was still less than 100. Other approaches were the application of alumina as a microwave substrate, system on package (SoP) using LTCC and organic packaging substrates for making spiral and helical RF inductors. These techniques can provide Q-factors higher than 100, but they all suffer from multi-layer and costly fabrication process.[19-21]

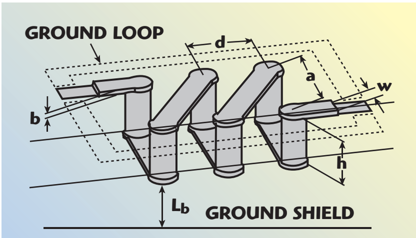
In a recent study, a microwave substrate material with a low relative dielectric constant of 2.2 was used for making micro-toroidals, using microstrip or stripline.[22] This research showed an improvement of 1.5 times, when compared to the conventional micro-spiral inductors. Due to the microstrip grounding layer in the middle of the toroidal, the maximum Q was obtained for frequencies less than 1.25 GHz and the thickness of the actual multi-layer dielectric board became more than 3 mm. They have shown quality factors higher than on-chip inductors, but the application of monolithic commercial microwave printed circuit boards (PCB) production method with common thicknesses for micro-electronic structures has not been investigated in the literature.

Standard PCB techniques decrease the cost and complexity of the devices, when compared to the other micro-inductor counterparts.

The use of microwave PCBs as a dielectric substrate for micro-inductors is not only an important factor for the commercialization and ease of fabrication, but it also benefits from a variety of different relative dielectric permittivity and substrate thicknesses available in PCB materials. The permittivity is a major parameter to decrease the loss in the substrate and optimize the quality factor. The current study, which is a preliminary research,[23] was done to find a commercial monolithic design and a creation method for micro-solenoids with low parasitic capacitance, using common microwave PCBs.

This article describes the design, fabrication and test of novel off-chip solenoid inductors for RF frequency applications. The inductor consists of a micro-solenoid embedded inside a RT/Duroid 5880 circuit board. The low relative permeability of 2.2 helps to keep a low stray capacitance as well as low loss for the fields inside it.[24,25] Due to the difficulty of drilling high aspect ratio vias close to each other, this effort was limited to a drilling diameter of 0.250 mm in order to achieve the maximum possible resonance frequency. Various lengths, heights and pitch sizes were modeled to find the best response. A set of the resulting devices, with different size parameters based on our modeling, were used to optimize the experimental resonant frequency and quality factor.

A schematic diagram of the solenoid is shown in ***Figure 1***. Each solenoid consists of at least ¾ of a turn patterned through the printed circuit board and two electrical feed lines of length a/2. Thus, for this design, the first turn of the solenoid begins at the start of the diagonal beam section patterned on



▲ *Fig. 1 Diagram of a two-turn solenoid on a Duroid substrate.*

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top of the substrate. Each diagonal section represents an additional turn in the device. This allows the user to quickly identify the number of turns present in the structure by counting the number of diagonal lines patterned on the top surface of the substrate. Using this design rule, the solenoid has two diagonal beam sections and is, therefore, a two-turn device.

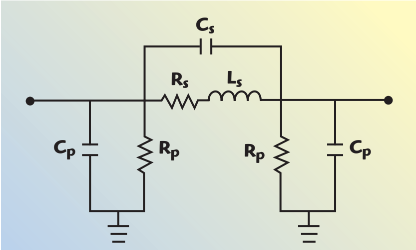
Two modeling techniques were used to investigate the circuit. The analytic modeling of the circuit was done using a single π-circuit model. An electromagnetic simulation of the device was also done with Ansoft-HFSS software. The simulated results were compared to the measured S-parameters of the fabricated devices, using a microwave probe station. Both the inductance and quality factor were evaluated. The experimental data shows close agreement between modeling and simulation. The low cost standard PCB production technique decreased the cost and complexity of device commercialization, when compared to micro-inductors counterparts.

THEORY

A single π-circuit model was used to describe the micro-solenoid. It can be used for solenoids with a considerable distance from the shielding.[26] Using the Greenhouse-Grover method, the self inductance of each segment as well as the mutual inductance between them[27] was determined. The capacitive behavior of this device includes the two different capacitances, which are C_s, the stray capacitance between segments, and C_p between segments and ground. Based on the position of the segments, the capacitances are in air or inside the Duroid substrate with a dielectric constant of 2.2. All segments and the capacitances between them have been considered in the following model. The resulting π-circuit is illustrated in ***Figure 2*** and the parameters of the circuit are evaluated as follows:

Inductances

The fabrication of the coil requires the use of both rectangular and cylindrical components. Each geometric condition must be solved in order to



▲ *Fig. 2 π-model schematic for a micro-solenoid inductor.*

find the inductance of the complete coil. The self inductance of a circular via inside the substrate is named L_{cs}, with the approximate value of:[27]

$$L_{cs} = 2h\left[\ln\left(\frac{2h}{0.5w}\right) - 0.75 + \frac{0.5w}{h}\right]$$

Likewise, the self inductance of each rectangular segment can be approximately evaluated by, L_{rs} in nano-Henries:

$$L_{rs} = 2l\left[\ln\left(\frac{2l}{b+w}\right) + 0.50049 + \left(\frac{b+w}{3l}\right)\right] \quad (2)$$

where l is the length, h is the height (and substrate thickness), b is the thickness and w is the width of the conductor. It should be noted that the beam rectangular segment length, l, has two values in this design. And, thus, there are two rectangular inductance values, one for l = a, and another for $l = \sqrt{a^2 + d^2}$.

The leads connecting the coil to the RF contact pads have a length of a/2.

The mutual inductance M, between each couple of segments, can be evaluated by:[27]

$$M = 2lG$$

It is positive if the current in both segments is in the same direction and negative if it is in opposite direction. To find the G, the following relations can be used:

$$G = \ln\left[\left(\frac{l}{D}\right) + \left(1 + \frac{l^2}{D^2}\right)^{1/2}\right] - \left[1 + \left(\frac{D^2}{l^2}\right)\right]^{1/2} + \left(\frac{D}{l}\right) \quad (3)$$

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where D is the geometric mean-distance relating the width and pitch of the line segments as defined by Greenhouse:[27]

$$\ln(D) \cong \ln(d) - \left[\frac{1}{12}\left(\frac{d}{w}\right)^2\right] + \left[\frac{1}{60}\left(\frac{d}{w}\right)^4\right] + \left[\frac{1}{68}\left(\frac{d}{w}\right)^6\right] + \left[\frac{1}{360}\left(\frac{d}{w}\right)^8\right] + \left[\frac{1}{660}\left(\frac{d}{w}\right)^{10}\right] \quad (4)$$

The total inductance is the sum of all self inductances and mutual inductances in a turn coil. Recalling that each n turn coil actually consist of n + ¾ turns, then the total inductance is the sum of the inductance due to n loops plus a three quarter turn loop with a rectangular beam length, l = a as follows:

$$L_{n\ turn} = L_{\frac{3}{4}loop} + L_{n\ loops}$$

$$L_{\frac{3}{4}\ loop} = 2L_{cs} + L_{rs}(l = a)$$

$$L_{n\ loops} = n\left[2L_{cs} + L_{rs}(l = a) + L_{rs}\left(l = \sqrt{a^2 + b^2}\right) + 2M\right] \quad (5)$$

The values of the mutual inductances are reduced by the distance between segments, so the major mutual inductances occur between top and bottom conductors. This helps to approximate the mutual and self inductances of one turn and simplify the formula due to the reoccurrence of the turns.

Capacitances

As previously stated, the single π-circuit model uses two capacitive elements, stray and parallel. The stray capacitances are between the segments from the first terminal to the second. These depend on the cross-section, distance, and the dielectric constant between segments.

Despite the fact that the capacitances between via are much higher than the other segments, the calculation of stray capacitance, C_s for an n turn solenoid of pitch, d, of individual line segments, relies on the capacitance between all adjacent segments and is formulated as follows:

$$C_s \cong \varepsilon_0 \frac{\left[(2_n - 1)\sqrt{a^2 + (0.5d)^2} + 2na\right]b}{(d - w)} + \varepsilon_r\varepsilon_0 \frac{n\sqrt{a^2 + (0.5d)^2}\,w}{\sqrt{h^2 + (0.5d)^2}} + \varepsilon_r\varepsilon_0 \frac{(2n+1)hw}{a} + \varepsilon_r\varepsilon_0 \frac{2nw(2b + h)}{d} \quad (6)$$

Each segment also demonstrates a capacitance to the ground, as stated by the parallel capacitive features, C_p, of the two-port network. This parasitic term consisted of the capacitances of lower segments to the ground, C_L, and capacitances of upper segment to ground, C_U. A few added dimensional constraints are required to adequately evaluate these capacitances. First, the distance between the line metal line segments on the bottom of the substrate and ground, l_b, is tailored to reduce these terms in the system. The width of the gap between the coil and the ground pads is approximately 25 μm (the thickness, b, of the rectangular section). Finally, the closest distance between the coil turns and the ground loop is approximately one half of the metallic lead width, w.

$$C_p = \frac{1}{2}(C_L + C_U)$$

where C_L and C_U are:

$$C_L = \frac{\varepsilon_0}{2}\frac{(n+1)wa + (2n+2)\left(\frac{w}{2}\right)^2\pi}{l_b}$$

$$C_u = \varepsilon_0\left(n\frac{wb + ab}{0.5w} + \frac{ab}{0.5w} + 4\frac{bw}{b}\right) \quad (7)$$

Resistances

The series resistance includes the resistances of surface conductors in series with the resistances of the columns. The skin effect should also be considered for this calculation.

$$R_s = \frac{c\rho\left[(2n+2)h\right]}{\delta(\pi w)} + \frac{c\rho\left[(n+1)a + n\sqrt{a^2 + (0.5d)^2}\right]}{\delta(2w + 2b)} \quad (8)$$

where c represents the resistivity ratio of the bulk metal to that of the electroplated metal. For simplicity, c was set to a value of one in this experiment.[7] Also ρ is the resistivity of copper, δ is the skin depth and is given by:[28]

$$\delta = \sqrt{\frac{\rho}{\pi\mu f}} \quad (9)$$

In which μ is the permeability of copper and f is the frequency of the electromagnetic field.

After developing terms for the individual circuit components, the π-model was then solved for in terms of a one-port measurement to match the experimental requirements for testing. In a one-port measurement, the second terminal of circuit model is connected to ground and the equivalent π-model of the circuit results in the following quality factor:[13]

$$Q = \frac{\omega L_s}{R_s}\cdot\left[1 - \frac{R_s^2(C_s + C_p)}{L_3} - \omega^2 L_s(C_s + C_p) - 2\omega R_3(C_s + C_p)\right] \quad (10)$$

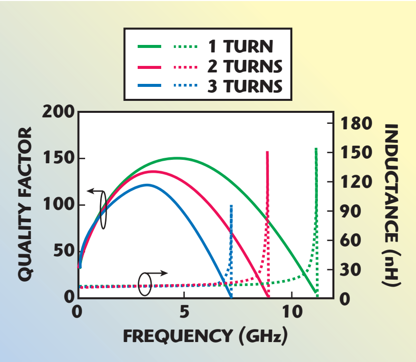
DESIGN AND FABRICATION

Based on the equation provided for the modeling, one can design a specific coil to match the Q factor desired in the range between 2 and 6 GHz. To achieve the highest resolution, this project is focused on the use of RT/Duroid 5880, with the very low relative permittivity of 2.2. This benefits low loss through the entire thickness of the board. Three-dimensional structures in RF substrates have multiple different applications, including high quality factor resonators, microstrip antennas and interconnects.[25,29] As such, the key to this design is to pattern the micro-solenoid through the Duroid to maintain a uniform magnetic field through the coil. This is achieved through the utilization of a small diameter coil comprised of a low resistivity metal that does not oxidize on the surface. While gold is ideal for such cases, copper is cheaper and, therefore, easier to demonstrate in a laboratory experiment.

In order to maintain the compatibility of standard printed circuit board process, the drilling size of 125 µm radius was used. To match this requirement, the width of each conductor would be 250 µm and the minimum distance between two conductors was 250 µm. Copper or silver can be used as the cladding layers. Here, copper cladding with silver immersion layer technology was used for the surfaces. A thin finishing layer of gold is added to avoid the oxide growth. Each via was electroplated simultaneously to make the columns. In the two-turn inductor depicted previously, h is the height of the vias, w is the width of the surface conductors, a is the bottom layer conductor length, d is the pitch size and b is the thickness of the cladding layer. The following variables were used to maximize the quality factor:

- Substrate thickness (h)
- Pitch size (b)
- Surface conductor length (a)
- Number of turns (n)
- Wire width (w)

To realize the effect of columns height on the design, two Duroid thicknesses of 3.0 and 0.380 mm were provided. In order to determine the maximum value for Q for each substrate thickness, 16 different sizes of solenoid have been designed, simulated, fabricated and tested. The original space included four different coil designs. Each design was studied for four different numbers of turns.



▲ *Fig. 3 Q factor and inductance as a function of the number of turns.*

The one-port quality factor, $Q_{11}(\omega)$, is considered a measure for the performance of the coils in most literatures.[5] It has been defined as:

$$Q = \frac{\text{Im}\left(Y_{11}^{-1}\right)}{\text{Re}\left(Y_{11}^{-1}\right)} \qquad (11)$$

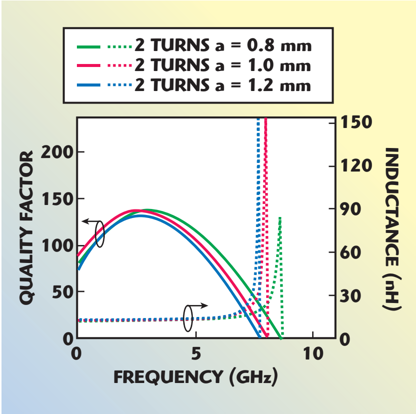
The Y_{11} can be calculated in port one, while the second port is short circuited. The inductance L is equal to:

$$L = \frac{\text{Im}\left(Y_{11}^{-1}\right)}{\omega} \qquad (12)$$

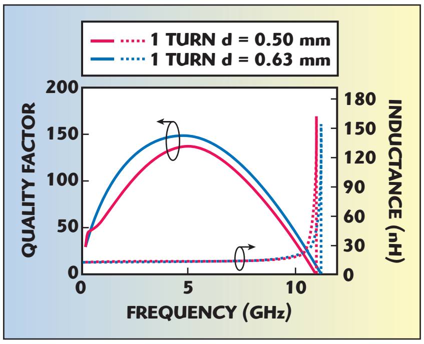
Figure 3 shows the Q-factor and inductance as a function of the number of turns, with a = 1 mm, d = 0.5 mm, h = 0.38 mm and w = 0.25 mm, using the electromagnetic simulation by Ansoft HFSS. ***Figure 4*** illustrates the influence of the top conductor length, a, on the Q-factor. ***Figure 5*** shows the result of change in the pitch size, d. Increasing the substrate thickness or height will increase the inductance, but the quality factor will decrease. Optimization of the results using the analytical modeling and electromagnetic simulation showed that a one-turn solenoid, with 0.380 mm columns height and 1 mm of the surface conductor length also 0.250 mm pitch, can provide the maximum Q factor of 160.3. A copper conductivity of 4×10^7 S/m was used to match the simulation with the conductivity of our electroplated copper. A photograph of the micro-solenoids is shown in ***Figure 6***.

RESULTS AND DISCUSSION

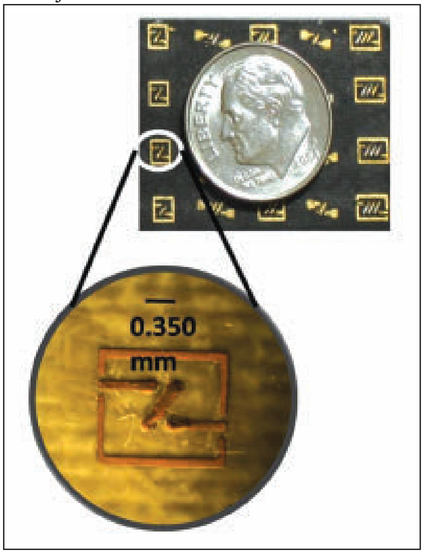
The S-parameters of the fabricated resonators were measured using a HP8363 network analyzer and GSG Cascade Microtech probes. The short-open-load-thru (SOLT) calibration has been done with an impedance standard substrate (ISS). The frequency span was measured using 6800 sampling points to increase the accuracy. Samples were put on a striped Duroid board of 3.0 mm thick to decrease the ground capacitance



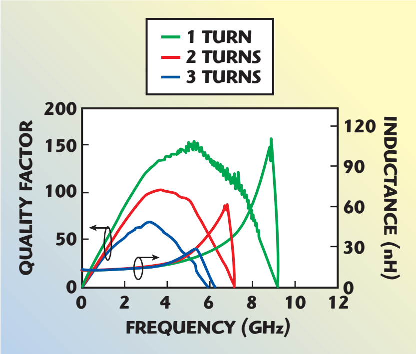
▲ *Fig. 4 Q factor and inductance as a function of a.*



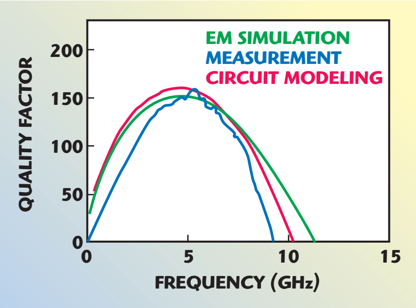
▲ *Fig. 5 Q factor and inductance as a function of d.*



▲ *Fig. 6 Top view of the micro-solenoids in their ground pad for a = 1 mm, w = 0.250 mm and d = 0.500 mm.*



▲ *Fig. 7 Measured Q and inductances of a micro-solenoid as a function of the number of turns.*

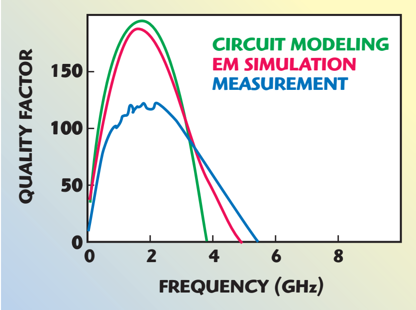


▲ *Fig. 8 Comparison between simulated and measured Q factors of a single turn micro-solenoid inductor.*

TABLE I

CIRCUIT PARAMETER VALUES FOR MICRO-SOLENOIDS INDUCTORS OF MODEL-1 IN TWO DIFFERENT THICKNESS AND TURNS

Turns	Height (h) (mm)	L_s (nH)	C_s (fF)	R_s (Ω)	F_{res} (GHz)	Q_{max}
1	0.380	3.5	84.0	0.19	9.26	160.3
2	0.380	4.5	90.1	0.28	7.91	104.0
3	0.380	5.9	115.6	0.35	6.48	68.9
1	3.010	9.8	164.9	0.21	4.21	122.1



▲ *Fig. 9 Q factor of a 3.01 mm thick substrate micro-solenoid with a single turn.*

during measurement. De-embedding of the pads was carried out after conversion of S-parameters to Y-parameters. The Y-parameters of an open pad was subtracted from the same measured one for a solenoid in the pad. Then the S-parameters were calculated using the new Y-parameters.[30] The Q-factors and inductances were evaluated using the equations shown previously.

The results of the measurement for one, two and three turns inductors of model-1, including a = 1 mm, d 0.5 mm, h = 0.38 mm and w = 0.25 mm, are illustrated in ***Figure 7***. The circuit parameters of this model for substrate thicknesses of 0.380 and 3.010 mm are given in ***Table 1***.

The resulting measurements showed that the application of low relative permittivity material like RT/Duroid 5880 did not degrade the quality factor due to the low dielectric permittivity. Furthermore, the Duroid was a good supporting substrate to fabricate a reliable solenoid structure. Optimization of the quality factor in the micro-solenoid resulted in closely spaced conductors to provide the highest coupling of the magnetic field. Besides that, the conductors should be wide enough to reduce the resistivity of the overall inductor. To show the compatibility of the measurement with the analytical modeling and EM-simulation all three results for the one-turn inductor are compared in ***Figure 8***. In this model, a quality factor of 160.3 has been measured for a one-turn solenoid with 0.380 mm column height and 1 mm of the surface conductor length and a 0.250 mm pitch size.

The major restriction for increasing the quality factor in this inductor was the resistivity of the electroplated copper, which was higher than the bulk copper. The increased resistance observed in the electroplated material lowered the measured Q-factor. As such, ***Figure 9*** shows that, for an inductor of 3.01 mm thickness, with a = 1 mm, w = 0.250 mm, h = 0.380

mm and d = 0.500 mm, the Q did not match the modeling results, due to higher resistivity of the actual fabricated device. Any improvement in the metal via fill process can result in a future enhancement of the quality factor for micro-solenoids.

If a resistivity close to that of the bulk metal could be achieved in the electroplated vias, then quality factors higher than 200 could be obtained. For example, if this research compared to the micro-spirals on the alumina substrate and micro-coils using SoP structures, it not only benefits from higher quality factor but also has a commercial production method that can be realized.[20,21] In contrast to the toroidal inductors reported by Philips and Settaluri with microstrip or stripline, the current results show that the monolithic structures decrease the capacitive effects of close grounding layer and increase the self resonance frequency of inductors.[23] Power management is also higher due to the increased cross-section for the conductors.[31] Finally, the device presented in this work benefits from a commercial thickness for the board, higher frequency for the maximum Q, and easier monolithic fabrication. These advantages make the resulting micro-solenoid a good candidate for the miniaturization of the commercial off-chip inductors.

CONCLUSION

Design, simulation and fabrication of novel off-chip micro-solenoids with high quality factor are reported. Low cost standard PCB fabrication was used. The S-parameters of the fabricated models were measured using a microwave probe station and the quality factor has been extracted. A maximum quality factor of 160 was recorded for a one-turn solenoid. It shows close agreement with modeling. The results have a potential application in microwave circuits to enhance their performance with keeping a very high quality factor. It would also decrease the cost, and complexity of fabrication compared to on-chip resonators, and MEMS structures. ■

ACKNOWLEDGMENT

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IMPROVED THERMAL MANAGEMENT OF MICROWAVE PCBs USING ADVANCED CIRCUIT MATERIALS

Thermal management in microwave printed-circuit boards (PCB) is more important than ever, with the growing demand for higher levels of circuit integration and PCB power densities. Understanding proper thermal management of a microwave PCB requires some basic theory regarding heat flow in a PCB, as well as the thermal properties of the materials used in PCBs. To illustrate PCB thermal management in practical terms, an experiment will be detailed to show the heat flow in a PCB at various power levels and using materials with a variety of different thermal properties. As an example, a simple microstrip circuit will help to illustrate heat flow through a PCB, including the effects of plated-through-hole (PTH) via holes (vias) used for signal-ground connections in isolated areas of the PCB.

A basic thermal model can be described by hot and cold areas or reservoirs connected by a thermally conductive material, such as copper (see ***Figure 1***). Copper has a thermal conductivity (TC) of approximately 400 W/m/K, which is considered to be very good. For a model that more closely resembles the thermal flow in a microstrip PCB with PTH via hole, the basic model is modified by having thermal insulators now surrounding the thermal conductor, with the PCB substrate serving as the thermal insulator (Figure 1b); a PCB substrate generally has a TC of approximately 0.25 W/m/K. In creating a model for a microstrip PCB (Figure 1c), the top copper layer is assumed to be the signal layer (or the hot reservoir) while the bottom copper layer is assumed to be the ground plane (or the cold reservoir).

In this basic thermal model, the relationship for the transfer of heat between the hot and cold reservoirs is:

$$H = -kA\frac{\Delta T}{L}$$

$$H = -kA\frac{\left(T_H - T_c\right)}{L} \qquad (1)$$

where H is the heat flow, k is the thermal conductivity, A is the area at the reservoir-thermal conductor interface, ΔT is the heat difference and L is the length of the thermal conductor joining the reservoirs. In this model, it is assumed that the temperature in the thermal conductor has reached equilibrium. The simple model and the equations indicate that less heat transfer will occur between reservoirs for a thermal conductor with low thermal conductivity. The distance between the reservoirs will also impact the amount of heat transferred, while a thinner thermal conductor will increase heat flow.

Fitting this simple model to a microstrip PCB, the PCB's signal layer is assumed as the hot reservoir and the PCB's ground plane is the cold reservoir (see ***Figure 2***). It is also assumed that the ground plane is thermally attached to an efficient heat sink to maintain a

JOHN COONROD
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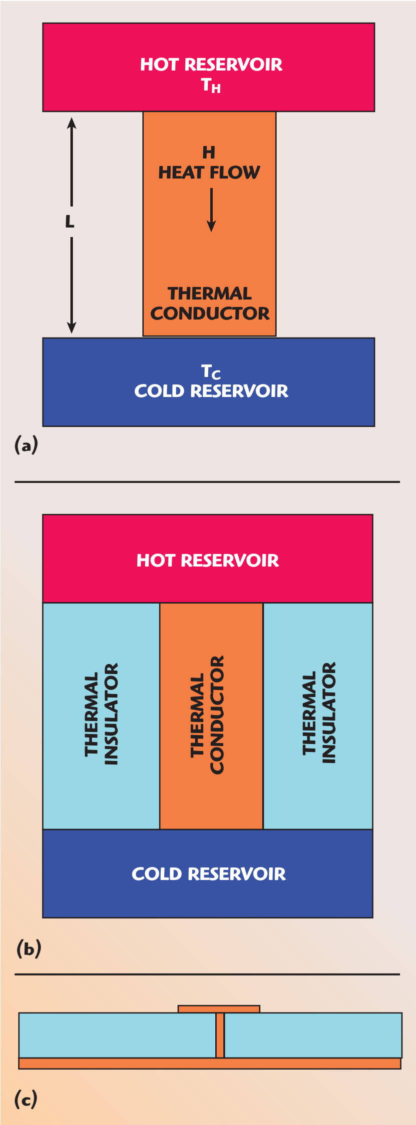
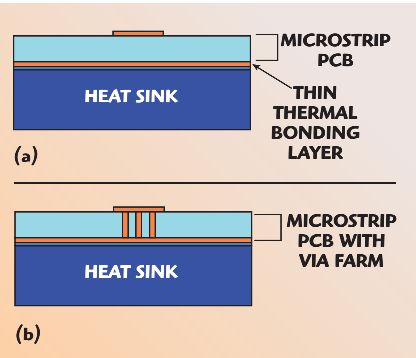


▲ *Fig. 1 Basic heat flow models.*



▲ *Fig. 2 Cross-sectional views of a microstrip PCB: (a) without via farm and (b) with via farm.*

TABLE I

COMPARISON OF MICROSTRIP LINES OF DIFFERENT THICKNESSES AND TC VALUES

	Thickness (mils)	TC (W/m/K)	Dk	Df	Freq. (MHz)	RF Power (W)	Temperature Rise Above Ambient (C)
Material A	20	0.25	3.50	0.0023	3000	30	45
Material A	10	0.25	3.50	0.0023	3000	30	36
Material B	20	0.50	3.50	0.0023	3000	30	23

TABLE II

THERMAL CONDUCTIVITIES FOR COMMON HIGH FREQUENCY CIRCUIT MATERIALS

	TC (W/m/K)
High Tg FR-4	0.24
Nearly Pure PTFE	0.20
Ceramic Filled PTFE	0.50
RO4350B™ Laminate	0.62
RT/duroid® 6035HTC Laminate	1.44

constant temperature, which is significantly lower than the signal plane.

The areas of a microstrip PCB may be with or without PTH via holes. A model corresponding to a microstrip PCB in an area with no PTH via holes is shown in Figure 2a, while a model representing a microstrip PCB in a grounded area, where numerous PTH via holes are used to join two copper layers, is shown in Figure 2b. The model of Figure 2(b) is common for microstrip PCBs on which an active device, such as a power transistor, is mounted and is generating heat. The numerous PTH holes under the heat generating device is called a via farm.

When several materials with different thicknesses and TC values are compared, as in ***Table 1***, and other key parameters are kept the same, such as input test power and frequency, the impact on the thermal rises of those different materials is easily seen. For example, the three materials in Table 1 are treated with similar values of relative dielectric constant (Dk) and dissipation factor (Df), and the same frequency (3000 MHz) and power level (30 W). There are no grounding via holes in any of the materials, but the temperature rise above ambient is different for all three materials, depending upon material thickness and TC value. The highest temperature rise above ambient occurs for the thickest PCB material with the lowest TC value. In this model, which is known to be very conservative but valid for the sake of this simple comparison, there is no grounding via hole.

As Table 1 shows, PCB materials with a lower value of TC suffer a higher temperature rise above ambient for a given amount of applied power, while higher values of TC result in lower temperature rises above ambient. Some of the TC values for materials commonly used in high frequency PCBs are shown in ***Table 2***. Unfortunately, most of the PCB materials used in the microwave industry exhibit relatively low TC values.

In terms of thermal conductivity, laminates, such as RO4350B™ and RT/duroid® 6035HTC from Rogers Corp., offer high values, compared to FR-4 substrates often used in high frequency circuits. Still, the TC of conductive copper metal is about 400 W/m/K, some orders of magnitude higher than the TC values for any of the substrates in Table 2. This shows that copper PTH vias can have a major impact on the heat flow within a microwave PCB.

To understand the effects of TC for different PCB materials, a thermal imaging study was performed using microstrip constructions and different substrate materials with significantly different TC values. Heat flow effects for these materials were also studied with and without via farms. DC heating was used to eliminate several microwave thermal variables and focus on the effects of TC on different PCB materials. All substrates in the study were 20 mils thick with a 100 Ω termination resistor and the same copper features, although different substrate materials were used. Once DC power was applied, each circuit and termination resistor was allowed to reach thermal equilibrium. ***Figure 3*** shows the difference in heating above ambient temperature (25°C) for circuits without a via hole farm, using different materials. As seen in Figure 3, and referenced in Table 2, materials with the highest TC values exhibit the lowest temperature rises. When these curves are compared to circuits using via farms, which can channel some of the heat, the heat rise

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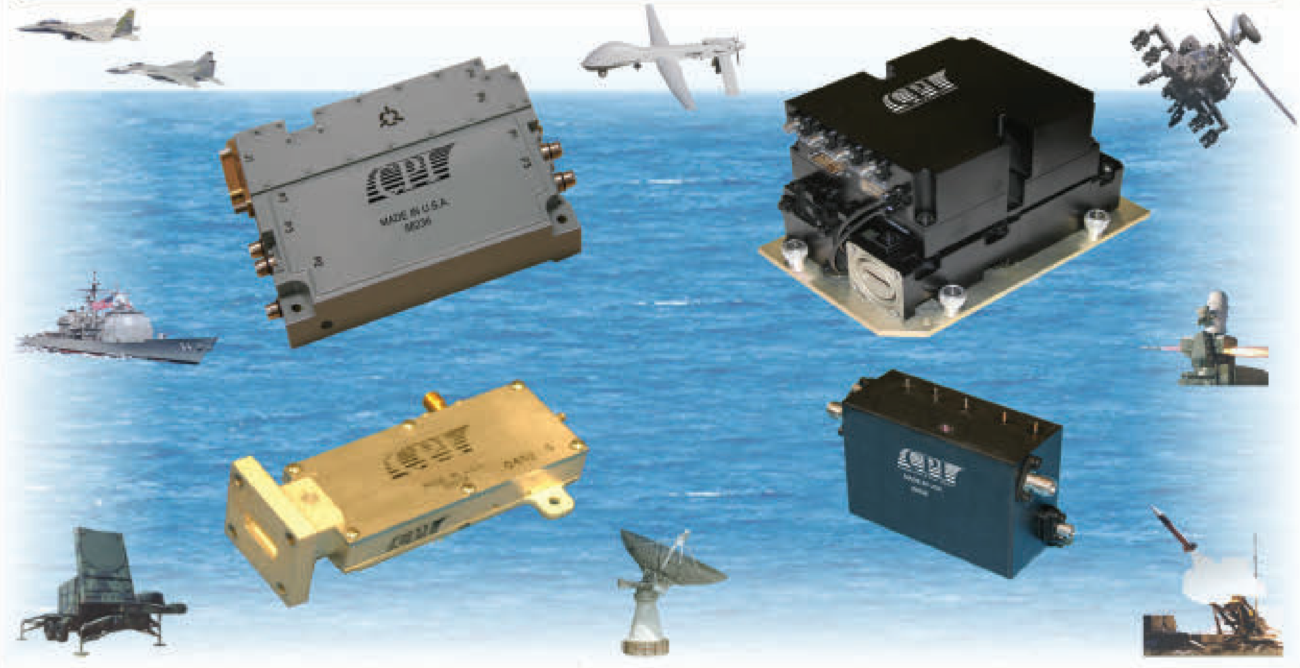

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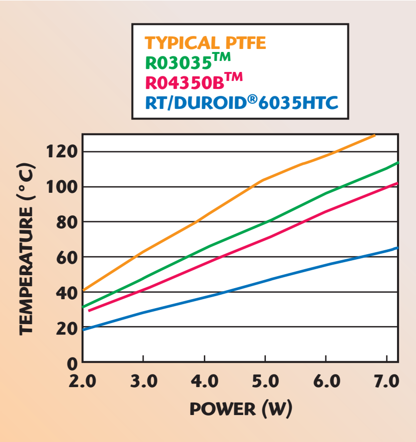
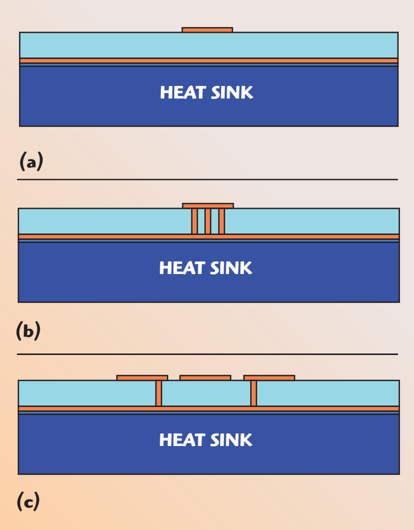


▲ *Fig. 3 Comparison of heat rise above ambient with substrates having different TC values.*

is less for each circuit, although the general trends are the same.

Figure 4 shows cross-section views of the microstrip example (a) without via holes, (b) with a via farm, and (c) with a via fence. The microstrip without via holes is typically of an RF signal, where the active signal trace cannot be connected to the ground plane. In this case, the TC property of the material is critical for minimizing the heat rise. Of course, a thinner substrate will also shorten the heat flow path and reduce the heat rise of the circuit.

For microstrip circuits with active devices that generate heat, the configuration in Figure 4b, with via holes, is commonly used to improve thermal dissipation. An active device may require ground connections anyway, so the use of copper PTH via holes as thermal connections from the active device to ground can greatly aid the thermal management of the PCB.



▲ *Fig. 4 Cross-sectional views of microstrips: (a) without via farm, (b) with via farm and (c) with a via fence.*

The microstrip PCB configuration shown in Figure 4c is somewhat more uncommon than the other circuits. According to the area of the cross-sectional view, the circuit configuration of Figure 4c is more like a grounded coplanar waveguide than microstrip, with the benefit of allowing active circuit traces that cannot be grounded by means of via hole connections to dissipate heat by means of PTH via holes through x-y plane thermal conduction. In such a case, the substrate material's TC value is critical for optimum heat dispersion. In this circuit configuration, the spacing on the signal plane between the active trace and the coplanar ground with the via hole fence should be small compared to the substrate thickness. The spacing can be in the range of 125 µm (5 mils). By minimizing the heat flow path, the transfer of heat from an RF signal trace to the ground plane is made more efficient. In this configuration, some electrical concerns must be addressed regarding the close proximity of the coplanar ground to the signal trace.

One part of proper thermal management in microwave PCBs involves understanding the relationship between circuit losses, applied power and heating effects. High frequency circuit heating is essentially associated with losses in the circuit. And in microstrip circuits, such as the example, there are several types of losses, including conductor losses, dielectric losses and radiation losses. Conductor losses are related to the circuit design as well as the choice of substrate. Most substrates are available with different types of copper cladding and the choice of copper can impact the loss performance. For example, copper conductors with rough surfaces will suffer higher losses than copper conductors with smooth surfaces. The quality of the copper-substrate interface can also impact the loss performance of a microstrip PCB.

Another material parameter that can affect loss is a PCB material's Df. A lower value for Df results in less di-

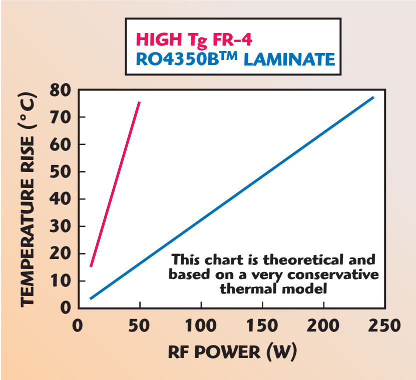
electric loss and less heat generated in the PCB. In addition, a PCB with low Dk will also yield less loss and less generated heat than materials with higher Dk values. This is assuming that a controlled-impedance circuit design is necessary and a material with a lower Dk allows the use of wide conductors. Wider conductors yield lower conductor losses than narrower conductors.

In brief, a short list of ideal material properties for improved thermal management includes high TC, low Df, smooth copper surface, thin laminate and low Dk. Of course, in practical designs, there are always tradeoffs involved. An example can help to demonstrate this. This example employs a 20 mil microstrip transmission line on a substrate with Dk of 3.5 and handling 30 W RF power at 3 GHz. The circuit is required to achieve good low loss performance. It is based on a ceramic-filled PTFE substrate with Df of approximately 0.0023. Because of the high cost of PTFE material and its associated fabrication processing, a lower cost alternative substrate was considered for the example, a hydrocarbon laminate with Df of 0.0037.

Using a simple model to compare the substrates, the predicted temperature rise above ambient temperature is approximately 45°C for the PTFE substrate and approximately 21°C for the hydrocarbon laminate. Although the PTFE substrate has a lower Df than the hydrocarbon laminate, the latter has a lower heat rise due to its TC value of 0.62 W/m/K compared to only 0.25 W/m/K for the PTFE laminate.

The maximum operating temperature (MOT) of a microwave PCB is an important parameter to consider as part of thermal management planning for a circuit design. Determined by a certification process from Underwriters Laboratory (UL), the MOT cannot be exceeded for any length of time to ensure the integrity of the PCB. Short-term elevated temperatures associated with soldering and assembly are not related to the MOT. Rather, it is long-term issues, at higher temperatures, that are a concern for achieving thermal management with a microwave PCB. In fact, MOT can be used in a simple circuit model to illustrate some differences in materials when considering a 20 mil microstrip transmission line.

The MOT in this example circuit is assumed to be +105°C, and the ambient (room) temperature is +25°C. The goal in this example is to avoid a temperature rise of more than 80°C, in order not to violate the MOT for this material. As ***Figure 5*** shows, the choice of PCB material can greatly impact the amount of power that can be carried by a microwave circuit, with materials having higher TC values and lower Df. The example is based on a frequency of 800 MHz; at higher frequencies, more heating will occur for the same RF power level. While the conductor copper roughness mentioned earlier may have minimal effects at lower frequencies, it can impact losses more at higher frequencies, translating into additional heat generated in a PCB with copper conductors having a rough copper surface.



▲ *Fig. 5 Example of a 20 mil microstrip line using two different substrate materials.*

In summary, it is possible to envision heat flow through a high frequency PCB by means of a simple model. Using such a simple model helps illustrate the benefits of circuit materials with high thermal conductivity and can help when developing strategies for effective PCB thermal management. Via farms can be an effective method of improving heat flow through a PCB, although it may not always be possible to employ this technique with active RF signal traces. In general, attention to selecting circuit material with favorable attributes, such as improved TC, low dissipation factor, smooth copper conductor surface and low dielectric constant, cannot only help in the design of a high performance PCB, but also lead to improved thermal management. ■

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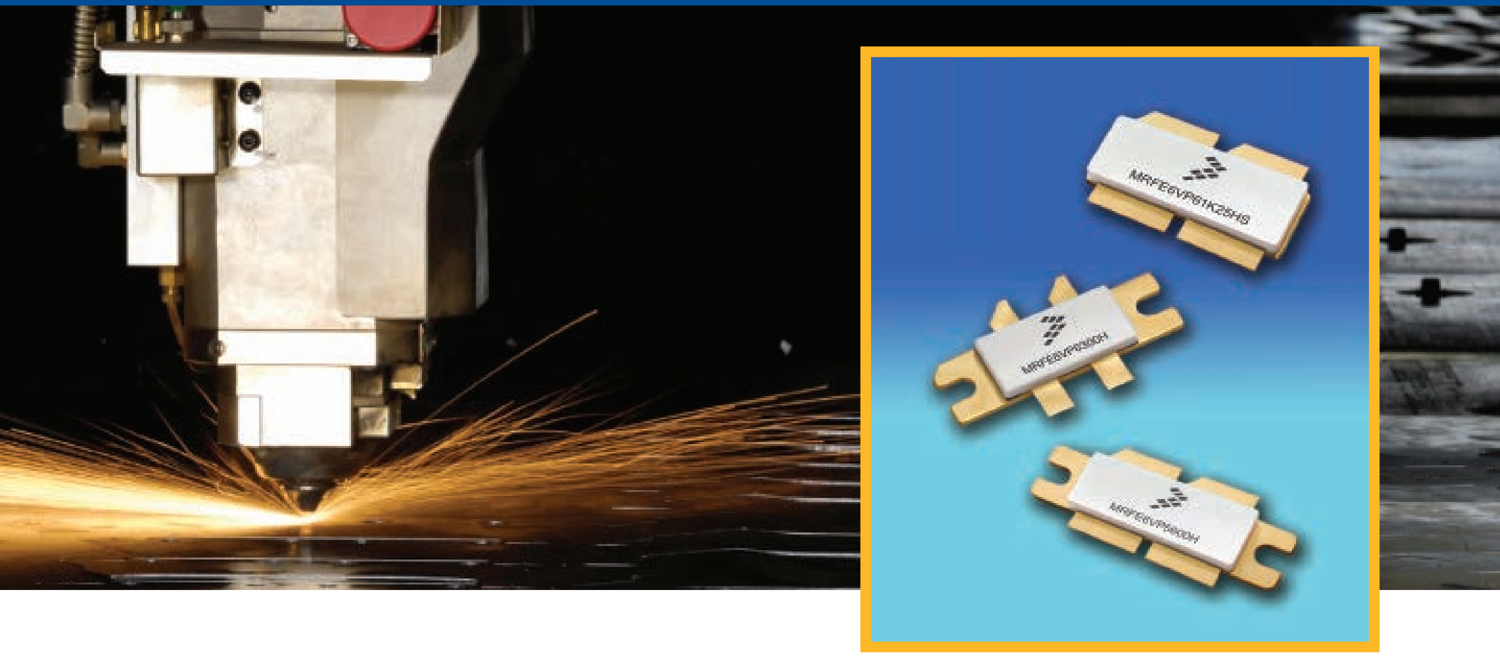

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A Compact Dual-Wideband Bandpass Filter Using Spiral-Shaped Multi-Mode and Complementary Split Ring Resonators

In this article, a novel miniaturized dual-wideband bandpass filter is introduced, using spiral-shaped multi-mode resonators. The proposed structure consists of a pair of λ/4 transmission lines and a loaded transmission line with two balanced spiral-shaped high impedance transmission lines, instead of the conventional λ/2. This replacement leads to a high level of miniaturization for these components. Then, a complementary split ring resonator is utilized to realize a dual-wideband BPF. A compact dual-wideband BPF is designed, analyzed and tested, where two transmission zeros, at both the lower and upper stopbands of each band, guarantee a high level of suppression in the rejection bands with sharp skirts.

Current advances in modern wireless communication systems have created the demand for smaller, more reliable and low cost microwave components. Meanwhile, many communication systems operate in dual-bands, which necessitate complicated technologies to realize such components. Dual-wideband bandpass filters (BPF) are one of the most popular components increasingly investigated in most recent studies. On one hand, these should be designed to realize a wide passband and, on the other hand, they should provide dual-band behavior. This duality makes the design of these elements so complicated that designers have to use a complex technology or a multi-layered one.[1-3]

Several investigations have introduced many dual-band BPFs using different topologies. However, they show a narrow bandpass and still occupy a relatively large area.[4,5] Additionally, several techniques have been proposed to design such components, which can provide dual-band behavior but with complicated technologies, including short-circuited stubs.[6,7]

One of the recent classes of wideband components, using a multi-mode resonator, is the best candidate to realize wideband structures.[8,9] However, it is not able to demonstrate a dual-band. While complementary split ring resonators (CSRR) are the best ones to realize dual-band components that may provide dual-

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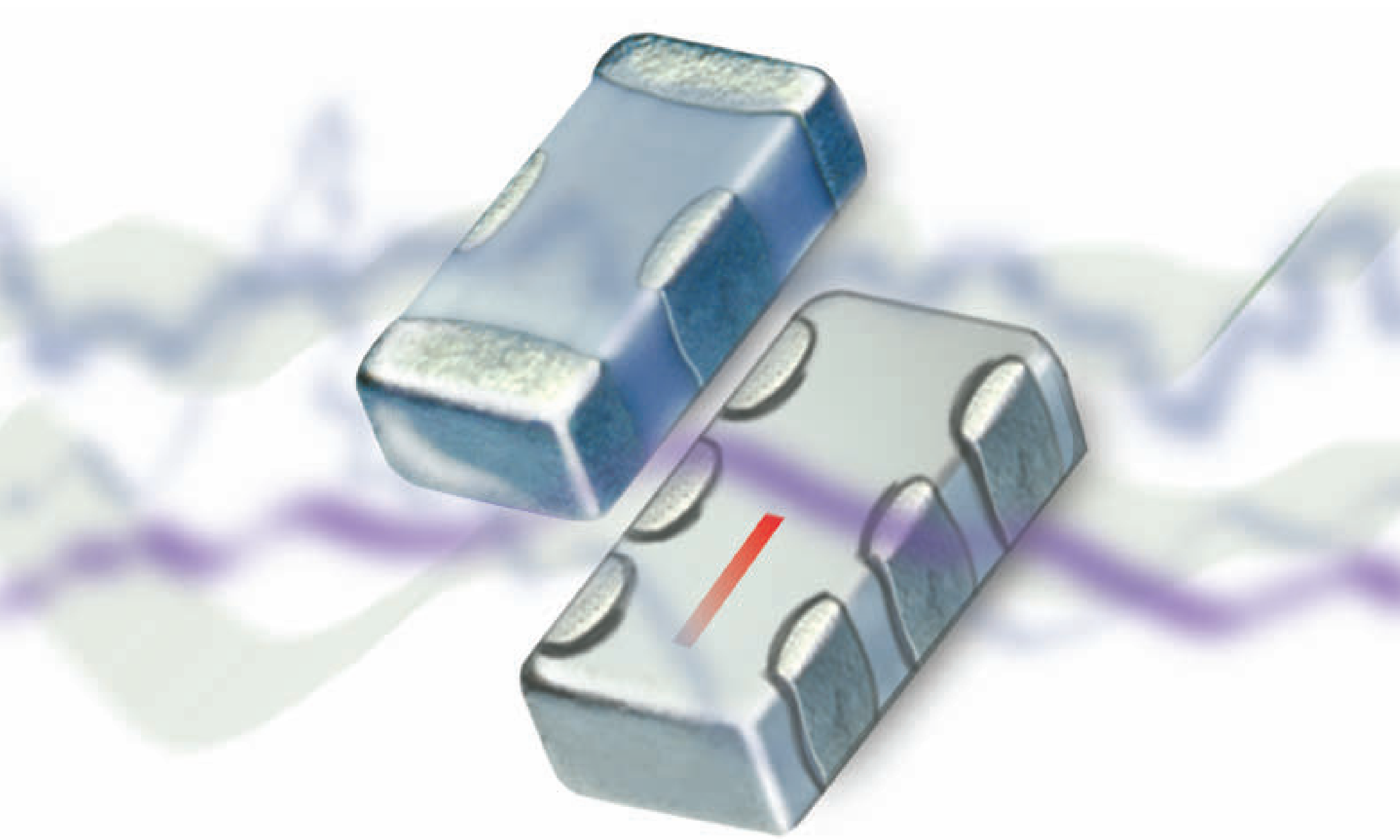

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wideband BPFs in combination with multi-mode ones, in the structures of these wideband components, there is no capacitive coupling to combine with CSRRs. However, it should be noted that there is a coupling structure between the feed and the quarter-wavelength transmission lines in the layout of these multi-mode ones. Simulation shows that this combination with CSRRs not only does not provide dual-band behavior, but also reduce their performance by reducing their zeros near the center frequencies.

In this article, a novel combination of a multi-mode resonator with CSRR is proposed, in which an extra coupling structure is used to combine with the second resonator. The developed structure consists of a pair of λ/4 transmission lines similar to the basic topology of these resonators, as well as a loaded transmission line with two balanced spiral-shaped, high impedance, transmission lines instead of the conventional λ/2. In addition to providing a dual-band performance, the overall size of these multi-mode resonators is significantly reduced, accompanied with wider passbands, using this proposed topology. A novel compact dual-wideband BPF was designed and fabricated, based on this technique, on a 0.755 mm thick substrate with $\varepsilon_r = 2.56$. The measured frequency response of the proposed filter agrees closely with the simulated one.

DESIGN PROCEDURE

Capacitive Gap Structure (CGS) of the Multi-Mode Resonator

As stated, to utilize CSRRs for the realization of a dual-wideband BPF, it is necessary to have a capacitive gap structure in the layout of multi-mode resonators. Here, the layout of these resonators is initially developed in order to provide a CGS and afterward, a CSRR is used to ascertain the idea. To get an analytical view of the design of the proposed dual-band BPF, the structure of the recent multi-mode resonator is initially followed as shown in ***Figure 1***. Observing the structure of the conventional multi-mode resonator, including two pairs of quarter wavelength and a loaded λ/2 transmission lines, the only coupling structure of this topology is between the feed and the quarter wavelength transmission line, for which EM simulation shows that it does not provide dual-band passband in combination with CSRRs. As indicated in the figure, this conventional layout is modified to realize a capacitive coupling structure. As demonstrated, two balanced high impedance transmission lines are added to the λ/2 transmission line of the structure as the main resonator to realize capacitive gaps between their ends and the main resonator.

By considering the reactance X for the coupling structure, it can be shown by calculating the ABCD matrix of the layout that the C component of this matrix can be expressed as follows:

$$C = \frac{A}{jZ_L Z_H \left[0.5Z_S(Z_S \tan\theta_2 - X) + Z_L \tan\theta_1 (Z_S + X\tan\theta_2)\right]} \quad (1)$$

where A is a coefficient in terms of the structure's parameters and the denominator values are provided in the diagram schematic given in Figure 1.

According to Equation 1, to determine the zeros of the structure near the center frequency f_0, the denominator is equated to zero, which implies the following equation:

$$0.5Z_s\left(X - Z_s \tan\theta_2\right) = Z_L \tan\theta_1 \left(Z_s + X\tan\theta_2\right) \quad (2)$$

To simplify the analysis, if Z_S is chosen to be equal to $2Z_L$, the following equation is derived:

$$X = Z_s \tan(\theta_1 + \theta_2) \quad (3)$$

where X is the reactance created by the coupling structure. Similarly and according to Equation 1, by choosing $\theta_1 + \theta_2 = 2\theta$, and simplifying the equation, it can be demonstrated that the zeros near the resonant frequency can be specified as $f_{z1} = f_0/2$ and, $f_{z2} = 3f_0/2$, which are exactly located at the lower and upper sides of the center frequency.

By replacing the layout of the recent conventional multi-mode resonator with the proposed one, it can be shown that this structure realizes a wider BPF in pass-

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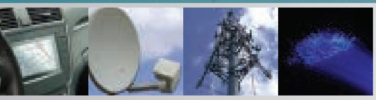

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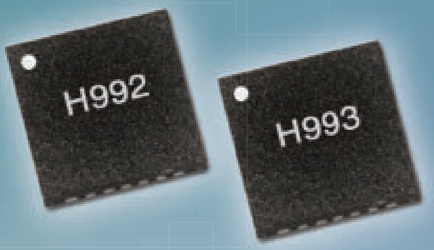

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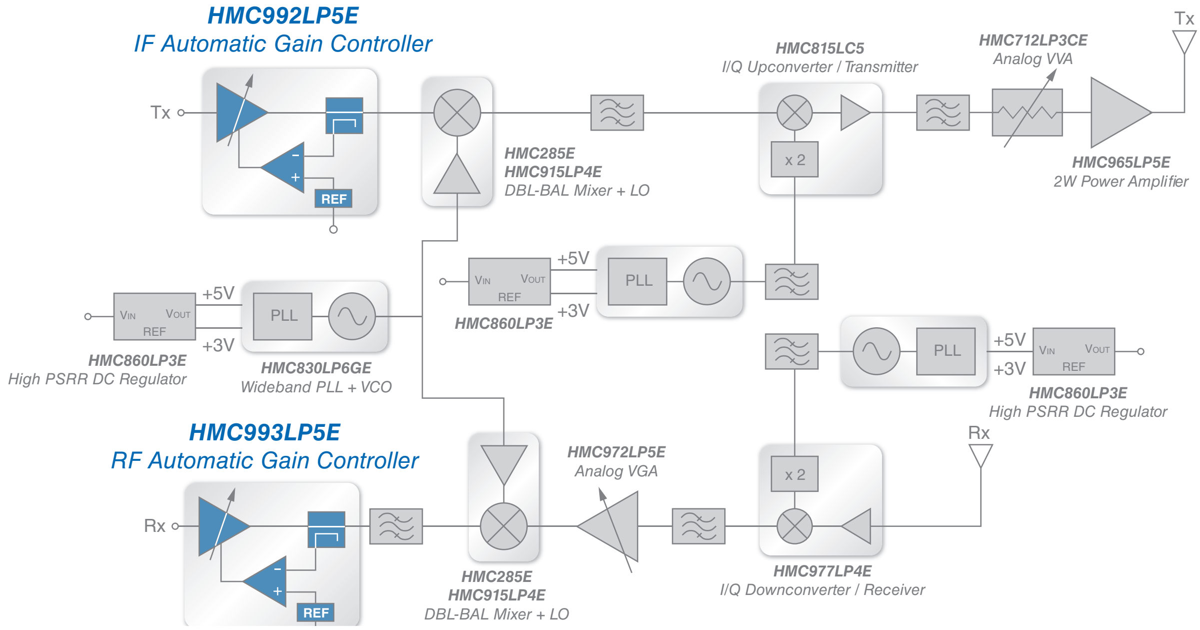

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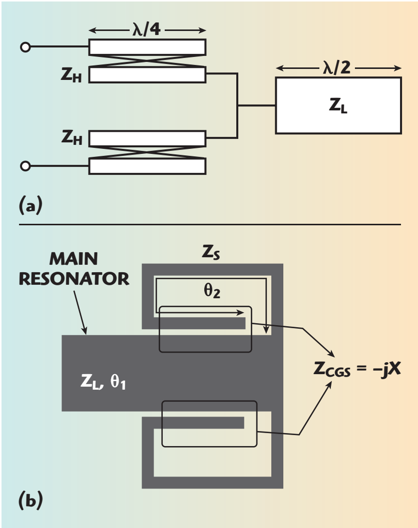


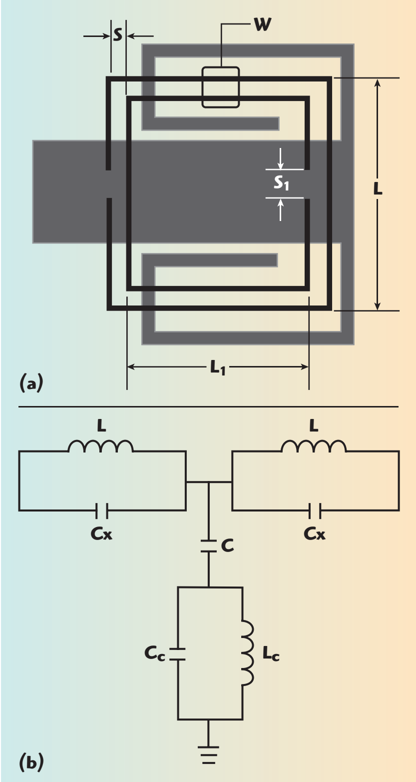
▲ *Fig. 1 (a) Schematic of the conventional multi-mode resonator and (b) proposed layout for the λ/2 transmission line of the conventional one.*

band, with a notable size reduction in comparison with a conventional one.[9] It is demonstrated that this compact multi-mode resonator realizes a dual-wideband BPF in combination with a simple CSRR.

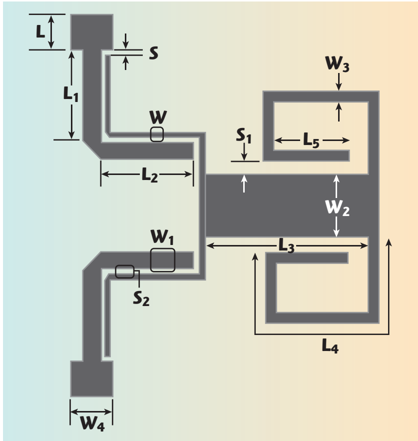
DUAL-WIDEBAND BANDPASS FILTER

As indicated in the previous section, the capacitive gap structures can be created in the structure of the conventional multi-mode resonator to utilize complementary split ring resonators and subsequently realize a dual-wideband bandpass filter. As indicated in the schematic diagram provided in ***Figure 2***, the CSRR is placed exactly at the bottom of the CGS in the proposed multi-mode resonator. Its dimensions are: L = 6.8 mm, L_1 = 2.6 mm, W = 0.2 mm, S = S_1 = 0.2 mm.

The equivalent circuit of the proposed model can be derived as indicated in Figure 2, where the L and C represent the inductor and capacitor created by the high impedance spiral-shaped TL with a characteristic impedance Z_S and the CGS, respectively, and other elements represent the LC equivalent circuit of the CSRR. Needless to say, the bandwidth of two bands of the filter is directly proportional to these parameters. It is shown that the proposed compact multi-mode resonator realizes a dual-wideband BPF with better performance than that of the conventional ones.



▲ *Fig. 2 (a) Combination of the proposed multi-mode and complementary split ring resonators and (b) equivalent circuit model.*



▲ *Fig. 3 Layout of the dual wideband BPF.*

Based on the schematic diagrams provided, the final layout of the proposed dual-wideband BPF is prepared as shown in ***Figure 3*** without the CSRR. The dimensions are: L = 3.1 mm, L_1 = L_2 = 4.2 mm, L_3 = 5.4 mm, L_4 = 11.37 mm, L_5 = 0.5 mm, W = 0.2 mm, W_1 = 0.4 mm, W_2 = 0.85 mm, W_3 = 0.1 mm, W_4 = 1.5 mm, S = S_1 = S_2 = 0.05 mm. Observing the layout, the quarter wavelength lines coupled with the feed lines are bent to distance the two ports from each other, in order to avoid isolation problems and affect the performance of the filter.

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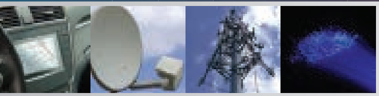

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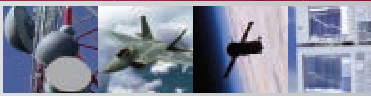

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	2 - 4	Analog	3.5	480° @ 2 GHz 450° @ 4 GHz	-40	0V to +13V	LP5	**HMC928LP5E**
	2 - 20	Analog	4	270° @ 2 GHz 180° @ 20 GHz	-45	0.5 to +11V	LP5	**HMC935LP5E**
	4 - 8	Analog	4	450° @ 4 GHz 430° @ 8 GHz	-40	0V to +13V	LP4	**HMC929LP4E**
	5 - 18	Analog	4	500° @ 5 GHz 100° @ 18 GHz	-80	0V to +10V	Chip	**HMC247**
	6 - 15	Analog	7	750° @ 6 GHz 500° @ 15 GHz	-40	0V to +5V	LP4	**HMC538LP4E**
	8 - 12	Analog	3.5	425° @ 8 GHz 405° @ 12 GHz	-35	0V to +13V	LP4	**HMC931LP4E**
NEW!	8 - 23	Analog Time Delay & Phase Shifter	-	500°	-35	2.7 to +3.9V	LC3	**HMC877LC3**
	12 - 18	Analog	4	405° @ 12 GHz 385° @ 18 GHz	-40	0V to +13V	LP4	**HMC932LP4E**
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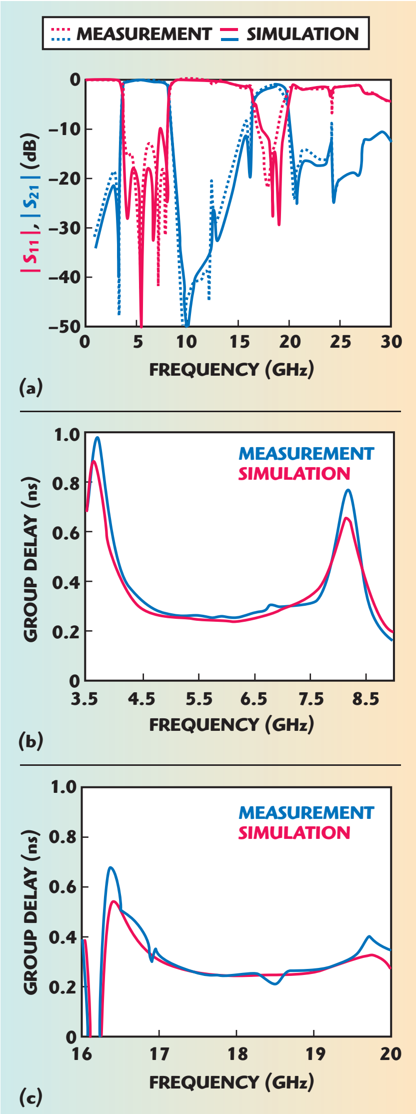
SIMULATION AND MEASUREMENTS

According to the specifications given in the previous sections, a compact dual-wideband BPF was designed and simulated. The design process of the filter is obvious, where the electrical length of the input lines (θ) coupled with the feed ones is initially chosen to be λ/4 for the given center frequency. Then, to make a simple analysis and have two zeros near the center frequency, the condition of $\theta_1 + \theta_2 = 2\theta$ is introduced, where the electrical length of θ_1 and θ_2 are chosen to be 50° and 110°C for size reduction and wideband properties, respectively.

It can be shown, by simulation and according to Equation 2, that the characteristic impedance Z_L plays a crucial role in the increase or decrease of the bandwidth of this filter, where the bandwidth is directly enhanced by increasing or decreasing this parameter. In the conventional investigations,[8,9] this parameter has usually been chosen with a low value as indicated in Figure 1. However, here it is chosen to be greater than the conventional ones and be approximately 84 Ω, for wideband properties. Additionally and based on the foregone approximation, Z_S is chosen to be equal to $2Z_L$ and subsequently as Equation 3 enforces, the reactance X is a high value, which can be practically realized by closing the ends of spiral-shaped TLs to the main resonator.

After the implementation of the proposed layout with initial values, a fine tuning process is carried out with an EM simulation tool (ADS software) to optimize the dimensions of the proposed BPF given previously for the CSRR and the multi-mode resonators, respectively.

The scattering parameters of the proposed dual-wideband BPF, measured with an Agilent 8722ES network analyzer over the frequency range from 1 to 25 GHz, are given in ***Figure 4***. The measured central frequencies are 6 and 18.1 GHz with 3 dB bandwidths of 75.83 percent (from 3.62 to 8.17 GHz) and 15.47 percent (from 16.6 to 19.4 GHz), respectively. Notably, the bandwidth of the first band of the proposed BPF is much wider than that of the conventional ones designed using multi-mode resonators,[8,9] presented as wide single band BPFs as well as the dual-band ones proposed by Chin and Zhu.[6,7]



▲ *Fig. 4 Performance of the proposed dual-wideband BPF (a) scattering parameters, (b) and (c) group delay at the first and second bands.*

Additionally, the proposed dual-wideband BPF occupies an active circuit area approximately 17.6 × 11.5 mm on its substrate in comparison with the conventional ones,[7,9] whose sizes have been reported as 32.8 × 15.8 mm and 24 × 24 mm. In addition, the measured group delay is linear and flat in the passband for both two bands.

DUAL-WIDEBAND BPF WITH DIFFERENT BANDWIDTH

According to the equations obtained in the previous section, the performance of the dual-wideband BPF directly depends on the specified parameters of the structure. The frequency response of the dual-wideband bandpass filter can be examined for different values of some param-

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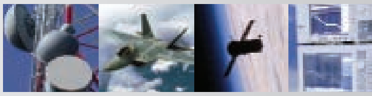

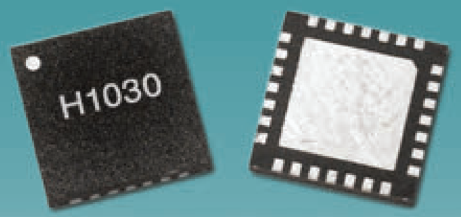

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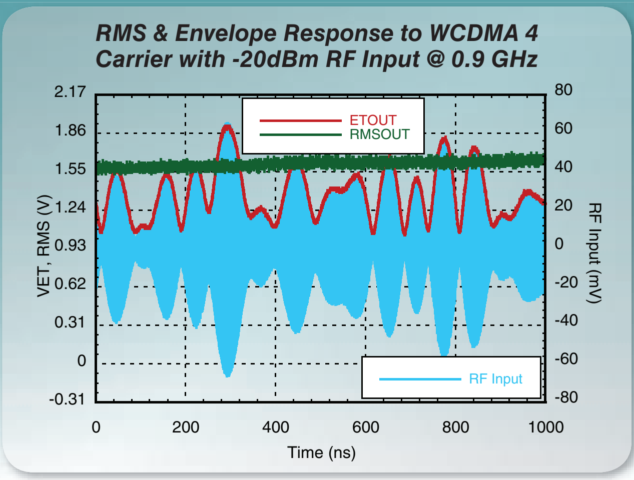

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	DC - 3.9	RMS, Single-Ended	71 ±1	35	-68	+5V @ 70 mA	LP4	**HMC1021LP4E**
NEW!	DC - 3.9	Dual RMS, Single-Ended	70 ±1	38.5	-66	+5V @ 143mA	LP5	**HMC1030LP5E**
	DC - 5.8	RMS, Single-Ended	40 ±1	37	-69	+5V @ 42mA	LP4	**HMC909LP4E**
	50 Hz - 3.0	Log Detector / Controller	74 ±3	19	-66	+3.3V @ 29mA	LP4	**HMC612LP4E**
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	0.1 - 2.7	Log Detector / Controller	54 ±1	17.5	-52	+5V @ 17mA	MS8	**HMC713MS8E**
	1 - 23	mmW Log Detector	54 ±3	14.2	-52	+3.3V @ 91mA	LP3	**HMC948LP3E**
	8 - 30	Log Detector	54 ±3	13.3	-55	+3.3V @ 88mA	LP3	**HMC662LP3E**
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NEW!	0.5 - 18.5	SDLVA, Extended Range	67	15	-62	+3.3 @ 183mA	LP4	**HMC1013LP4E**
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	0.6 - 20	SDLVA	59	14	-54	+3.3V @ 80mA	LC4B	**HMC913LC4B**
	1 - 20	SDLVA with Limited RF Output	55	15	-53	+3.3V @ 153mA	LC4B	**HMC813LC4B**
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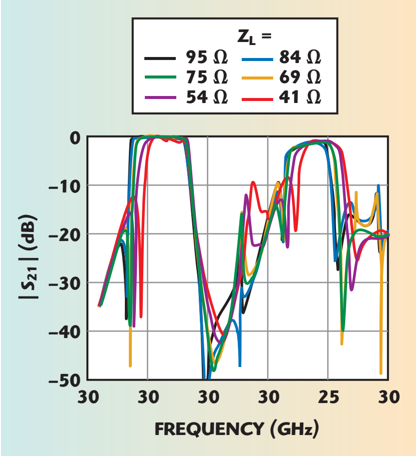

▲ *Fig. 5 Frequency response of the proposed dual-wideband BPF for different values of Z_L.*

eters. The performance of this filter was evaluated for different values of the characteristic impedance Z_L of the main resonator. Based on Equation 1, the zeros of the structure are derived by equating the denominator to zero. Since the impedance Z_L plays a crucial role in determining the zeros and subsequently the bandwidth of the filter, the performance of the filter was simulated for different values of this parameter. By keeping fixed the optimized values of the other parameters except S_1, Z_L is varied from 41 to 95 Ω and the frequency response of the proposed filter is simulated. ***Figure 5*** provides the performance of this filter for these different values.

Observing the performance of the proposed structure, it is obvious that the more Z_L is reduced, the more the bandwidth of the first band is reduced and the center frequency of the second band is also shifted toward the higher frequencies. According to this, it can be concluded that the zeros of this structure can be tuned and controlled by varying the impedance Z_L.

CONCLUSION

A compact dual-wideband bandpass filter (BPF) has been designed and proposed using spiral-shaped multi-mode and complementary split ring resonators. The diagram schematic of the proposed dual-band BPF has been reported to consist of a pair of λ/4 transmission and a loaded transmission line with two balanced spiral-shaped high impedance transmission lines instead of the conventional λ/2, which leads to a high level of size reduction in such components. Following, a complementary split ring resonator has been utilized to realize a dual-wideband BPF. A compact dual-wideband BPF has been designed, analyzed and tested, where two transmission zeros at both the lower and upper stopbands of each band guarantee a high level of suppression in the rejection bands with sharp skirts. The size of this filter has been reported to be decreased by approximately 64.86 percent and 60.94 percent in comparison with that of the conventional dual-band[7] and single wideband,[9] respectively, with a wider bandwidth. ■

ACKNOWLEDGMENT

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A Compact Microstrip Diplexer Using Composite Right-/Left-Handed Transmission Line with Enhanced Harmonic Suppression

In this article, a novel microstrip diplexer operating at 1.8 GHz (GSM band) and 2.2 GHz, based on composite right-/left-handed transmission line (CRLH TL), is presented. The CRLH TL, using only one cell, is initially proposed based on Koch-shaped extended complementary single split ring resonator pair (K-ECSSRRP) etched in the ground plane and a series capacitive gap etched in the conductor strip. The extended Koch ring has been demonstrated, resulting in a wideband harmonic suppression, enhanced frequency selectivity and a lower operating frequency of the diplexer. The high performance of the new structure enables the single cell to be well qualified for diplexer design and thus facilitates the compactness. The design concept has been verified by both numerical and experimental results of a fabricated prototype whose effective occupied area is only 15.6 × 28 mm.

The diplexer, commonly used to make receiving and transmitting share a common antenna, is an essential three-port device and typically consists of several bandpass (BPF) and bandstop (BSF) filters. Consequently, the performance of the BPF determines the comprehensive performance of the diplexer to a great extent. However, with recent advances and development in microwave and millimeter-wave receiver technology, a great demand for compact, low cost and high performance diplexers has been created. Several authors have focused on these issues and extensive research has been performed[1-8] using microstrip technology.

Although open-circuited stubs[1,2] can be adjusted for bandwidth and out-of-band rejection requirement, they increase the insertion loss and circuit size. Stepped impedance coupled-line resonators have been used to realize a high isolation hairpin line diplexer,[3] but it also brings other issues of large size and design complexity. The miniaturization issue was considered,[4] but the suppression of spurious response is still

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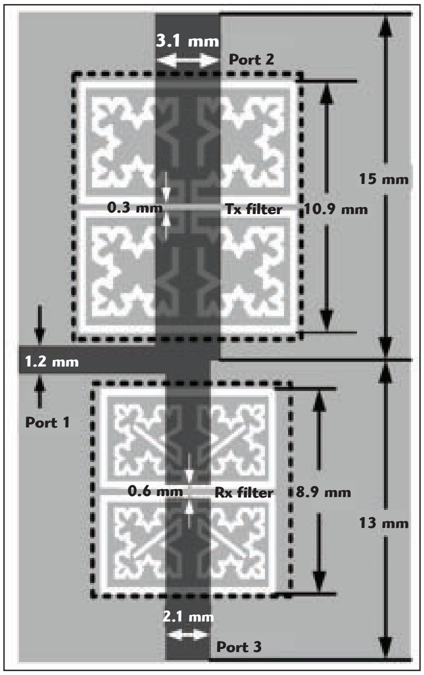
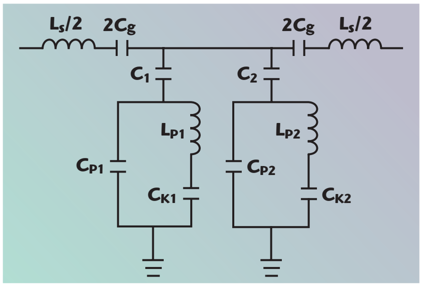


▲ *Fig. 1 Topology of the proposed diplexer.*

dependent on a tapped open-circuited stub. The frequency selectivity and isolation is fulfilled by cascading multi-complementary split ring resonators (CSRR),[5] but the occupied area is still a little large. Lumped-element loaded composite right-/left-handed transmission lines (CRLH TL)[6,7] is a good strategy for size reduction, but the operating frequency is limited due to self resonance. The integration of a diplexer and balun by adopting half-wavelength open-loop resonators[8] is implemented for low cost but the circuit area is a problem. In this article, the compact and high performance issues are addressed by introducing the fractal geometry into the design of new concept CRLH TL. The wideband harmonic suppression and frequency selectivity are realized by only one CRLH cell, which distinguish the current design from previous ones.

DIPLEXER DESIGN

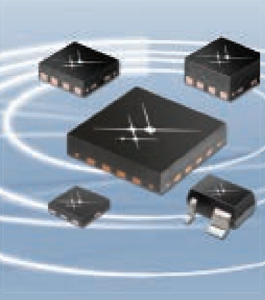
Figure 1 shows the topology of the fabricated microstrip diplexer, with an occupied area is only 15.6 × 28 mm (namely $0.15\lambda_g \times 0.275\lambda_g$, λ_g being the signal wavelength at 1.8 GHz). Note that the K-ECSSRRP, the ground plane and the conductor line are depicted in white, light grey and dark grey, respectively. The width of the K-ECSSRRP Tx filter is 0.3 mm and 0.2 mm for the Rx filter. The inner ring of the Tx filter is constructed by three Koch curves of the



▲ *Fig. 2 Circuit model of the K-ECSSRRP-loaded CRLH TL.*

second order and a Koch curve of the first order. The ring for the Rx filter is almost the same, but a stub is added at the end of the first order curve. As can be seen, the diplexer consists of three ports, a receiver (Rx) and a transmitter (Tx) filter cascaded at the output lines. The Rx and Tx filters, engineered to provide passbands centered at 1.8 and 2.2 GHz, respectively, are implemented by only one CRLH TL cell, which is the key factor of super compact performance. The CRLH TL cell is composed of a Koch-shaped extended complementary single split ring resonator pair (K-ECSSRRP), etched in the ground plane and a series capacitive gap etched in the conductor strip. The K-ECSSRRP can be constructed by inserting four identical Koch-curve-shaped rings in the complementary single split ring resonator pair (CSSRRP). The resultant four rings extend the current paths, thus allowing a more compact unit cell, and introduce additional attenuation poles at the frequency of spurious responses, which enables better frequency selectivity and wideband harmonic suppression.

The circuit model (losses have been excluded) of K-ECSSRRP-loaded CRLH TL is shown in ***Figure 2***. An additional shunt branch is added to model the influence of four inserted Koch-shaped rings on the overall performance of the filter. Consequently, the current structure enhances the design flexibility to a great extent. In this model, L_s represents the line inductance, C_g models the series gap capacitance, CSSRRP is described by means of a parallel resonant tank formed by L_{p1}, C_{p1}, and C_{k1}, C_1 represents in part the line capacitance and in part the electrical coupling through the series gap to the CSSRRP. In like manner, the other shunt branch formed by C_2, L_{p2}, C_{p2}, and C_{k2}, models the corresponding effect of the Koch-shaped small ring.



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SKY67100-396LF	Cellular Infrastructure	1200–2300	1950	17.5	0.7	34	18.5	4 (3.3–5.0)	55 (20–90)	DFN 8L 2 x 2 x 0.75
SKY67102-396LF	Cellular Infrastructure	2000–3000	2600	17.2	0.8	34	15	4 (3.3–5.0)	50 (20–90)	DFN 8L 2 x 2 x 0.75
SKY67001-396LF	Cellular Infrastructure	700–1000	900	17.5	0.6	40.5	21	5 (3.3–5.0)	100 (50–120)	DFN 8L 2 x 2 x 0.75
SKY67002-396LF	Cellular Infrastructure	1600–2100	1950	17.5	0.65	39.5	20	5 (3.3–5.0)	95 (50–120)	DFN 8L 2 x 2 x 0.75
SKY67105-306LF	Cellular Infrastructure	600–1100	850	37	0.7	41	26	5 (3.5–5.0)	140 (120–155)	QFN 16L 4 x 4 x 0.90
SKY67106-306LF	Cellular Infrastructure	1500–3000	1950	35	0.65	37	24	5 (3.5–5.0)	100 (80–125)	QFN 16L 4 x 4 x 0.90
SKY67014-396LF	General Purpose	1500–3000	2450	13	0.95	26	15	3.3 (1.8–5.0)	15 (5–30)	DFN 8L 2 x 2 x 0.75
SKY65047-360LF	GPS and ISM Band	400–3000	1575	16.6	0.8	19.5	0	3.3 (2.7–3.8)	7 (6.5–7.5)	DFN 8L 2 x 2 x 0.90
SKY65050-372LF	Broadband Low Noise FET	450–6000	2400	15.5	0.65	23.5	10.5	3 (2.7–3.8)	20 (5–55)	SC-70 4L 2.2 x 1.35 x 1.1
SKY65404-31	5.8 GHz WLAN and ISM Band	4900–5900	5800	13	1.2	20	9	3.3 (2.8–5.0)	11 (10–15)	DFN 6L 1.5 x 1.5 x 0.45
SKY65405-21	2.4 GHz WLAN and ISM Band	2400–2500	2450	15	1.1	24	15	3.3 (2.8–5.0)	12 (10–16)	DFN 6L 1.5 x 1.5 x 0.45

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Two transmission zeros are obtained and calculated as follows, when the two shunt branches resonate according to the circuit model.

$$f_{T1} = \frac{1}{2\pi}\sqrt{\frac{C_{p1}+C_{k1}+C_1}{(L_{p1}C_{k1}(C_{p1}+C_1)}} \quad (1)$$

$$f_{T2} = \frac{1}{2\pi}\sqrt{\frac{C_{p2}+C_{k2}+C_2}{(L_{p2}C_{k2}(C_{p2}+C_2)}} \quad (2)$$

The lower limit of the RH band f_{RH}^{L} can be inferred when the series branch resonates.

$$f_{RH}^{L} = f_{se} = 1/2\pi\sqrt{L_s C_g} \quad (3)$$

The admittance of the shunt branch consisting of two shunt admittances is formulated as

$$Y = Y_{p1} + Y_{p2} = \quad (4)$$

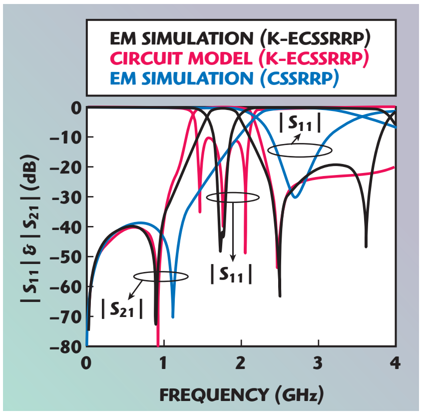
$$\frac{j\omega C_1\left[C_{p1}+C_{k1}-\omega^2 L_{p1}C_{p1}C_{k1}\right]}{C_{p1}+C_{k1}+C_1-\omega^2 L_{p1}C_{k1}\left(C_{p1}+C_1\right)} + \frac{j\omega C_2\left[C_{p2}+C_{k2}-\omega^2 L_{p2}C_{p2}C_{k2}\right]}{C_{p2}+C_{k2}+C_2-\omega^2 L_{p2}C_{k2}\left(C_{p2}+C_2\right)}$$

Therefore, the upper limit of LH band f_{LH}^{H} is achieved by forcing Y to be null. When $f_{RH}^{L} = f_{LH}^{H}$, the balanced condition is fulfilled and there is continuous transition between a left-handed (LH) band and right-handed (RH) band. Moreover, the Bloch impedance, which is associated with series impedance Z_s and shunt impedance Z_p as follows, is forced to be null to obtain the lower limit of LH band f_{LH}^{L} and the upper limit RH band f_{RH}^{H}

$$Z_\beta = \sqrt{Z_s(jw)\left[Z_s(jw)+2Z_p(jw)\right]} \quad (5)$$

The deductions of f_{LH}^{H}, f_{RH}^{L} and f_{RH}^{H} involve tedious calculation, thus are not reproduced here, but can be easily illustrated by their representations with a computer.

Equations 1 to 5 have been engineered as design guidelines to control the center frequency, bandwidth and selectivity (transmission zeros) of the Tx and Rx filters. As a demonstration, the frequency response (see ***Figure 3***) of a K-ECSSRRP-loaded CRLH TL whose geometrical parameters are kept the same as Tx filter but with a narrower conductor line and series



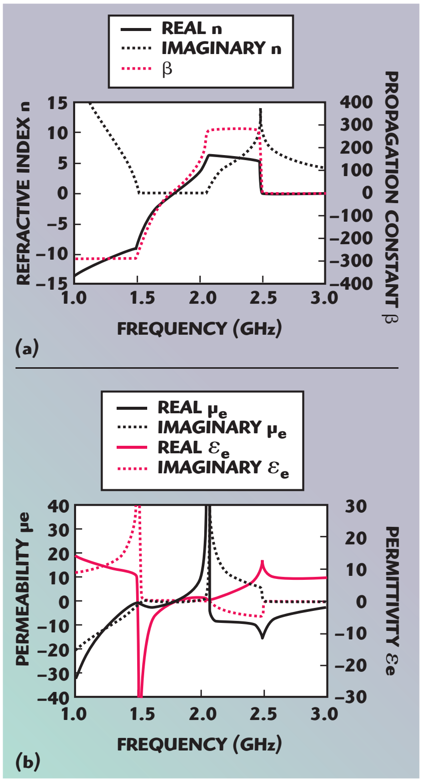
▲ *Fig. 3 Comparison of S-parameters obtained by EM simulation and electrical simulation.*

gaps whose widths are 2 and 0.2 mm, respectively, is obtained from a full-wave electromagnetic (EM) simulation using Ansoft Designer and an electrical simulation (circuit model) through Ansoft Serenade. The frequency response of CSSRRP-loaded CRLH TL with identical geometrical parameters is also provided for comparison. The analysis and current diplexer design are implemented on RT/duroid 4300C substrate with a dielectric constant of 3.38 and a thickness of 0.5 mm. The extracted lumped elements are: L_s = 31.2 nH, C_g = 0.26 pF, C_1 = 6.74 pF, C_{k1} = 351.4 pF, C_{p1} = 0.59 pF, L_{p1} = 4.26 nH, C_2 = 1.33 pF, C_{k2} = 2.16 pF, C_{p2} = 0.1 pF, L_{p2} = 4.84 nH.

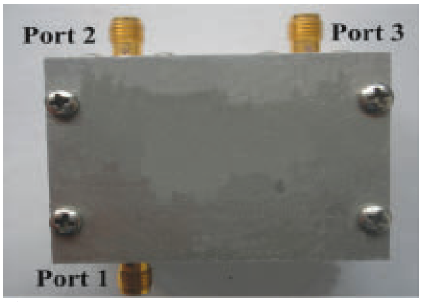
Consistent results between EM and electrical simulations can be observed. The slight discrepancy is due to the wideband considered, because any circuit model would deteriorate when the scope exceeds an appropriate frequency range. It is worth mention that the third attenuation pole in the EM simulation is due to the inherent periodicity of the physical structure and is, hence, impossible and does not need to be considered in the circuit model. A further inspection reveals that the Koch-shaped ring in CSSRRP, not only produces an additional transmission zero and shifts the inherent attenuation pole toward the lower band above the edge of the passband, but also results in a significant lower operating frequency, which is reduced from 2.7 to 1.8 GHz (a frequency downscale of 33 percent). The retrieved constitutive EM parameters shown in ***Figure 4***, based on an improved NRW method,[9] give strong support to the balanced composite

LH and RH passband behavior. Very obvious negative refractive index and backward wave propagation are obtained in the frequency range of 1.53 to 1.79 GHz (namely LH band). The RH band occurs around 1.79 to 2.05 GHz when these values are positive. Moreover, the K-ECSSRRP is still responsible for the negative permittivity. The negative permeability in the vicinity of the magnetic resonance is the key factor of the transmission zero located above the passband.

Given the determined Tx and Rx filters, the optimization of the final geometry of the diplexer is indeed very crucial. The conductor line is set to be 1.2 mm, corresponding to characteristic impedance of a standard 50 Ω SMA connector, while the width of the upper conductor lines of the Tx and Rx filters is adjusted for the comprehensive impedance match performance, which accordingly distinguishes them from ones in separate Tx or Rx filters.



▲ *Fig. 4 Retrieved constitutive EM parameters of K-ECSSRRP-loaded CRLH TL based on S-parameters.*



▲ *Fig. 5 Photograph of the fabricated diplexer in an enclosure.*

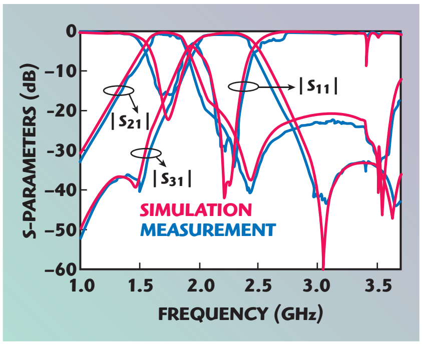
NUMERICAL AND MEASUREMENT RESULTS

The performance of the proposed diplexer has been assessed with Ansoft Designer. For verification, the diplexer was fabricated and measured with Anritsu ME7808A vector network analyzer. **Figure 5** shows a photograph of the fabricated prototype in an enclosure for practical military multi-service and multi-band communication systems application, while **Figure 6** compares the simulated and measured S-parameters. Reasonable agreement can be observed. The measured bandwidth of the Tx filter is 220 MHz for the 1.61 to 1.83 GHz range, in which the return loss $|S_{11}|$ is better than 10 dB and the insertion losses $|S_{21}|$ and $|S_{31}|$ are better than 1.5 dB. The measured bandwidth

of Rx filter is 330 MHz for the 2.08 to 2.41 GHz range, in which $|S_{11}|$ is better than 10 dB, $|S_{21}|$ and $|S_{31}|$ are less than 1.3 dB. Moreover, at the two target frequencies, $|S_{11}|=13.3$ dB, $|S_{21}|=0.95$ dB, $|S_{31}|=14.8$ dB and $|S_{11}|=28.5$ dB, $|S_{21}|=23.9$ dB, $|S_{31}|=0.58$ dB. The wide out-of-band suppression, better than 20 dB up to 3.66 GHz, should be highlighted.

CONCLUSION

For the first time, a compact diplexer has been presented by means of an initially proposed K-ECSSRRP. The proposed K-ECSSRRP with a dimension of $0.107\lambda_g$ is electrically very compact. The induced addition of transmission zero and frequency-shift transmission zero can be engineered at the frequency of spurious responses and thus enhance the harmonic suppression and selectivity to great extent. The resultant diplexer, which exhibits a low profile and a highly integrated circuit in conjunction with the enhanced selectivity and harmonic suppression, can find wide applications in transceiver front-ends of mobile and wireless local area network (WLAN) systems, phased-array transceiver systems and even military multi-service and multi-band communication systems where miniaturization is a concern. ■



▲ *Fig. 6 Measured and simulated S-parameters of the diplexer.*

ACKNOWLEDGMENTS

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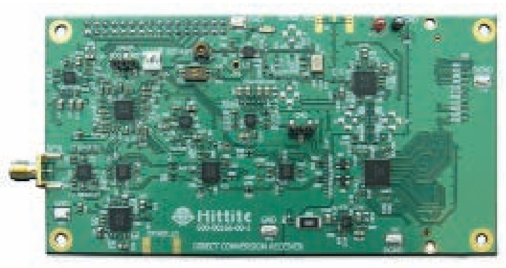

HIGH PERFORMANCE PROGRAMMABLE DIRECT CONVERSION RECEIVER PLATFORM

For many years, the wireless industry has been seeking a generic RF receiver that could adapt its frequency of operation and bandwidth to the desired signal, digitize the signal at high resolution and then demodulate the signal in software. The coexistence of various cellular (2G, 3G and 4G) and microwave point-to-point standards and bands of operation around the globe have created a real and pressing need for a flexible, multi-carrier, multi-standard, modular radio design that can be configured on the fly. To date, the so-called Software Defined Radio has been an elusive target due to the practical performance limitations of RF hardware.

Hittite Microwave has integrated a number of its discrete components onto a single direct conversion receiver (DCR) demonstration evaluation board. Hittite's DCR platform design features unparalleled receiver flexibility with no sacrifice in the high performance of its discrete parts (see ***Table 1***). The DCR can be configured to operate with input frequencies from 700 to 3000 MHz, with fully field programmable I and Q baseband bandwidths anywhere from 3.5 to 50 MHz, or equivalently 7

TABLE I

TYPICAL PERFORMANCE OF HITTITE'S DCR PLATFORM

Parameter	Typical Performance
Operating Frequency Range	700 to 3000 MHz
Analog-to-Digital Converters	14-bit @ 105 MSPS 12-bit @ 320 MSPS
Programmable Bandwidth	3.5 to 50 MHz Baseband 7 to 100 MHz at the Antenna
Receiver Bandwidth Accuracy	±2.5% of the Programmed Bandwidth
Gain Control Range	0 to 90 dB
Input IP2	>+60 dBm
Receiver Image Rejection	>90 dB

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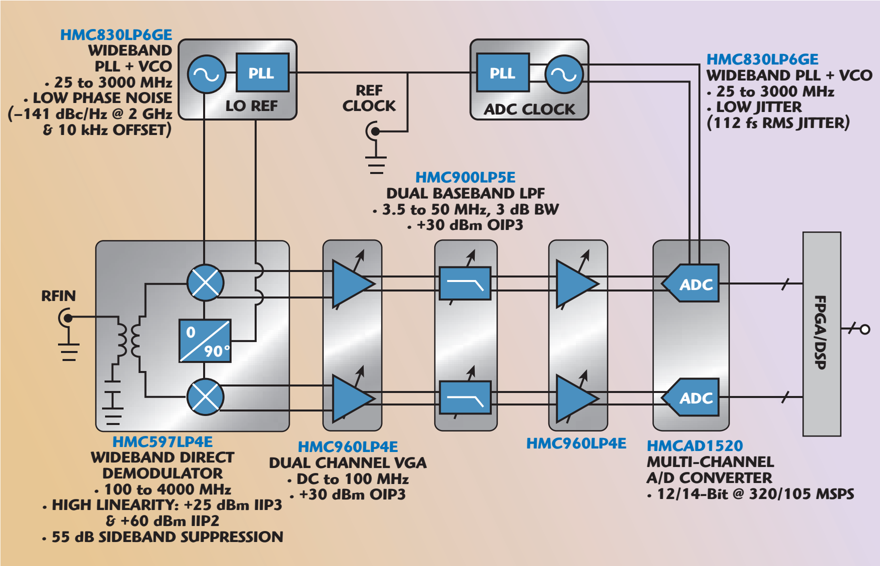


▲ *Fig. 1 Hittite DCR block diagram.*

to 100 MHz receiver RF bandwidths that are captured and digitized by Hittite's high resolution data converters.

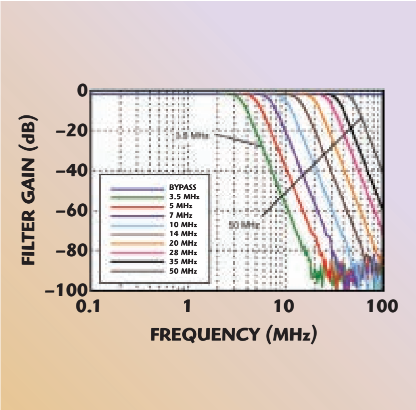
The DCR features programmable analog filtering bandwidth accurate to ±2.5 percent, and up to 90 dB of baseband gain. Distributed adaptable gain provides optimal application-specific noise figure, blocker, and linearity performance – all software configurable.

Field configurable frequency of operation, bandwidth and gain make Hittite's DCR evaluation platform design an ideal subsystem receiver module for multi-carrier, multi-standard cellular base stations, microwave point-to-point radio, adaptive IF strips, wireless LAN, test equipment and software-defined radio applications. Programmable bandwidth and complete cellular frequency band coverage enable the DCR to be paired with a low noise amplifier, such as the HMC374E and an RF bandpass filter, to form a complete cellular receive chain with a low noise figure. All of this is available with bandwidth, gain distribution and frequency of operation software configurable to comply with the cellular standards of today, and hardware ready to adapt to the standards of tomorrow.

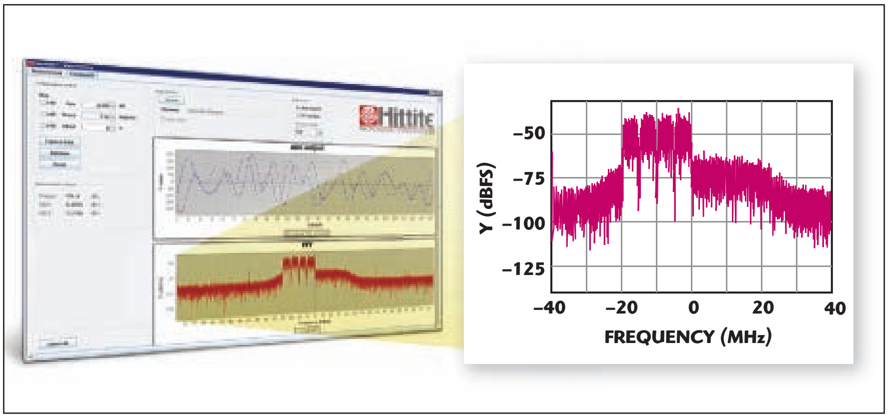
The Hittite DCR platform presents an ideal IF receiver subsystem in a microwave radio. Wideband frequency of operation enables configurable microwave IF frequencies. Field programmable bandwidth enables operators to deploy the same platform while only adjusting the receiver bandwidth depending on the particular microwave standard and data rate requirements. The microwave radio bandwidth, IF frequency and gain distribution can be dynamically adjusted with software to optimize radio performance in the presence of new or existing blocker signals, thereby eliminating the need for a site visit and drastically reducing the cost of ownership.

Being fully software field programmable, Hittite's DCR enables suppliers to offer a single hardware receiver platform across various standards, jurisdictions, and bands of operation and either pre-configuring or field configuring the receiver to suit each individual deployment. This capability significantly reduces cost and complexity of manufacturing, deploying and supporting standard and region-specific equipment. OEMs no longer need to source, design and manufacture multiple parts for each region or standard. Hittite's DCR enables the user to focus on one design that is configurable for all standards and jurisdictions that can be software field configured optimally for each application.

Hittite's DCR achieves flexibility by utilizing a homodyne receiver architecture with exceptionally high IP2 performance (> +60 dBm), which results in minimum baseband DC offset. Hittite's DCR block diagram is shown in ***Figure 1***. It includes a built-



▲ *Fig. 2 DCR field programmable filter bandwidth.*



▲ *Fig. 3 Hittite's DCR receiving a multi-carrier W-CDMA signal.*

in receiver calibration algorithm that is capable of over 90 dB if receiver image rejection is after digital filtering. The calibration algorithm operates on the incoming data signal and does not require any receiver down time. Excellent IP2 performance and digitally calibrated receiver amplitude and gain mismatch enable Hittite's DCR to overcome the traditional challenges of direct conversion receiver architectures while reaping all of the benefits. The benefits include lower sampling rate requirement of the analog-to-digital converters (ADC), therefore, increasing ADC SNR, and, most importantly, removing the need for application and band-specific image rejection filtering.

The HMC830LP6GE wideband PLL with integrated VCO is used as the local oscillator (LO) for the wideband RF demodulator (I and Q mixer) HMC597LP4E. A second HMC830LP6GE also provides an ultra-low jitter clock for the HMCAD1520 dual-channel ADC. The wide bandwidth PLL and demodulator enable operation over a wide range of input frequencies (700 to 3000 MHz) while maintaining the industry-leading phase noise performance, resulting in minimal receiver contribution to received signal EVM and ACPR. Exceptionally low jitter specification of the HMC830LP6GE (112 fs rms in integer mode) ensures minimum ADC aperture error and maximum SNR performance. The very low noise floor (<–170 dBc/Hz) further maximizes ADC SNR performance.

The integrated HMC900LP5E programmable sixth order Butterworth lowpass filter (LPF) allows the bandwidth of the DCR to be programmed anywhere from 3.5 to 50 MHz baseband (7 to 100 MHz RF) with ±2.5 MHz accuracy (see ***Figure 2***). The filter includes programmable 0 or 10 dB gain settings and has an output IP2 greater than +60 dBm throughout the passband, ensuring little contribution to ADC DC offsets. The high performance HMCAD1520 data converters minimize the need for gain in the receiver and also reduce the effects of DC offsets.

Two integrated HMC960LP4E dual-programmable variable gain amplifiers (VGA) provide the DCR with a total of 80 dB (40 dB each) of precisely distributed programmable gain. Exceptional VGA Output IP2 of > +75 dBm throughout the band also ensures minimal VGA contribution to DC offset at the ADC. The VGA's low noise figure (NF) of 6 dBm, combined with large available gain, ensures little contribution from follow-on components to the overall noise figure of the receiver.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The integrated HMCAD1520 12/14 bit ADC with 70 dB SNR relative to full scale and 77 dBc SFDR excluding interleaving spurs (60 dBc including interleaving spurs) ensure excellent received signal SNR. Integrated programmable digital gain of the HMCAD1520 allows calibration of internal ADC gain errors. Often overlooked, ultra-low noise power supply regulation and isolation are critical to the success of a high performance DCR. The DCR includes three ultra low noise regulators: two HMC860LP3Es, one HMC976LP3E, and one HMC6048LP5E. These regulators supply full current while maintaining low noise densities, typically at the 3 nV/√Hz level.

An integrated HMC1031MS8E jitter cleaner PLL improves the quality of the reference signal, and provides reference clock flexibility and cost savings. The jitter cleaner allows the radio to lock to a standard low cost, low frequency crystal, while generating a locked internal reference at 1×, 3× or 5× frequency multiplication. The higher frequency reference generated by the HMC1031MS8E contributes to market-leading phase noise performance of the integrated HMC830LP6GE PLLs and, therefore, better SNR performance of the entire DCR, while saving the cost of a higher frequency crystal oscillator.

The DCR evaluation development kit includes a full software suite that enables complete control and configuration of all parts of the DCR (see ***Figure 3***). This flexibility enables system designers to observe and understand the effects and implications of any parameter on their overall system performance. In fact, the DCR can be connected via coaxial cable to a wide variety of Hittite evaluation boards, including high performance LNAs, or microwave demodulators such as the HMC977LP4E, to form a complete cellular or microwave radio receiver evaluation board. This capability allows designers to test and fine tune their system design under real-world conditions.

Hittite's DCR has addressed the classical challenges of direct conversion architectures. First, the DCR is composed of individual components with exceptionally high output IP2 performance, resulting in minimal second order distortion products and DC offsets. Second, the DCR utilizes a digital receiver calibration algorithm that does not require any receiver down time, and achieves over 90 dB of image rejection after digital filtering. The combination of market-leading components and a robust fully configurable design, makes the Hittite DCR evaluation platform an ideal starting point from which to design a modular, highly configurable, multi-standard multi-carrier receiver module.

VENDORVIEW

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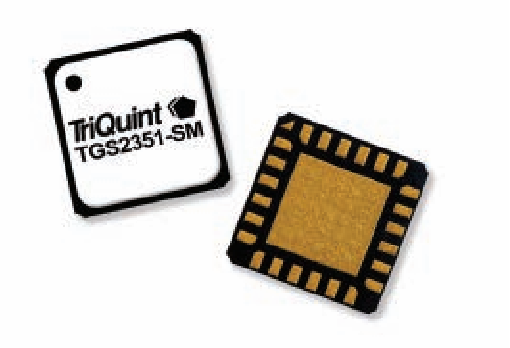


GaN MMIC Switch Handles 40 W from DC to 6 GHz

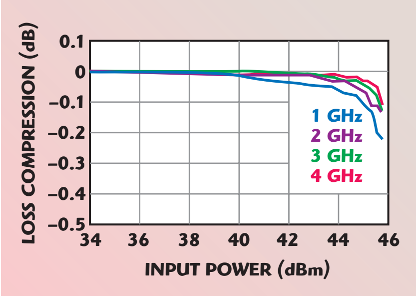
RF and microwave switches based on PIN diodes or GaAs FETs have been key microwave design components for decades, with each type establishing itself in specific applications based on its inherent characteristics. In short, GaAs FETs offer fast switching speed and can operate down to DC, but can handle typically only a few watts of RF power, while PIN diodes can handle much greater power levels, but consume more DC power. Truly high power levels remain the domain of electromechanical switches, which can handle hundreds of watts but are also orders of magnitude greater in size and weight than solid-state switches.

Gallium nitride changes the equation. Having firmly established itself in RF power amplifiers for its ability to deliver higher RF output power than GaAs or silicon (above ~3 GHz) over broader bandwidths, gallium nitride now offers another switching option that provides performance not achievable with other semiconductor technologies. The TGS2351-SM GaN MMIC SPDT switch from TriQuint Semiconductor exemplifies what can be achieved with FET-based GaN MMICs. The reflective switch operates from DC to 6 GHz, can handle up to 40 W CW, switches in less than 35 ns, has insertion loss of less than 1 dB and isolation greater than 40 dB. The product offers a new realm of possibilities for designers addressing defense, aerospace or high performance commercial RF design needs.

The high breakdown voltage that is a fundamental characteristic of GaN lends itself well for use in high power RF switches. The high power-handling ability and wide 0/-40 V DC control voltage range of the TGS2351-SM are directly attributable to GaN's high power density, which is also the key to its appeal in RF power amplifiers. The TGS2351-SM is fabricated using the company's 0.25 µm HEMT GaN-on-SiC process. When compared to a FET switch fabricated in a typical 0.25 µm GaAs process, the TGS2351-SM can handle two and a half times the on-state power, eight times the off-state power and is highly stable with little or no performance degradation over temperature. RF power handling ability is shown in ***Figure 1***.

For switch applications, TriQuint's GaN process yields a breakdown voltage of 70 V DC compared to 13 V DC for GaAs and can handle current of more than 1 A/mm of device area versus 650 mA/mm for GaAs. In addition, the high thermal conductivity of the insulating SiC substrate reduces leakage caused by high RF voltage swing while also improving heat trans-

TRIQUINT SEMICONDUCTOR
Richardson, TX



▲ *Fig. 1 Insertion loss change as a function of input power at four different frequencies.*

TABLE I

KEY TGS2351-SM PERFORMANCE SPECIFICATIONS

Operating Frequency (GHz)	DC to 6
Power Handling (W, CW)	40
Insertion Loss (dB)	Less than 1
Isolation, Off-state (dB)	>40
Switching Speed (ns) ***On*** ***Off***	 31 18
Control Voltage Range (V DC) (for operation at 40 W)	0/-40
Control Current (mA)	<1
Input/Output Return Loss (dB)	20
Maximum CW Input Power (dBm)	47
Package Type	4×4 mm, 24-lead, air-cavity QFN

fer to the back of the device. These are compelling metrics when considered in the context of applications such as electronic warfare, radar and high power communications systems.

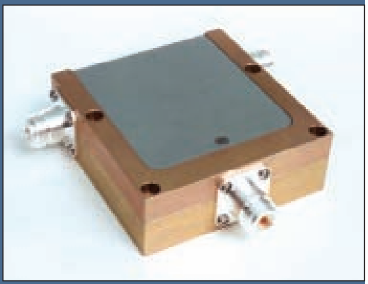
A FET's main control parameters are its on-state resistance and off-state capacitance that together determine a switches' RF impedance in the two switching states; insertion loss and isolation performance are strongly dependent on them. The TGS2351-SM's on-state resistance is 2.4 Ω-mm and its off-state capacitance is 0.17 pF/mm, which are similar to such specifications achieved by GaAs FET switches. The insertion loss of the switch is less than 1 dB over its frequency range and varies minimally with increases in input power (see Figure 1). Isolation is typically 40 dB and switching speed compares favorably with that of all other types of solid-state switches. Typical performance for the TGS2351-SM is shown in ***Table 1***.

The TGS2351-SM is housed in a 4 × 4 mm, 24-lead, air-cavity QFN package. The air-cavity approach is a proprietary TriQuint process development that utilizes industry-standard ceramic packages to provide enhanced protection for GaN die as well as a means for mitigating high temperatures commonly found in high power GaN devices. The air cavity QFN helps mitigate heat in a way not possible with fully encapsulated plastic packaging alternatives. TriQuint offers full packaging services for its die-level devices through a wide selection of industry-standard form factors. The company also provides custom solutions for unique customer requirements through its Advanced Microwave Module Assembly (AMMA) in-house facilities that deliver secure, one-stop convenience.

TriQuint offers its new GaN switch in die form as the TGS2351, which differs in performance only in its insertion loss, which is less than 0.8 dB. Both devices are members of TriQuint's growing family of SPDT GaN switches that includes the TGS2352 and TGS2353 die-level devices. The TGS2352 operates from DC to 12 GHz, handles up to 20 W CW, has insertion loss of less than 1 dB, switches in less than 25 ns and has isolation greater than 35 dB. The TGS2353 operates from DC to 18 GHz, handles 10 W CW, has insertion loss of less than 1.5 dB, isolation greater than 30 dB and switching speed of less than 25 ns. In the TGS2351-SM as well as the other devices, control voltages are available from either side of the MMIC. Packaged versions of the 12 and 18 GHz die-level devices will be offered in the future.

TriQuint Semiconductor,
Richardson, TX
(972) 994-8200,
www.triquint.com/defense.

HIGH POWER
100 MHz to 20 GHz

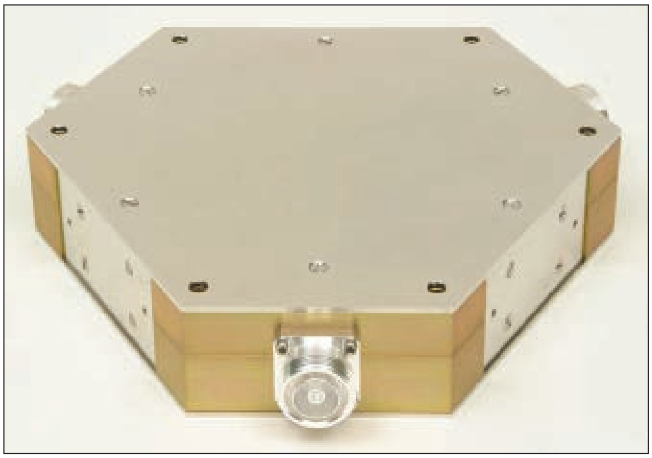


For Military / Radar Applications.

Isolators/Circulators

As one of the leading suppliers of ferrite components in the industry, UTE Microwave has pioneered innovative designs, quality craftsmanship and exceptionally high quality products. Custom designs, standards...many of them off-the-shelf, are the result of over 35 years of experience in the industry. UTE Microwave continues this tradition with new products for ever changing applications. Our broad line of HIGH POWER, low loss circulators and isolators spans the spectrum from below 100 MHz in coax/stripline units to waveguide devices at 18 GHz for both peak and average powers.

100 MHz HIGH POWER Circulator for Medical, Scientific and Industrial applications



A new HIGH POWER Circulator suitable for FM Broadcast, Scientific and Medical applications is now available. The unit provides 10 MHz bandwidth in the 85–110 MHz spectrum.

Specifications are 20 dB min. isolation, 0.3 dB max. loss and 1.25 max. VSWR. Operating power is 1 kW average and 25 kW peak. The 8-1/2" hex x 2" thick unit operates over a 15°–50° C temperature range. DIN 7/16 connectors are standard. Other units are available at higher frequencies.

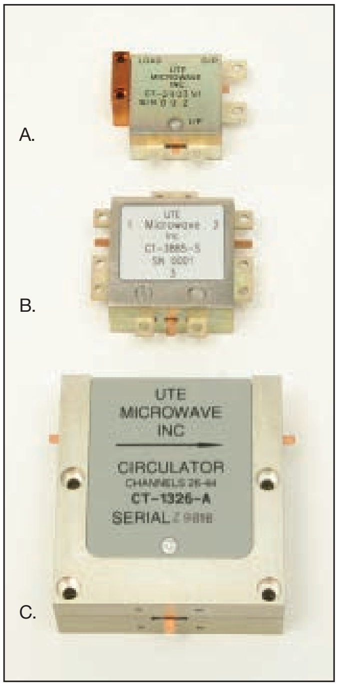
HIGH POWER Drop-in Series

A broad line of low loss HIGH POWER Drop-in circulators are available from VHF to Ku band including Kilowatt average power levels at VHF thru S band. L and S band radar are a specialty. A few of these are shown here.

A) 2.7–3.1 GHZ 1 kW pk, 100 W av

B) 1.2–1.4 GHZ 3 kW pk, 300 W av

C) UHF TV Band 5 kW pk, 500 W av



Our "POWER-LINE" serves the COMMUNICATIONS, TELECOM, MEDICAL, SCIENTIFIC, TV, PCS and INDUSTRIAL markets.

The following models are examples of our High Power units

Model No.	Power	Connectors	Freq. Range
CT-1542-D	10 Kw Pk 1 Kw Av	DIN 7/16	420–470 MHz
CT-2608-S	3 Kw Pk 300 W Av	"Drop-in"	1.2–1.4 GHz
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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- Low Intermod Units
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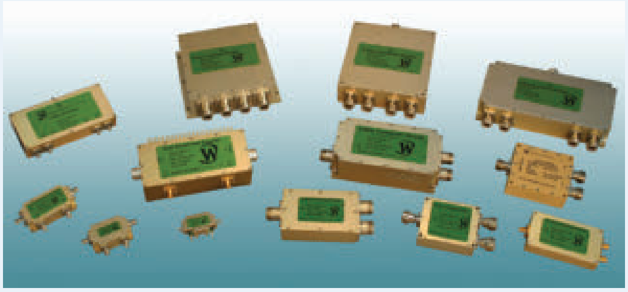
3500 Sunset Ave., Asbury Park, NJ 07712
Tel: 732-922-1009 Fax: 732-922-1848
E-mail: info@utemicrowave.com

Contact us for more information on our extensive product line and current catalog. We accept Visa, MC, Amex



Werlatone's New Line of 20 to 1000 MHz High Power Combiners and Directional Couplers

Werlatone recently expanded its offering of high power combiners and directional couplers to include a new product line supporting a full 20 to 1000 MHz bandwidth. These broadband units are a perfect fit for military and commercial applications alike, as they are all designed for extreme operating conditions.

The new low loss 20 to 1000 MHz combiners address power requirements ranging from 10 to 500 W CW and tolerate severe power unbalances, while maintaining excellent port-to-port isolation. In addition, the patented circuits significantly reduce the heat generated during operation, allowing smaller package sizes to be utilized. Werlatone's line of two-way and four-way combiners will tolerate full input failures at rated power and operate over a temperature range of –55° to +85°C. Their tolerance to input failures insures that the remaining inputs, and thus the amplifier system may continue to operate in a degraded mode until the system can be properly shut down for maintenance. Units may be supplied RoHS compliant and in non-connectorized packages on a case-by-case basis.

The new 20 to 1000 MHz high power dual-directional couplers provide a low loss solution for broadband amplifier manufacturers seeking non-connectorized couplers at the module level or connectorized components at the amplifier output. The new couplers address the same power levels as the company's combiner products, while the patented structure of these small form factor circuits provides the low loss and extremely flat coupling required of a protection circuit or in test and measurement applications. These new dual-directional couplers join the company's other products supporting multi-octave bandwidths (up to 6 GHz) with low-loss and excellent flatness.

VENDORVIEW

Werlatone Inc., Patterson, NY (845) 278-2220, www.werlatone.com.

Up to 250 W, 1 to 6 GHz Power Amplifier Family

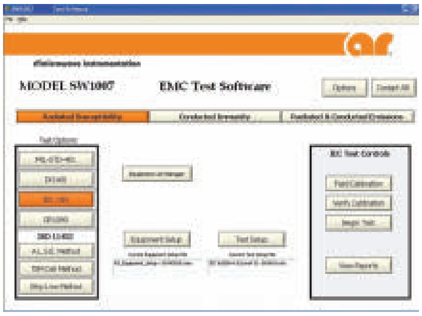
Instruments for Industry (IFI), S61 Series solid-state GaN-based amplifiers operate over the frequency range from 1 to 6 GHz and can be supplied at power levels from 5 to 250 W, offering all the control and communication features needed for today's automated test systems. Spurious outputs are less than -60 dBc nominal and harmonics are -20 dBc minimum at linear power levels. From the ground up, the S61 series amplifiers are built to withstand rugged handling, whether it is being shipped or hauled around from site to site. These amplifiers feature heavy-duty aluminum chassis construction with a modular approach for easy access and service.

Operation safety and ease of use are paramount in IFI product designs. The IFI S61 series includes a full complement of RF and hardware protection circuits, including high VSWR (the unit operates without damage or oscillation into any magnitude of phase or load impedance, open and short circuit protection), over-current, voltage protection, redundant thermal and airflow sensors for the module and the system level. In addition, the S61 series includes a state-of-the-art interface that is sophisticated, comprehensive and yet simple to use.

The backlit LCD screen shows forward/reverse power indication, system status and self-diagnostic information. All the amplifier's operating parameters are simultaneously available in the amplifier front panel display as well as over the remote bus. Selection switches allow you to switch the amplifier to the desired mode of operation for local control if the unit is not being operated remotely.

For computer automation, both an RS-232 and IEEE interface are provided as standard. To meet individual application needs, the S61 series amplifiers can be easily customized with other options. With this capability and its reliable elegant design, the S61 series amplifiers are the perfect system for your applications.

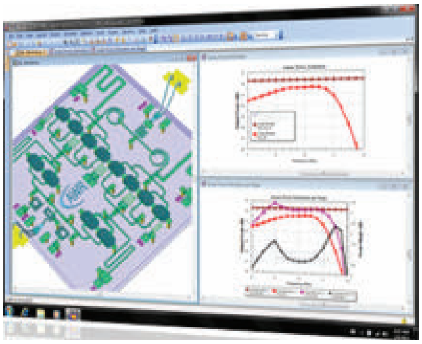
Instruments For Industry, Ronkonkoma, NY (631) 467-8400, www.ifi.com.



EMC TEST SOFTWARE

AR's SW1007 EMC test software combines radiated susceptibility and conducted immunity testing into one package to offer more control and a more intuitive interface. Built-in standards include IEC, MIL-STD, DO160, automotive standards and the ability to create your own test standards. The software has the ability to control more equipment and the report-generating feature has been enhanced to offer more control and customization.

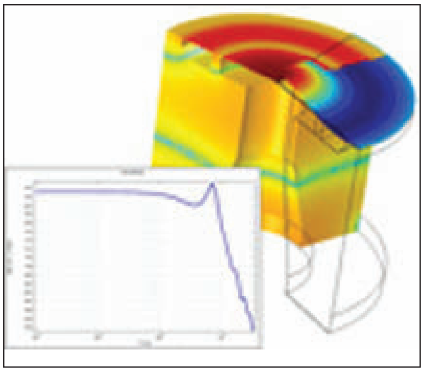
AR RF/Microwave Instrumentation,
Souderton, PA (215) 723-8181,
www.arworld.us.



LIBRARY FOR GaAs, GaN RF DEVICES

AWR Corp., an innovation leader in high frequency EDA, announced the availability of a Microwave Office™ model library for Mitsubishi Electric's nonlinear GaAs and GaN RF devices. The model library includes high power and low noise HEMT devices, which are commonly used in base station and DBS receivers and other radio communications equipment, given their high power, high efficiency, broadband and low noise advantages. This new model library helps designers better explore design alternatives while meeting demanding performance specs with a cost-effective solution.

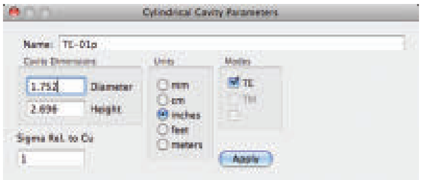
AWR Corp.,
El Segundo, CA (310) 726-3000,
www.awrcorp.com.



ACOUSTICS MODULE UPGRADE

COMSOL Inc. released a major upgrade of its add-on Acoustics Module for its flagship product COMSOL Multiphysics. This latest version of the Acoustics Module offers new capabilities and expanded multiphysics user interfaces for simulating thermoacoustic effects, poroelastic waves, acoustic-shell interactions, and piezo-acoustic devices. Additional application areas for the Acoustics Module include speakers, microphones, and sonar devices as well as noise control in areas such as muffler design, sound barriers and building acoustics. The module's physics interfaces provide easy-to-use tools to model acoustic pressure wave propagation in air, water and other fluids.

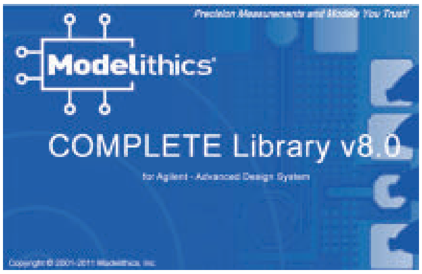
COMSOL Inc.,
Burlington, MA (781) 273-3322, www.comsol.com.



CAVITY™ SOFTWARE

Damaskos Inc. (DI) Cavity™ Software has been expanded to include TE-01p mode cavities. This complements other types, such as Open Resonator, Courtney, Thin Sheet Tester, Harmonic Stripline, and Circular Cavities, which have been part of the software for many years. The TE-01p modes are valuable, as sample contact with the cavity walls is not important in order to obtain accurate results. The circular disc-like samples are easy to prepare and to load into the cavity. Cavity software works with automated network analyzers from the three major analyzer manufacturers.

Damaskos Inc.,
Concordville, PA (610) 358-0200, www.damaskosinc.com.



MODELITHICS LIBRARY VERSION 8.0

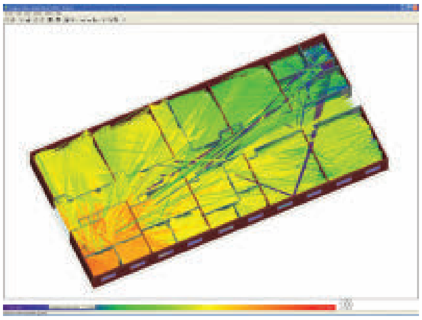
Modelithics Inc. has released an enhanced version of its linear and nonlinear device and system level component model Libraries. The Modelithics Library version 8.0 encompasses all four of Modelithics popular CLR, NLT, NLD and SLC Sub-Libraries™ and is now compatible with Agilent ADS 2011. This upgrade introduces 46 new Global Models for passive RLCs, and nonlinear models for diode, switch, amplifier and transistors. Version 8.0 also includes performance upgrades for more than 90 of library models – ensuring designers have the most accurate models available in the RF/microwave industry. Designers can download the free model library, Modelithics SELECT™ from www.modelithics.com.

Modelithics Inc.,
Tampa, FL (888) 359-6359,
www.modelithics.com.

PCB SOFTWARE

Numerical Innovations (NI) announced the release of its new product: "DFM Now!™" DFM Now! allows PCB designers and engineers to verify that their Gerber and Drill files are ready for PCB manufacturing. It also facilitates PCB quotation and has many other high end CAM features only found in software costing thousands of dollars. DFM Now! is being offered free, supported by advertising sponsorships (a new concept for the PCB software industry), and may be downloaded from www.dfmnow.com.

Numerical Innovations,
San Diego, CA (800) 269-5054,
www.dfmnow.com.

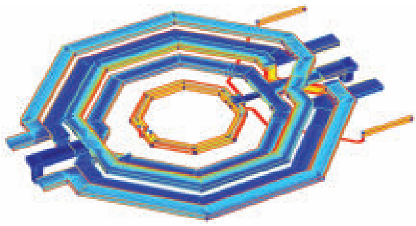


WIRELESS INSITE EM PROPAGATION SOFTWARE

VENDORVIEW

Remcom announces a new version of Wireless InSite®, its suite of ray-tracing models and 2D field solvers for the analysis of site-specific radio propagation and wireless communication systems. This major point release, which updates the product to Release 2.6, includes important performance enhancements and new modeling capabilities. Most notable are the introduction of the X3D Ray Model with multi-threading and XStream® GPU acceleration, as well as the extension of XStream technology to the Moving Window FDTD (MWFDTD) model. As with Remcom's XFdtd® software, XStream will be bundled at no additional cost with the new release of Wireless InSite.

Remcom,
State College, PA (814) 861-1299,
www.remcom.com.



3D PLANAR EM SOFTWARE

Sonnet Software introduces the latest in its 3D planar EM software, the Sonnet Suites Release 13, featuring up to 3× faster analysis for large circuits, efficient micro-via array meshing, enhanced integration to its high frequency EDA design framework partners and introducing diagonal ports and components. In Release 13, Sonnet's entry-level EM software suites have been revamped to double the allowed memory from previous releases and offer more features than ever before.

Sonnet Software,
North Syracuse, NY (877) 776-6638,
www.sonnetsoftware.com.

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Voltage:	*20-300 Volts*
Current:	*.1 - 5 Amps*

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MDL

Microwave Development Laboratories, 135 Crescent Road, Needham Heights, MA 02494
V: 781-292-6680/6684 F: 781-453-8629 E-mail: mdlsales@mdllab.com www.mdllab.com

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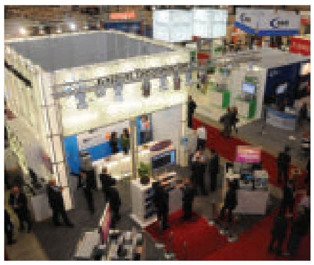

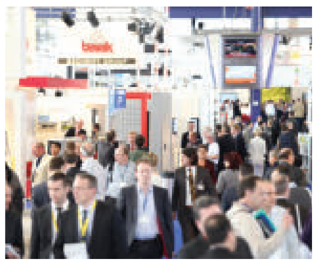

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Components

X-Band Hybrid Coupler

VENDORVIEW

Florida RF Labs has expanded the HybriX® coupler product line with the introduction of a new X-Band hybrid coupler, HPX2F. With operating frequency of 8 to 12 GHz, HPX2F is the world's first multi-layered PTFE coupler designed for X-Band applications. HPX2F offers low insertion loss, excellent amplitude balance, and high isolation in a surface-mountable package measuring only 0.250" × 0.200." The multi-layered PTFE construction is thermally stable and compatible with common PWB materials. HPX2F is available in both RoHS-compliant and tin-lead plating. HPX2F can be ordered with a space-level qualification test package that includes a true multipaction test performed at atmospheric pressure of 10^{-5} torr or lower. HPX2F is delivered in tape and reel packaging.

Florida RF Labs,
Stuart, FL (772) 600-1632,
www.emc-rflabs.com.

1-Bit Digital Attenuator

VENDORVIEW

M/A-COM Technology Solutions Inc. introduced a 1-bit digital attenuator for CATV and set-top box (STB) front-end applications. The MAAD-010305 is a 15 dB step GaAs MMIC digital attenuator. It is designed to condition cable input signals to the STB. The device is ideally suited for use where high accuracy, very low power consumption, and low intermodulation products are required. The MAAD-010305 is fabricated as a monolithic GaAs integrated circuit using a mature PHEMT process. The process features full chip passivation for performance and reliability. The attenuator is designed for operation from DC to 1.1 GHz. It is packaged in a RoHS-compliant lead free SOT-25, five-lead surface-mount plastic package. The MAAD-010305 is characterized by low insertion loss and allows for positive and negative voltage control, complemented by 75 Ω impedance.

M/A-COM Technology Solutions Inc.,
Lowell, MA (800) 366-2266,
www.macomtech.com.

WiFi 5.8 GHz Cavity Filter

VENDORVIEW

NIC recently developed a narrowband cavity filter at 5745 MHz, perfectly suitable for use in WiFi 5.8 GHz applications. This filter offers a narrow passband of 40 MHz with low passband insertion loss of less than 1.5 dB and adjacent channel rejection of greater than 20 dB, built in a compact package size of 3.5" × 3.5" × 1.50" plus connectors.

Networks International Corp.,
Overland Park, KS (913) 685-3400,
www.nickc.com.

Power Divider

Pulsar model PS2-56-450-15S covers the frequency range of 8 to 60 GHz with 3 dB typical insertion loss, 10 dB typical isolation, and VSWR 2.00:1 typical. Amplitude and phase balance are 1 dB and ±15 degrees, respectively. Maximum input power is 10 W. 1.85 female connectors are utilized in a housing with dimensions of 1.04" × 0.6" × 0.38."

Pulsar Microwave Corp.,
Clifton, NJ (973) 779-6262,
www.pulsarmicrowave.com.

Wideband Circulators

RADITEK's newest coaxial circulator model, RADC-225-400-N23-200WR covers the full-band 225 to 400 MHz with guaranteed specifications of 0.7 dB insertion loss, 17 dB isolation, and 1.40:1 VSWR over the full operating temperature range of 0° to 50°C. The 225 to 400 MHz wideband coverage of these circulators and isolators give outstanding performance. This frequency band is used mainly for military, aviation and government communication. Standard power options range from 1 to 400 W. These units are proven in the field and are fully RoHS compliant.

RADITEK,
San Jose, CA (408) 266-7404,
www.raditek.com.

Phase Shifter

RLC Electronics' manually adjustable delay line (phase shifter) offers continuous adjustment of electrical delay over the frequency range of DC to 40 GHz. Adjustment is through a multi-turn, locking shaft. Low insertion loss (2.5 dB maximum) and VSWR (2.0:1 maximum) are maintained throughout the adjustment range. The unit comes with a choice of male or female 2.92 mm connectors. The PSM40 has an impedence of 50 Ω and a power rating of 5 W average. It operates in a temperature range of -55° to +85°C.

RLC Electronics Inc.,
Mount Kisco, NY (914) 241-1334,
www.rlcelectronics.com.

Monoblock Filters

Sangshin Elecom announces a suite of monoblock filters for ADS-B/UAT/TCAS applications. These filters are designed with a common footprint allowing for increased design flexibility. The MBP44RC978S05C, MBP44RC1030S15C and MBP44RC1090S15C all offer excellent performance and stability in a small, cost-effective package. Sangshin filters can be quickly and easily modified to a variety of specification configurations based on specific customer requirements.

Sangshin Stocking Distributor,
RFMW Ltd.,
San Jose, CA
(408) 414-1450,
www.rfmw.com.

Cable Assemblies

VENDORVIEW

San-tron Inc. has announced a new series of PIM cable assemblies. They feature intermodulation performance as low as -181 dBc with an eSeries 7/16 connector terminated on TFlex-402 cable. Typical performance across the lineup of assemblies terminated with eSMA and eSeries Type Ns is -162 dBc. The eSMA cable assemblies perform DC to 20 GHz and the eSeries Type N cable assemblies perform DC to18 GHz. These assemblies are phase and attenuation stable, provide excellent shielding, support UL/NEC Plenum class CMP, are corrosion resistant, and are low in weight and highly flexible.

San-tron Inc.,
Ipswich, MA
(978) 356-1585,
www.santron.com.

RV-13 Full-Band Receiver

Spacek Labs model RV-13 is a full-band receiver that downconverts all of V-Band (50 to 75 GHz) to an IF band from 1 to 26 GHz. The LO is derived from a free-running Gunn oscillator at 49 GHz. The RF port is WR-15 and the IF port is K"F." The LO bias is +7 V at 1A typical. This receiver can be used to extend the frequency range of a spectrum analyzer.

Spacek Labs Inc.,
Santa Barbara, CA
(805) 564-4404,
www.spaceklabs.com.

Bandpass Filters

These miniature surface-mount bandpass filters can be specified for passbands from 8 to 20 GHz with bandwidths from 5 to 10 percent of the center frequency. The insertion loss of these custom filters is dependent on frequency and bandwidth, but ranges from as low as 1 dB at lower frequencies and narrower passbands to as high as 3.5 dB at the highest frequencies and widest passbands with a VSWR of better than 2:1 and power handling of 1 W. The ripple performance of these filters is outstanding, at ±0.5 dB. The center-frequency drift is also impressive at only ±0.6 percent across an operating frequency range of -35° to +85°C.

Synergy Microwave Corp.,
Paterson, NJ
(973) 881-8800,
www.synergymwave.com.

0.5 W BTS RFIC

The skyrocketing popularity of smartphones and other MIDs makes products like TriQuint's new TQP7M9102 essential for 3G/4G base station, repeater, femtocell and similar applications. This innovative new product integrates ESD, RF over-drive and DC over-voltage protection while delivering its highly linear signal with very low power consumption. Only TriQuint offers all these benefits, plus industry-standard packaging.

TriQuint Semiconductor,
Hillsboro, OR
(503) 615-9000,
www.triquint.com.

Four-way Combiner/Divider

VENDORVIEW

This four-way combiner operates from 20 to 1000 MHz at 100 W CW, measured at the sum port. This small package enables customers to combine four 25 W modules in a harsh military environment, often operating into other than 50 Ω. Designed for military and commercial applications, this unit will tolerate a full input failure, at rated power. The unit provides exceptionally low loss (0.75 dB maximum). It measures 5" × 2" × 1" and weighs 0.75 pounds. It operates from -55° to +85°C. It can be supplied with several connector options, including N Female and SMA Connectors.

Werlatone Inc.,
Patterson, NY
(845) 278-2220,
www.werlatone.com.

Amplifiers

4 to 18 GHz Solid-state Amplifiers

VENDORVIEW

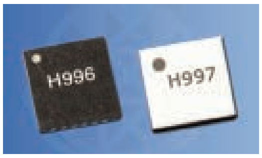
AR RF/Microwave Instrumentation has redesigned several of its "S" Series solid-state amplifiers to extend the bandwidth from 18 GHz down to 4 GHz. The models previously went down to 6 GHz. These redesigned amplifiers are available in 5, 10, 20 and 40 W.

AR RF/Microwave Instrumentation,
Souderton, PA (215) 723-8181,
www.ar-worldwide.com.

High Linearity VGAs

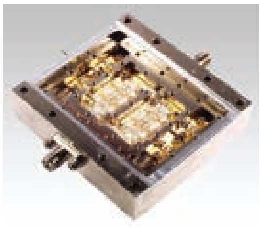
VENDORVIEW

The HMC996LP4E and the HMC997LC4 are GaAs PHEMT MMIC analog variable gain amplifiers that operate from 5 to 12 GHz and from 17 to 27 GHz, respectively. These amplifiers deliver up to 20.5 dB of gain, +24 dBm, of output P1dB, and +34 dBm of output IP3 in their maximum gain state. Each of these amplifiers is controlled by a single analog control voltage between 0 and -4.5 V, and provides up to 22 dB of gain control range. The high linearity performance of the HMC996LP4E and the HMC997LC4 allows them to be used as either buffer amplifiers, or as power amplifier pre-drivers in microwave transmitter applications. The HMC996LP4E consumes 120 mA from a +5 V supply, and is housed in a RoHS-compliant 4 × 4 mm QFN leadless package. The HMC997LC4 consumes only 170 mA from a +5 V supply, is housed in a RoHS-compliant 4 × 4 mm ceramic QFN leadless package.



Hittite Microwave Corp.,
Chelmsford, MA (978) 250-3343,
www.hittite.com.

X-Band Amplifier



Microsemi specializes in the design and supply of ultra low phase noise amplifiers. This low phase noise X-Band high power amplifier, model AML812PND1501, operates in the frequency range of 8 to 12 GHz and provides output P1dB of +34 dBm minimum (2.5 W). This amplifier delivers 1/f phase noise -155 dBc/Hz at 1 KHz and -165 dBc/Hz at 100 KHz offset. Dimensions are 2.24" × 2.45" × 0.58."

Microsemi,
Camarillo, CA (805) 388-1345,
www.amlj.com.

Wideband Amplifier

VENDORVIEW

The ZHL-22LM-75+ is a high performance, push-pull amplifier featuring very low second-


Fairview Microwave Inc.
ADAPTERS
SM5250 $58.16
SMA SWEPT 27 GHZ
SM4979 $38.77
SMA 27 GHZ
SM4923 $97.25
SMA FLANGE 27 GHZ
SM3224 $226.17
2.92 BULKHEAD 40 GHZ
SM3221 $148.48
3.5-3.5 34 GHZ
SM3935 $440.50
1.85-1.85 65 GHZ
SM8867 $195.00
SMP-2.4 40 GHZ
SM2927 $138.94
GMS-SMA 23 GHZ
SM3358 $226.17
7mm-3.5 18 GHZ
SM3397 $51.76
7/16 90° 6 GHZ
SM4531 $172.00
N 90° 18 GHZ
SM3547 $38.77
TNC-BNC 8 GHZ
SM5514 $145.40
ZMA-SMA 18 GHZ
SMW75ACN $297.95
WR75-N 10-15 GHZ
28AC206 $363.60
WR28-2.92 26-40 GHZ
SM4835 $172.53
SSMA-2.92 40 GHZ
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N 5W 18 GHZ
SA18N25WA $232.24
N 25 W 18 GHZ
SA18N507 $343.09
N 50 W 18 GHZ
SA3015 $13.55
SMA 2 W 3 GHZ
SA18S50W $337.81
SMA 50 W 18 GHZ
SA3N511 $162.41
N 50 W 3 GHZ
SA4020 $738.96
2.92 10 W 40 GHZ
SA5074 $274.47
2.4 1 W 50 GHZ
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MC0618 $341.38
SMA COUPLER 6-18 GHZ
MC4061 $757.50
N-SMA COUPLER 1-12 GHZ
SMC4037 $52.52
N COUPLER 700-2700 MHZ
MP0218-4 $600.95
SMA 4-WAY 2-18 GHZ
MP1540-2 $1,045.15
2.92 2-WAY 15-40 GHZ
MP8769 $472.68
N 2-WAY 2-8 GHZ
MP8758-4 $82.98
N 4-WAY 800-2500 MHZ
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N 700-700 MHZ LOW PIM
ST3N501 $129.56
N 50 W 3 GHZ
ST3D-50 $206.96
7/16 50 W 3 GHZ
ST1831 $19.57
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and third-order distortion products across its 5 to 200 MHz bandwidth. Designed for a 6 V/300 mA typical power supply, with F connectors in/out, it is a high value, low cost solution providing a 15 dB gain for CATV return path applications under DOCSIS 2 and 3. The rugged, aluminum alloy case measures 3.75" × 2" × 0.8."

Mini-Circuits,
Brooklyn, NY (718) 934-4500,
www.minicircuits.com.

26 to 40 GHz Amplifier

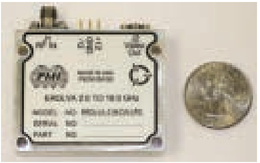
VENDORVIEW

MITEQ's new model JS4-26004000-27-10P is a low noise medium power amplifier with only 2.7 dB maximum noise figure and +10 dBm P1dB. This model has a gain of 28 dB minimum in a small hermetically sealed package with field replaceable K-connectors. MIL-883 screening is also available. Different options, such as gain, noise figure and power output, are also available.

MITEQ Inc.,
Hauppauge, NY (631) 439-9469,
www.miteq.com.

Video Amplifier

VENDORVIEW

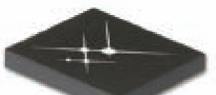


PMI model ERDLVA-218-CW-LPD is a CW Immune, Extended Range Detector Logarithmic Video Amplifier (ERDLVA) designed for ultra low DC power consumption. This model operates over the 2 to 18 GHz frequency range and has the ability to interface with an output cable measuring over 100 feet in length. This model provides very high speed, excellent flatness and accuracy in an ultra small hermetically sealed housing measuring only 2.04" × 1.67" × 0.472." It has an ultra low DC power consumption of less than 3.9 W total.

Planar Monolithics Industries Inc.,
Frederick, MD (301) 662-5019,
www.pmi-rf.com.

Low Noise Amplifiers

VENDORVIEW



Skyworks introduced a series of high gain, two-stage LNAs employing both GaAs PHEMT and GaAs HBT technology that offer very low noise figure, high linearity and excellent return loss in a small, quad flat, 4 mm squared leadless package. On-die, active-bias design ensures consistent performance and enables unconditional stability. The PHEMT front-end enables ultra low noise figure, while the HBT-based output stage provides customers a compelling solution with both high linearity and efficiency. The SKY67105-306LF (0.6 to 1.1 GHz) and the SKY67106-306LF (1.5 to 3 GHz) high gain, low noise amplifiers are well suited for cellular infrastructure applications.

Skyworks Solutions Inc.,
Woburn, MA (781) 376-3000,
www.skyworks.com.

Low Noise Amplifier

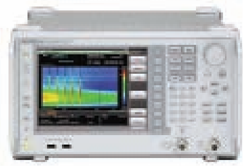
The ASL40-B2010L is a 18 to 40 GHz frequency bandwidth LNA consisting of gain blocks with 20, 30, 40 dB and output P-1 dB of +10 and +15 dBm. These products are battle-tested and backed with a four-year warranty program.

Wright Technologies,
Roseville, CA (916) 773-4424,
www.wrighttec.com.

Software

WLAN Software

VENDORVIEW



Anritsu Co. introduces software for its MS269xA and MS2830A series signal analyzers, as well as its MG3700A Vector Signal Generator to create single-instrument solutions that support the IEEE802.11n/p/a/b/g/j wireless LAN (WLAN) standards. With the software installed, the instruments provide developers of WLAN devices, modules and boards used in home entertainment and automobile onboard wireless systems with accurate, cost-effective solutions to verify design performance. The WLAN measurement software allows the MS269xA and MS2830A to support EVM modulation analysis, which is required for evaluating the Tx characteristics of IEEE802.11n/p/a/b/g/j WLAN signals. The analyzers can also measure key characteristics, such as spectrum mask, spurious, and adjacent channel leakage power.

Anritsu Co.,
Morgan Hill, CA
(800) 267-4878,
www.anritsu.com.

Sources

3200 MHz DRO Replacement

The ESP-3200 phase-locked oscillator operates at 3200 MHz and features exceptionally-low phase noise (less than -120 dBc/Hz at 10 KHz) and high stability (±0.25 ppm). The unit is supplied with an internal reference and offers +15 dBm output power and low spurs (less than -80 dBc). The internal reference can be optionally phase-locked for phase coherence to a customer's external frequency reference used for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Email: Sales@Spectrum-et.com
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other circuits in the system. Designed for ruggedized ground mobile or airborne operation, the ESP-3200 also features an extended operating temperature range (-40° to +85°C), high vibration tolerance and low power consumption. The ESP units are designed as DRO replacements in Hi-Rel, ruggedized applications. Custom units are available.

EM Research Inc.,
Reno, NV (775) 345-2411,
www.emresearch.com.

Temperature Compensated Crystal Oscillator

VENDORVIEW

The VFTX250 is the industry's smallest size Temperature Compensated Crystal Oscillator (TCXO). It offers outstanding performance for wireless communication systems. The device delivers frequency stability of ±0.5 ppm and is also available across the industrial temperature range of -40° to +85°C in a miniaturized 2.5 × 2.0 mm SMD ceramic package. The VFTX250 TCXO offers output frequencies up to 52 MHz in the low power clipped sine wave output with supply voltages ranging from 2.8 to 2.5 V. Typical current consumption is as low as 1.1 mA and to minimize battery drain the device also has an output enable/disable option. Its ultra miniature size, 2.5 × 2 mm, allows for efficient use of board space and product designs expansion.

Valpey Fisher Corp.,
Hopkinton, MA (508) 435-6831,
www.valpeyfisher.com.

Holdover Oscillators

Vectron International released another high performance OCXO for its growing family of Holdover Oscillators. The OX-203 Holdover Oscillator allows the customer to specify a level of holdover in a small footprint, cost effective, quartz-based solution. Specific features of Vectron's OX-203 include a package size of 25.4 × 25.4 × 13.4 mm, holdover specifications of 8 µsec over 24 hours, temperature stability of 0.8 ppb over -40° to 85°C, aging of 0.15 ppb/day, low phase noise 10 MHz outputs, and internal digital correction algorithms.

Vectron International,
Hudson, NH (603) 578-3052,
www.vectron.com.

VCO with Low Phase Noise

Z-Communications announces a new RoHS-compliant VCO model CRO3500C-LF in S-Band. The CRO3500C-LF operates at 3500 MHz with a tuning voltage range of 0.5 to 4.5 V DC. This VCO features a typical phase noise of -111 dBc/Hz at 10 KHz offset and a typical tuning sensitivity of 5 MHz/V. The CRO3500C-LF is designed to deliver a typical output power of 2 dBm at 5 V DC supply while drawing 20 mA (typical) over the temperature range of -40° to 85°C. This VCO features typical second harmonic suppression of -15 dBc and comes in Z-Comm's standard MINI-16-SM package measuring 0.5" × 0.5" × 0.22." It is available in tape-and-reel packaging for production requirements. The CRO3500C-LF is also ideal for automated surface-mount assembly and reflow. CRO3500C-LF is well suited for digital radio and satellite communication applications that require ultra low phase noise performance.

Z-Communications Inc.,
Poway, CA (858) 621-2700,
www.zcomm.com.

Test Equipment

Tunable Laser Module

VENDORVIEW

Agilent Technologies Inc. introduced a new compact tunable laser module for its 816x Series lightwave measurement platform. In addition, the company introduced a fast spectral loss engine, a new software package for the N7700A photonic application suite. The new module and

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Now you can rely on Delta, a source of high-quality RF connectors for over fifty years, for all of your cable assembly needs, as well as other connector-related value-added products:

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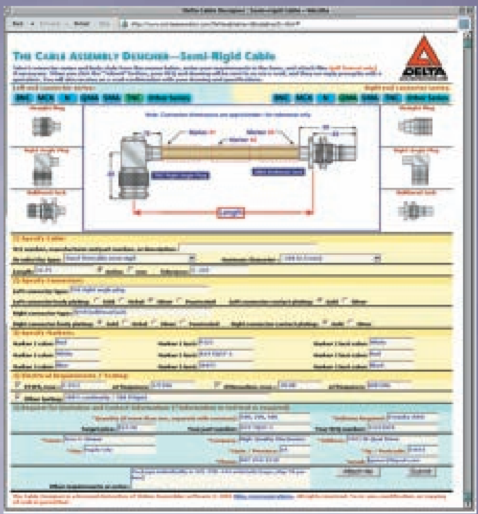
www.DeltaRF.com



Our website offers the unique *Cable Assembly Designer* tool to assist with all your cable assembly needs. Simply select the cable type, connectors, testing and marker requirements and click to send the RFQ to us.

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Beverly, MA 01915 USA

ISO 9001:2008 CERTIFIED   RoHS COMPLIANT   SOMWBA Woman-Owned CERTIFIED software help boost test throughput in optical component manufacturing by achieving a measurement repetition rate that is unparalleled for solutions in this class. The Agilent 81960A compact tunable laser has 200 nm/s sweep speed and increased acceleration, combined with the dynamic accuracy specifications needed for measuring dense-wavelength division multiplexing (DWDM) components, all packaged in a compact module. The new and unique capability of dynamically specified sweeps in both directions enhances the repetition rate to 2 Hz for real-time use in adjustment and calibration procedures.

Agilent Technologies Inc., Santa Clara, CA (800) 829-4444, www.agilent.com.

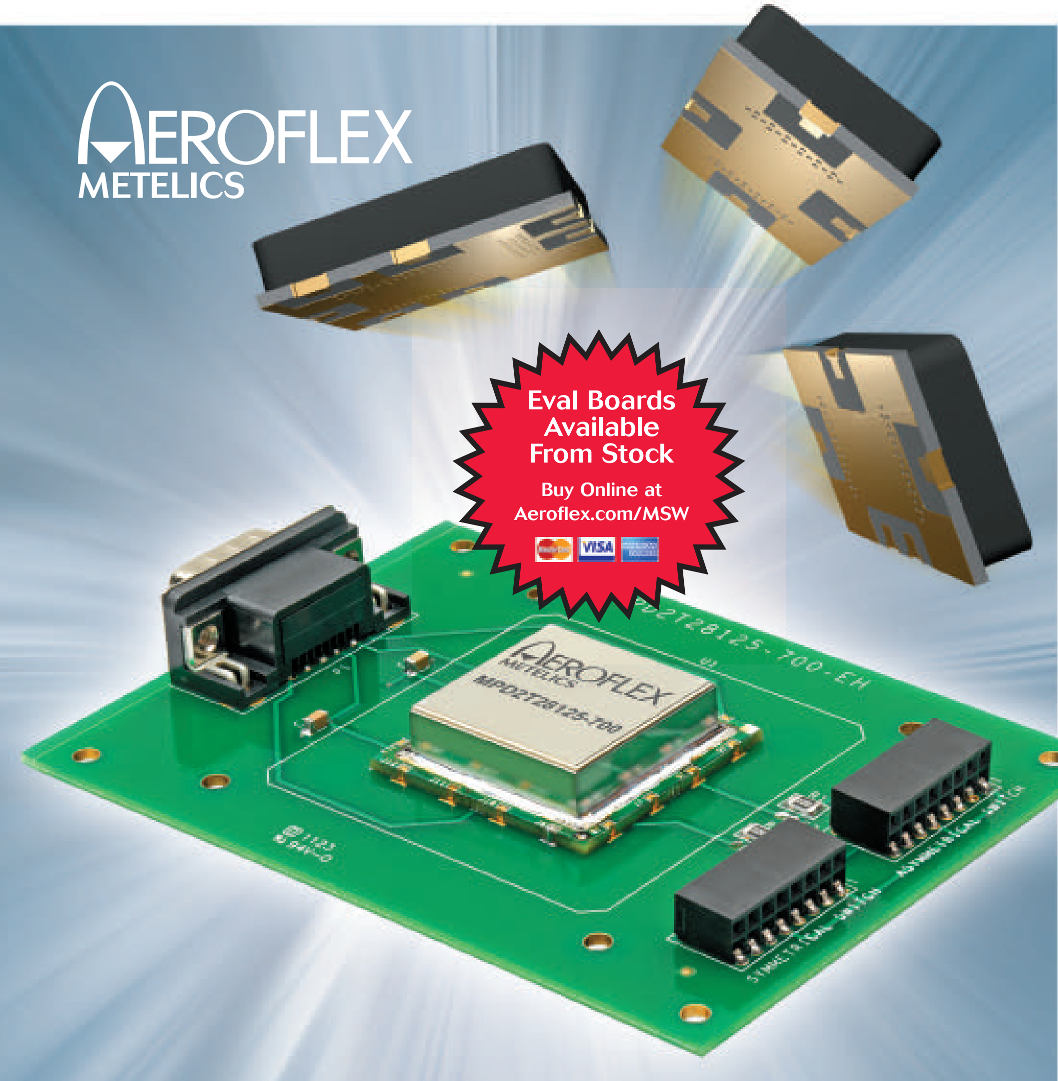
Electromagnetic Field Meters

VENDORVIEW

Narda Safety Test Systems, an L-3 Communications company, introduced two portable instruments designed exclusively for measurement of electromagnetic fields found in industrial environments. The battery-powered meters allow users to accurately ensure compliance with the IEEE C95.1-2005 standard and recommendations from ICNIRP that dictate Maximum Permissible Exposure (MPE) to electromagnetic fields. The NIM-511 and NIM-513 industrial field meters measure 1.5" × 2" × 8.1" and weigh 1.3 pounds. The NIM-513 operates from 10 to 42 MHz and its calibration reference frequencies include 27.12 MHz and 13.56 MHz. The NIM-511 operates over a frequency range of 300 kHz to 100 MHz with a calibration reference frequency of 13.56 MHz.

Narda Microwave-East, Hauppauge, NY (631) 231-1700, www.nardamicrowave.com/east.

Under powered and over budget? Problem solved.



If you're in need of driving up the power handling and driving out cost in your next switch design, Aeroflex / Metelics' MSW series surface mount PIN diode switches and super-charged (+125V, -200V) MPD drivers are the perfect combination. It only takes a single driver to drive several of our high power (100 W C.W. or 500 W peak input power) switches—even symmetrical and asymmetrical T-R switches at the same time—saving you precious real estate and overhead. MPD drivers are TTL input compatible (single or double logic) and offer a typical switching speed of 2 µS. Covered with a high performance RF shield they're also worry free. Get your hands on an evaluation board today and put the perfect switch in your control.

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www.aeroflex.com/metelics

PIN Diode Switch and Driver Combinations

Part Number	Configuration	Drive Voltage*	Recommended Switch Driver	Frequency Band (MHz)
MSW2000–200	T-R Switch, TX Left	+V Only	MPD2T28125-700	10 to 1,000
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 to1,000
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	MPD2T5N200-703	10 to 1,000
MSW3201-320	Symmetrical SP3T	+V & -V	MPD2T5N200-703	400 to 4,000

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

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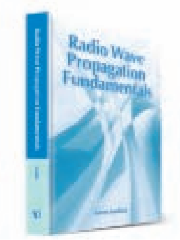

Radio Wave Propagation Fundamentals

Artem Saakian

Radio Wave Propagation Fundamentals attempts to satisfy the growing demand in radio wave propagation study materials for students and specialists. The core materials were developed from lecture notes that have been offered by the author for graduate students at Patuxent Graduate Center of Florida Institute of Technology. The materials included in the text have been extended beyond the needs of the single-semester course and may be used for continuous self-study.

The objective is to support senior-level undergraduate and graduate electrical engineering students with an introduction of the basic principles of electromagnetic waves propagation of radio frequencies in real conditions relevant, but not limited, to communications and radar systems. It is also to emphasize the primary role of the antenna-to-antenna propagation path in the overall performance of those systems. Practicing engineers who need a quick reference to the basics of propagation mechanisms and principles of engineering estimates and designs may use this text in their everyday routine. It would also be useful to engineers and scientists in related areas for learning about the fundamentals of RF.

The book covers electromagnetic wave theory, antennas for radio links, impact of the environment on wave propagation and receiver basics. While this is a good book to learn about the basic of radio waves, it primarily covers the theory and equations related to the topic, but it does not go into many practical applications or real world examples. It is a good text for students covering the theory and for engineers to review the theory or have it handy for reference. However, it would not extend to practical design and applications information for the engineer or scientist in the field.

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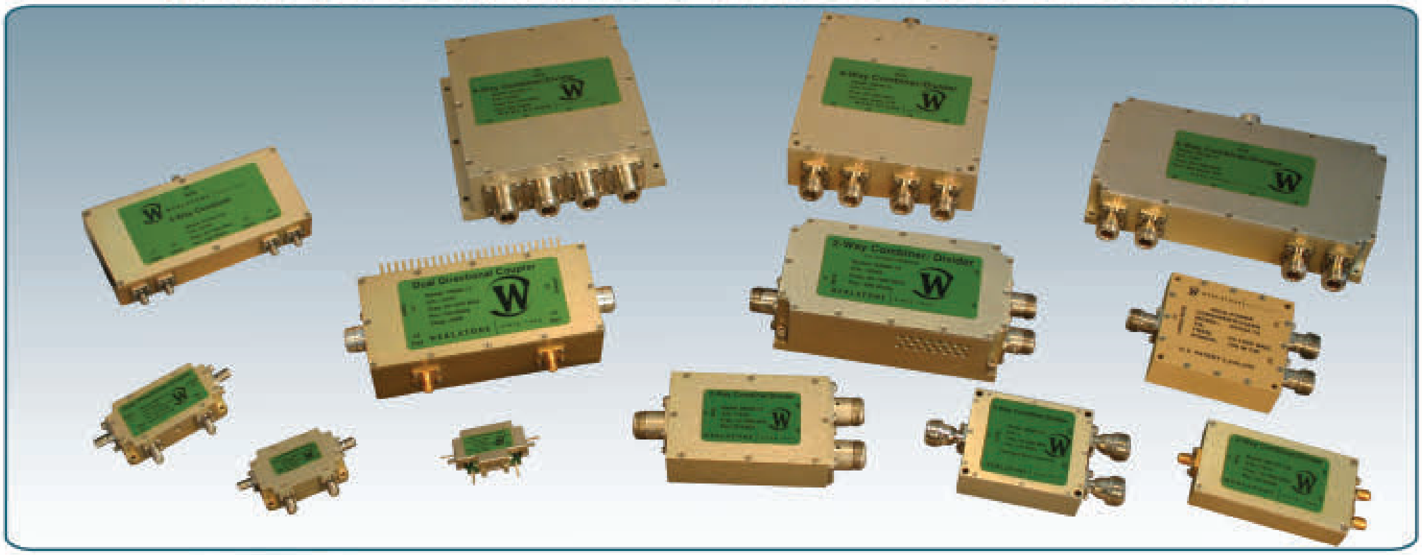

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D8632	2-Way	20-1000	50	2.2 x 2.02 x 1.5	0.7	1.40:1	20
D8300	2-Way	20-1000	100	2.45 x 2 x 0.91	0.5	1.35:1	20
D8544W*	2-Way	20-1000	100	2.85 x 2.5 x 1	0.5	1.35:1	18
D8682	2-Way	20-1000	500	5.2 x 2.65 x 1.8	0.6	1.35:1	15
D8851W*	2-Way	20-1000	500	5.6 x 3.05 x 1.8	0.6	1.35:1	15
D7365	4-Way	20-1000	100	5 x 2 x 1	0.75	1.35:1	20
D7439	4-Way	20-1000	250	5 x 5 x 1.5	0.75	1.35:1	18
D8746	4-Way	20-1000	500	7.2 x 3.5 x 1.4	0.7	1.35:1	15
D9048	4-Way	20-1000	500	5 x 4.7 x 1.4	0.6	1.35:1	17

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C8631*	40	20-1000	150	1.5 x 0.95 x 0.5	0.35	1.25:1	20
C8696	40	20-1000	150	1.76 x 1.16 x 0.57	0.35	1.25:1	20
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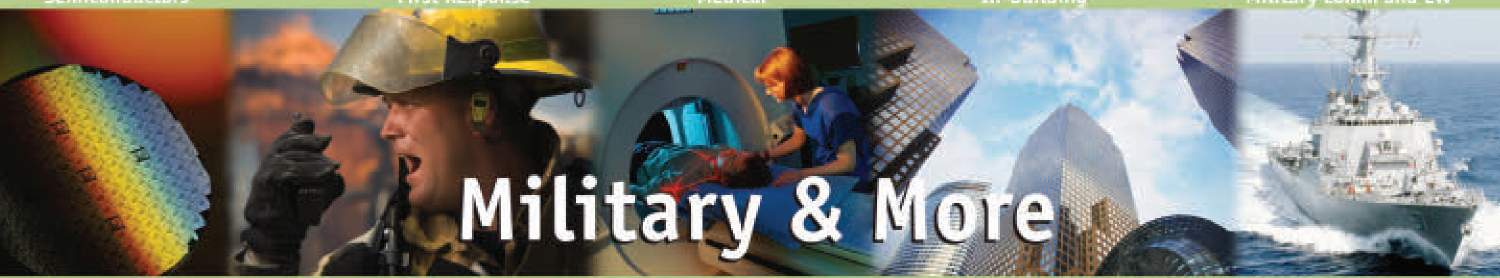


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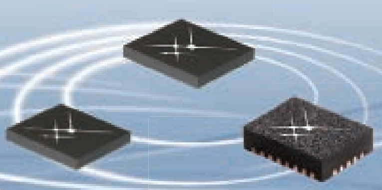

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SP8T–SP10T Antenna Switch Modules—With GSM Harmonic Filter								
SKY18106-455LF SP8T, SPI DigRF interface	6	0	No	-0.6/-0.9	-30	-106	-50/-45	QFN 26L 3.0 x 3.8
SKY18110 SP8T, GPIO logic	6	0	No	-0.8/-0.9	>35	<-102	-45/-42	MCM 20L 3.2 x 3.2
SKY18116 SP8T, small form factor	6	0	No	-0.8/-0.9	>35	<-102	-45/-42	MCM 18L 3.2 x 2.5
SKY18108 SP9T, WCDMA, and TD-SCDMA	3	4	No	-0.8/-0.9	>35	<-102	-45/-42	MCM 20L 3.2 x 2.5
SKY18120 SP9T, WCDMA, and TD-SCDMA	3	4	No	-0.8/-0.9	>35	<-102	-45/-42	MCM 16L 2.5 x 2.5
SKY13364-389LF SP10T	4	4	No	-0.6/-1.0	>35	<-105	-40/-40	QFN 26L 3.0 x 3.8
SKY13362-389LF SP10T	5	3	No	-0.7/-1.1	>35	<-105	-40/-40	QFN 26L 3.0 x 3.8
SKY13402-466LF SP10T	6	2	No	-0.7/-1.1	>35	<-105	-48/-42	QFN 26L 2.6 x 3.4

Part Number / Description	Linear TRx Ports	GSM Rx Ports	GSM Harmonic Filter	GSM Rx Band SAW Filter	Typ. IL TRx/Tx @ 2.0 GHz (dB)	Typ. Isolation (dB)	IMD (dBm)	H2/H3 Typ. (dBm)	1.8 V Logic Compatible	Package (mm)
SP2T–SP6T Rx Diversity, Band, Mode Switch, and Differential Rx Switch										
SKY13374-397LF SP2T	2	–	–	No	0.5	>28	–	-50/-50	–	QFN 16L 2.0 x 2.0
SKY13373-460LF SP3T	3	–	–	No	0.5	>23	–	-50/-50	–	QFN 12L 2.0 x 2.0
SKY13388-465LF SP4T	4	–	No	No	0.5	>25	–	-45/-45	Yes	QFN 12L 2.0 x 2.0
SKY13380-350LF SP4T	4	–	–	No	0.4	>23	<-115	-45/-45	–	QFN 16L 3.0 x 3.0
SKY13358-388LF SP5T	5	–	–	No	0.7	>27	<-102	-50/-45	–	QFN 16L 2.3 x 2.3
SKY13360-388LF SP6T	6	–	No	No	0.5	>23	< 100	-40/-40	Yes	QFN 16L 2.3 x 2.3
SKY13354-368LF DP4T	0	2	No	No	0.5	> 23	–	–	No	QFN 12L 2.0 x 2.0
SKY13397-388LF DP5T, 3G band switch	5	–	–	No	0.4	>32	–	-50/-50	–	QFN 16L 2.3. x 2.3

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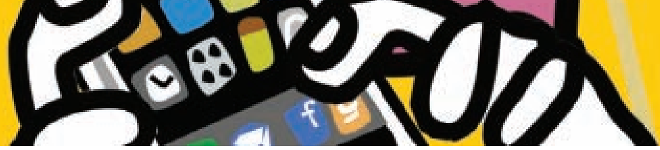

Mobile Communications

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Attending Mobile World Congress

David Vye, Microwave Journal *Editor*

For the cover of this month's Mobile Communications supplement, we found artistic inspiration from one-time Barcelona resident Pablo Picasso in our tribute to the city's other famous resident – GSMA Mobile World Congress (MWC). This annual event combines the world's largest exhibition for the mobile industry and gathering of Chief Executives and other dignitaries from up and down the global mobile supply chain. And in 2012, Barcelona has even more reason to celebrate the return of MWC.

MWC, initially called 3GSM when it started in 1987, was hosted in Cannes until 2006 after which it moved to Barcelona. Over the past few years, rumors of a new location have been spreading throughout the exhibition halls as the organizers put the show out to bid. In considering a possible new venue, GSMA undertook a thorough and complex evaluation process, starting with 30 cities, narrowing it down to six before reducing the number of candidates down to a short list of four finalists. Cities such as Munich, Milan and Paris aggressively vied for the opportunity to host the event. But then in July, after an 18-month search, the GSMA announced that Barcelona had been selected as the "Mobile World Capital" from 2012 to 2018.

As the Mobile World Capital, Barcelona will remain as the host of the industry's largest yearly event. The cornerstone of the Mobile World Capital is the four-day MWC, which attracted more than 60,000 attendees from 200 countries in 2011. Attendees included 3000 CEOs, government delegations from 131 countries and more than 2900 media representatives. Starting in 2013, the MWC will be relocated within the city to the cutting-edge venue Fira de Barcelona Gran Via.

In addition to MWC, the Mobile World Capital features two additional elements: the Mobile World Centre and the Mobile World Festival. The Mobile World Centre will be composed of permanent and temporary exhibitions that meld culture and technological innovation, facilities for the development and incubation of mobile solutions, and retail and hospitality venues. The Mobile World Festival, which is targeted to the general public, will incorporate a range of activities, including sporting events, music and art festivals, film awards, applications and technology fairs and more.

According to estimates from the Barcelona Candidacy, the Mobile World Capital would bring, in the first year alone, more than 300 million euro, along with thousands of part-time jobs. As some of the initiatives have a mid-term reach and will grow steadily during their implementation, the economic impact is expected to increase progressively and, based on Barcelona's assessments, could reach 3.5 billion euro over the seven years.

(Continued on page 5)

As for MWC 2012, the keynote speakers are once again C-level telecommunication executives representing the top of the food chain. Network CEOs from AT&T, Alcatel-Lucent, Deutsche Telekom, NTT DOCOMO, Vodafone, Ericsson and Telecom Italia will join CEOs from major handset OEMs, such as Nokia and HTC, to discuss the future direction and immediate concerns of the industry. Some of the focus sessions will examine mobile innovations, strategies, addressing network capacity, regional focus and network technology evolution.

From the RF/microwave component sector, companies participating at MWC are particularly active in the commercial communications side of test and measurement equipment, semiconductor and chipsets, cables/connector and high power passive components, antennas, femto-cells and backhaul equipment manufacturing. On the test and measurement side, we are anticipating major product announcements from companies such as Aeroflex, Agilent, Anritsu, Rohde & Schwarz and Spirent. RFIC manufacturers, such as TriQuint Semiconductor, RFMD, Skyworks, ANADIGICS and Avago, will most likely show up with a hail of new products as well.

In this month's special mobile communications supplement, we are pleased to have Fred Schindler, Director of RFMD's Boston Design Center, and his colleagues discuss how power amplifier design is impacted by the higher data rates and linearity requirements called for by LTE. This is no small challenge for the RFIC designer and should be of considerable interest to anyone working with a mobile device front-end.

Complementing this cover story, we are also featuring a perspective piece from Ron Williamson of Aeroflex Test Solutions on the future of RFIC test strategies. Williamson talks about the growing cost and equipment investment for RFIC ATE systems and how PXI/AXIe instrumentation and infrastructure offer an alternative production test environment with the benefit of high MTBF, fast test times and system coherency. Also discussing test issues for mobile communications, Agilent Technologies writes about the design and test challenges for the physical layer of base station and user equipment brought on by the carrier aggregation called for by ITU's IMT-Advanced 4G.

Along with articles on the co-existence of point-to-point microwave links, the design of a compact MIMO antenna using metamaterials, addressing traffic and channel power distribution, low PIM connectors and GPS ICs, *Microwave Journal* covers a lot of ground in this month's supplement, not unlike the new Mobile World Capital. So here is to Barcelona and MWC. I am glad mobile decided to be stationary. ■

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Wireless Data Connectivity with LTE Power Amplifiers

Consumers are demanding more from their mobile devices – including increased bandwidth. They have become accustomed to the near universal data connectivity of smartphones, and are voracious for the applications that continually demand higher and higher data rates. Tablet computers also are becoming more popular, and their demands for constant connectivity and data usage are reportedly five times higher than those of smartphones.[1] Laptops have not disappeared either. Consumers expect their laptops to have the same universal connectivity as their phones, running applications that demand higher data rates. Most laptops have wireless network connectivity built-in, and there is a growing market for USB dongles to provide connectivity with the latest high data rate standards. There is also an emerging market for new categories of connected devices, ranging from Internet Protocol TV (IPTV) to connected vehicles with wireless diagnostic, safety and infotainment capabilities.

What is driving these increased data rates? In the US, for example, the introduction of advanced smartphones is pushing some networks to their limits and frustrating consumers. We have all seen the growth of streaming audio and video, and this is just the tip of the iceberg. The exponential growth of social networking-related traffic is another key driver, as is online gaming. Perhaps the most compelling trend is the growth of cloud computing. With cloud computing, data is stored remotely, not on the device. As we have all seen, the amount of data that we want to store continues to increase. More data can be stored in the cloud than can be practically stored on a mobile device. Reducing the permanent memory demands in the mobile device reduces cost and size and increases speed and battery life. Thus, we have a hardware trade-off between permanent memory and network connectivity. The balance is tipping in the direction of data connectivity.

Mobile data traffic increased by a factor of 2.6 in 2010, and is expected to increase 26 fold from 2010 to 2015.[1] By the end of this year, it is expected that video will be more than 50 percent of all mobile traffic. In fact, in the US we have already seen streaming video services like Netflix dominating Internet traffic at peak times.[2] Consumers are migrating to mobile devices and that is driving mobile traffic.

In order to support this growing demand, connection speeds are expected to increase by a factor of ten by 2015. Today, the average mobile network connection worldwide is only 215 kbps. By 2015, it will be more than 10 times that, 2.2 Mbps. With 7.1 billion mobile connected devices, that is a lot of data.[1] Network

Fred Schindler, Virender Sadhir, Brian Robbins, David Guo and Jerry Paradis
RF Micro Devices, Greensboro, NC, and Billerica, MA

infrastructure is already responding to meet the challenge. Long Term Evolution (LTE) and LTE-Advanced have been developed specifically to provide high mobile data capacity.

LTE CONNECTIVITY

Connections to LTE networks are already available from various cellular service providers in limited service areas. These deployments continue to grow. But there are other LTE deployment options. For example, in-home range extenders can be used to provide enhanced connectivity, especially in rural or remote areas. Personal gateways will also find use, primarily by businesses, to provide higher data rates either in office facilities or in public service areas to provide an enhanced experience for customers, much as many cafés offer free WiFi today.

There are of course alternatives to LTE. WiFi is a leading alternative, and currently can offer connection speeds of 300 Mbps. Future variants on the 802.11 standard will offer even higher data rates. WiFi is pervasive and offers an attractive option to connect to a local access point, typically with a range of tens of meters. WiFi uses either the 2.4 to 2.5 GHz ISM band or the 4.9 to 5.85 GHz band (4.9 to 5.15 GHz in Japan). The ISM band is crowded – it is used for a variety of other data connections, including Bluetooth® and microwave ovens. This ultimately limits the practical achievable data rate. The 5 GHz band is an attractive alternative, but many devices lack 5 GHz capability and the band remains lightly used.

WiMAX is another alternative. It was designed with many of the same applications in mind as LTE, and is approximately equivalent in capability. WiMAX has been deployed in the 2.3 to 2.4 GHz, 2.5 to 2.7 GHz and 3.3 to 3.8 GHz bands, but it has seen limited acceptance in the marketplace. LTE can also use these frequency bands and many WiMAX compatible uplink products (such as datacards) can be redesigned to operate in high data rate LTE systems. Future migration trends point to growing adoption of the LTE standard.

LTE operates in a variety of bands between 728 MHz and 3.8 GHz, depending on the service provider and the location. Bandwidths, data rates, and TDD/FDD implementation vary, but the overall standard is universal. Data rates of up to 300 Mbps are possible for LTE and 3.3 Gbps for LTE Advanced (though this is only under ideal conditions with 8 × 8 MIMO). One of the main advantages of LTE is that it has been selected as the 4G standard by a large number of cellular service providers throughout the world.

UPLINK VS. DOWNLINK

Every wireless system has an uplink and a downlink. Typically, we carry a terminal device (smartphone, tablet, laptop or other connected device). The devices connect to an access point or a base station, see ***Figure 1***. The downlink is from the access point to the networked device. Conversely, the uplink is from the network device to the access point. Typically, the devices we carry download more data than they upload. In this article, we are highlighting power amplifiers because they are a critical component in the system. The requirements for uplink and downlink power amplifiers are very different.

Downlink power amplifiers are found in access points and base stations and are used to transfer data to various mobile devices. An access point must connect to multiple network devices simultaneously, multiplying the total data rate, so power and linearity requirements for the downlink are tougher than for an uplink. For LTE, linearity is measured as Adjacent Channel Leakage Ratio (ACLR),[3,4] which is similar to the ACPR measurement used for CDMA and W-CDMA. LTE linearity is typically required to be -44 dBc for the downlink, usually targeting an OFDMA waveform for the greatest data rate, with bandwidths of 10 to 20 MHz (up to 100 MHz for LTE Advanced).

Uplink power amplifiers are found in smartphones, USB dongles, laptops, tablets, IPTVs, connected automobiles, etc. Each device provides its own uplink so the requirements on power and linearity are less stringent. System ACLR is typically -35 dBc with a 10 MHz standard bandwidth.

In LTE, modulation also differs from uplink to downlink. In the uplink, a single carrier frequency division multiple access (SC-FDMA) modulation is used. The downlink, in contrast, uses orthogonal frequency division multiple access (OFDMA).

▲ *Fig. 1 A networked device uses an uplink and a downlink.*

Whereas SC-FDMA uses a single carrier, OFDMA uses multiple orthogonal carriers. This provides greater spectral efficiency for the downlink, but challenges PA linearity even more.

ACLR is not the only linearity requirement for an LTE PA. There is also a requirement for error vector magnitude (EVM). For the LTE downlink, depending on the specifics of the modulation, the EVM limits are 12.5 to 17.5 percent.[4] As a practical matter, the ACLR limit of -44 dBc is always reached long before EVM approaches 10 percent, so EVM is not a significant PA design concern. Other systems, such as WiMAX and WiFi tend to be EVM limited, with EVM specifications in the 3 to 4 percent range.

LINEARITY AND MODULATION BANDWIDTH

As systems are designed to provide even higher data rates, the linearity requirements inevitably continue to increase. And, as air standards evolve to handle greater bandwidths and modulation techniques become more advanced, the general trend is for greater linearity burden on the power amplifier.

LTE supports a range of modulation bandwidths. For an uplink, the modulation bandwidth may be 1.4, 3, 5, 10, 15 or 20 MHz. For the downlink, the standard modulation bandwidths are 10 and 20 MHz. The standard WiMAX downlink modulation bandwidth is 10 MHz, optionally 20 MHz (LTE-Advanced supports up to a 100 MHz modulation bandwidth). In addition to linearity challenges, the modulation bandwidths themselves create design challenges for a PA.

DESIGNING PAS FOR NETWORK ACCESS POINTS

As already noted, system linearity is stated in terms of ACLR. The downlink power amplifier must be capable of -44 dBc ACLR or better, up to its rated power. Rated power for the PA is dependent on a number of factors. First, consider the type of access point. See ***Table 1*** for a listing of access point types. A macrocell is what we typically think of as a base station – a tower servicing a large geographic area. A microcell is a base station that services a more limited area, often in an urban area, with denser cell spacing allowing for increased network capacity. A picocell covers an even smaller area, often a specific office facility, mall, or sporting complex. A femtocell is smaller yet, and is typically intended to service a home or small business. Picocells and femtocells will be deployed to offload high data traffic onto local fixed network connections.[1]

We need to work back from the output power at the antenna to determine the requirements for our power amplifiers. In a Time Division Duplex (TDD) system, we typically see 1.5 to 2 dB of loss from switching and filtering between the PA and the antenna. A Frequency Division Duplex (FDD) system requires additional filtering, so the loss between the PA and the antenna is higher, 2.5 to 3 dB. There is a range of power requirements for every access point type, but there is a typical requirement that satisfies most implementations. We have found that power outputs in the 23 to 26 dBm range satisfy most femtocell and some picocell requirements.

KEY PA DESIGN CONSIDERATIONS

One of the first steps in designing a PA is process selection. The best design philosophy is always to pick the process that best fits the full set of requirements. Forcing a non-optimal process on an application will almost always yield an inferior product in terms of performance and/or cost. A fundamental choice is between Si and GaAs. For an access point downlink, performance is very important. There has been considerable progress in CMOS and SiGe power amplifiers, but up to now performance has typically lagged GaAs. In addition to a performance advantage, GaAs typically offers much shorter development times, thereby quickening time to market.

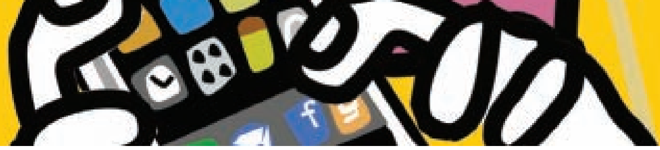
Within the family of GaAs processes, there are many options. HBTs and PHEMTs can both provide excellent PA performance. HBTs have an advantage in size, ease of matching and bias, so are a logical choice. There are a number of HBT processes available, and of those, InGaP shows a modest advantage for linear PAs. So an InGaP HBT is a good process to choose for an LTE downlink PA. GaAs BiFET can also be attractive – BiFET offers HBTs and PHEMTs on the same die. This makes it easy to integrate control functions, switches and receive circuitry. We are interested in a PA without switching or a receive path, and only modest control functionality is required. So the added complexity of a BiFET process is not necessary.

Once the transistor and process have been selected, it is time to architect the PA. The first priority is to determine how many stages of amplification are needed. We know that 30 dB gain is adequate for the vast majority of applications. While this can be achieved with two stages, three stages are preferable. It is generally necessary to sacrifice some gain to meet the wide range of other requirements – linearity, input and output match, bandwidth, passband flatness, temperature, process variation, stability, and harmonic output levels are just some of the additional specifications that need to be met. The extra gain of an added stage avoids over constraining the design. Current consumption is also a key requirement and an added stage does increase the total current draw. But the

TABLE I

CHARACTERISTICS OF ACCESS POINT TYPES

Access Point Type	*Typical Range*	*Output Power at the Antenna*
Femtocell	10 to 50 meters	10 to 25 dBm
Picocell	Up to 200 meters	22 to 30 dBm
Microcell	Up to 2 km	1s to 10s of watts
Macrocell	Up to 30 km	10s to 100s of watts



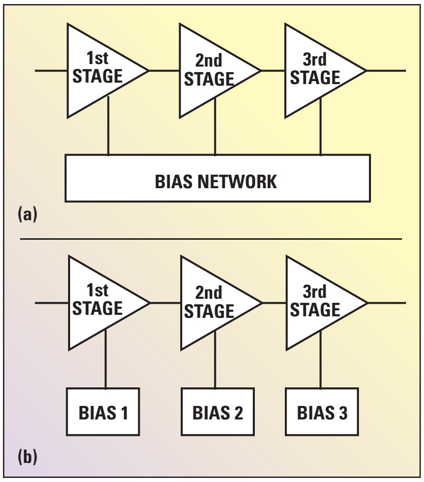
increased transistor area from the added stage can be modest, so with careful bias design the impact on total power consumption is minimal.

Sizing transistors is also critical. We start with the output, which must be large enough to provide the necessary combination of power and linearity. It must also be large enough to ensure that power density and temperature do not exceed reliable limits. We can rely on load-pull characterization of the transistors, as well as past experience of what is necessary for a certain level of output power.

While uplink PAs are typically powered by a battery (2.7 to 4.8 V), downlink PAs are typically powered by a fixed supply (4.5 to 5.0 V). It has been determined that 1900 μm^2 of emitter area is about right for the output stage of picocell to femtocell downlink PA delivering 22 dBm of linear power. Having determined the size of the output stage, we can determine the area of the other stages. The output stage will deliver about 8 dB gain, so the first and second stages will deliver about 11 dB each. We need to ensure that the earlier stages do not limit linearity. To do this with adequate margin over all conditions, we choose a 4:1 transistor size ratio between stages. Our final transistor configuration is 120, 480 and 1920 μm^2.

Now that we have selected the transistors, we have to determine how to best bias them. The simplest and physically smallest is to have a common bias path for all three stages, as ***Figure 2a*** shows. In such an approach, transistors in all three stages are biased at the same operating point, running at the same current density. An alternative is shown in ***Figure 2b***. This allows us to adjust the operating point, or current density for each stage. There are significant benefits to using this method. The output transistors should be the only ones limiting linearity, so their bias points should be set with that in mind. Similarly, the input stage is primarily providing gain, which can best be done at a different operating point. Finally, current consumption at each stage can be set to the minimum necessary for each, minimizing total current draw.

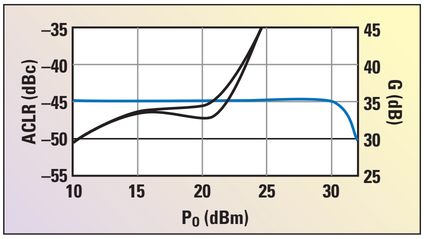
Also related to bias is thermal management. The duty cycle of an LTE downlink signal is high and with a long duration, so from a thermal management perspective, we can consider it to be CW. Once the power dissipation has been determined, the PA needs to be laid out for reliable operation, with particular emphasis on the transistor layouts. A PA in a picocell or a femtocell needs to operate in an ambient temperature of up to 80°C.



▲ *Fig. 2 Two approaches to biasing a multi-stage PA (a) common bias for all stages and (b) individual bias for each stage.*

The next critical step is matching. For many PA applications, it is important to determine the optimal match for linearity for the output transistor. For an LTE downlink PA, it is best to use an optimal power match. Because the LTE downlink uses OFDMA, it has a peak to average power ratio of about 10 dB.[5] The result is seen in ***Figure 3***. ACLR starts to increase significantly above an output power of about 21 dBm. This is about 10 dB below the level where output power starts to compress heavily. Peaks in power 10 dB above the average cause the limiting nonlinearities. A similar effect can be found in an LTE uplink PA, but because it uses SC-FDMA, it is 2 to 3 dB less severe.[6] To first order, maximizing output power is the key objective to achieve LTE downlink PA linearity, so an optimum power match is used for the output stage.

Modulation bandwidth also imposes requirements on matching and bias circuitry. The modulation bandwidth is up to 20 MHz. The key concern is baseband products at 20 MHz. The HBTs have very high gain at these low frequencies. Matching circuits and bias circuits need to incorporate filtering to minimize these low frequency products. Otherwise, the low frequency products will limit power amplifier linearity. The high gain of the HBTs at low frequencies can also cause instabilities. Care must be taken in designing low frequency filtering in the matching and bias circuits to avoid possible oscillations and spurious outputs.



▲ *Fig. 3 Output performance of a typical LTE downlink power amplifier; ACLR (black traces) starts to increase significantly ~10 dB before gain (blue trace) compresses.*

SUMMARY

We have provided some background on LTE, specifically the downlink, and what it means to the PA designer. The LTE downlink signal has a high modulation bandwidth with many orthogonal carriers. This results in very high PAPR, and drives the entire PA design. We have gone through many of the choices a PA designer must make in addressing LTE downlink requirements and provided a roadmap to complete a successful design. This illustrates how the next generation of LTE PA for access points is being developed. There are more complex design approaches that have been taken for the uplink, where DC power is critically limited.[7] These too may find their way into access points in the future. ■

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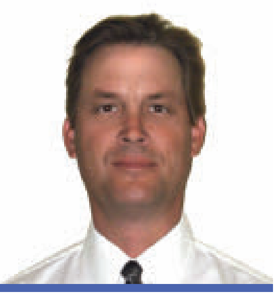
The Future of RFIC Test Strategy



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The future of Radio Frequency Integrated Circuit (RFIC) test strategy is a provocative topic these days. This is especially true for the consumer RF and connectivity integrated circuit (IC) markets, where ramping volumes and surging competition are shifting the market's mindset. Driven by cell phones, tablets, and other mobility devices, most RF devices are approaching commodity status, including the discrete power amplifier, front-end module, Bluetooth, WiFi and tuner segments. Price pressure is so extreme that a once-manageable test strategy is now overkill for low-end to mid-range devices. IC vendors are pulling all the punches to procure "just enough" production test capability.

For the past 20 years, standard automated test equipment (ATE) served this segment well. Competent RF technology led the way, augmented by reliable production worthiness. The general-purpose nature of production test was also suitable for the few silicon vendors whose product portfolio spanned the entire RF offering. But as we have seen in recent years, the technology has branched out. Multiple protocol standards, varying foundry processes and distinct Served Available Markets have created a more specialized supplier base.

This specialization has unearthed fertile soil for many new fabless companies. For example, in the Asia Pacific (APAC) region, accessible IC design technology and a maturing regional supply chain has fostered aspirations of dominating local markets. These players are especially sensitive to cost and are keen to "blaze a new trail" by adopting new test strategies. If these strategies are proven out, they will offer time-to-market advantages. These advantages may allow APAC suppliers to challenge the "blue chip" suppliers in the US and Europe in the years to come. However, the APAC suppliers have one primary dilemma – RF test is still an enigma in most Asian technology centers. Their local subcontracted manufacturers, although owners of many indigenous or legacy testers, possess limited RF test options. They see RF test capability as their final puzzle piece. They need to find a solution, either through low cost means and/or augmenting their current installed base with RF functionality.

These APAC "upstarts" are not the only IC vendors seeking alternative RF test solutions. IC manufacturers whose core competencies are digital or mixed signal are now integrating antennas into their devices. This creates significant test challenges. The IC manufacturing supply chain also possesses a large installed base of production test equipment with limited RF functionality. They want to view the RF pin as "just another device pin." But the question remains: How do they validate RF quality without overhauling their production strategy and/or excessively increasing their cost of test?

As we have seen in digital test over the past 20 years, the $8,000/digital pin in 1993 has become less than $500/pin in many current testers. Can the same economies be realized in RF? Commercial off-the-shelf (COTS) RF instrumentation is capable, proven, relatively inexpensive, and readily plays within industry standard form factors. Using these tools, can someone develop a cost-sensitive, focused solution for commoditized RF semiconductors? The ideal solution would:

- Meet the RF functionality requirements with seamless integration
- Be modular in nature, and offer a multitude of capability options
- Be production worthy with high reliability and throughput

- Stand alone, or assume a slave role for integration into a current tester environment

At Aeroflex, we believe the answer is yes – a solution can be developed. A precedent has already been set in semiconductor validation and characterization labs. These labs have successfully employed standard instruments to validate and debug their initial devices. VME, VXI and standalone instruments have all found a place in semiconductor test lore. However, the integration was usually custom, slow, cable-awkward and manual by nature.

Today's COTS instrumentation is a different beast. The PXI form factor has revolutionized the lab environment and is universally accepted. In the RF space, powerful instruments like 13 GHz sources and analyzers, vector network analyzers, single slot bi-directional port modules, local oscillators, intermediate frequency arbitrary waveform generators (AWG) and digitizers are one click away. Other non-proprietary standard technologies are building momentum as well. AXIe, PXI's big brother, has a quickly growing instrument portfolio, including RF AWGs, 48-channel digital pin electronics, 12-channel device power supplies, relay and load board controls, plus logic and protocol analyzers.

But the tipping point in RFIC ATE goes well beyond instrument functionality. Integration of the components by a team that understands semiconductor test is paramount. Moreover, PXI/AXIe instrumentation and infrastructure are proving to have exceptional reliability, fast data/signal busses and valuable multi-stage triggering. All of these benefits translate to key elements of a production test environment – high MTBF, fast test times and system coherency. The proof manifests itself in the cell phone manufacturing lines where 30 to 40 percent of all phones are tested with PXI solutions. Leveraging our cell phone success, coupled with the ever-increasing adoption of the PXI and AXIe form factors, Aeroflex recently introduced two industry standard, instrument-based test solutions that uniquely meet the four requirements above, including the AXRF RF Subsystem and AX-Series RF Characterization and Production Test System (PXI and AXIe).

In summary, competition and market dynamics in the consumer RFIC space has changed the industry mindset about RF product testing. Specialization and end-user product diversity opened doors for new and current IC vendors willing and eager to take risks for a market advantage. They see production test as a means to an end. They have pushed the test and measurement industry to accommodate their needs. This solution would not have come to fruition two years ago. Functionality alone did not create the tipping point. It took many intangibles to breach the precipice – customer adoption of PXI/AXIe instruments, proof of production worthiness in real world manufacturing, architectural improvements for fast test times with high accuracy, and most importantly, semiconductor-savvy teams to integrate the entire solution into a sophisticated, competent and user-friendly tool. ■

Coexistence of Terrestrial Microwave Point-to-Point Links and Wind Turbines

As one of the potential sources of alternative energy, wind turbines are considered an emerging industry and have been erected in many locations in the US, as well as around the world. Wind turbines work on the principle of conversion of the kinetic energy from wind into mechanical energy, which is then used to generate electricity. Wind turbines in large numbers are called wind farms and could potentially impact radio communications systems, including broadcasting stations, weather radars, airport radars and terrestrial microwave point-to-point systems.

Any time engineers are designing a new microwave link in a desolate area, they should investigate existence and proximity of wind turbines. This brief article will discuss and summarize some of the concerns engineers have to address during the microwave network design, in order to ensure a peaceful coexistence of microwave links and wind turbines. The same conclusions are also applicable to projects that might be considering a construction of a new wind farm in an area with existing microwave links.

WIND TURBINES AND WIND FARMS

1.5 MW turbines can be very large structures, with blades exceeding 67 m (220 feet) in diameter and tower heights exceeding 55 m (180 feet).[1] The wind farm concerns include the fact that they are composed of highly reflective materials, they can be up to 400 feet tall and have a large radar cross section (RCS), with blade tips spinning up to 200 mph; wind farms could have hundreds of these high profile structures in a relatively small area.[2]

Simply speaking, RCS is the measure of a target's ability to reflect radar signals in the direction of the radar receiver (which may or may not be collocated with the radar transmitter). Although it is difficult to actually calculate the RCS of a wind turbine, some measurements show that its value could be close to the RCS of a jumbo-jet. It is easy to conclude that a large wind farm could cause false alarms (or holes in the coverage in case they are ignored by the radar) on the screens of nearby airport radars, so planes flying over the wind farm may or may not be detected.

Wind farms are usually located in elevated and exposed regions, where they can experience an unobstructed exposure to the wind. This type of exposure is also preferred in fixed telecommunication installations, like microwave sites. There has been very little research done on this topic, which is becoming increasingly interesting as more and more wind farms are being constructed. Generally speaking, microwave engineers should carefully consider

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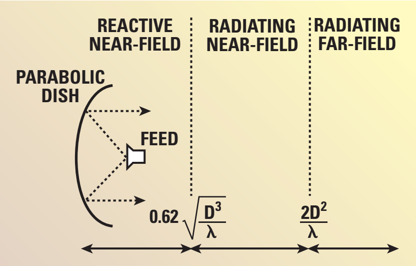
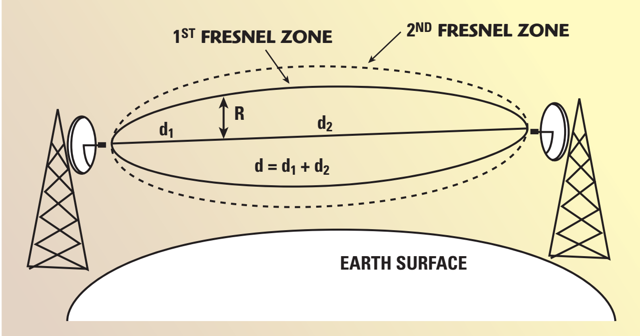


▲ *Fig. 1 Radiation fields of an antenna.*



▲ *Fig. 2 Fresnel zones.*

three criteria that potentially could cause degradation of an RF communications system, such as near-field, diffraction and reflection/scattering.

NEAR- AND FAR-FIELD

The terms far-field and near-field describe the fields around an antenna or, more generally, around any electromagnetic radiation source. The names imply that two regions, with a boundary between them, exist around an antenna. Actually, as many as three regions and two boundaries exist, and it is important to notice that these boundaries are not fixed in space (see ***Figure 1***).

Usually, two- and three-region models are used. In the near-field, the field strength does not necessarily decrease steadily with distance away from the antenna, but it may exhibit an oscillatory character and, therefore, it is difficult to predict the antenna gain and radiation pattern in that region.[3]

Engineers perform microwave link engineering, including Fresnel's clearances and path profiles, based on the assumption that microwave antennas are in the far-field region, that is the distance between them is sufficiently large. Any large object (reflective or not), including wind turbines, in the near-field of the antenna may distort the radiation pattern of the antenna and, therefore, should be avoided.

CONCEPT OF THE FRESNEL ZONE

The concept of the Fresnel zone is an integral part of the terrestrial microwave point-to-point link design. The most common use of Fresnel zone information on a profile plot is to check for obstructions that penetrate the zone and calculate a possible diffraction. Fresnel zones are specified employing an ordinal number that corresponds to the number of half-wavelength multiples that represents the difference in radio wave propagation path from the direct path. The first Fresnel zone is, therefore, an ellipsoid whose surface corresponds to one half-wavelength path difference and represents the smallest volume of all the other Fresnel zones (see ***Figure 2***).

In microwave engineering, the radius of the first Fresnel zone is the parameter currently employed to establish appropriate clearance of the link from different types of obstacles. The general formula (assuming that $R_n << d_1$ and $R_n << d_2$) to calculate the radius of n^{th} Fresnel zone is approximated by:

$$R_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}} \qquad (1)$$

In this formula, λ is a wavelength, R is a radius of the Fresnel zone, and d_1 and d_2 are distances from the antennas to the point of interest, and d is a microwave link length.

A more practical formula to calculate the radius of the first Fresnel zone in feet, which uses distances in miles, frequency in gigahertz, is given by:

$$R_{feet} = 72.1\sqrt{\frac{d_1 d_2}{f(d_1 + d_2)}} \qquad (2)$$

Diffraction theory indicates that the direct path between the transmitter and the receiver needs a clearance of at least 60 percent of the radius of the first Fresnel zone to achieve free-space propagation conditions.

If the geometry of the path is such

that an even-numbered Fresnel zone happens to be tangential to a good reflecting surface (such as a lake, highway, or smooth desert area, or wind turbines in this case), signal cancellation will occur as a result of interference between the direct and indirect (reflected) signal paths.

What is not included in this discussion is that the refractive properties of the atmosphere are not constant and the variations of the index of refraction in the atmosphere (expressed by the Earth-radius factor k) may force terrain irregularities to totally or partially intercept the Fresnel zone. A much more detailed discussion of the effects of climate on clearance requirements is given in reference 3.

MICROWAVE LINK ENGINEERING IN THE PROXIMITY OF WIND TURBINES

Perhaps the most dangerous situation is if the wind turbine is blocking or impinging the first Fresnel zone. Diffraction (obstruction) or reflection of radio waves by a wind turbine can degrade the performance of a point-to-point microwave link due to the effect of large blades rotating at approximately 32 rpm (typically there are two or three blades). Thus any significant interfering signal, such as a delayed multipath component, will fluctuate in signal level approximately 1.0 to 1.5 Hz.[4]

Based on some measurements, a single turbine can cause fades of 2 to 3 dB on microwave links with frequencies up to 18 GHz. A wind farm with only 17 turbines can produce up to 20 dB of fading if it is inside the Fresnel zone. Considering that the microwave link fade margin is typically 30 to 35 dB, this is a very significant loss of signal.[5]

It is important to remember that the horizontal axis of blade rotation varies in azimuth according to the wind direction, so this is not a static obstacle, like a tree or a building. Although typically 60 percent clearance of the first Fresnel zone is sufficient to guarantee undisturbed performance of the microwave link, in this situation the recommendation is to keep the first Fresnel zone completely, 100 percent clear. In addition, even a clear first Fresnel zone may not be sufficient, so a more stringent requirement of also keeping the second Fresnel zone clear should be implemented.

Signal reflection from the physical structure of a turbine propagating into the microwave receiver can potentially result in receiver's threshold degradation, resulting in a critical increase in the carrier-to-interference (C/I) ratio, usually expressed in decibels, depending on the modulation and coding schemes) requirement for the link. Care should be taken with respect to a possible multiple reflections from the individual turbines of a wind farm. A long string of wind turbines running in parallel with the microwave link could be especially detrimental.

CONCLUSION

The process of designing a microwave link in the vicinity of wind turbines follows the usual good practices of microwave engineering – avoid obstacles in the near-field of the antennas, keep first (and second, in this case) Fresnel zone clear of obstacles, and pay special attention to reflections when running microwave link in parallel to the long string of wind turbines. In some special cases, space diversity or some other method of reducing effects of multipath and improving reliability of the microwave link may be required. ■

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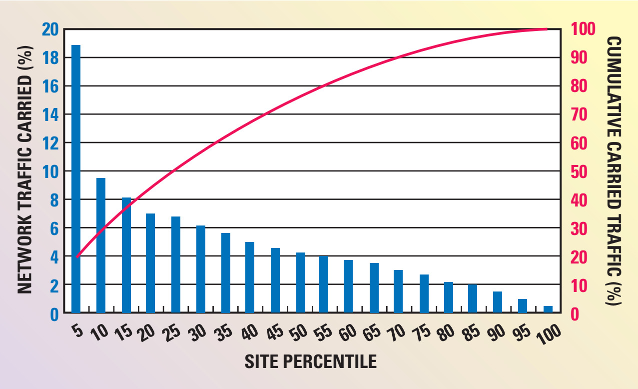
Addressing Traffic and Channel Power Distributions in 3G Networks

Providing capacity to keep pace with the explosive growth in wireless data services is a highly complex task due to the time variant and geographically inhomogeneous nature of offered traffic. To ensure a consistent, high quality user experience, both site and carrier density must be tailored to match the offered traffic density, with sufficient margin to accommodate large fluctuations in traffic loading.

A white paper from ISCO International discusses the statistical distributions of traffic and interference from a network perspective, and how poor correlation between measured traffic and uplink channel power can be used to assess interference severity. Interference is a pervasive problem, and as networks strain to handle growth in wireless data traffic, the importance of identifying and resolving performance degradation due to interference is growing more acute.



▲ *Fig. 1 Total percentage of network traffic carried vs. site percentile.*

Traditional approaches address severely impaired sites on a case-by-case basis, and are often identified by customer complaints of poor service quality. Applying a more network-centric approach, by jointly analyzing RTWP and traffic loading distributions to identify potential trouble sites, represents a more proactive approach to interference management that allows operators to identify RF impairments before they turn into customer complaints.

Figure 1 illustrates the distribution of traffic, ranked vs. site percentile from highest to lowest in five percent bins, for a typical urban 3G wireless network. If site coverage perfectly matched the geographical distribution of offered traffic, each bin would carry the same fraction of the total network traffic and the histogram would appear uniform. The actual distribution, however, is highly skewed: Sites in the first bin (the busiest five percent of sites) carry 19 percent of the total network traffic, and the busiest 25 percent carry half of the total traffic.

Read the complete white paper online at www.mwjournal.com/ISCOtraffic.

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LTE-Advanced Physical Layer Design and Test Challenges: Carrier Aggregation

Achieving the ITU's IMT-Advanced 4G target peak data rates of 1 Gbps in the downlink and 500 Mbps in the uplink requires bandwidths that are wider than the maximum 20 MHz bandwidth specified in 3GPP Release 8/9 LTE. To achieve those targets, 3GPP Release 10 LTE-Advanced supports carrier aggregation, allowing two or more component carriers (CC) to be aggregated to create wider transmission bandwidths of up to 100 MHz. Most operators are unlikely to find 100 MHz of contiguous bandwidth in the available spectrum resources, so the ITU has allowed the use of both contiguous and non-contiguous carrier aggregation. In the latter case, the component carriers can be non-contiguous in the same spectrum band (intra-band) or non-contiguous in different spectrum bands (inter-band). This article presents an overview of carrier aggregation along with some of the associated design and test challenges from the physical layer perspective for both the base station and the user equipment (UE). The type of test equipment that will be required to tackle these challenges is also considered.

To meet different spectrum and deployment plans, 3GPP Release 8/9 LTE introduced six carrier bandwidths of 1.4, 3, 5, 10, 15 and 20 MHz. However, to achieve the ITU's IMT-Advanced 4G target downlink peak data rate of 1 Gbps, even wider bandwidths are required. IMT-Advanced sets the upper limit at 100 MHz, with 40 MHz the expectation for minimum performance. Because most spectrums today are occupied and 100 MHz of contiguous spectrum is not available to most operators, the ITU has allowed the creation of wider bandwidths through the aggregation of multiple component carriers. Carrier aggregation has been adopted in 3GPP Release 10, better known as LTE-Advanced.

Three aggregation scenarios are defined in Release 10: single-band (or intra-band) contiguous carrier aggregation, single-band non-contiguous carrier aggregation and multi-band (inter-band) non-contiguous carrier aggregation. Component carriers of the same or different bandwidths (1.4 to 20 MHz) may be aggregated.

Release 10 component carriers are essentially the same as the carrier bandwidths defined in Release 8/9. In this way, LTE-Advanced maintains backward-compatibility with LTE. A Release 10 UE, with carrier-aggregation reception or transmission capability, can simultaneously receive or transmit on multiple component carriers corresponding to multiple serving cells. However, a Release 8/9 UE can receive or transmit on a single component carrier corresponding to one serving cell only.

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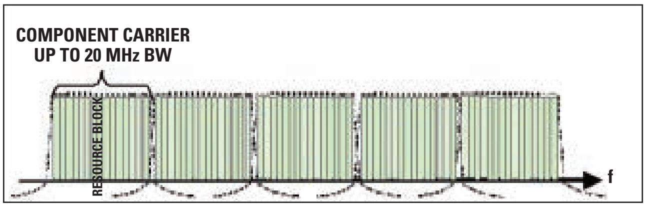


Fig. 1 Contiguous allocation of component carriers.

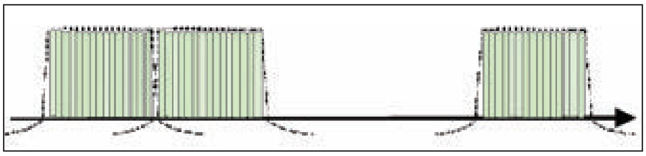


Fig. 2 Intra- or single-band non-contiguous allocation of component carriers.

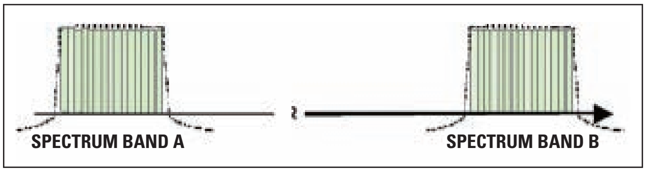


Fig. 3 Inter- or multi-band non-contiguous allocation of component carriers.

Figure 1 shows an example of inter-band carrier aggregation, in which five adjacent component carriers, each 20 MHz wide, covering the maximum 100 MHz LTE-Advanced bandwidth. For most operators today, this scenario is not realistic, since most operators do not have more than 20 MHz in a given frequency band. However, such contiguous allocation of component carriers may be realistic when new spectrum bands, such as 3.5 GHz, become available to operators in some countries.

Figure 2 shows an example of intra-band non-contiguous aggregation, in which the component carriers are separated within a single frequency band. This scenario can be applied if multiple operators share a network or if the frequency band allocated to an operator is fragmented.

Figure 3 shows an example of inter-band non-contiguous aggregation, in which component carriers belonging to different frequency bands (such as 1.8 and 2.6 GHz bands in some parts of Europe) are aggregated. Carriers aggregated in each frequency band can be contiguous or non-contiguous. The inter-band scenario for the downlink (base station to UE) is more realistic today because spectrum allocation for operators is often scattered across multiple frequency bands. However, for the uplink (UE to base station), this scenario would be very challenging because it would require multiple transceivers in the UE.

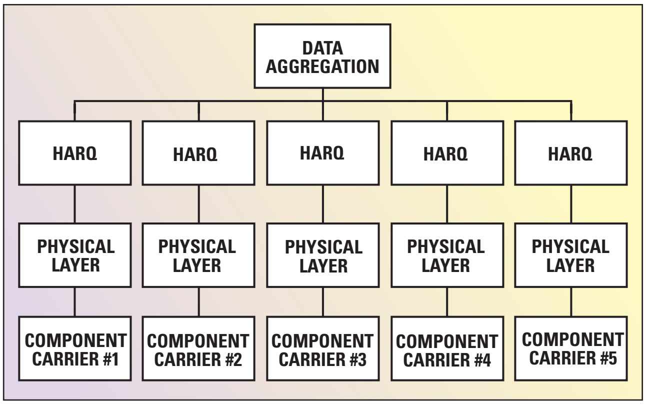


Fig. 4 Data aggregation from the PHY up to the MAC interface.

Mapping of the component carriers, from the physical layer (PHY) up to the medium access control (MAC) layer interface, is shown in ***Figure 4***. There is one transport block (in the absence of spatial multiplexing) and one Hybrid Automatic Repeat Query (HARQ) entity for each scheduled component carrier (HARQ is the control mechanism for retransmission). Each transport block is mapped to a single component carrier only. A UE may be scheduled over multiple component carriers simultaneously. The details of how the control signaling will be handled across the multiple component carriers are still being developed by 3GPP.

OPERATING BANDS FOR CARRIER AGGREGATION

The operating bands currently specified in Release 10 for LTE-Advanced carrier aggregation are defined in ***Tables 1*** and ***2***. These bands are defined for intra-band

TABLE I

INTRA-BAND CA OPERATING BANDS [3GPP TS 36.101 V 10.3.0 (2011-06)]

E-UTRA CA-Band	E-UTRA Band	Uplink (UL) Operating Band			Downlink (DL) Operating Band			Duplex Mode
		BS Receive/UE Transmit			BS Transmit/UE Receive			
		FUL_low-FUL_high			FDL_low-FDL_high			
CA_1	1	1920 MHz	to	1980 MHz	2110 MHz	to	2170 MHz	FDD
CA_40	40	2300 MHz	to	2400 MHz	2300 MHz	to	2400 MHz	TDD

TABLE II

INTER-BAND CA OPERATING BANDS [3GPP TS 36.101 V 10.3.0 (2011-06)]

E-UTRA CA-Band	E-UTRA Band	Uplink (UL) Operating Band			Downlink (DL) Operating Band			Duplex Mode
		BS Receive/UE Transmit			BS Transmit/UE Receive			
		FUL_low-FUL_high			FDL_low-FDL_high			
CA_1-5	1	1920 MHz	to	1980 MHz	2110 MHz	to	2170 MHz	FDD
	5	824 MHz	to	849 MHz	869 MHz	to	894 MHz	

contiguous and inter-band non-contiguous cases. As more deployment scenarios are agreed upon based on operator input, more band definitions will be added to the specification independent of the Release version.

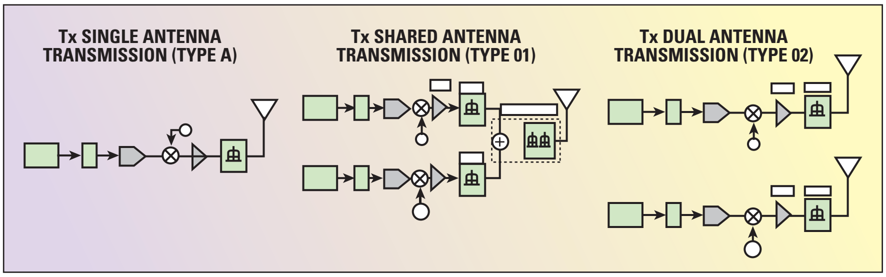
DESIGN CHALLENGES

Carrier aggregation brings new technical challenges, especially for the LTE-Advanced UE. The complexity of the UE's radio frequency (RF) front-end implementation can vary greatly, depending on which type(s) of carrier aggregation are supported, with contiguous carrier aggregation being the least complex. In Release 10 devices, contiguous carrier aggregation will not exceed two component carriers or 40 MHz maximum. It may be possible to support this configuration with a single wideband transceiver in the UE.

For non-contiguous component carrier allocations, the UE will have to use multiple transceivers or a single, very wide wideband transceiver. Using multiple transceivers may be realistic in the sense that such configuration requires only the addition of parallel paths to process each spectrum band, as in current multi-band devices. However, using multiple transceivers also increases the size and cost of the mobile device and shortens the battery life.

In the case of the wideband transceiver, a single transceiver must process the multi-band non-contiguous aggregation using wideband RF components. There are two main issues with this approach. First, as the bandwidth increases, the effective noise increases as well. Second, with a wider bandwidth, more undesired signals are likely to be received from other services. Thus for non-contiguous aggregation, most proposals today are trending toward the use of multiple transceivers instead of a single wideband approach.

In addition to increasing the RF front-end complexity, using simultaneous non-contiguous transmitters creates a highly challenging radio environment in terms of spur management and self-blocking. Because these challenges particularly impact UE design, more work needs to be done before inter-band carrier aggregation can be successfully introduced in the uplink. This is expected in 3GPP Release 11. However, for the LTE-Advanced base station, intra- and inter-band cases are defined in Release 10.



▲ *Fig. 5 Release 10 transmission architecture options [3GPP TR36.807 VO.1.0 (2010-08)].*

DEFINING THE TEST REQUIREMENTS

Some of the test complexity in designing and testing LTE-Advanced equipment arises from the existence of simultaneous transceiver chains that require simultaneous tests of multiple transmitters. ***Figure 5*** shows three different transmission architectures defined in Release 10. Type A supports two scenarios: intra-band contiguous carrier aggregation with a maximum of two Release 8 component carriers and a maximum uplink bandwidth of 40 MHz; and inter-band non-contiguous carrier aggregation with a maximum of two Release 8 component carriers. In this case, simultaneous transmission on both bands is not supported. Intra-band non-contiguous is not supported.

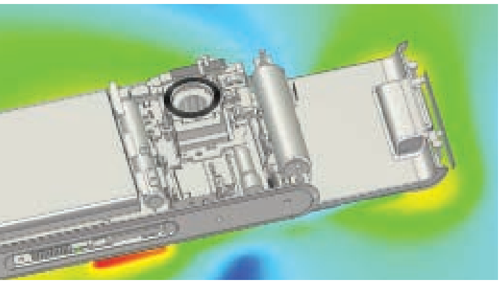
Type D1 currently supports two scenarios. One is intra-band contiguous carrier aggregation with a maximum of two Release 8/9 component carriers and a maximum uplink bandwidth of 40 MHz. The other is inter-band non-contiguous carrier aggregation with a maximum of two Release 8 component carriers, a maximum uplink bandwidth of 20 MHz, and support of simultaneous transmission on both bands. Type D1 has the capability to support intra-band non-contiguous carrier aggregation in future releases of the specification.

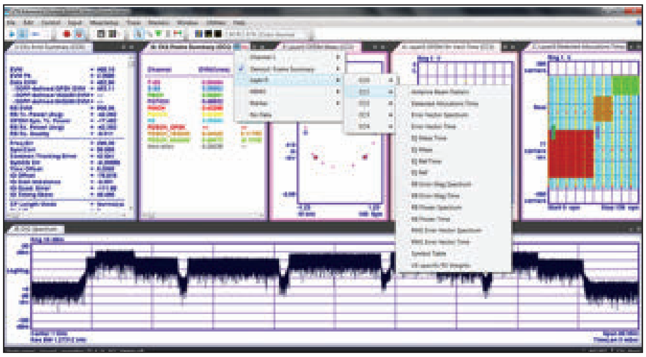
Type D2 currently supports two scenarios. One is intra-band contiguous carrier aggregation with a maximum of two Release 8/9 component carriers, a maximum uplink bandwidth of 40 MHz, and uplink MIMO support to address uplink peak data rate requirements. The other is inter-band non-contiguous carrier aggregation with a maximum of two Release 8 component carriers, a maximum uplink bandwidth of 20 MHz, and support of simultaneous transmission on both bands. Type D2 also has the capability to support intra-band non-contiguous carrier aggregation in future releases of the specification.

The different transmission configurations introduce a number of test challenges. For example, if a transmission configuration uses multiple transmitter antenna connectors, most of the evolved Node B (eNB) RF performance requirements will need to be applied at each antenna connector. Current LTE specifications for the eNB will be reused for LTE-Advanced as much as possible. For example, Release 8/9 requirements for transmitted signal quality tests (frequency error, EVM and downlink reference signal power) will be applied for each component carrier in a carrier aggregation scenario. The requirement for time alignment error between component carriers is being considered and the operating band unwanted emissions requirements for carrier aggregation transmissions have been aligned with those defined for the Release 8 multiple-carrier base station.

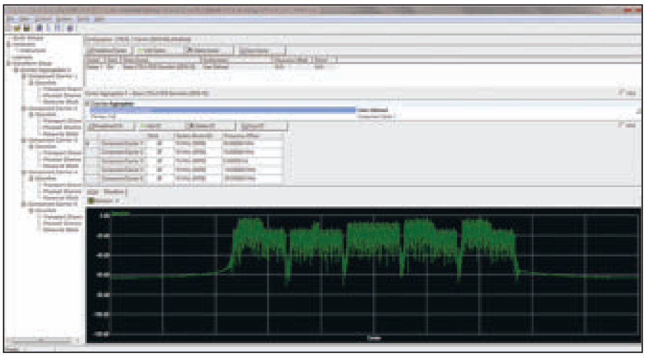
However, translating test requirements from Release 8/9 to Release 10 presents a number of difficulties. In the case of inter-band aggregation, synchronization must be maintained between the multiple transceivers, to allow simultaneous error vector magnitude (EVM) measurements on multiple component carriers. It has therefore been proposed for uplink to specify EVM only for those cases in which the power density is the same for both carrier allocations.

With intra-band non-contiguous carrier aggregation, there is a gap between the component carriers in which other technologies (for example, GSM or W-CDMA) could be transmitted. Physical layer transmit





▲ *Fig. 6 Agilent 89600 VSA Software for LTE-Advance controls two signal analyzers and measures up to five components simultaneously displaying results of each in a separate trace.*



▲ *Fig. 7 Agilent Signal Studio Software generates an aggregated signal consisting of five contiguous component carriers.*

and receive measurements will need to be extended across the gap, to assess the interference caused by the co-existing, uncoordinated systems. This scenario increases the difficulty of defining limits to out-of-band emission tests, such as adjacent channel power and spectrum emission mask, and the details are still being worked out.

Multicarrier in-band emissions for the uplink pose another problem. The Release 8/9 requirement, based on a single wanted contiguous physical resource block (PRB), is too complex to scale up to a generalized multi-carrier requirement. Alternative ways of specifying carrier aggregation in-band emissions are being studied. The intention is to specify a general requirement that would apply, regardless of whether a single or dual transmitter architecture is used.

Characterizing the LTE-Advanced UE or eNB power amplifier presents still another RF challenge. The different carrier aggregation configurations will stress the amplifier in different ways, because each will have different peak-to-average ratios. In the case of the UE, a single transceiver may be used for contiguous carrier aggregation. Although the design is similar to that of a Release 8/9 UE, the power amplifier in the LTE-Advanced UE has to be capable of covering the wider bandwidth created by carrier aggregation.

TEST TOOLS FOR LTE-ADVANCED CARRIER AGGREGATION

Testing carrier aggregated signals requires instruments that can generate and analyze multiple-component carriers simultaneously. The key word here is "simultaneously." One of the biggest challenges facing engineers working on LTE-Advanced is how to analyze the multiple-component carriers at the same time, especially in the case of inter-band carrier aggregation, as no signal analyzer on the market has a bandwidth wide enough to cover multiple frequency bands. Existing LTE measurement instruments are capable of analyzing component carrier in one frequency band at a time, but to capture and analyze multiple component carriers, in different frequency bands simultaneously, requires advanced tools.

This problem has been solved by using two signal analyzers, each tuned to a relevant frequency band and synchronized. The analyzers are controlled with software developed specifically for LTE-Advanced testing that has the ability to acquire all the component carriers simultaneously from the two synchronized instruments, demodulate the captured signals and analyze them all simultaneously. An example of the results is shown in ***Figure 6***. The software displays each component carrier measurement in a separate trace.

LTE-Advanced downlink and uplink signals compliant to the Release 10 standard are required to test power and modulation characteristics of components and transmitters. In ***Figure 7***, signal generation software is used to create an aggregated signal with five component carriers. The software's built-in tools, such as CCDF, can be used to analyze compression and evaluate the required amplifier power back-off for different signal configurations.

CONCLUSION

Although the concept of carrier aggregation is simple, the changes it introduces at the physical layer are complex. With the introduction of carrier aggregation, asymmetric uplink and downlink allocations will become commonplace, driven by different numbers of component carriers in the uplink and downlink signals, the different bandwidths of component carriers that can be aggregated and the resulting combinations of component carrier number and bandwidth in an aggregated signal. The number of test cases for carrier aggregation would quickly become unmanageable if all contiguous and non-contiguous intra-band and inter-band combinations were considered. How to limit the allowed allocations in order to minimize the number of test scenarios is a major topic of discussion within the 3GPP. ■

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THE MASTERS OF MIMO

A Compact MIMO Antenna using ZOR Split Ring Resonator Radiators with a Decoupling Structure

This article presents a novel compact MIMO antenna for mobile communication devices, which has miniaturized antennas with increased isolation and operates in the WiMAX and LTE high bands. Each of the proposed element antennas is designed to have the in-phase electric field distributions of the zeroth order resonance (ZOR) in the form of a CRLH type split ring resonator (SRR), which is much smaller than the conventional SRRs and other antennas for MIMO communications. These antennas can be placed in close vicinity, using a small planar mushroom decoupling structure between them, in order to meet the required isolation level. The design is carried out by full-wave electromagnetic simulations, which prove the ZOR characteristic of the antennas and the suppressed interference from one antenna to the other. This proposed MIMO antenna was fabricated and measured to show a return loss better than 10 dB, an isolation greater than 12 dB and a radiation efficiency over 50 percent in the WiMAX and LTE high bands for both antennas. The total size is 26 × 5.5 × 2 mm, which fits within half of the top-edge of the ground of handset phones.

As people are taking advantage of the convenience of mobile and wireless communications, the demands are increasing on technological evolution in the field of telecommunications. From communication methodologies to portable device fabrication, developers are facing challenges and striving to tackle the problems. In the meantime, smartphones have provided numerous application programs and mobile Internet services, started through WiMAX and LTE technologies. The handset phones for the aforementioned function should be robust, in a complicated and tough environment, to guarantee the quality of communication and be small for commercial success. This is heavily determined by the hardware of the phones, including the antennas.

The multi-input multi-output (MIMO) antenna was proposed to handle the harsh wireless communication environment, by providing

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diversity in RF signal transmission and reception and has motivated the antenna community, where size reduction is a hot issue, along with high isolation between multi antennas. A. Mak et al.[1] introduced a set of antennas with a structure that traps the near-field coming from one antenna to the other, based upon a local current loop disconnecting a fictitious enlarged loop of current in order to secure the isolation. The antennas have acceptable radiation pattern and isolation, but in terms of size, the radiators and the trap take the top edge and two sides of the handset ground. K. Payandehjoo et al.[2] adopted an EBG geometry to increase the diversity gain by preventing coupling between two antennas. However, the size exceeds the industrial standard and the working frequency is away from the WiMAX band. X. Wang et al.[3] described two microstrip-fed antennas. Their vertical and layered radiating parts stand perpendicular to the handset stratified ground by folding and periodically meandering a decoupling structure for improving the isolation. Although it has an isolation greater than 12 dB, this structure is a microstrip-fed, monopole-type, decoupling geometry, with three dimensionally folded radiators, the volume of which takes most of the ground.

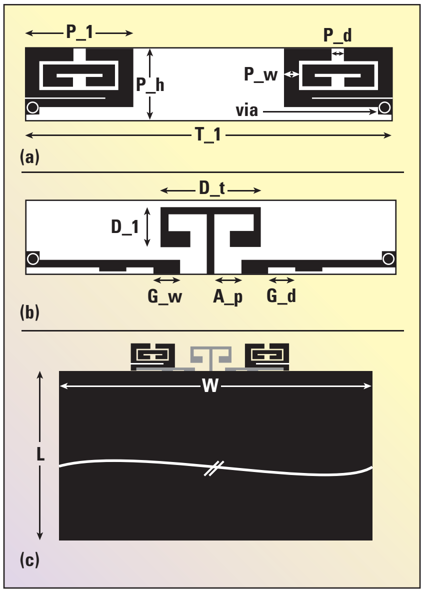
It is pointed out that these antennas and the decoupling structure should be size-reduced while having antenna performances meeting the industrial requirements. Recently, metamaterials (MTM) technologies were introduced and have suggested alternative ways to overcome the limitations in improving electrical performances and reducing the sizes of components and resonators.[4,5] Lumped elements of series capacitance and shunt inductance are loaded in a transmission line to generate nonlinear dispersion characteristics due to the composite right- and left-handedness (CRLH), including the ZOR due to the in-phase field over a corresponding MTM resonator. While the CRLH and ZOR are mentioned with the electromagnetic bandgap (EBG) of an array of the mushroom (a patch connected to the ground through a pin),[4] the SRRs are adopted to fit a resonator into a confined area, on account of the end-gap and inter-ring capacitances.[6] The SRRs create a resonance, so they can be applied to not only to filters, but also to antennas.[7] The SRR is designed to make one antenna, but its size is approximately 30 × 40 mm and not appropriate for the mobile MIMO antenna, considering that two antennas of its kind and the decoupling structure between them, will result in an overall horizontal length over 90 mm. This shortcoming results from the fact that their SRRs do not have the ZOR or metamaterial properties.

In this article, a miniaturized MIMO antenna that has novel antenna elements and a decoupling geometry is described. It aims to satisfy size, antenna performance and isolation required by WiMAX and LTE high band communications. The antenna elements look similar to SRRs, but they are much smaller than ordinary SRR antennas, since the proposed structure has a CRLH configuration and a ZOR field distribution. To suppress the coupling between the novel antennas, a planar mushroom is placed between them. Because this mushroom is planar, it is conveniently and inexpensively formed in the bottom grounding surface of the substrate of the MIMO antenna geometry. The design goes through full-wave simulations for monitoring and tuning S_{11}, radiation pattern, ZOR field and isolation of the proposed antenna. It is then fabricated on an FR4 substrate and experimentally tested on the board of a real mobile phone. As a result, it is revealed that the return loss, isolation and radiation efficiency are better than 10 dB, over 12 dB, and over 50 percent, respectively, in the WiMAX and LTE high bands, for both the antennas, whose overall size is 26 × 5.5 × 2 mm. This is less than half of the top-edge of the handset ground, even when the proposed MIMO antenna is mounted in a mobile phone platform.

TABLE I

MIMO ANTENNA DESIGN SPECIFICATIONS

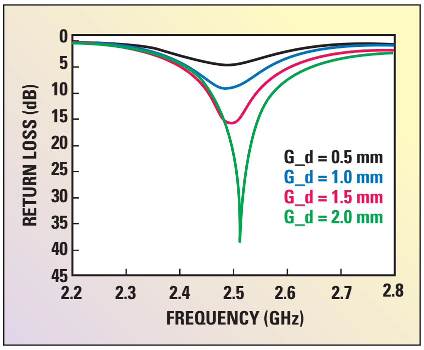
Item	*Specification*
f_0, Bandwidth	2.4 GHz, ≥ 100 MHz
Application	WiMAX, LTE high band
Return loss (S_{11})	≤ 10 dB
Radiation efficiency	≥ 50%
Isolation (S_{21})	≥ 12 dB
Overall antenna length	< 30 mm
Condition for test	Coaxial feeding, On the real board



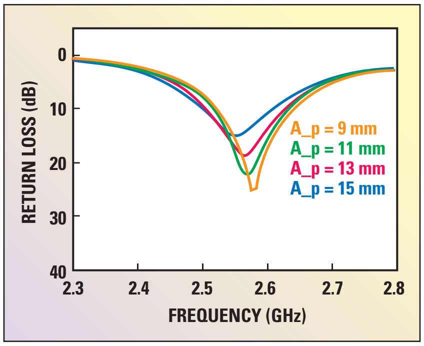
▲ *Fig. 1 Structure of the proposed MIMO antenna (a) top surface, (b) bottom surface and (c) antenna at top edge of handset ground.*

DESIGN OF THE PROPOSED MIMO ANTENNA

Prior to the design, the specifications shown in ***Table 1*** are addressed. The element antennas have similarity to SRRs in that the inner open-gap ring is surrounded by the outer ring. Different from the ordinary SRRs, one corner of the outer ring is connected to a transmission line (upper transmission line or UTL), that is coupled through the electric field and current to another transmission line (lower transmission line or LTL), attached to the ground. The element antennas' SRRs and the UTL are placed on the top surface of the 2 mm-thick FR4 substrate, whose bottom surface has the feeding points with the handset ground, the planar mushroom and the LTL as shown in ***Figure 1***. The handset ground has an area (W × L) of 50 × 80 mm. The aim of the proposed design is to reduce the size of the resultant antenna to less than 70 percent of W. Since the conventional SRR has a right-handed resonance, at first sight, it seems improper for effective size-reduction. So each of the anten-

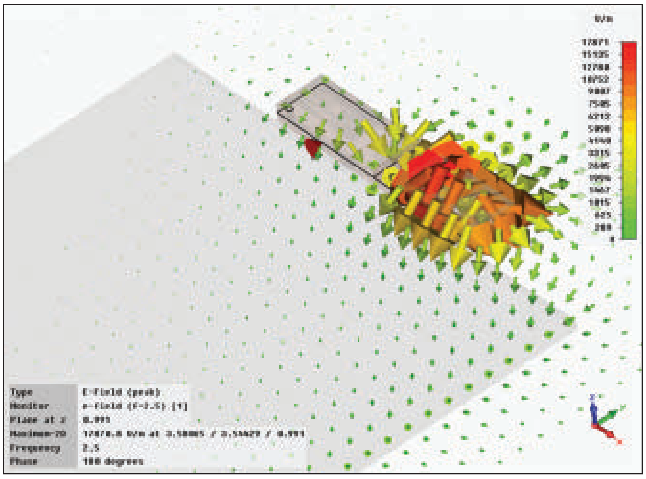


▲ *Fig. 2 Return loss of the proposed antennas as a function of G_d.*

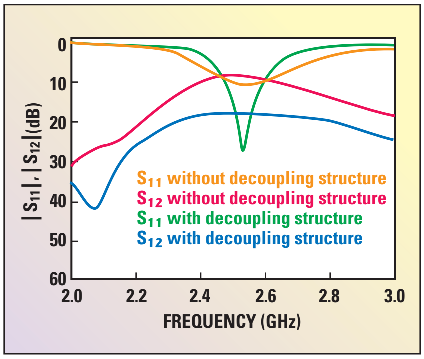


▲ *Fig. 3 Return loss of the proposed antennas as a function of A_p.*

nas, 1 and 2, has the SRR play the role of the series capacitance (C_L) and part of the series inductance (L_R) in implementing the CRLH characteristics. Simultaneously, the electric field coupling and current flowing between the upper and bottom transmission lines are equivalent to part of the shunt capacitance (C_R) and the shunt inductance (L_L), respectively. Besides, the bottom transmission line provides inductance and capacitance factors of the right-handed transmission line as L_R and C_R. In principle, the approach of the CRLH equivalent circuit is very similar to that of Jang et al.[5] The factors are adjusted to have the CRLH ZOR, which enables the proposed SRR to be much smaller than the conventional SRRs. The ZOR field will be given later in the article. Pursuing the realization of the metamaterial ZOR properties for this structure, the following parametric studies are conducted. Along with G_w, G_d accounts for the impedance matching and manipulating the main part of CR. In ***Figure 2***, the return loss (S_{11}) is plotted for different values of G_d, with P_l, P_h, P_d, P_w and G_w set to 10, 5, 1, 0.8 and 2.0 mm, respectively. G_d ranges from 0.5 to 2.0 mm and four samples are taken. With a 10 dB



▲ *Fig. 4 In-phase electric field distribution of the ZOR at the center frequency.*



▲ *Fig. 5 Return loss and isolation before and after placing the planar mushroom.*

criterion, G_d values of 1.5 mm and above are acceptable. This implies that the proposed miniaturization method requires a certain collective shunt capacitance of CR, maintaining G_d. ***Figure 3*** shows the return loss of the antenna as a function of the feeding positions (A_p), with respect to the decoupling structure, with the other parameters P_l, P_h, P_d, P_w, G_w and G_d fixed as 10, 5, 1, 0.8, 2.0 and 2.0 mm, respectively. A_p is varied from 9 to 15 mm. It shows that once A_p is set over 9 mm with the other parameters chosen as above, the change of the return loss seems insensitive to the distance between the planar mushroom and either of the element antennas. In a similar manner, all the physical dimensions are found to achieve the antenna functions required by the WiMAX and LTE high bands, through impedance matching and electromagnetic interactions between the radiators, transmission lines, feeding points, handset ground, etc. Before moving to the proposed planar mushroom to decouple the interference between antennas 1 and 2, the ZOR characteristic is proven by the electric field distribution over either of the element antennas. This full-wave simulation is performed with the CST-MWS.[8] While the conventional SRRs have an out-of-phase electric field distribution, in a physical structure that is manipulated for the same resonance frequency and larger than the proposed antenna, the ZOR antenna with a size 0.2 times that of the top-edge is resonant at the center frequency. The ZOR results in the in-phase electric field vectors (all directed upward) and contribute the lower interference to the neighboring antenna (see ***Figure 4***).

Next, a planar mushroom is proposed to enhance the isolation. As far as the MIMO antenna is dealt with, the isolation between the multiple antennas is one of the most crucial factors in the design. The less the antennas are correlated or coupled, the higher the antenna isolation is, which means the signal survives multiple reflection and fading in a wireless environment with higher probability. As shown in ***Figure 5***, with the help of the planar mushroom as the decoupling structure, the isolation is increased from 8 to 19 dB, which is far better than the specification. When the MIMO antenna is designed for increasing the best isolation, the return loss (S_{11}) is optimized as 27 dB. These values, S_{11} and S_{12}, are preparation for the possible degradation that can be caused by the physical placement on the real phone platform. Besides, the frequency response of the two antennas with the decoupling structure of D_t of 6.5 mm and D_l of 3.0 mm, the surface current densities are plotted in ***Figure 6*** to determine how the increased isolation is obtained. Obviously, the planar mushroom, centered in the entire MIMO antenna system, decouples the connection between antennas 1 and 2. In other words, the decoupling structure draws the surface current due to the near-field from one excited antenna and

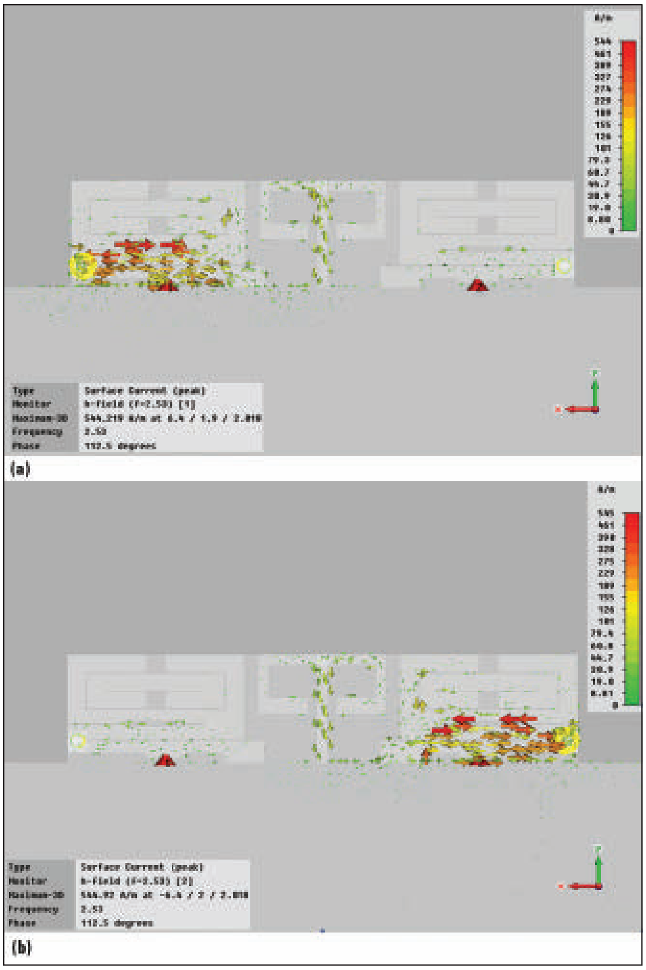


Fig. 6 *Surface currents on isolated antennas (a) from antenna 1 to antenna 2 and (b) from antenna 2 to antenna 1.*

Fig. 7 *Proposed antenna tested on a real board.*

plays the role of a trap. Consequently, the isolation between the element antennas is enhanced.

FABRICATION AND MEASUREMENT

After the design phase, based upon the theoretical and numerical approaches, the proposed antenna was manufactured for experimental verification. As simulated in a full-wave analysis frame, a simple microstrip MIMO antenna is made on an FR4 substrate with $\varepsilon_r = 4.3$ and a thickness of 2 mm. The overall size of the proposed antenna is 26 × 5.5 × 2 mm, which amounts to just within half of the top-edge of the ground of handset phones. ***Figure 7*** shows the antenna mounted on the phone platform with a cover. After extra trimming work, the proposed antenna was simulated to give the return loss and isolation as shown in ***Figure 8***. The best performance ($|S_{11}|$ and $|S_{22}| < -25$ dB, $|S_{21}| < -19$ dB) is achieved, in case of degradation in manufacturing and real environment test. The measured return loss and isolation ($|S_{11}|$ and $|S_{22}| < -22.5$ dB, $|S_{21}| < -12$ dB) complies with the specifications. ***Figure 9*** presents the radiation patterns in the E- and H-planes, where the two antennas have similar omni-directional far-field plots, desirable in MIMO communications, even with the isolation of over 12 dB. Lastly, the radiation efficiency and peak and average gains are measured as shown in ***Figure 10***. The plot shows that the efficiency is over 50 percent. Simultaneously, the peak gain is 2.25 dBi at the center frequency, which is acceptable to the industry, with an average gain of –2.7 dB. In summary, all the electrical performances and the physical size of the proposed MIMO antenna are compliant to the design specifications.

CONCLUSION

This article has presented a novel compact MIMO antenna, which has enhanced isolation between very small antenna elements. The antennas are miniaturized for the first time with the proposed ZOR SRRs, which have the in-phase field behavior and a size

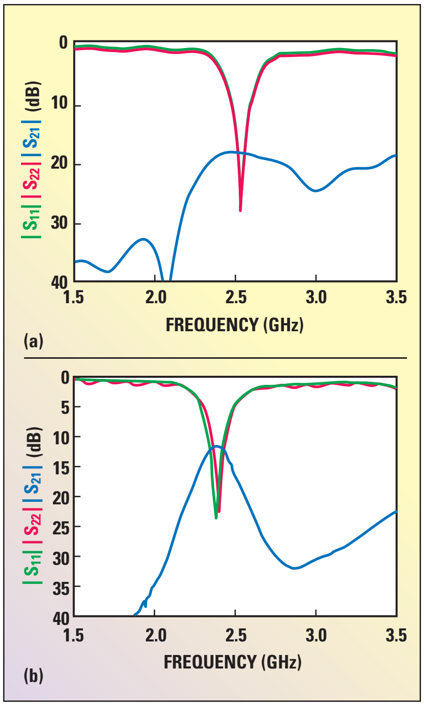


Fig. 8 *Antenna performance while mounted on a real board (a) simulation and (b) measurements.*

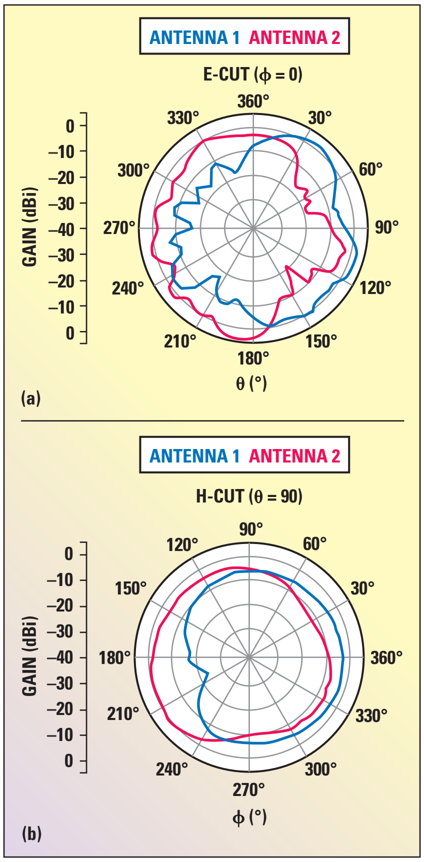


Fig. 9 *Radiation patterns of the antenna (a) E-plane and (b) H-plane.*

of 0.2 times the top-edge of the handset ground. A planar mushroom, used

(Continued on page 42)

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LTE PAs Offer Fast, Powerful Wireless Data Options

Consumers are demanding more from their mobile devices, including increased bandwidth. They have become accustomed to the near universal data connectivity of smartphones and tablets, including applications that continually demand higher and higher data rates. Given the variety of LTE frequency bands, and the range of preferred power levels, RFMD has developed a family of LTE-compatible power amplifiers for data connectivity applications. They are summarized in ***Table 1***.

TABLE I

RFMDs FAMILY OF POWER AMPLIFIERS FOR LTE DATA CONNECTIVITY

Part Number	Frequency Range (GHz)	Integration	Linear Power (dBm)	Supply Voltage (V)	Current (mA)
RF5602	2.3 to 2.7	Unmatched PA	21 to 23	3.3 to 5	350 to 450
RF5603	3.3 to 3.8	Unmatched PA	23	3.3	425
RF5607	1.9 to 2.7	Unmatched PA	22	5	350
RF5612	2.5 to 2.7	Matched PA	22	3.3	470
RF5623	3.3 to 3.8	Unmatched PA	24	5	600
RF5652	2.3 to 2.7	Unmatched PA	28	5	1200
RFFM7600	2.3 to 2.7	Matched PA+SPDT	24	5	650

As can be seen, a wide range of LTE bands can be covered by these PAs. The RF5607, for example, has a large frequency coverage capability of 1.9 to 2.7 GHz. This allows the customer to tune to a desired frequency band within this range. The RF5602 is similar and offers higher output power with less frequency coverage. It can also be efficiently operated at lower power with a reduced V_{cc}. The linear power listed for each of these amplifiers is for a nominal linearity requirement, and varies depending on the specific modulation used. The RF5612 is intended for uplink applications, the others are primarily intended for the downlink. Many of the amplifiers in Table 1 can also be used in WiMAX applications, typically at higher output powers. RFMD continues to add to its LTE power amplifier family, with higher power levels in particular, soon to be available.

RF5607

The RF5607 is a versatile member of RFMD's LTE power amplifier family. It is

RF Micro Devices
Greensboro, NC

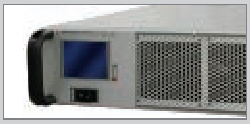
POWER AMPLIFIER SOLUTIONS

[Broad Selection - COTS and Custom Products]

COMMUNICATIONS

MODULES	SKU	Start (MHz)	Stop (MHz)	Pout (Watt)	Size (Inch)	Gain (dB)
	1058	1	100	300	8.3x6.4x1.2	18
	1067	0.01	500	25	7.0x5.0x1.3	44
	1094	20	520	100	6.4x3.4x1.1	50
	1100	20	1000	80	6.4x3.4x1.1	49
	1119	500	2500	50	7.4x3.6x1.1	46
	1164	800	3000	50	6.4x3.4x1.1	50

Wireless Infrastructure MODULES	SKU	Start (MHz)	Stop (MHz)	Pout (Watt)	Size (Inch)	Gain (dB)
	7086	869	894	16	4.4x6.7x1.1	49
	7083	1930	1990	30	5.1x6.7x1.2	49
	7082	1930	1995	16	4.4x6.7x1.1	49
	7084	2110	2170	16	4.0x5.5x1.3	49

SYSTEMS	SKU	Start (MHz)	Stop (MHz)	Pout (Watt)	Size	Gain (dB)
	2073	1	100	1000	R5U	60
	2101	20	500	500	R5U	56
	2126	20	500	1000	R5U+R5U	60
	2066	500	1000	1000	R5U+R5U	60
	2151	500	2500	200	R3U	52
	2154	20	3000	250	C19U	54
	2153	700	3800	200	R3U	54

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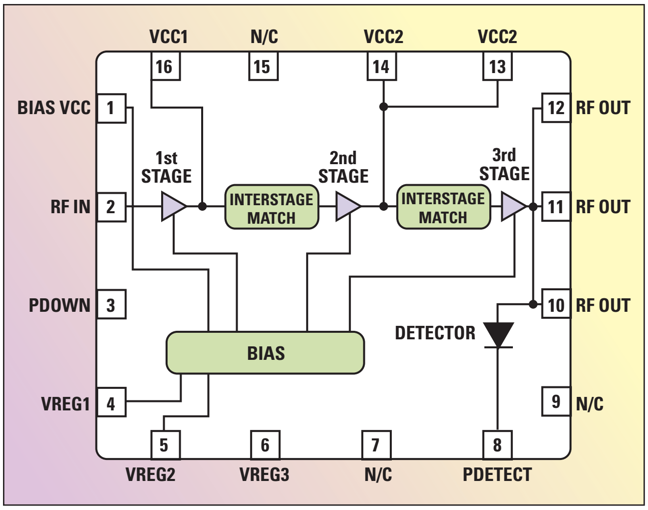

Fig. 1 *Block diagram of the RF5607.*

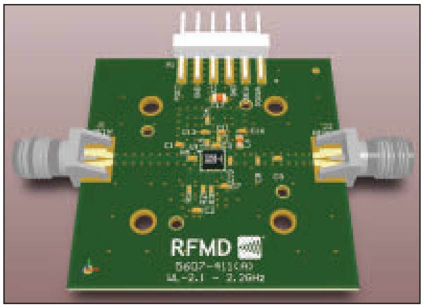

Fig. 2 *The RF5607 LTE downlink PA application board for 2.1 to 2.2 GHz operation.*

designed using RFMD's InGaP HBT process. The block diagram, ***Figure 1***, shows that this is a three-stage power amplifier with integrated power detection and active bias control. All stages use a 3 × 20 µm dual emitter HBT unit cell. Two cells are used in the first stage. The second and third stages are scaled up to 8 and 32 cells, respectively.

The PA operates in Class AB mode. The second harmonic termination at the output is implemented with an on-chip capacitor and an in-package down bond. The first and second stages are each biased with a two-diode emitter follower. RFMD's proprietary active bias circuit supplies bias to the final stage while providing low impedance for linear operation over the operating range.

A unique feature of the RF5607 is that the input and output matching networks are off chip. Interstage matching is broadband to cover the entire 1.9 to 2.7 GHz frequency range. Actual applications are in much narrower bands within this range. Ultimate performance is critically dependent on output match and to a lesser extent on input match. Therefore, optimized matching for specific LTE downlink bands has been developed for implementation off-chip. ***Figure 2*** shows an application board for 2.1 to 2.2 GHz operation. The application boards for other bands are identical, only the values of the matching components change.

The schematic, with matching components optimized for a 2.1 to 2.2 GHz LTE downlink is shown in ***Figure 3***. The RF5607 uses a 3 × 3 mm QFN package. ESD protection is included on all pins to both Human Body Model (HBM) and Charged Device Model (CDM) requirements. The exact band of operation is tunable with external components.

The key performance attributes for an LTE power amplifier are power, ACLR and current consumption. Typical power and linearity for the RF5607 are shown in ***Figure 4***. As shown, ACLR remains well below the -44 dBc requirement up to 22 dBm output power. At that point, nonlinearities resulting from the large peak to average power ratio (PAPR) of the modulated signal begin to degrade ACLR. The RF5607 actually provides -45 dBc ACLR.

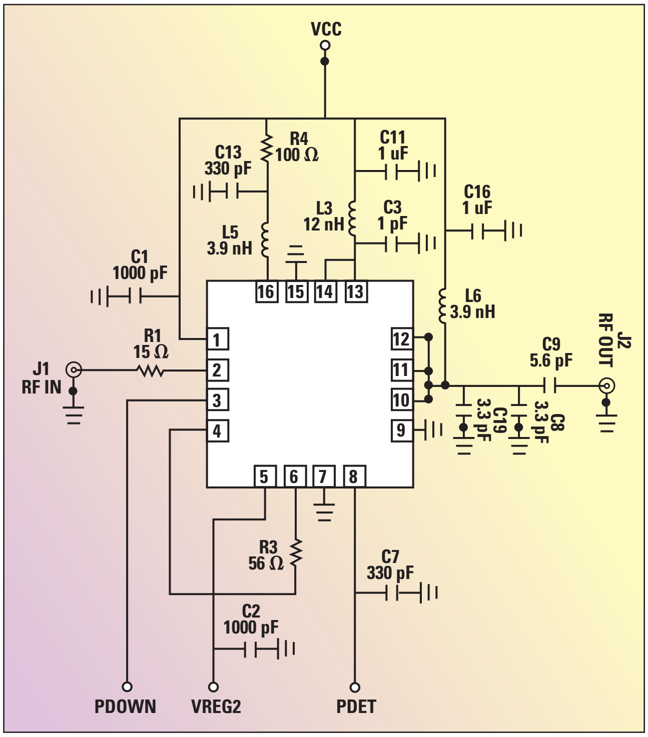

Fig. 3 *Schematic of the RF5607 in a 2.1 to 2.2 GHz application.*

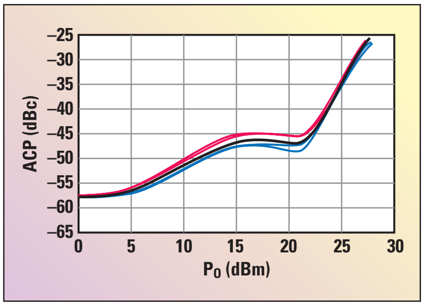

Fig. 4 *Typical linearity performance of the RF5607 with a 10 MHz modulated LTE signal at frequencies between 2.11 and 2.17 GHz.*

Gain and current consumption are also important power amplifier characteristics. They are shown versus output power in ***Figure 5***. Note how gain is only lightly compressed even at the full LTE rated power of 22 dBm. This highlights the very linear operation that LTE downlinks demand. The current consumption is below 330 mA, even at 22 dBm. Current increases gradually from about 230 mA at quiescence. Since the output stage operates in deep Class AB, the low impedance active bias

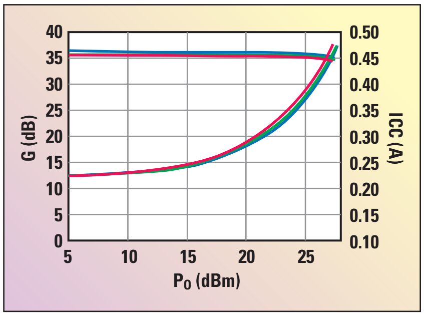

Fig. 5 *Typical gain and current consumption performance of the RF5607 with a 10 MHz modulated LTE signal at frequencies between 2.11 and 2.17 GHz.*

(Continued on page 38)

GPS RFIC Preventing LightSquared and Other LTE Interference

Tahoe RF Semiconductor has introduced the industry's first single chip integrated dual-channel (L1 and L2 bands) GPS RFIC that provides 60 dB of dynamic range in high level interfering environments. The TRFS15011 was developed to address the use of position information in a wide variety of industrial and consumer electronic products where high level interferers may exist. Specifically, because of the impending FCC frequency allocation of the Mobile Satellite System (MSS) frequency band to terrestrial transmitters, commercial GPS receivers may need to operate in environments with high levels of interference. However, commercial GPS receivers currently do not have sufficient dynamic range to mitigate interfering signals from MSS transmitters. One possible solution is to use highly selective filters, but these filters are costly and bulky.

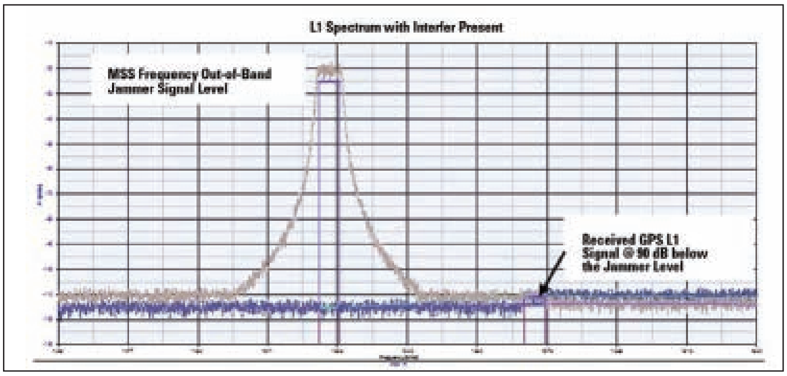

Fig. 1 Interferer and GPS signal.

The TRFS15011 reaches new levels of functional integration for high dynamic range GPS receivers. It embodies high levels of integration and combines Tahoe RF Semiconductor's proprietary wireless signal integrity implementation to deliver superior interferer mitigation, lower system cost and eliminate the use of highly selective external filter solutions. The TRFS15011 is currently the only integrated solution that allows GPS receivers to operate in the presence of a high power interferer from terrestrial MSS band transmitters.

DYNAMIC RANGE AND POTENTIAL INTERFERER FROM TERRESTRIAL MSS BAND TRANSMITTERS

The GPS L1 band is from 1560 to 1590 MHz. The proposed portion of the MSS band that will be used by terrestrial transmitters is 1526 to

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Auburn, CA

1536 MHz. The MSS anticipated power level at the transmitter is 32 dBW. With free space path loss, the input of a GPS receiver antenna could be as high as -20 dBm. The L1 signal level difference compared to the interferer can be as much as 90 dB (see ***Figure 1***).

New GPS receivers need to operate in the presence of high level interfering signals. Current GPS RF receivers typically do not operate over more than 18 dB of dynamic range. The embedded filtering in most GPS RF receivers is not sufficient to suppress the interferer and typically requires highly selective external filter solutions to mitigate interference as illustrated in Figure 1.

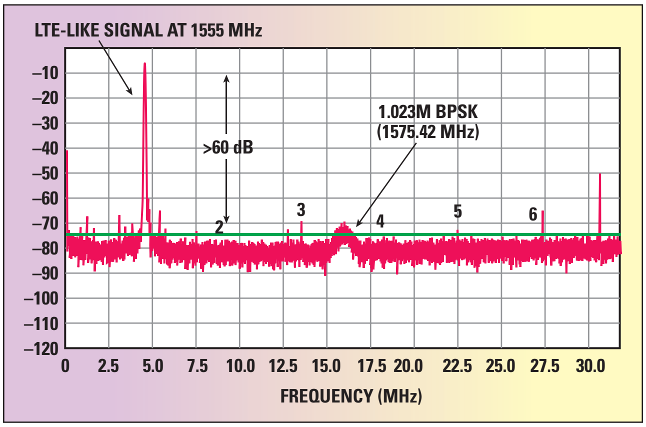

Fig. 2 FFT of the output with CW tone representing LTE interferer and GPS signal.

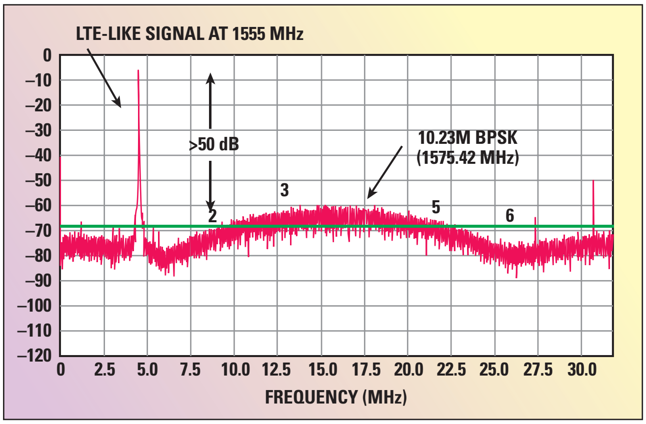

Fig. 3 FFT of the output with CW tone representing LTE interferer and GPS signal.

TRFS15011 PERFORMANCE

The TRFS15011 integrates high dynamic range 12-bit analog-to-digital converters (ADC) and full receive paths for both L1 and L2 bands. The result is a fully integrated L1/L2 GPS receiver with 60 dB instantaneous dynamic range, providing significant power savings over more discrete systems. Commercial GPS receivers are hampered by low resolution ADCs, which are used in an effort to conserve power. The TRFS15011 solves this problem by including two programmable ADC modes – a low power mode with 3 bits of resolution and a high dynamic range mode with 12 bits of resolution.

PERFORMANCE IN LTE ENVIRONMENTS

A single-tone interferer at 1555 MHz was inserted at the front-end of the TRFS15011 along with a low power GPS-like narrowband signal. The signals were down-converted and sampled with the high resolution ADC. The spectral plot of the output shown in ***Figure 2*** represents the typical dynamic range of the TRFS15011 that can be further improved, if needed, with external filtering and baseband processing.

Of more concern is how the receiver processes wider bandwidth signals. A single-tone interferer at 1555 MHz was inserted at the front-end of the receiver along with a low power GPS-like wideband signal. The signals were down-converted and sampled with the high resolution ADC. The spectral plot of the output is shown in ***Figure 3***. The TRFS GPS receiver has enough instantaneous dynamic range to mitigate a high level interferer signal such as the terrestrial MSS.

DEVICE DESCRIPTION

The GPS receiver block diagram is shown in ***Figure 4***. The dual fractional-N synthesizers are completely integrated. The received signal is level controlled by the internal AGC where each signal path includes an RF isolation amplifier, RF mixer, variable gain amplifiers and lowpass filter before the ADCs. There is a low resolution mode with reduced current and lower linearity for low power operation. With minimal external components, the TRFS15011 provides an integrated low cost solution for the interference that is inevitably to come from reallocation of FCC frequency use.

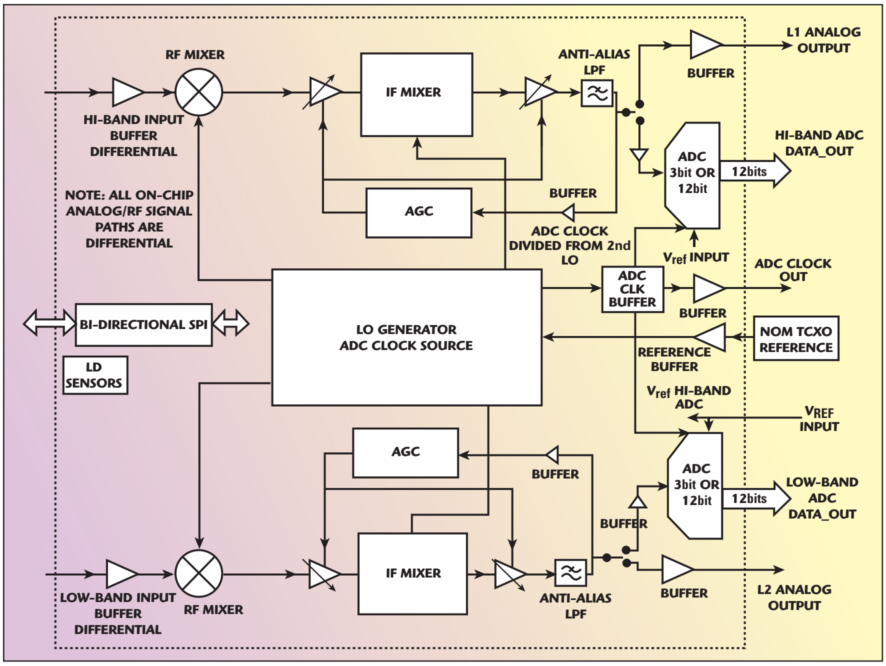

Fig. 4 Block diagram.

Tahoe RF Semiconductor,
Auburn, CA (530) 823-9786,
sales@tahoerf.com.
www.tahoerf.com.

Intermod Squad: Low PIM Cable Assemblies

Dubbed the Intermod Squad, San-tron has developed a new series of low PIM cable assemblies that feature intermodulation performance as low as -181 dBc with an eSeries 7/16 connector terminated on TFlex-402 cable. Typical performance across the lineup of assemblies terminated with eSMA and eSeries Type Ns is -162 dBc. The eSMA cable assemblies perform from DC to 20 GHz and the eSeries Type N cable assemblies perform from DC to 18 GHz. These assemblies are phase and attenuation stable, provide excellent shielding, support UL/NEC Plenum class CMP, are corrosion resistant, and are low in weight and highly flexible.

The key component in San-tron low PIM cable assemblies are their latest series of connectors. eSeries connectors, which include SMA (trademarked as eSMA), Type N, TNC and 7/16 styles, offer evolved cable/connector transitions. The repeatability of these transitions from the cable into the connector is key to the consistent high performance of these cable assemblies. The center contact is a solder-free connection so the transition is controlled to machined tolerances via an internal stop within the bodies, which are much tighter than the variations seen by cable assembly personnel and solder joints. Another advantage of the elimination of this center conductor solder joint is that it precludes the heat induced damage to the dielectric densities that would affect changes in the dielectric constant.

Reliability is improved with these connectors with an extended ferrule that is crimped onto the body that provides longitudinal protection out past the solder wick line, which is a traditional failure point. For added protection, dual wall heat shrink is positioned within the saddle of this crimp ferrule and further extends the strain relief from this wick line offering high reliability in applications that involve repeated flexure.

The Albaloy plating provides a robust surface that easily accepts the braid solder joint and supports corrosion resistance per salt fog testing. The eSMA center contacts are BeCu; they are plated gold over a copper strike providing excellent RF performance, corrosion resistance and control over porosity. The eSeries N and 7/16 center contacts are plated silver over a copper strike, which contains cost versus gold, and also provides good RF performance and corrosion resistance.

VENDORVIEW

San-tron Inc.,
Ipswich, MA
(978) 356-1585,
www.santron.com.

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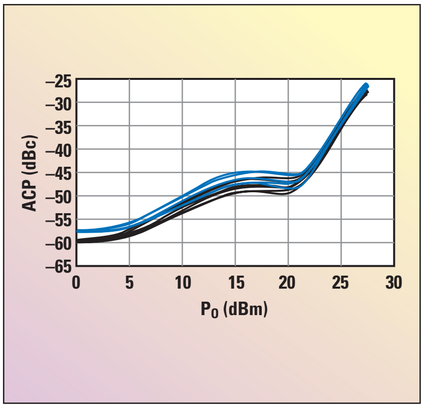

▲ *Fig. 6 Typical linearity performance of the RF5607 with a 10 MHz modulated LTE signal (blue) and a 5 MHz W-CDMA modulated signal (black) at frequencies between 2.11 and 2.17 GHz.*

network allows current to increase so that linearity is maintained as drive level grows.

Figure 6 shows the power and linearity performance of the RF5607 with both a LTE downlink signal and a W-CDMA signal. LTE has a wider modulated bandwidth and a higher data rate than W-CDMA. This increases the linearity demands on the system and on the PA. As Figure 6 shows, this can be directly seen in power amplifier performance. Linearity is 1.5 to 2.5 dB better with the W-CDMA signal.

LTE provides users with very high data rates in mobile devices enabling streaming multimedia and supporting the growth of social networking and the push to cloud computing. LTE imposes unique system requirements and presents challenges to the power amplifier designer, particularly of the downlink. RFMD has developed a family of products to address these needs. They cover the key downlink frequency bands, provide an ACLR of better than -44 dBc and provide efficient operation with LTE modulation bandwidths of up to 20 MHz.

RF Micro Devices,
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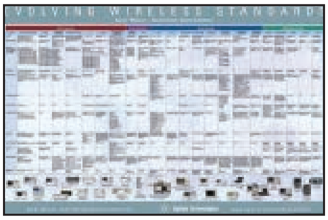
Company Showcase



Wireless Standards Poster

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Gain greater insight into wireless design and test with the new Agilent Evolving Wireless Standards poster. Agilent offers one place to review the latest evolving wireless technologies any time. This FREE poster is designed to give information about wireless test for greater understanding of the wireless connectivity technologies with a full range of design and test solutions. Order your Agilent Wireless Standards poster at www.agilent.com/find/postermwj.

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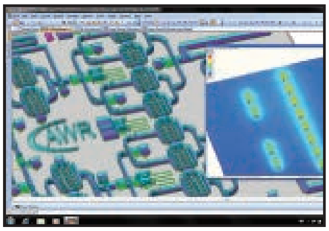

Product Portfolio

VENDORVIEW

AWR Corp. dramatically reduces development time and cost for products employed in wireless, high speed wired, broadband, aerospace and defense, and electro-optical applications. The 2011 version of its product portfolio – Microwave Office™, Visual System Simulator™, AXIEM® and Analog Office® – features electrical-thermal MMIC co-simulation design flow, simulation-state management technology, yield analysis/optimization via a graphical shape-based manipulation approach, envelope simulator and asynchronous electromagnetic (EM) simulation support.

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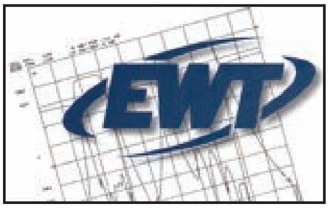
El Segundo, CA (310) 726-3000, www.awrcorp.com.



EWT: Where Performance Counts

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Eastern Wireless TeleComm Inc. (EWT) specializes in custom design and manufacture of RF and microwave filters and filter-based products for mobile communications applications. The staff encompasses more than 50 years of combined experience in the design, development, and high volume manufacturing of cavity and waveguide filters to 50 GHz and lumped element filters up to 10 GHz. All of the company's products are manufactured to strict guidelines set forth in its ISO:9001 compliant quality system, ensuring the highest level of product performance and reliability. Through utilization of the company's in-house machining capabilities and state-of-the-art manufacturing processes, rapid turn-around is standard. EWT can develop any cavity, lumped element, waveguide, or wireless filter to meet your needs. Visit EWT online to request a quote today.

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Compact Communications Amplifier Module

VENDORVIEW

The PCM3R3SCO (SKU 7091) is one of a series of communications amplifiers. This 900 MHz compact linear power amplifier is one of a series that covers 450, 700, 800, 900, 1800, 1900 and 2100 MHz bands and is suitable for use in commercial LTE networks and public safety wireless communication applications. The amplifier employs latest generation LDMOS device technology and is highly efficient. The amplifier has an advanced built-in predistortion engine with wide instantaneous correction bandwidth, which ensures low distortion and wide dynamic range operation. Efficiency of up to 40 percent is possible in this series where the high performance is achieved by employing advanced RF design techniques. Empower RF's ISO:9001 Quality Assurance Program assures consistent performance and the highest reliability.

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Low PIM Power Divider/ Combiners

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LOW PIM (-150 dBc typical) two-way through 16-way power divider/ combiners are optimized for excellent performance across all wireless bands from 0.698 to 2.700 GHz and their rugged construction makes them ideal for both base station and in-building wireless systems. Weather-proof models are also available. Always available from STOCK to four weeks ARO in N, SMA, BNC or TNC connector configurations for your next generation equipment deployments. Made in the USA – 36 month warranty.

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Component CD Catalog

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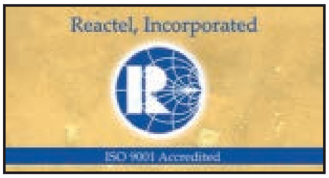
MITEQ recently released its full-line CD Components Catalog (CD-02M), which offers one of the most comprehensive displays of standard and custom capabilities in the industry. The CD includes thousands of pages of product specifications, outline drawings, test data, manufacturing flow diagrams, and a wide assortment of technical application notes.

MITEQ,
Hauppauge, NY (631) 439-9220, www.miteq.com.



Filters, Multiplexers and Multifunction Assemblies

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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.

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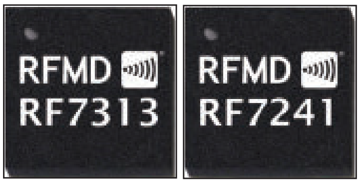

Power Amplifiers

The RF7241 and RF7313 represent an extensive family of high efficiency 3G/4G power amplifiers addressing the vast majority of the global frequency bands. Optimized for use with DC-DC converters, this family of 3G/4G PAs delivers industry-leading peak efficiency – directly translating into increased data usage time, increased battery life, and lower thermal dissipation. The 3G/4G handset OEMs can leverage these unique benefits to influence end user perceptions of handset quality, raising the value of the OEM's devices.

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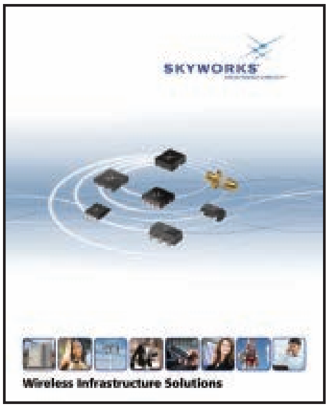

Wireless Infrastructure Solutions

VENDORVIEW

Skyworks' broad portfolio of RF/microwave products includes solutions for today's demanding wireless infrastructure systems, including cellular base stations, WiMAX access points, land-mobile radio systems and point-to-point radio links. Skyworks offers components and subsystems from the antenna connection to the baseband output, including low noise amplifiers, power amplifiers, general-purpose amplifiers, mixers, modulators, demodulators, phase shifters, switches, attenuators, detectors, directional couplers, hybrid couplers, power splitters/combiners, ceramic filters and resonators, plus discrete control components, including PIN, tuning varactor, Schottky diodes and chip attenuators.

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Mobile Communication Catalog

This new edition of SPINNER's mobile communication catalog has been extended and adapted to the needs on the wireless communications market. You can find SPINNER's new MultiFit™ connector family and the range of jumper cables with the innovative SPINNERFlex™ Hybrid Jumper. The "MNCS® – Mobile Network Combining System" – has been considerably extended – e.g. with several new multiplexers for all current systems from LTE700 to LTE2600. The "Analog Fiber Optic Links" for the supply of remote antennas and repeaters are totally new.

SPINNER GmbH,
Munich, Germany (Europe): +49 89 12601-0, USA: (770) 263-6326,
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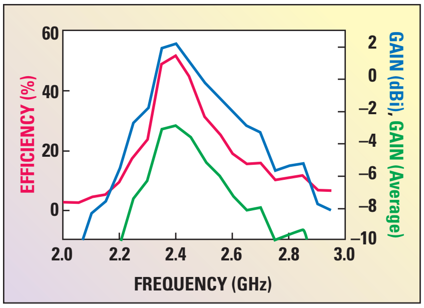

▲ *Fig. 10 Gain and efficiency of the antenna.*

as the decoupling structure between antennas 1 and 2, suppresses the mutual coupling and improves the isolation. Through full-wave simulations, the ZOR properties of the antennas and the decoupling between them have been proven. The antenna has been fabricated and tested in a real phone platform, showing a return loss better than 10 dB, an isolation greater than 12 dB and a radiation efficiency over 50 percent in WiMAX and LTE high bands, for both antennas, which have a total size of 26 × 5.5 × 2 mm. Considering these performances, this proposed antenna can be employed for developing small MIMO communication systems. ■

ACKNOWLEDGMENT

Sungtek Kahng, as the principal author with the University of Incheon, would like to thank LG Innotek for providing great opportunities to work on the MIMO antenna development. This work is part of a patent being filed.

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Sungtek Kahng *received his doctorate in electronics and communication engineering from Hanyang University, Korea, in 2000, with specialty in radio science and engineering. From 2000 to early 2004, he was with the Electronics and Telecommunication Research Institute, where he worked on numerical electromagnetic characterization and developed RF passive components for satellites. In March 2004, he joined the Department of Information and Telecommunication Engineering at the University of Incheon, where he has continued research on analysis and advanced design methods of microwave components and antennas, including metamaterial technologies, MIMO communications and wireless power transfer.*

Jong-Guk Kim *received his master's degree in mechatronics engineering from Gwang-ju Institute of Science & Technology (GIST) Graduate School, Gwang-ju, Korea, in 2004, with the design and analysis of X-Band mixer-type phase detectors. He is working on his doctorate in management of technology in the University of Sungkyunkwan, Suwon, Korea. In June 2004, he joined the department of Network Solution Group at the LG Innotek Co. Ltd.*

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RFMD offers a family of high-power discrete switch products, which are available in SPDT, SP3T, and SP4T type architectures. These switches are tailored to address coexistence issues in WiFi, BT, GPS, and LTE bands, which require extremely high linearity. These switches have very low current consumption making them ideal for use in battery-powered cellular devices where talk time and standby time are critically important. Other possible applications for these switches include antenna tuning and cellular band switching.

SPECIFICATIONS

	Control Lines	*Freq Range (MHz)*	*Power Handling (dBm)*	*Control Voltage (V)*	*Insertion Loss (dB)*	*Isolation (dB)*	*Switching Speed (uS)*	*IIP2 (dBm)*	*IIP3 (dBm)*	*Package (mm)*	*Mass Production*	*Part Number*
SPDT	1	DC to 3500	36	0 / +1.8	0.3	43	2.00	129	74	2.0 x 2.0 x 0.55	NOW	RF1602
SP3T	2	DC to 3500	36	0 / +1.8	0.4	40	2.00	120	73	2.5 x 2.5 x 0.55	NOW	RF1603A
SP4T	2	DC to 3500	36	0 / +1.8	0.4	40	2.00	120	73	2.5 x 2.5 x 0.55	NOW	RF1604

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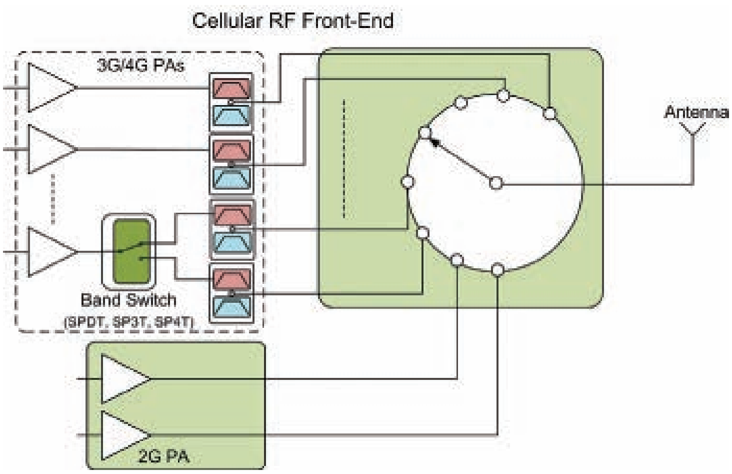

FEATURES

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- **1.8V GPIO compatible**
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