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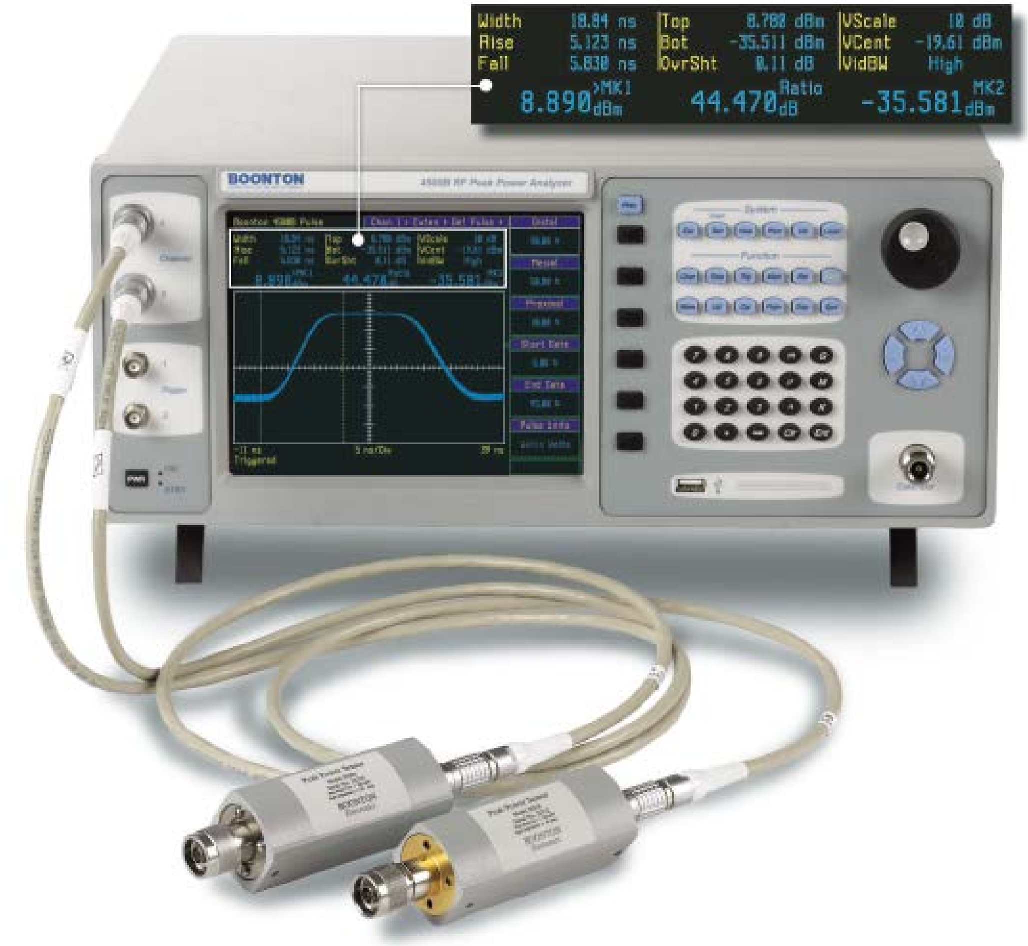

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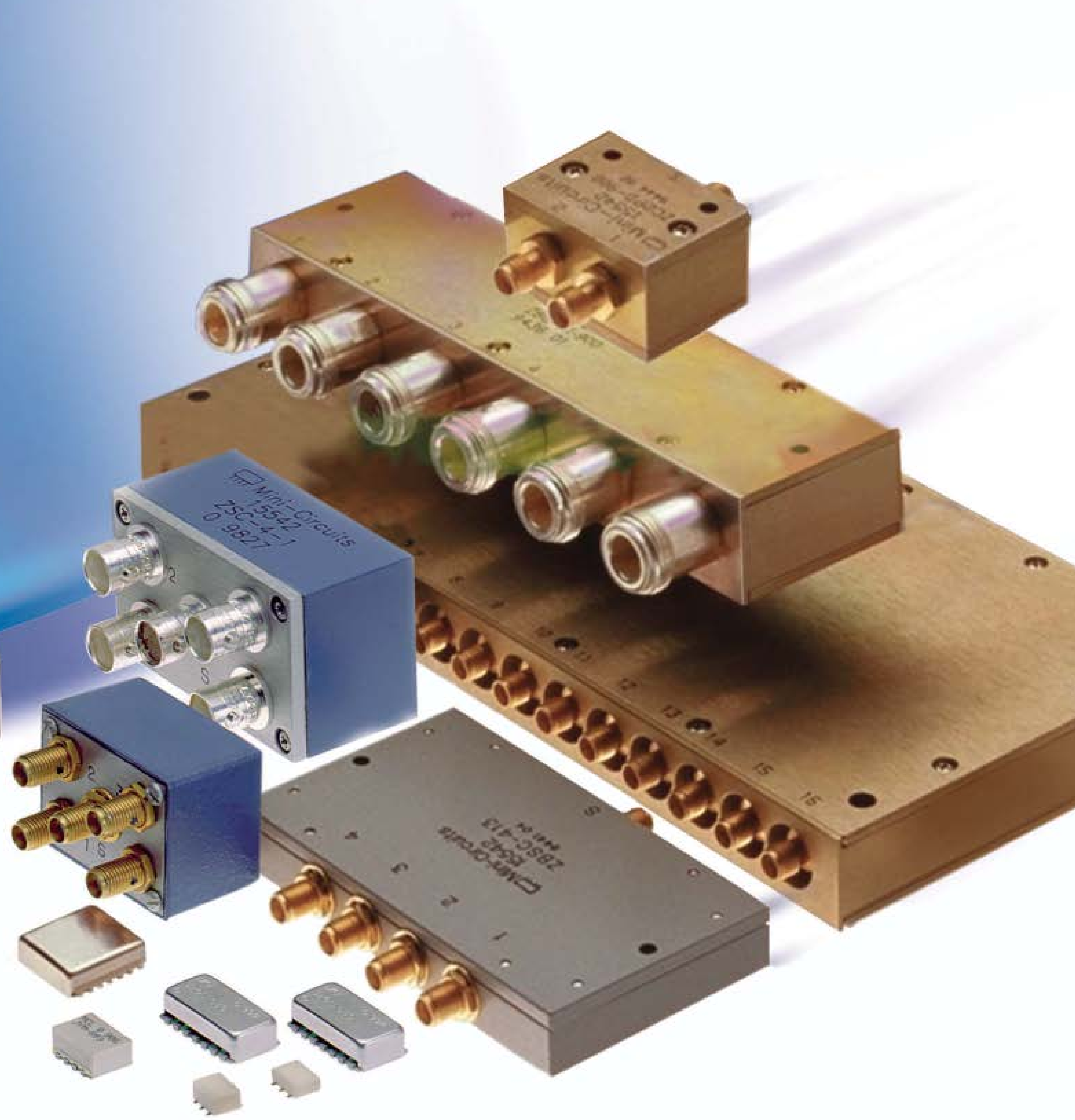
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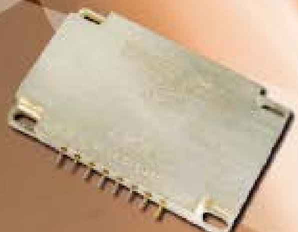

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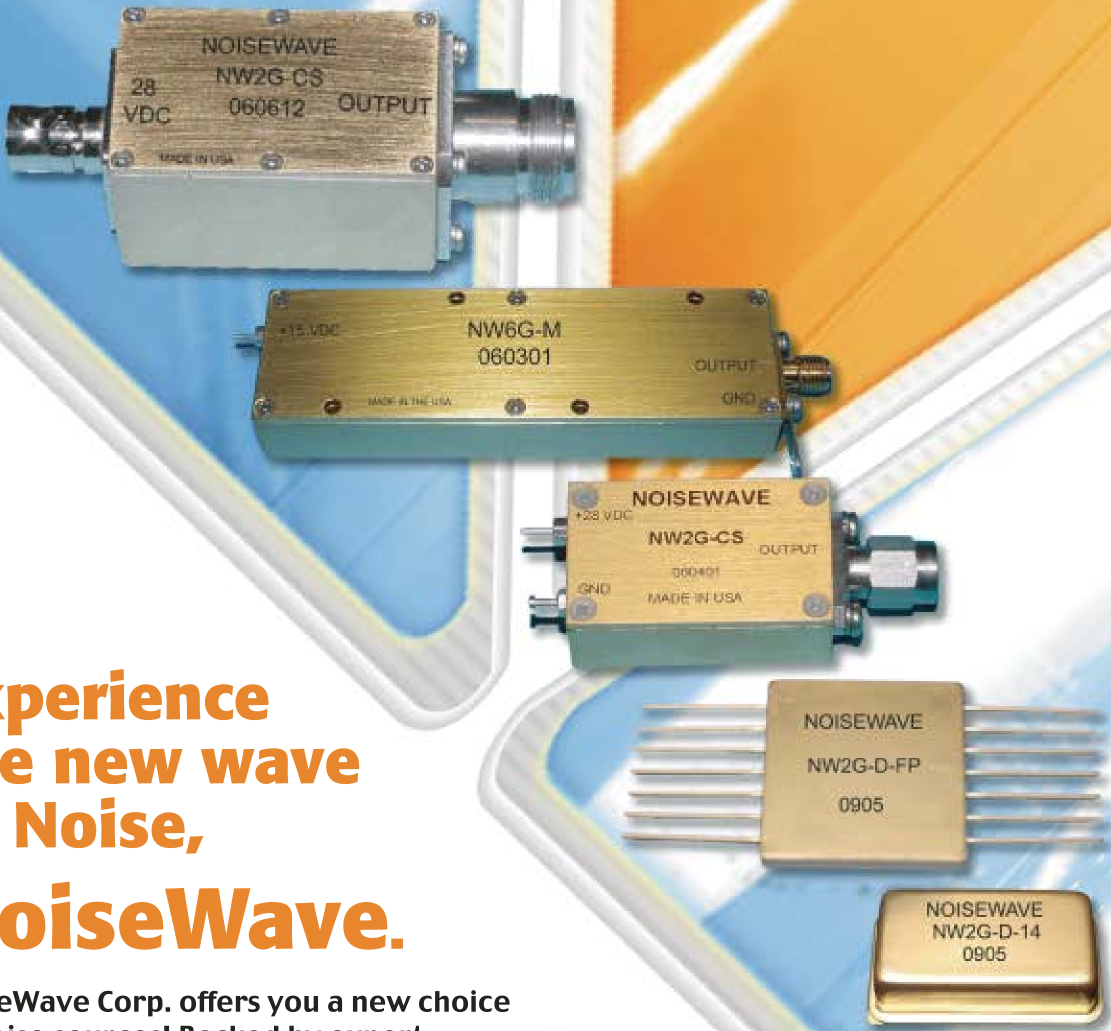

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COVER FEATURE

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Ask Harlan

"Ask Harlan," a technical question and answer session with Harlan Howe, Jr., an industry veteran and long-time *Microwave Journal* editor, has been a regular part of our web site (www.mwjournal.com) for almost two years now. In an effort to better combine the editorial content of our magazine with our newly developed and retooled on-line presence, we have decided to develop Harlan's RF and microwave engineering advice into a monthly feature.

How it works: Harlan has selected one question from his "Ask Harlan" column to be featured in the magazine. Please visit www.mwjournal.com/askharlan to provide an answer to this month's featured question (see below). Harlan will be monitoring the responses and will ultimately choose the best answer to the question. Although all of the responses to the featured question will be posted on our web site, we plan to publish the winning answer in the January issue. All responses must be submitted by **December 6, 2006**, to be eligible for the participation of the November question.

The winning response will win a free book from Artech House, along with an "I Asked Harlan!" t-shirt. In addition, everyone who submits a legitimate response will be sent an "I Asked Harlan!" t-shirt.

September Question and Winning Response

The September question was submitted by Edson Wander from Electrolux:

Dear Harlan,

I am looking for information about measuring microwave oven cavity reflexion (SWR). I am having difficulty finding the correct probe to simulate the magnetron with the network analyzer. Could you provide any direction?

The winning response to the September question is from Robert Kim of Newgen Telecom:

As I know, a microwave oven is using a magnetron as a signal source operating at mostly 2.45 GHz (there is also an exception of using 915 MHz for other industrial use) and a magnetron has an ANT part for signal radiation to the oven chamber, the small extruded part out of magnetron assembly. And to my knowledge, there is a waveguide between the oven chamber and the magnetron. I think you better insert a probe where the magnetron is attached to simulate what you want. The probe should be the same dimension as the ANT part of the magnetron and the opening should be properly shielded like a magnetron does in a real product. Connect the probe to the network analyzer through coax and measure S_{11} to monitor the reflection under various conditions, such as no load (food) or turntable moving condition, etc. Since the oven is thought to be a kind of passive device, the level of test signal is not of our concern if it can properly monitor the reflection. One thing you should make sure of, however, is that the ANT part might not be 50 Ω when connected to the coax, so you need to check the ANT first comparing its return in free space to that after installed to the oven whether it shows sufficient S11 as an ANT.

Harlan's response:

Since most oven magnetrons feed into a waveguide structure, if you simulate that structure with a WG to coax adapter you should be able to feed your network analyzer. Keep in mind that most ovens have a "stirrer" in the feed structure to change the field pattern for more uniform cooking. This will have a significant effect on the reflections.

This Month's Question of the Month

(answer on-line at www.mwjournal.com/askharlan)

Subhash Janakiraman from Icon Systems Inc. has submitted this month's question:

Dear Harlan,

I am trying to test a RF communication link inside an enclosed chamber which is free from RF leakage. I want to emulate a test in the same set up in such a way that the receiver and transmitter are 30 metres apart. I thought calculating the signal strength at this distance and attenuating the transmit power accordingly will justify my testing. Is that true? Am I justified to introduce that attenuation to account for the distance despite the fact that there is no free space loss? Can you point me to a link to calculate the attenuation in the transmit power due to varying distances?

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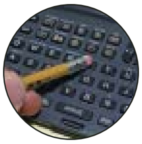

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NOVEMBER

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November 12–15, 2006 • San Antonio, TX
www.csics.org

electronica 2006
November 14–17, 2006 • Munich, Germany
www.electronica.de

68th ARFTG Conference
Nov. 28–Dec. 1, 2006 • Broomfield, CO
www.arftg.org

DECEMBER

IEEE Wireless and Microwave Technology 2006 (WAMICON 2006)
December 4–5, 2006 • Clearwater Beach, FL
http://wamicon.eng.usf.edu

International Electron Devices Meeting
December 11–13, 2006 • San Francisco, CA
www.his.com/~iedm

Asia-Pacific Microwave Conference (APMC 2006)
December 12–15, 2006 • Yokohama, Japan
www.apmc2006.org

JANUARY

IEEE Topical Workshop on Power Amplifiers for Wireless Communications (PA Workshop)
January 8–9, 2007 • Long Beach, CA
http://paworkshop.ucsd.edu

IEEE Radio and Wireless Symposium (RWS 2007)
January 9–11, 2007 • Long Beach, CA
www.radiowireless.org

7th Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems (SiRF 2007)
January 10–12, 2007 • Long Beach, CA
www.ece.wisc.edu/sirf07

WCA International Symposium and Business Expo
January 16–19, 2007 • San Jose, CA
www.wcai.com

FEBRUARY

IEEE International Solid-state Circuits Conference (ISSCC 2007)
February 11–15, 2007 • San Francisco, CA
www.isscc.org/isscc/

3GSM World Congress
February 12–15, 2007 • Barcelona, Spain
www.3gsmworldcongress.com

Satellite 2007
February 19–22, 2007 • Washington, DC
www.satellite2007.com

MARCH

Military Technologies Conference
March 27–28, 2007 • Boston, MA
http://mtc07.events.pennnet.com

CTIA Wireless 2007
March 27–29, 2007 • Orlando, FL
www.ctiawireless.com

RF & Hyper 2007
March 27–29, 2007 • Paris, France
www.rfhyper.com

International Wireless Communications Expo (IWCE 2007)
March 28–30, 2007 • Las Vegas, NV
www.iwceexpo.com

APRIL

IEEE Radar Conference 2007
April 17–20, 2007 • Waltham, MA
www.radar2007.org

JUNE

IEEE MTT-S International Microwave Symposium and Exhibition
June 3–8, 2007 • Honolulu, Hawaii
www.ims2007.org

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■ **Site:** Stillwater, OK
■ **Dates:** November 13–17, 2006
■ **Contact:** For more information, visit http://rc-course.okstate.edu.

"LEADING INSIGHT" APPLICATION WORKSHOPS

■ **Topics:** Ansoft's "Leading Insight" Application Workshops for High Performance Design provide attendees with an opportunity to exchange ideas and learn from experts in the design of high performance electronics. Presentations and interactive poster sessions by invited speakers together with Ansoft's technical staff will cover: IC design and verification; signal- and power-integrity simulation; RF, microwave and antenna design; and advanced packaging, SIP and SOC design.
■ **Sites:** Asia, North America, Europe
■ **Dates:** Nov. 13–Dec. 5, 2006
■ **Contact:** For more information, visit www.ansoft.com/leadinginsight/papers.cfm.

NI TECHNICAL SYMPOSIUM

■ **Topics:** The NI Technical Symposium Professional Development Series is designed to help engineers stay competitive. This improved once-a-year opportunity is a chance to explore the latest technologies for test, control and design applications. The advanced technical information in this series covers the latest virtual instrumentation applications through hands-on training and presentations. The agenda has an open format, so a participant can select from nearly 20 training sessions to meet specific needs.
■ **Sites:** For location information, please visit url.
■ **Dates:** Nov. 14–Dec. 7, 2006
■ **Contact:** For more information, visit www.ni.com/techsym/.

TEKTRONIX DESIGN INSIGHT DIGITAL RF SEMINAR

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■ **Sites:** Richardson, TX; Sunnyvale, CA
■ **Dates:** Nov. 14; Nov. 16, 2006
■ **Contact:** For more information, visit www.tektronix.com/design06fall/reg or call (877) 894-1407.

MICROWAVE MEASUREMENTS FOR EMERGING TECHNOLOGIES

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■ **Site:** Broomfield, CO
■ **Dates:** November 28–29, 2006
■ **Contact:** David Walker, NIST, M.S. 813.01, 325 Broadway, Boulder, CO 80305 (303) 497-5490 or e-mail: dwalker@boulder.nist.gov.

PHASED ARRAY ANTENNAS AND ADAPTIVE TECHNIQUES

■ **Topics:** This five-day course presents an in-depth look at the hardware and software that comprise state-of-the-art adaptive phased array systems. The objective is to present the student with the diverse spectrum of technologies and algorithms available and to show how they fit together into a design. The principles of phased array antennas are covered first, followed by the details of the underlying hardware. Practical issues in system implementation and performance are addressed throughout the course. For more information, visit www.pe.gatech.edu.
■ **Site:** Denver, CO
■ **Dates:** February 13–16, 2007
■ **Contact:** Georgia Institute of Technology, Professional Education, PO Box 93686, Atlanta, GA 30377 (404) 385-3500.

COVER FEATURE
INVITED PAPER

TECHNOLOGY ENABLES NEW COMPONENTS

In last year's November *Microwave Journal* article on components, Harlan Howe, Jr. authored an insightful and interesting article covering the history of microwave components. A whimsical Figure 1 depicted a dinosaur staring into the antenna of the first stone-age radar, while Figure 4 depicted a lady sitting on top of a high power WR-2100 waveguide diplexer that was several times her size. These images appropriately represent the birth of the microwave industry. These images also remind us of an undeniable trend in the industry: components are shrinking.

For 50 years after World War II the miniaturization trend was gradual with steps associated with solid-state and then surface-mount devices. More recently this trend is head spinning. We all benefit in our daily use of smaller commercial products. But military applications also benefit with greater functionality in smaller spaces. Advancements in this area are enabled by two primary factors: technology and integration. With small surface-mount devices, packaging and the clearance required for manufacturing consumes more space than the devices. This problem is solved for active circuits via integrated circuits (IC). Advancements in material technology now provide this option for passive microwave components. Manufacturers and users of passive components who do not embrace developing technologies ultimately risk the fate of the dinosaur.

Fig. 1 Unloaded Q for a 1 mm diameter solenoid, Q/mm² (FOM) for an optimum size solenoid and the optimum size (mm) for a single-layer wire-bound solenoid in air.

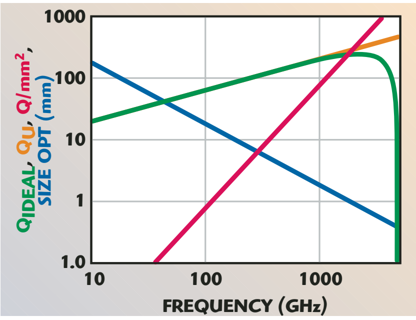

FIGURE OF MERIT

Just as dizzying as the degree of miniaturization is the range of technologies that must be considered for a given application. Which of these technologies is best suited for a given application? In this article I'll refer to inductors, capacitors, transmission lines and resonators as devices. I'll refer to assemblies that use these devices such as couplers, splitters, phase-shifters, switches and filters as components.

Were it not for quality factor (unloaded Q, or Q_u), devices could be as small as manufacturing allows. With today's photolithographic techniques, that is small indeed. But unlike ICs, a primary factor that differentiates passive circuits and limits their performance is Q_u, defined as the energy stored in a device divided by the energy dissipated. Energy is stored in a volume in some devices such as transmission lines, inductors and bulk quartz crystals, and in an area in piezoelectric surface devices. PWB and wafer area are viewed as limiting resources. Therefore, given the need for small size and good unloaded Q, one figure of merit (*FOM*) in passive devices could be Q_u per occupied area. I will use Q_u per square millimeter (Q/mm^2) as that *FOM*.

BACKGROUND

To fully understand this *FOM*, let's step back and consider in more detail a foundational device for the microwave industry, the single-layer wire-wound solenoid. In ***Figure 1***, plotted in brown is the computed Q_u of a 1

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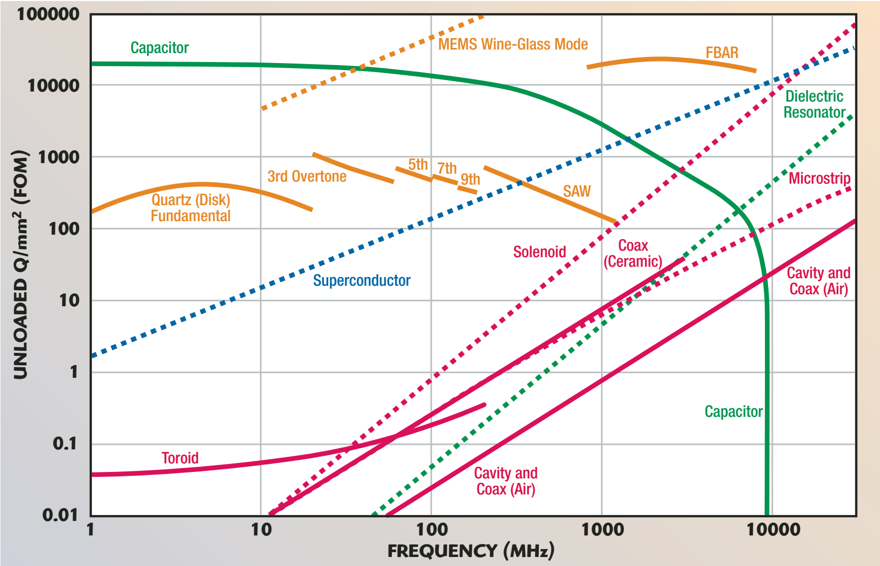

▲ *Fig. 2 Unloaded Q/mm² (FOM) for various device technologies. Dashed traces represent unshielded or unpackaged devices and are therefore optimistic. Red traces represent devices that are primarily limited by conductor loss. Orange traces represent devices utilizing mechanical vibration.*

mm diameter, 4 mm long, 10-turn copper-wire solenoid mounted vertically with one end grounded. The dashed curve is the ideal Q_u ignoring parasitic capacitance. This curve is based on empirically derived data published by Medhurst[2]

$$Q_u = 7.48 d \psi \sqrt{f}$$

where d is the solenoid mean diameter in millimeters, ψ is a factor depending on the solenoid mean length to diameter ratio and f is the frequency in megahertz. ψ ranges from about 0.5 to 0.9. Curve fit data for ψ is given in Rhea.[3]

For a given solenoid, Q_u would rise continually with the square root of frequency were it not for parasitic capacitance. Medhurst also provided empirical data for solenoid capacitance and curve fit data is given in Rhea.[3] For decades it was believed that the parasitic capacitance was inter-winding capacitance. However, it is primarily solenoid to ground capacitance.[4] For this solenoid the capacitance is about 0.048 pF. For a vertically mounted solenoid, with increasing frequency, this capacitance increases the effective inductance and decreases Q_u, as shown in the solid brown trace in Figure 1. The inductance approaches infinity and the Q_u approaches zero at the resonant frequency of the low frequency inductance and parasitic capacitance. This causes Q_u to peak at a frequency below the self-resonant frequency.

The solenoid capacitance is directly proportional to the solenoid diameter. To utilize a solenoid at higher frequency it is necessary to decrease the diameter and thus increase the resonant frequency of the solenoid. The approximate solenoid diameter in millimeters that results in maximum Q_u is plotted as the blue trace in Figure 1. While the length to diameter ratio and wire spacing can be adjusted to maximize solenoid Q_u, the most critical parameter is the diameter. At low frequency the optimum diameter may be larger than available space and at microwave frequencies the optimum diameter can be quite small. When so optimized, the maximum Q_u of the solenoid is about 200. Plotted in red in Figure 1 is the *Q/mm²* or *FOM* of the optimum sized solenoid. The *FOM* of the solenoid is proportional to f^2.

SENSITIVITY OF MICROWAVE COMPONENTS TO THE *FOM*

The importance of device Q_u varies among components. Hybrids, splitters, combiners, phase shifters, switches and other naturally broadband components have a high tolerance for relatively low Q_u. Bandpass filters, oscillators, narrowband matching networks, high power and low loss networks require higher Q_u.

Also, not all applications require small size. In certain applications,

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maximum Q_u is more critical than Q/mm^2. Bandpass filters with low loss requirements and percentage bandwidths less than five percent are a classic example. They often require relatively large machined cavities. The *FOM* is important when both size and Q_u are important, which is an increasingly prevalent requirement. Other factors being equal, small size also means lower cost, particularly with high volume products.

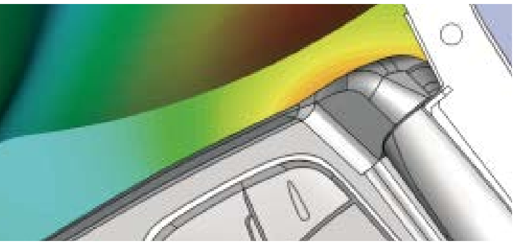
FOM OF VARIOUS TECHNOLOGIES

Plotted in **Figure 2** is the unloaded Q per square millimeter (*FOM*) for various device technologies. Dashed traces represent unshielded or unpackaged devices and are therefore optimistic. Brown traces represent devices that are primarily limited by conductor loss. Red traces represent devices utilizing mechanical vibration.

First consider the green trace for an AVX U series NPO 1 pF 0402 chip size capacitor.[5] At low frequency I estimated Q_u is limited by the dielectric. At higher frequency Q_u is limited by the effective series resistance (ESR) that is approximately 0.1 for this capacitor. Since the Ω reactance decreases with frequency, Q_u decreases linearly with frequency from about 300 MHz to 6 GHz. Above 6 GHz Q_u is limited by the series inductance of the capacitor and Q_u falls to zero at the series resonant frequency. From this graph we see that at UHF and lower frequencies the *FOM* for the capacitor is very high. RF engineers can almost ignore Q_u for capacitors but microwave engineers must be more careful. Nonetheless, the struggle for Q_u with classic devices is with loss in the conductors of inductors, transmission lines and even capacitors.

The *FOM* for the solenoid is repeated from Figure 1. As the frequency increases the diameter of the solenoid is decreased. Notice that the solenoid has a higher *FOM* than all other technologies except superconductors and those utilizing mechanical vibration. This often comes as a surprise because we know that transmission lines and cavities can have higher Q_u than inductors. This highlights an important consideration for this *FOM* graph. Inductors have a very high volumetric efficiency. Transmission lines yield higher Q_u but only if they are large. Inductor Q_u is limited because parasitic capacitance limits the maximum size. The high volumetric efficiency for the inductor explains the aversion to transmission line elements in ICs and low temperature cofired-ceramic (LTCC) components and the use of lumped elements in these devices. LTCC devices are covered later. The dashed trace indicates the data is for an unshielded solenoid. For components where component-to-component coupling is a minor issue such as splitters, or when the inductor is surrounded by capacitors, this is not a limiting factor. For filters with multiple inductors and needing high attenuation stopbands, inductors must either be shielded or widely spaced, so this data is optimistic. The *FOM* of the toroid is better than the solenoid at low frequency. At higher frequency hysteresis loss in the core becomes excessive.

Transmission line devices are represented by the cavity and coax, mi-



crostrip, superconductor and ceramic-loaded coax traces. The coax data is for a 75 Ω line with air dielectric and 10 μm metalization roughness. Both Q_u and area decrease linearly with coax diameter so the *FOM* is essentially independent of coax diameter. The cavity data is for a square copper cavity with height equal to ½ each side and a cut-off frequency of 90 percent of the operating frequency. Interestingly, the *FOM* for cavities and coax are similar. Cavities possess higher Q_u but also greater area. You might question utilizing area for coax and cavities but this was necessary to keep the data consistent. The microstrip data utilizes Arlon AD1000 0.508 mm thick substrate with electrodeposited copper.[6] At low frequencies copper loss dominates and as with coax, the *FOM* is independent of substrate thickness. The microstrip data is unshielded and includes no margin for edge spacing. Again when surrounded by lumped elements, additional spacing may not be required. Otherwise this data is optimistic and the *FOM* is comparable to coax. An improved *FOM* is realized by loading the coax with high dielectric constant material. In this example Trans-Tech 9000 material is used.[7] Essentially the *FOM* improves over air coax because the length shrinks as the square root of the relative dielectric constant, in this case the square root of 90.

The data labeled Superconductor is for a superconducting microstrip resonator on MgO substrate. The resistance of superconductors is zero only at DC. At 100 GHz the loss of superconductors and copper converge. However, over the plotted frequency range, the *FOM* is limited primarily by the substrate. The required cooling equipment would destroy the *FOM* and this data presumes a future day when room temperature superconductors are available. Superconducting filters are in use now not because of high volumetric efficiency but because of high Q_u and therefore low loss in narrow band filters.

Since World War II, the high Q_u and temperature stability of bulk piezoelectric quartz resonators have made them invaluable for excellent long- and short-term stability in oscillators and for very narrow band filters. Inexpensive resonators realize Q_u over 100,000 and Q_u exceeding 1,000,000 are readily available. Bulk quartz crystals are limited to an upper frequency limit of approximately 200 MHz but phase-locking offers both frequency extension and tunability for a plethora of communications devices. For data plotted in Figure 2, resonators are packaged in an HC 49/U metal case measuring 10.24 × 12.7 × 3.81 mm. The two large dimensions are used to compute the area for the *FOM*.

A well-proven technology that extends the upper frequency limit is piezoelectric surface acoustic wave (SAW) devices. They have been developed for resonators and monolithic filters with excellent shape factors and naturally flat group delay. The two large dimensions of a ceramic surface-mount 5 × 5 × 1.35 mm package are used for the *FOM* data.

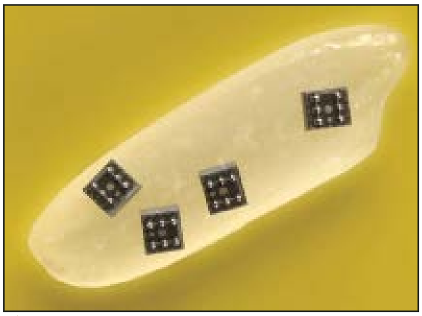
A new technology that has matured in this decade is the film bulk acoustic resonator (FBAR).[8] Devices are similar to SAWs except sound en-

ergy is longitudinal. Typically a AlN piezoelectric thin film is used with non-standard IC processing techniques. FBARs have been used with great success for duplexers in wireless phones replacing ceramic loaded TEM mode diplexers. $f_{(GHz)} \times Q$ for FBAR is approximately constant. For data plotted in Figure 2, an $f_{(GHz)} \times Q$ of 4000 was used in a 0.4 × 0.5 mm wafer level package (WLP) at 1 GHz down to a size of 0.14 × 0.24 mm at 8 GHz. As can be seen, the *FOM* is two orders of magnitude better than ceramic-loaded TEM devices. Four FBAR WLP filters are displayed on a grain of rice in ***Figure 3***. Many applications can be expected to arise from rapidly developing FBAR technology.

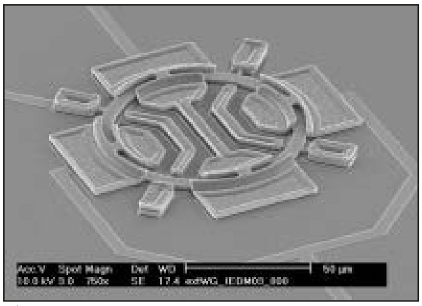
An even newer technology that has yet to see significant commercial application but that shows great promise is mechanical vibration devices constructed using MEMS processing. Multiple operating modes have been explored including miniature vibrating beams clamped on each end, beams free on the ends and contour mode disk resonators.[9] These devices are currently limited to an upper frequency of approximately 200 MHz. A promising technology for higher frequencies is the wine-glass mode ring resonator. An example resonator is given in ***Figure 4***. Data plotted in Figure 2 is for an unpackaged device. While this is significantly advantageous to the wine-glass mode resonator *FOM*, it should be considered that MEMS devices integrate directly into IC structures. Q_u in air of 4550 has been achieved at 651 MHz and 2300 at 1470 MHz. Better results are obtained in a vacuum.[10]

INTEGRATION

The power of integration to reduce the size and cost of high volume products is undeniable. Integration of RF and microwave functions into ICs has historically been limited because of a poor *FOM* of inductors and transmission lines. The use of planar spirals in both MIC and MMIC has been only partially successful because the turn-to-turn magnetic coupling of the spiral is poor and planar structures have notoriously high parasitic capacitance.



▲ *Fig. 3 Four microcap'd FBAR filters using Wafer Level Packaging (WLP) displayed on a grain of rice. The resonators are hermetically sealed in an all-silicon package* (photo courtesy of Rich Ruby, Avago Technologies).



▲ *Fig. 4 MEMS Wine-Glass Mode ring resonator* (photo courtesy of Discera Co.).

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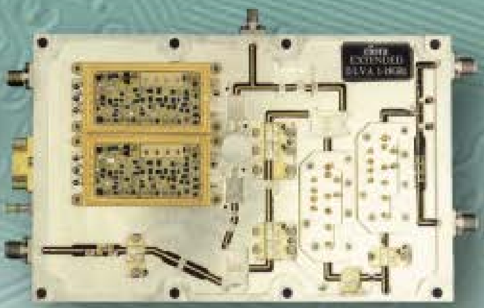

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The absence of LTCC technology in Figure 2 does not indicate unimportance. LTCC technology is missing because it embodies the implementation of many different technologies. LTCC devices are becoming more prevalent because they offer the ability to integrate inductors, transmission lines and other discrete devices on a substrate utilizing three-dimensional structures. The third dimension provides the option to create square cross-section solenoids. LTCC design guidelines also support closely spaced transmission lines to aid realization of tight couplers. The strength of LTCC is a degree of integration and miniaturization difficult to realize in MIC components.

Besides the vibration mode devices mentioned earlier, MEMS offers integration of classic microwave devices at the silicon level. MEMS can be used to create closed cavities, solenoids and other structures that are far more volumetric efficient than previously used planar devices. In the future, high volume applications will no longer need off-chip devices to realize high performance communications products. Over time, more microwave circuit designers will be IC designers. ■

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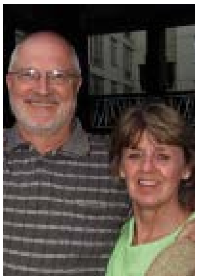
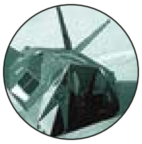


Randy Rhea *is a graduate of the University of Illinois (1969) and Arizona State University (1973). His thesis was construction of an earth station that monitored Apollo 16 & 17 Unified S-band signals from the moon. He worked briefly at the Boeing Co. and Goodyear Aerospace and for 14 years at Scientific-Atlanta, where he became principal engineer. He founded Eagleware Corp. in 1985, recently acquired by Agilent Technologies, and Noble Publishing in 1994, recently acquired by SciTech Publishing. He has authored numerous technical papers, tutorial CDs and the books* Oscillator Design and Computer Simulation *and* HF Filter Design and Computer Simulation. *He has taught oscillator and filter design techniques to over 1000 engineers through full-day seminars at trade shows, the Georgia Institute of Technology and corporations. His hobbies include antiques, historical properties, astronomy and amateur radio (N4HI). He and his wife Marilynn have two adult children and reside near Thomasville, GA.*



Raytheon System Key to Successful Ballistic Missile Intercept in Space

Raytheon Co. components played key roles in the destruction of a ballistic missile target in the latest successful flight test of the Ground-based Midcourse Defense (GMD) system. The Raytheon-built Exoatmospheric Kill Vehicle (EKV) intercepted the ballistic missile target in space over the eastern Pacific Ocean. The Raytheon-developed Upgraded Early Warning Radar (UEWR) at Beale Air Force Base, CA, successfully tracked the target system for approximately 15 minutes during its flight down-range to the test several hundred miles west of California.

The test marked the first time an operationally configured ground-based interceptor was launched from an operational GMD site, Vandenberg Air Force Base, CA. The target was launched from Kodiak, AK. This test, designated Flight Test-2 (FT-2), did not have a target interception as a primary objective, but it demonstrated the EKV's ability to successfully detect, track, discriminate and destroy a target in space. "This highly successful test of the GMD system demonstrates Raytheon's systems performance and reliability," said Louise Francesconi, Raytheon's Missile Systems president. "FT-2 clearly demonstrates the maturity of our technology and our ability to provide this critical capability to the nation."

"We are pleased that once again the Beale UEWR performed as expected, successfully demonstrating its missile defense capability," said Pete Franklin, vice president, Raytheon Integrated Defense Systems, Missile Defense Business Area. "This test confirms the radar's ability to provide information to the GMD Ground Fire Control to support an intercept." During the flight, the EKV received target updates from the In-flight Interceptor Communications System and performed a star shot to calibrate its own position. The EKV observed the target complex with its advanced multi-color infrared seeker and successfully selected the target. During the end game, as the target grew in the seeker's field of view, EKV selected the aimpoint and maneuvered for a direct, lethal hit. The closing velocity was in excess of 15,000 miles per hour. This test follows another successful GMD mission in December 2005, which demonstrated the system's capability to launch a ground-based interceptor, conduct EKV separation and deliver the EKV to the desired point in space and time.

Raytheon is a major subcontractor to the Boeing Co. on the GMD program, providing the EKV, the UEWR and the radar component for the Sea-based X-band (SBX) radar. Continuing the Raytheon heritage with UHF phased-array radar, the Beale UEWR program upgrades existing Pave Paws and Ballistic Missile Early Warning System radars by adding missile defense capabilities while retaining missile warning and space surveillance missions. The UEWR provides mid-course target detection and tracking for the GMD.

Lockheed Martin Team Awarded Contract for US Air Force AOC Integration

The US Air Force has selected an industry team led by Lockheed Martin to be the Air and Space Operation Center Weapon System Integrator (AOC WSI). Under this multi-year contract, the team will work with the Air Force to standardize, modernize, sustain and transform the more than 20 AOCs worldwide into interoperable net-centric weapon systems that will provide commanders with real-time, common operational views of the global battle field. The indefinite delivery/indefinite quantity, cost-plus-fixed-fee and cost-plus-award-fee contract, including funding for operations, maintenance and sustainment is worth $589 M.

"Our team is honored to support the Air Force in this transformational effort," said Stan Sloane, executive vice president of Lockheed Martin's Integrated Systems and Solutions (IS&S) business area. "With our customer, we will evolve today's AOCs into integrated net-centric operations, incorporating essential combat capabilities that will enable joint and coalition warfighters to continue to dominate command and control of future conflicts, while improving operational efficiencies." The Lockheed Martin team includes Raytheon, SAIC, IBM, L-3 Communications, Dynamics Research Corp., Intelligent Software Solutions, Gestalt and Computer Science Corp.

As the primary system used by Joint Force Air Component commanders to exercise command and control of air and space power worldwide, AOCs are highly complex facilities with up to 48 discrete systems that support diverse missions. While they share some functions, their missions are supported by different systems, operating procedures and personnel requirements. The AOC WSI effort will evolve this heterogeneous infrastructure into a standardized, seamless, integrated enterprise. This will enable interoperability across the AOCs for faster access to intelligence, surveillance, reconnaissance, targeting and other important operational data. It will provide a common technical baseline for efficient and cost-effective technology upgrades while reducing the cost and footprint for deployed personnel and material.

"By implementing an open, service-oriented architecture across the AOC enterprise, the government and Lockheed Martin team will enable greater collaboration internally within the AOC and externally with other joint and coalition warfare elements," said John Mengucci, vice president and general manager of Department of Defense Systems for Lockheed Martin IS&S. "This approach will also allow the Air Force to quickly and easily accommodate new capabilities and technologies, ensuring a cost-effective, low risk growth path to net-centric operations. Warfighters can expect rapid operational improvements that consistently meet or exceed expectations."

The AOC WSI team will take full advantage of the Lockheed Martin Center for Innovation in Suffolk, VA, relying on the facility's powerful analysis, modeling and simulation tools in a "C2ISR Wind Tunnel" configuration for rapid analysis of potential improvements to operating concepts, processes and systems. The center provides a rich experimentation environment as well as an infrastructure for collaboration with AOC Weapon System stakeholders and organizations. This shared access to innovative industry and joint C2ISR experimentation, along with powerful net-centric warfare analysis tools such as the C2ISR Wind Tunnel, will enable rapid combat upgrades and reduce program risk.

Harris Corp. Introduces the RF-300U Secure Personal Radio

Harris Corp. has introduced the RF-300U, its Secure Personal Radio (SPR) to the worldwide market. The radio system provides secure, digitized voice and data communications to the individual soldier and fits seamlessly into a variety of network-centric systems, including those based on the highly successful Harris Falcon® II family of tactical radios. The system features selectable high grade encryption, and its 350 to 450 MHz frequency band provides worldwide coverage and excellent range in both urban and rural environments.

"The SPR's small, lightweight design fits easily in a pocket and offers completely automatic and hands-free operation," said Steve Marschilok, vice president and general manager of Harris International Products and Systems. "It offers both traditional narrowband communication, as well as a sophisticated wideband waveform that provide secure, full-duplex voice conferencing, situational awareness and high speed data. The flexibility of the new SPR helps to bring greater command and control capability to the squad level and to the individual soldier."

The radio is designed for highly integrated C^4I capability, incorporating a Global Positioning System receiver and standard USB interfacing, allowing easy-to-use position tracking and messaging services while reducing the load carried by the soldier. All transmissions are secured by standard AES or customer-unique Citadel® digital encryption that protect tactically relevant command and situational information from eavesdroppers. The SPR's unique wireless network does not require infrastructure and provides reliable communication even where backbone and trunk services are not available. ■

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ITA Wins Transatlantic Research Agreement

The United Kingdom Ministry of Defence and the United States Army Research Laboratory have selected the newly formed International Technology Alliance (ITA) in Network and Information Sciences—an IBM-led consortium—to undertake a research programme exploring advanced technology for secure wireless and sensor networks to support future coalition operations, over a potential 10 year period, with a value of up to $135.8 M.

Successful future military operations will depend on the capability of coalition forces to quickly gather, interpret and share battlefield information to coordinate actions, so the research will enable interoperability and communications across disparate military units, allowing them to operate more effectively.

This Alliance represents a new way of conducting collaborative research by fostering close partnerships among government, academic and industry researchers in both countries. The ITA creates a critical mass of private sector and government researchers focused on solving military technology challenges central to future coalition military operations; enabling staff rotations among all organisations in the Alliance; and facilitating rapid and affordable transition of technologies with an innovative transition model.

The ITA brings together leading US and UK commercial and academic organisations in four interconnected areas of research: network theory; security across a system of systems; sensor information processing and delivery; and distributed coalition planning and decision making. The programme will provide open collaborative research cutting across national, institutional and technical area boundaries, and, with 25 partners, is one of the world's largest collaborative technology programmes.

New Technology Centre for EADS in India

EADS, a global leader in aerospace, defence and related services, has underlined its intentions to make India a priority with the announcement that it will be opening the EADS Technology Centre India. The move follows on from the company registering EADS India Private Ltd., a 100 percent owned subsidiary of EADS, earlier this year, which has the role of developing the Group in India.

The campus-style technology centre will bring both EADS subsidiaries and Indian partners under the same roof, performing engineering and information technology services. Operations are expected to begin in the second quarter of 2007 and the entire campus will be inaugurated in early 2008. Central to the campus will be a state-of-the-art engineering unit called the Engineering Centre Airbus India. It will be a 100 percent owned subsidiary of Airbus and will represent the biggest on-site unit owned by an EADS Division.

The EADS Technology Centre India will become a major employer in the aerospace and defence sector in India with the potential to create up to 2000 jobs. Over the next 15 years, the volume of investment and high tech activities generated thanks to the EADS Technology Centre, including the Airbus Engineering Centre and other cooperation programmes will reach approximately €2 B.

TEAMSAIC Selected for NATO Contract

Science Applications International Corp. (SAIC) as the lead in TEAMSAIC, has been selected to negotiate a firm fixed-price contract to support the integration of the NATO Active Layered Theatre Ballistic Missile Defence (ALTBMD). The contract will establish a six-year period of performance with an estimated value of €75 M and the majority of the work will be performed in the Netherlands.

NATO is working to tie existing and planned national weapon systems, sensors, battle management, command, control and communications into an integrated defence for the protection of alliance military forces and critical assets. The SAIC-led multinational team will assist in this effort by developing and verifying proposed ALTBMD architectures using an integration test bed that it will design and operate under the contract.

The members of TEAMSAIC are drawn from six NATO nations including France, Germany, Italy, the Netherlands, the United Kingdom and the United States. Team members include: Datamat SpA, Diehl BGT Defence GmbH & Co. KG, European Aerodynamic Defence Systems (EADS) – Space, Industrieanlagen-Betriebsgesellschaft mbH (IABG), QinetiQ, the Raytheon Co., Thales, ThalesRaytheonSystems and the Netherlands Organisation for Applied Scientific Research (TNO).

Finnish Technology for Planck Satellite

VTT Technical Research Centre of Finland has coordinated the development of an extremely sensitive high frequency radio receiver for the Planck Mission. The receiver, valued at approximately €8 M, will be used to measure cosmic microwave background radiation originating from the early life of the universe. It will help scientists determine, among other things, the age and structure of the universe. The radio receivers are currently being installed in the satellite, which will be launched into space in 2008.

A European Space Agency (ESA) undertaking, the Planck probe will be equipped with a 1.5 m radio telescope and two receivers: one for measuring lower frequencies, one for higher. The Finnish team designed and constructed the most challenging components of the low frequency receiver. The development work was lead by VTT and the Finnish firm Elektrobit Microwave was responsible for constructing and testing the equipment.

The technology developed in the project is already available for use, for example, in security checks, detecting vehicles through fog and telecommunications applications. It is also suitable for high precision cloud radars and for making unique astronomical discoveries.

Europe Must Watch This Space

The WEU Assembly and the European Interparliamentary Space Conference joined forces to hold a colloquy on Space, Defence and European Security in Kourou (French Guiana) in association with the European Space Agency (ESA), France's national centre for space studies, the Centre National d'Etudes Spatiales (CNES) and Arianespace. The event brought together over a hundred Members of Parliament from European nations along with Members of the European Parliament and senior executives from ESA, CNES, Arianespace and the space industry in Europe.

The main aim of the discussions was to examine the space sector in its application to security and defence and assess industrial capabilities in the light of the challenges Europe faces at the present time. The participants noted the gulf between the strategic ambitions Europe had of its space dimension and the level of funds it was prepared to commit to it, with the risk that Space Europe could lose its head start.

The president of the Interparliamentary European Security and Defence Assembly (WEU Assembly), Jean-Pierre Masseret, emphasised the importance of Europe being able to draw on the full gamut of space-based facilities: earth observation, telecommunications, intelligence, navigation and ballistic missile early warning systems, noting further that this comprehensive range of capabilities played a crucial part in preventing, managing and exiting crises, and would guarantee Europe genuinely autonomous powers of decision and action in security and defence matters. ■

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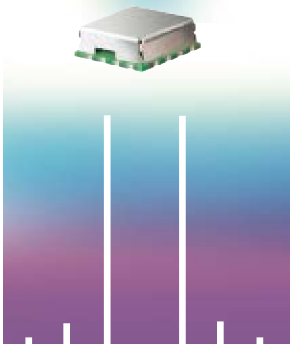

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LAVI-22VH+	425-2200	525-2400	100-700	+21	+31	+20	7.7	50	45	24.95
LAVI-2VH+	2-1100	2-1100	2-1000	+23	+34	+23	7.5	48	47	24.95
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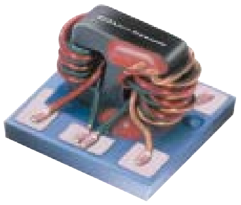

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SBTC-2-25+	1000-2500	50Ω	3.49
SBTC-2-10-75+	10-1000	75Ω	3.49
SBTC-2-15-75+	500-1500	75Ω	3.49
SBTC-2-10-5075+	50-1000	50/75Ω	3.49
SBTC-2-10-7550+	5-1000	50/75Ω	3.49

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RF/IF MICROWAVE COMPONENTS

354 Rev E

RF Industry Outlook Brightens

Strategy Analytics, the global research and consulting company, released "RF Component Industry Review: January – March 2006," noting that financial performance reported by RF component suppliers in Q1 improved.

Demand for RF components in Q1 remained strong, supported by strength in the cell phone market. Fifty-three percent of the top RF component suppliers covered reported significant profits and the number of suppliers reporting net losses remained relatively low, by recent historical standards.

"As a sign of optimism in the industry, funding in RF start-ups approximately doubled from the previous quarter to $250 M, led by VC interest in basebands for multimode 3G and WiMAX," said Chris Taylor, director of the RF and Wireless Component service.

Asif Anwar, director of the GaAs and Compound Semiconductor service, added, "Volumes remained at historical highs for the leading power amplifier (PA) suppliers, most of whom made cautious plans to expand capacity."

Obstacle Detection Technology Offers "Priceless" ROI

Accident statistics attract worldwide attention. In the US and Europe more than 40,000 people per year are killed in automobile accidents and countless more are injured. A new study by ABI Research reveals that available technologies, including ultrasonic, radar, lidar and camera-based safety systems can address many of the causes.

"Some of these obstacle detection systems have been available for a number of years," says senior analyst David Alexander, "but only at the top of the market. Costs are coming down with volume, but not by the same amount across the board."

ABI Research's study, "Automotive Obstacle Detection Systems," finds that the market is primed to take advantage of the benefits of a number of different approaches to obstacle detection and that some technologies are going to drop in cost more rapidly than others. But in the absence of legislation, how many buyers will choose to pay for them?

"In the consumer market, education is critical to the uptake of obstacle detection systems," says Alexander. "Widespread adoption is needed if we are to achieve a significant improvement in accident statistics. Car buyers need to learn more about how the technology works and to understand that they really will benefit from purchasing these systems."

While initial cost is still an issue, the benefits are huge. Avoiding costly body and paint repairs may deliver a big enough ROI, but saving a life or avoiding an injury is priceless. Market interest could bode well for Tier 1 system developers such as Visteon, Delphi, Siemens, Bosch, Continental, Hella and TRW, and coordinated public relations coverage, with help from the government, will deliver strong demand for the technology.

"Luxury cars have had obstacle detection options long enough to get the bugs out," concludes Alexander. "The first OEMs to make them available to the mass market could reap huge rewards."

"Automobile Obstacle Detection Systems" provides an analysis of global market trends, cost and technological evaluations of different approaches and strategies used by safety system developers and discussion of existing product announcements and design wins. System and sensor forecasts for vehicles are provided globally, by region though 2012.

Airship Sheds Wire Antennas: Paint-on Antennas Tested Without Errors

The new paint-on antenna technology was tested successfully during flights on the SA-60 Spherical Airship in the Nevada desert. Derived from a series of polymer-based dielectrics and highly conductive paint, the paint-on antennas are designed to be used to establish new high altitude communications and surveillance platforms. With no protruding physical antennas that can get damaged or destroyed in high altitude flights, the paint-on electromagnetic antennas communicated during the flight with an Iridium Global satellite. The paint-on antennas transmitted and received data links in an overall radio frequency performance considered outstanding. Iridium bit error rate data transmission and receptions and voice communications to and from the Airship with teleconferencing were tested without errors.

When painted on an SA-60 airship, the antennas can provide unhampered communication with minimal chance of interruption. The SA-60 shed their wire antennas and bore the paint-on antennas for the antennas first test flight. Staying airborne for days at altitudes from 10,000 to 20,000 feet over a geographic area, the SA-60, armed with the impervious paint-ons, high resolution cameras, infrared sensors and over-the-horizon radar, could be deemed a surrogate-satellite performing all the same features as a satellite in outer space.

By patrolling or positioning over a particular area, SA-60 tagged with the paint-on antennas is expected to offer flawless communications when used to secure ports, borders and coastlines, observe hurricanes, assist with hurricane disaster relief, perform science observations and improve military operations protecting warfighters.

Global Navigation Satellite System Receiver Shipments to Increase Seven-fold

Over 40 million Global Navigation Satellite System (GNSS) receivers were shipped in 2005, but in 2011 the market will have grown to nearly 300 million shipments, according to a new study from ABI Research that tracks GNSS markets across eleven vertical industry segments.

That growth will not occur evenly across the board. In 2005, in-vehicle navigation systems accounted for just 26 percent of the total shipments, but 34 percent of worldwide GNSS hardware revenues. In 2011, in contrast, in-vehicle navigation shipments will represent just 16 percent of the total market, but will still deliver 29 percent of the hardware revenue.

Research director Frank Viquez says that the most significant trend, however, is the growing importance of the communication sector, almost entirely made up of GPS-enabled handsets. "In 2005, communications accounted for 43 percent of the total market in terms of shipments. In 2011 that will have grown to 69 percent, but the revenue derived from it will have doubled, from just 9 percent in 2005." Much of that added growth will come from the mass uptake of GNSS services by the majority of the world's mobile subscribers who use GSM handsets. As that trend develops, the fastest regional growth, which until now has been seen in North America and parts of Asia, will shift to Europe.

While communications will be the standout, and portable navigation—buoyed by falling prices and a flood of new offerings—will remain a strong and popular application, other sectors will show more modest gains. Garmin, TomTom, Magellan, Thales, Trimble and more specialized GNSS vendors, such as Rockwell Collins, Leica and Honeywell, will see a variety of expanding opportunities.

"Military applications will increase," says Viquez, "especially driven by the military's aggressive push to equip not just vehicles, but individual soldiers with GPS. Civil aviation will see some growth due to the increasing popularity of regional commuter and executive jets. The deployment of the European Galileo GNSS satellites will boost mapping and surveying applications as well: the more satellites in the sky, the greater the availability of the signal and the more accurate the location data it provides." "Global Navigation Satellite Positioning Systems and Devices" examines all the end-use market segments for GPS/GNSS, and identifies individual market drivers and barriers for each. ■

Does Cosite Interference Keep you Up at Night?

Resolving interference issues between closely spaced transmitters and receivers can be a real nightmare. Transmitter broadband noise, receiver desensitization, spurious signals, and rusty bolt effects result in unintentional jamming in your communications system. The result is a system that provides only a fraction of the required communications range. What are you going to do?

Contact Pole/Zero today to conduct an analysis of your system and shed light on how best to improve the dynamic range on your platform. We have many years of experience in analyzing and providing solutions for RF interference issues.

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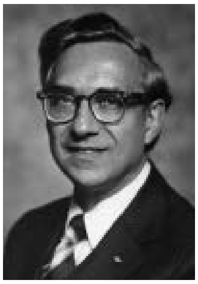
INDUSTRY NEWS



Dr. Leo Young died September 14, 2006, of complications from cancer. He was 80 years old. He was a pioneer in the microwave industry and served as president of both MTT-S and IEEE.

He received his BS degree in physics and math in 1946 and his master's degree in electrical engineering in 1949, both from Cambridge University. In 1957 he received his doctorate in electrical engineering from Johns Hopkins University.

As a young engineer, he worked at Westinghouse on microwave components and antennas. He is best known for his work on filter technology at the Stanford Research Institute in Menlo Park, CA, and later as superintendent of the Electrical Engineering Division of the Naval Research Laboratory in Washington, DC.

Young held 20 patents, was the author of many papers as well as author, co-author or editor of 14 books, including the classic *Microwave Filters, Impedance-Matching Networks and Coupling Structures*. Originally published in 1964, it is still available and continues to sell well even after 42 years. He was a researcher, a teacher, a mentor to many young engineers and a frequent contributor to *Microwave Journal*. He made many significant contributions to the microwave industry and will be remembered both for his work and as a friend to many of us.

■ October 15th, 2006 marked the beginning of **Maury Microwave Corp.**'s 50th year in business. On that day in 1957 the company first opened its doors as Maury and Associates, under the leadership of founder Mario A. Maury. With the help of his sons, Mario A. Maury, Jr. and Marc A. Maury, the company earned a solid reputation in the microwave test and calibration industry, while developing a comprehensive line of precision instruments, coaxial and waveguide components, and calibration standards. For the complete story, visit www.maurymw.com/events_media/press_releases/pubrel/pr028.htm.

■ **Freescale Semiconductor Inc.**, a global leader in the design and manufacture of embedded semiconductors for wireless, networking, automotive, consumer and industrial markets, announced that it has entered into a definitive merger agreement to be acquired by a private equity consortium in a transaction with a total equity value of $17.6 B. The consortium is led by The Blackstone Group, and includes The Carlyle Group, Permira Funds and Texas Pacific Group.

■ **RF Monolithics Inc.** (RFM) announced the closing of its acquisition of high performance wireless products manufacturer **Cirronet Inc.** With the acquisition, which was initially announced on August 28th, RFM will add Cirronet's proprietary, Bluetooth™ and Zigbee™ embedded modules and box products to its existing portfolio of low power radio technologies. With the expansion of its product line—and its recent acquisition of Caver-Morehead's asset management software—RFM will be strategically positioned to serve the rapidly growing and higher value-added market for comprehensive wireless solutions.

■ **Elcoteq SE** and **Andrew Corp.** have signed a global, long-term manufacturing supply agreement, which further strengthens Elcoteq's position as a strategic partner to Andrew Corp. in Europe and the Americas. The agreement is expected to increase Elcoteq's net sales by approximately 80 million euros (100 million US dollars) during 2007. As a result of this new agreement, Elcoteq will be responsible for consolidating and managing the whole supply chain of Andrew's filter business in Europe and will start manufacturing and system assembly in Mexico on a turnkey basis. In addition, Elcoteq and Andrew have agreed that Elcoteq will acquire Andrew's manufacturing unit in Arad, Romania, including related equipment, work in progress and inventories. The total consideration to be paid by Elcoteq will amount to some 15 million euros. Elcoteq will take over the manufacturing unit immediately.

■ **Agilent Technologies Inc.** announced a multi-year, multi-site agreement in which **Peregrine Semiconductor** has expanded its investment in Agilent Technologies' RFIC design tools, designed to boost productivity and production yields.

■ **EMS SATCOM**, a division of EMS Technologies Inc., reported that, in collaboration with **Thales**, it will provide high speed mobile satellite communications systems to OnAir for use on Airbus aircraft. System deliveries, expected to start in late 2006, are estimated to be worth at least $30 M over the next five years. The systems will be used to provide in-flight cell phone and Internet service.

■ **Credence Systems Corp.**, a provider of test solutions from design to production for the worldwide semiconductor industry, announced a partnership with **Integra Technologies** to offer mixed-signal and RF application development support for design houses located in North America. Integra is also expanding its RF and mixed-signal test capabilities with the purchase of an additional Credence ASL 3000RF test system.

■ **WJ Communications Inc.** announced that it has signed an OEM agreement with **Hitachi America Ltd.** to supply fixed readers for use with Hitachi's RFID u-chip. This agreement involved joint development between Hitachi and WJ of an industry leading 2.45 GHz fixed reader, available exclusively through Hitachi America. Hitachi America will market the reader as part of its overall RFID solutions offerings including item authentication such as event tickets and manufacturing process automation.

■ **Microwave Products Group**® (MPG), composed of Dow-Key Microwave and K&L Microwave, announced the opening of a new office in Stockholm, Sweden. This new location significantly enhances MPG's ability to serve new and existing customers in Scandinavia. It also supports company initiatives to improve customer relations and corporate growth globally. To head the new MPG

Ultra WIDE BANDWIDTH

RoHS Voltage Controlled Oscillators

Model	Frequency (MHz)	Tuning Voltage (VDC) *	DC Bias VDC @ I (Max)	Typical PhaseNoise @ 10 kHz (dBc/Hz)
DCMO514-5	50 - 140	0.5 - 24	+5 @ 30 mA	-105
DCMO616-5	65 - 160	0.5 - 24	+5 @ 35 mA	-108
DCMO1027	100 - 270	0 - 24	+5 to 12 @ 35 mA	-112
DCMO1129	110 - 290	0.5 - 24	+5 to +12 @ 35 mA	-105
DCMO1545	150 - 450	0.5 - 24	+5 to 12 @ 35 mA	-108
DCMO1857	180 - 570	0.5 - 24	+5 to 12 @ 30 mA	-108
DCMO2260-5	220 - 600	0.5 - 24	+5 @ 35 mA	-108
DCMO2476	240 - 760	0.5 - 24	+5 to 12 @ 35 mA	-108
DCMO3288-5	320 - 880	0.5 - 24	+5 @ 35 mA	-109
DCFO35105-5	350 - 1050	0 - 25	+5 @ 40 mA	-112
DCMO50120-5	500 - 1200	0.5 - 24	+5 @ 40 mA	-118
DCMO50120-12	500 - 1200	0.5 - 24	+12 @ 35 mA	-103
DCMO60170-5	600 - 1700	0 - 25	+5 @ 35 mA	-99
DCMO80210-5	800 - 2100	0.5 - 24	+5 @ 35 mA	-96
DCMO80210-10	800 - 2100	0.5 - 24	+10 @ 35 mA	-100
DCMO90220-5	900 - 2200	0.5 - 24	+5 @ 35 mA	-98
DCMO90220-12	900 - 2200	0.5 - 25	+12 @ 35 mA	-99
DCMO100200-12	1000 - 2000	0.5 - 24	+12 @ 35 mA	-105
DCMO100230-12	1000 - 2300	0.5 - 24	+12 @ 35 mA	-101
DCMO100230-5	1000 - 2300	0.5 - 24	+5 @ 35 mA	-98
DCMO110250-5	1100 - 2500	0.5 - 28	+5 @ 35 mA	-100
DCMO135270-8	1350 - 2700	0.5 - 20	+8 @ 35 mA	-93
DCMO150318-5	1500 - 3200	0.5 - 20	+5 @ 30 mA	-93
DCMO150320-5	1500 - 3200	0.5 - 18	+5 @ 60 mA	-92
DCMO172332-5	1720 - 3320	0.5 - 24	+5 @ 30 mA	-94
DCMO190410-5	1900 - 4100	0.5 - 16	+5 @ 50 mA	-90
DCMO250512-5	2500 - 5125	0.5 - 24	+5 @ 50 mA	-78

** Guaranteed sub bands with lower tuning voltages. See specification sheet for details.*

Features:
- Ultra Wide Bandwidth
- High Immunity to Phase Hits
- Exceptional Phase Noise
- Very Low Post Thermal Drift
- Small Size Surface Mount
- Lead Free - RoHS Compliant
- Patent Pending
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sales office, Fredrik Knutsen has been named Scandinavian regional sales manager.

■ **Radio Waves Inc.** has announced that it will be offering high quality Radio Waves HP6 antennas manufactured at the company's UK facility. Until now the largest antennas Radio Waves manufactured in its UK facility was HP4 and SP6 style antennas. Radio Waves also offers Flex Twist and can provide LMR® jumpers and cables.

■ **Lytron Inc.** recently announced the completion and opening of its new factory and corporate office space in Woburn, MA. With this new space north of Boston, Lytron has doubled its square footage and increased its manufacturing capabilities, positioning itself for continued growth. It has also made room for equipment and the addition of staff from its recent acquisition of Lockhart Industries Inc., a designer and manufacturer of advanced aluminum-brazed cooling components for the military and electronics markets.

■ **Microwave Filter Co. Inc.** was recently honored by the Defense Supply Center Columbus as one of the government's best suppliers at an award ceremony held during the 2006 Land and Maritime Supply Chains Business Conference and Exhibition, August 28–30, 2006, in Columbus, OH. The firm supplies passive electronic filters to the Department of Defense and other government agencies.

■ **Xirrus Inc.**, a provider of high capacity, long range Wi-Fi products that can effectively extend wired network capabilities to wireless, announced the issuance of United States Patent Number US D526,973 S by the US Patent and Trademark Office.

■ **ANADIGICS Inc.** announced that the company is shipping production volumes of power amplifiers for new handset models from a large handset OEM. ANADIGICS' ultra-compact AWT6314 dual-band CDMA power amplifier enables a new handset from this tier-one OEM.

CONTRACTS

■ **Micronetics Inc.** announced that it has received an order for integrated microwave subsystems from a leading direct broadcast satellite (DBS) antenna manufacturer valued at over $1 M. These microwave subsystems will be installed onboard a fast growing regional commercial airline. This order is expected to ship over the next nine months, starting in the third quarter of the current fiscal year.

■ **picoChip** announced that its WiMAX solution is part of **M/A-COM**'s recently announced 4.9 GHz VIDA broadband solution for Public Safety Grade Applications. This solution by M/A-COM, a business unit of Tyco Electronics, utilizes the standard WiMAX 802.16 protocol to deliver integrated, public safety-grade wireless broadband video and data services for mission-critical applications.

■ The US Department of Defense's (DoD) Naval Inventory and Control Point (NAVICP) has awarded **Technical Communities Inc.**, a leading marketplace operator and service provider for the IT, network maintenance and test and measurement industry, a contract to operate and enhance the strategic sourcing on-line marketplace for the General Purpose Electronic Test Equipment (GPETE) division. The terms of the agreement extend the original five-year contract signed in 2001, through August 1, 2007. Technical Communities originally developed and now operates the existing on-line marketplace located at www.navicp-mart.org.

■ **CPI International Inc.**, the parent company of Communications and Power Industries Inc., a provider of microwave, radio frequency, power and control solutions for critical defense, communications, medical, scientific and other applications, has recently enjoyed excellent success providing a solid-state power amplifier to **SWE-DISH Satellite Systems** for use in the SWE-DISH® IPT Suitcase. CPI International (CPI) currently delivers large quantities of power amplifiers to SWE-DISH for use in its small, satellite terminals.

■ **Inphi® Corp.**'s recently launched GigaTrack™ family of high frequency Track-and-Hold Amplifiers (THA) has been selected by **Wavecrest** as a fundamental building block for its sophisticated family of signal integrity analysis (SIA) solutions, beginning with its SIA-4000. Wavecrest's test equipment is used to analyze serial data communication and clock signals for a wide variety of applications. The SIA-4000 tests serial data applications with speeds up to 12.5 Gbps including applications such as PCI Express™ Gen 2, FB DIMM, 8X Fibre Channel and OC-192 SONET.

■ **Unity Wireless Corp.** has received an order for two of the company's point-to-point microwave radio products, the UNI 50 and UNI 100, from a new customer in North Africa.

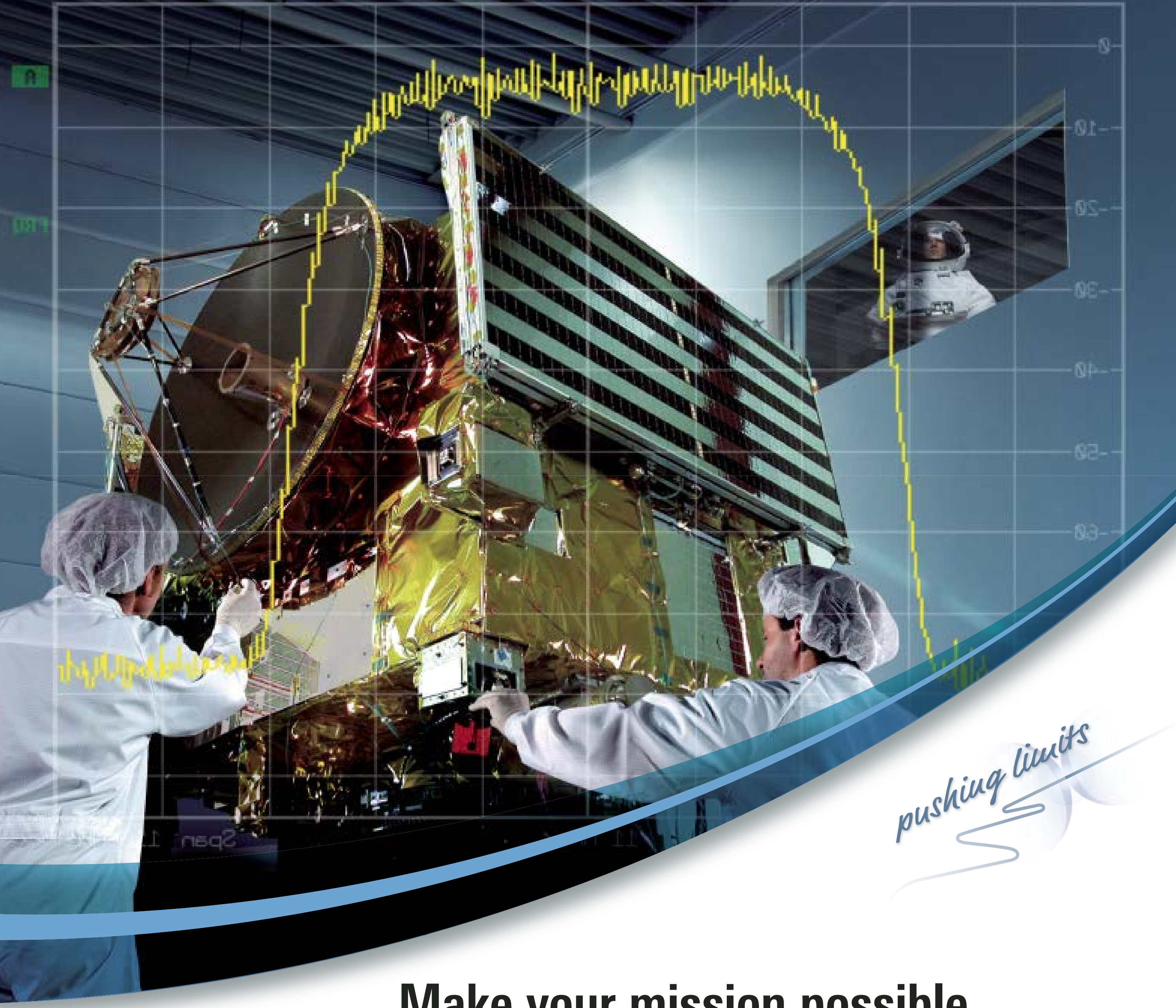
FINANCIAL NEWS

■ **RF Micro Devices Inc.** (RFMD), a global leader in the design and manufacture of high performance radio systems and solutions for applications that drive mobile communications, announced that, as a result of the pending merger of **Jazz Semiconductor** with a wholly owned subsidiary of **Acquicor Technology Inc.**, RFMD expects to sell its equity interest in Jazz Semiconductor for an aggregate cash consideration of approximately $24 to $27 M. Upon completion of the merger, which is expected in the first quarter of calendar year 2007, Jazz Semiconductor will become a wholly owned subsidiary of Acquicor.

■ **SiGe Semiconductor**, a supplier of RF front-end solutions for wireless systems, announced it has raised US $19.5 M in an expansion round of financing. The investment will fund new product development from conception to launch, as well as the growth of operations in support of the company's expanding global customer base. TD Capital, Prism Venture Partners, VenGrowth Private Equity Partners and 3i Technology Partners led the round, joined by previous investors, including Hunt Ventures, RWI Group, GrowthWorks and Vista Ventures.

■ **Ansoft Corp.** reports sales of $17.3 M for the first quarter of fiscal 2007 ended July 31, 2006, compared to $14.8 M for the same period in 2006. Net income for the quarter was $2.3 M ($0.09/per diluted share), compared to $1.2 M ($0.05/per diluted share) for the first quarter of last year.

■ **Merrimac Industries Inc.** reports sales of $8.3 M for the second quarter ended July 1, 2006, compared to $7.6 M for the same period in 2005. Net income for the quar-



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ter was $529,000 ($0.17/per diluted share), compared to $332,000 ($0.10/per diluted share) for the second quarter of last year.

■ **RF Industries Ltd.** reports sales of $3.9 M for the third quarter of fiscal 2006 ended July 31, 2006, compared to $3.3 M for the same period in 2005. Net income for the quarter was $407,000 ($0.11/per diluted share), compared to $194,000 ($0.05/per diluted share) for the third quarter of last year.

PERSONNEL

■ **Frank Padula** has been appointed president/chief operating officer at Wide Band Systems Inc., Franklin, NJ. Padula succeeds William B. Sullivan, the company's founder and former president who passed away earlier this year. Prior to this new position, Padula served as vice president/operations at Wide Band responsible for administrative duties involving materials control, purchasing, accounts payable, program management, contracts administration and associated functions.

■ Quantum Leap Packaging Inc. announced the appointment of **David Grooms** to chief executive officer. Grooms has held the top post at several large public and small emerging technology companies to include president of Kyocera America Inc. and Kyocera Mexicana S.A.de C.V., both based out of San Diego, CA, where he served a 20-year tenure.

▲ Hans Petter Hauge

■ Nordic Semiconductor ASA announced that it has appointed **Hans Petter Hauge** as its new chief financial officer (CFO). Hauge joins the company from a long and distinguished background including three years as financial director of the Nordic's largest consumer food supplier, Orkla Foods ASA, and more recently, five years as CFO for OSE-listed wireless software company Birdstep Technology ASA.

▲ Keith Horn

■ Fujitsu Microelectronics America Inc. (FMA) named **Keith Horn** to be its chief operating officer (COO). Horn will manage the day-to-day operations of FMA. He has already been responsible for FMA's four business groups, as well as marketing communications and engineering. In his new role, the four vice presidents heading operations, IT, human resources, accounting, finance and legal will also report to him.

■ D2 Technologies announced that it has appointed **Doug Makishima** to the post of vice president of marketing. Makishima reports to Dr. David Wong, president of D2. Makishima has over 19 years of marketing and engineering experience in the networking and communications industries. He served as vice president of marketing for Intoto, a network security vendor. Prior to joining Intoto, Makishima served as vice president of marketing for Hifn, a leading provider of security and network proces-

sors, and vice president of marketing and sales for Parkervision, a wireless communications solutions company.

■ TRU Corp. announced that **Robert St. Pierre** has joined the company as director of sales, a new position, reporting to Tony Martiniello, vice president of business development and engineering. St. Pierre will have direct responsibility for all TRU sales functions both internally and externally, and the regional managers will report directly to him. St. Pierre has a long and distinguished career in the RF and microwave industry, beginning at M/A-COM in applications engineering and sales, then at Sage Laboratories, Richardson Electronics and most recently at UltraSource Inc.

■ MicroMetrics Inc., a manufacturer of semiconductor devices, announced the appointment of **Michael Hebert** as director of marketing and new product development. Hebert was formally the general manager and director of semiconductor operations for M/A-COM, a Tyco Electronics company. Hebert brings over 20 years of experience to the MicroMetrics team and will help enhance the company's high voltage surface-mount PIN and limiter diodes as well as assist the company in new product development projects.

REP APPOINTMENTS

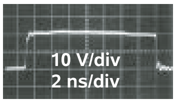
■ **Electro Rent Corp.** announced that it has entered into North American distribution agreements with **Agilent Technologies**, **Hioki** and **RAE Systems** for a range of basic test and measurement (T&M) products from these leading manufacturers, and created a Distribution Products Group to manage this new sales channel.

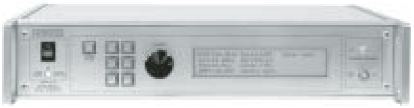
■ **Fox Electronics**, a supplier of frequency control products, and **Digi-Key Corp.**, an electronic component distributor that ships to more than 140 countries around the globe, announced the signing of a global distribution agreement. Digi-Key will stock Fox's broad range of crystals, oscillators, VCXOs, TCXOs and OXCOs.

■ **Lorch Microwave** announced the appointment of **dBm Technical Sales** as the exclusive sales representative in the New England area. They may be contacted at One Olde North Road, Chelmsford, MA (978) 256-7100, fax: (978) 256-9705 or e-mail: jhoffman@dbmsales.com. Lorch Microwave has also appointed **J-Squared Marketing** as the exclusive sales representative for FL, GA, AL, NC and SC. They may be contacted at 2280 N. Ronald Reagan Blvd., Longwood, FL 32750 (407) 831-4901, fax: (407) 884-0252 or e-mail: j2m1958@aol.com.

■ **Mica Microwave** announced the appointment of **mmwave Technologies Inc.** as its exclusive sales representative in Canada. mmwave Technologies can be contacted at the main office located at 6200 Tomken Road, Unit A, Mississauga, Ontario L5T 1X7 (905) 696-2820, fax: (905) 696-2821 or visit www.mmwave.com. Additional offices are located in Ottawa, Montreal and Calgary.

■ **TRAK Microwave Corp.** announced the appointment of **Eastern Optx LLC** (EOX) as its exclusive sales representative for Southeast United States. EOX will cover the states of GA, AL, TN, MS, AL and FL. To contact EOX, visit: www.eoxsales.com.





■ **Modelithics Inc.** and **Netwell Corp.** announced that Netwell will be representing Modelithics' unique model library products and measurement and modeling services in Japan. Modelithics will be joining Netwell in Tokyo this year as an exhibitor for the December 12-15, Asia Pacific Microwave Conference.

■ **EMC Technology/Florida RF Labs**, manufacturers of high reliability microwave passive components and cable assemblies, announced the appointment of **JS Commtech** as exclusive representative for the country of South Korea. JS Commtech can be contacted at RM #301, Taeyang Bldg., 194-7 Poi-Dong Gangnam-Gu, Seoul, Korea 135-962 +82-2-574-6100, fax: +82-2-579-0085 or visit www.jscommtech.com.

■ Triton Electron Technology Division (ETD) of **Triton Services Inc.** has appointed several new rep appointments for the company. **Eastern Instrumentation**, Philadelphia, PA, will be responsible for the territory of south NJ, PA and DE. **EOX Sales** will handle the territory of MD, DC, VA, NC, SC, GA, FL and AL. **CDB Enterprises Inc.** will represent northern New Jersey, metropolitan New York and western Connecticut, and **Northern Technical Sales** will cover the upstate New York territory.

WEB SITES

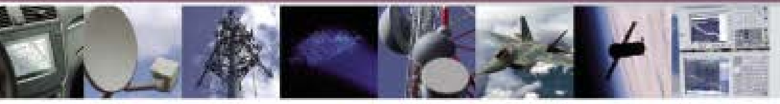
■ **Reactel Inc.** has enhanced its web site, www.reactel.com, with an on-line Filter RFQ tool. Filter quotes have never been easier, and are now just a click away. The site also features Reactel's full-line of RF/microwave filters, diplexers and sub-assemblies. Additionally, in support of customers worldwide, Reactel's product catalog and data sheets are available by download.

■ **Applied Computational Sciences** (ACS) has revamped its web site (www.appliedmicrowave.com) to include new features of the LINC2 RF and microwave circuit design software suite. LINC2 from ACS combines high performance RF and microwave circuit design, synthesis, simulation and optimization into a single integrated program at an affordable cost. The software includes a comprehensive suite of design tools for the exact synthesis of a wide variety of active and passive circuits.

■ **Aeroflex/Inmet** has recently updated its site at www.aeroflex-inmet.com to include new features such as "Click to Quote" and "Click to Buy." The site allows a user to obtain a quote for any one of the listed products simply by clicking on the quote button pictured next to the particular model number. In addition, a "Buy Now" button has been added next to each item that is available for immediate purchase.

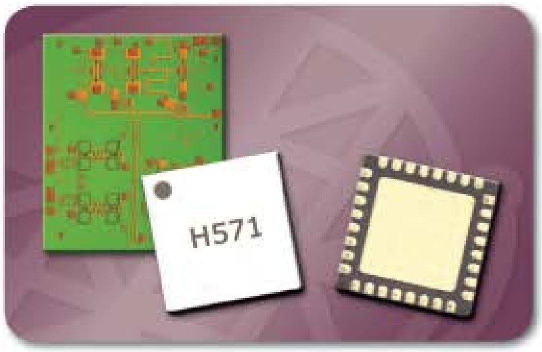
■ **Chip Estimate Corp.** announced that it has launched an integrated chip planning portal including an extensive database of digital, mixed signal and analog intellectual property components. Visitors to www.chipestimate.com can use a "rank-by-relevance" search engine to find IP components, and view comprehensive data sheets with details on IP status in silicon and overall quality. Over 4000 components are in the on-line catalog, representing over 150 IP suppliers.

9 New Receiver MMICs



Analog & Mixed-Signal ICs, Modules & Subsystems

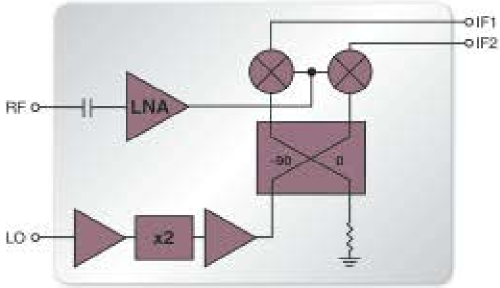
Low Noise Microwave Receiver IC Solutions



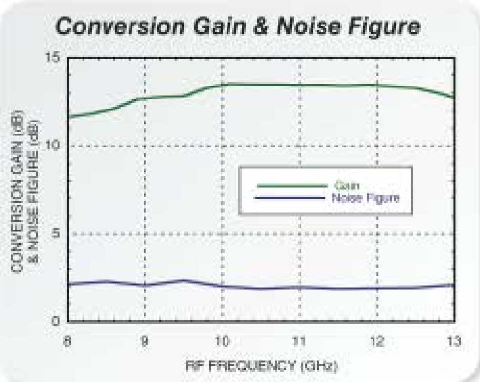
Product Family Covers 7 to 28 GHz!

- ***Conversion Gain from 8 to 14 dB***
- ***Noise Figure as low as 2 dB***
- ***Excellent Image Rejection to 35 dB***
- ***Available in Die or RoHS 5x5 mm SMT Package***

RoHS✓ E EARTH FRIENDLY



Integrated LO Multiplier!



IN STOCK I/Q RECEIVER MMICs

	RF/LO Freq. (GHz)	Function	IF Frequency (GHz)	Conversion Gain (dB)	Image Rejection (dB)	Noise Figure (dB)	Package	Part Number
NEW!	7 - 9	I/Q Receiver	DC - 3.5	10	35	2.5	LC5	HMC567LC5
NEW!	9 - 12	I/Q Receiver	DC - 3.5	14	33	2	LC5	HMC568LC5
NEW!	12 - 16	I/Q Receiver	DC - 3.5	14	32	2.5	LC5	HMC569LC5
NEW!	17 - 21	I/Q Receiver	DC - 3.5	10	17	3	Chip	HMC570
NEW!	17 - 21	I/Q Receiver	DC - 3.5	10	18	3	LC5	HMC570LC5
NEW!	21 - 25	I/Q Receiver	DC - 3.5	11	24	3.5	Chip	HMC571
NEW!	21 - 25	I/Q Receiver	DC - 3.5	10	20	3.5	LC5	HMC571LC5
NEW!	24 - 28	I/Q Receiver	DC - 3.5	8	20	3.5	Chip	HMC572
NEW!	24 - 28	I/Q Receiver	DC - 3.5	8	20	3.5	LC5	HMC572LC5

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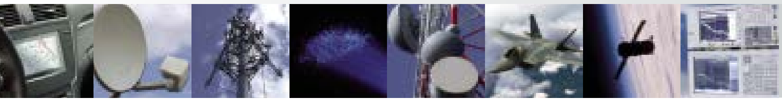


TEST & MEASUREMENT ♦ MILITARY

In Stock Module Products!

We continue to build our module product line with new wideband / power / low noise amplifiers, attenuators, frequency dividers (prescalers), frequency multipliers, I/Q mixers, mixers, phase shifters & switches. Utilizing our standard MMIC products, we take advantage of our design, manufacturing and quality knowledge base. Contact us to discuss your custom module requirements.

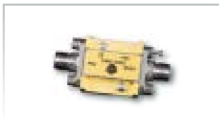
AMPLIFIERS - Low Noise, Drivers, PAs & >10 Watt PA Modules

	Frequency (GHz)	Function	Gain (dB)	OIP3 (dBm)	NF (dB)	P1dB (dBm)	Bias Supply	Package	Part Number
NEW!	29 - 36	Low Noise	20	22	2.9	11	+3V @ 80mA	C-10 Module	HMC-C027
	2 - 20	Wideband LNA	15	24	2.2	14	+12V @ 65mA	C-1 Module	HMC-C001
	2 - 20	Wideband LNA	14	26	2	18	+12V @ 60mA	C-2 Module	HMC-C002
	2 - 20	Wideband LNA	14	27	2	16	+8V @ 75mA	C-2B Module	HMC-C022
	7 - 17	Wideband LNA	22	25	2.5	14	+8V @ 93mA	C-1 Module	HMC-C016
	17 - 27	Wideband LNA	18	25	3	14	+8V @ 96mA	C-1B Module	HMC-C017
	0.01 - 20	Wideband Driver	16	33	3	23	+12V @ 195mA	C-3 Module	HMC-C004
	0.01 - 20	Wideband Driver	15	30	3	23	+12V @ 225mA	C-3B Module	HMC-C024
NEW!	2 - 35	Wideband Driver	11	26	4	16	+11V @ 92mA	C-10 Module	HMC-C038
NEW!	0.01 - 15	Wideband PA, 1/2 Watt	12	36	4	28	+11V @ 360mA	C-10B Module	HMC-C036
NEW!	0.01 - 15	Wideband PA, 1/2 Watt	12	36	4	28	+11V @ 360mA	C-12 Module	HMC-C037
	2 - 20	Wideband PA	15	34	4	26	+12V @ 310mA	C-2 Module	HMC-C003
	2 - 20	Wideband PA	14	30	4	24	+12V @ 310mA	C-2B Module	HMC-C023
	2 - 20	Wideband PA	28	30	3	25	+12V @ 400mA	C-3B Module	HMC-C026
NEW!	17 - 24	Wideband PA	22	33	3.5	24	+8V @ 250mA	C-10 Module	HMC-C020
NEW!	21 - 31	Wideband PA	15	32	5	24	+8V @ 215mA	C-10 Module	HMC-C021
	0.4 - 1.0	10 Watt PA	40	54	12	40	+12V @ 6.5A	C-7 Module	HMC-C012
	0.8 - 2.0	10 Watt PA	43	56	12	40	+12V @ 6.5A	C-7 Module	HMC-C013
	1.8 - 2.2	15 Watt PA	42	53	6	42	+14V @ 6.5A	C-7 Module	HMC-C008

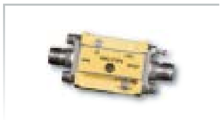
ATTENUATORS - Digital

	Frequency (GHz)	Function	Loss (dB)	Atten. Range (dB)	Input IP3 (dBm)	Control Input (Vdc)	Package	Part Number
NEW!	DC - 13	6-Bit Digital, Serial Control	3.6	0.5 to 31.5	32	Serial TTL/CMOS	C-6 Module	HMC-C018
	DC - 13	6-Bit Digital	3.2	0.5 to 31.5	38	0 / +5V	C-6 Module	HMC-C025

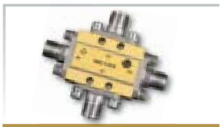
C-1 / C-1B
35.31 x 17.78 x 7.38 mm



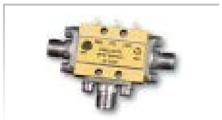
C-2 / C-2B
38.1 x 17.78 x 7.38 mm



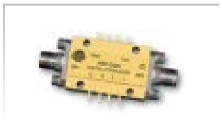
C-3 / C-3B
40.89 x 17.78 x 7.38 mm



C-4
41.66 x 36.32 x 8.50 mm



C-5
41.66 x 29.84 x 8.50 mm



C-6
45.34 x 17.27 x 8.50 mm

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CROWAVE MODULES

Analog & Mixed-Signal ICs, Modules & Subsystems

& SPACE ♦ COMMUNICATIONS

FREQUENCY DIVIDERS *(PRESCALERS)*

Input Freq. (GHz)	Function	Input Power (dBm)	Output Power (dBm)	100kHz SSB Phase Noise (dBc/Hz)	Bias Supply	Package	Part Number
DC - 18	Divide-by-2	-15 to +10	-4	-150	+5V @ 75mA	C-1 Module	HMC-C005
DC - 18	Divide-by-4	-15 to +10	-4	-150	+5V @ 93mA	C-1 Module	HMC-C006
DC - 18	Divide-by-8	-15 to +10	-4	-150	+5V @ 98mA	C-1 Module	HMC-C007

FREQUENCY MULTIPLIERS - *Active*

	Input Freq. (MHz)	Function	Output Freq. (GHz)	Input Power (dBm)	Output Power (dBm)	100kHz SSB Phase Noise (dBc/Hz)	Package	Part Number
NEW!	3000 - 5000	Active x2	6 - 10	3	17	-140	C-10 Module	HMC-C031
NEW!	9000 - 14500	Active x2	18 - 29	3	16	-132	C-10 Module	HMC-C032
NEW!	12000 - 16500	Active x2	24 - 33	3	17	-132	C-10 Module	HMC-C033
NEW!	16000 - 23000	Active x2	32 - 46	3	13	-130	C-10 Module	HMC-C034

I/Q MIXERS

RF/LO Freq. (GHz)	Function	IF Frequency (GHz)	Conversion Gain (dB)	Image Rejection (dB)	Input IP3 (dBm)	Package	Part Number
4 - 8.5	I/Q Mixer	DC - 3.5	-7.5	37	23	C-4 Module	HMC-C009

MIXERS

RF Freq. (GHz)	Function	IF Frequency (GHz)	Conversion Gain (dB)	LO/RF Isol. (dB)	Input IP3 (dBm)	Package	Part Number
16 - 32	+13 LO, DBL-BAL	DC - 8	-8	28	19	C-11 Module	HMC-C014
24 - 38	+13 LO, DBL-BAL	DC - 8	-8.5	35	20	C-11 Module	HMC-C015

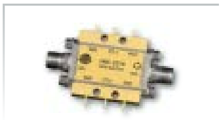
PHASE SHIFTERS - *Analog*

Frequency (GHz)	Function	Insertion Loss (dB)	Phase Range (deg)	2nd harmonic Pin = 10 dBm (dBc)	Control Voltage Range (Vdc)	Package	Part Number
6 - 15	Analog	7	750° @ 6 GHz 450° @ 15 GHz	40	0V to +5V	C-1 Module	HMC-C010

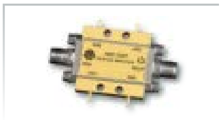
SWITCHES

	Frequency (GHz)	Function	Insertion Loss (dB)	Isolation (dB)	Input P1dB (dBm)	Control Input (Vdc)	Package	Part Number
NEW!	DC - 20	SPST, Hi Isolation	3	100	23	0 / +5V	C-9 Module	HMC-C019
	DC - 20	SPDT, Hi Isolation	2.0	40	23	0 / -5V	C-5 Module	HMC-C011

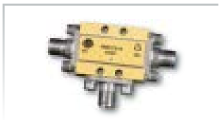
C-7
192.3 x 106.7 x 35.0 mm



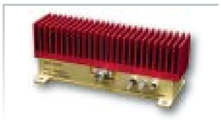
C-9
41.66 x 27.59 x 8.50 mm



C-10 / C-10B
41.66 x 27.59 x 8.50 mm



C-11
41.66 x 29.84 x 8.50 mm



C-12
107.6 x 43.0 x 43.0 mm

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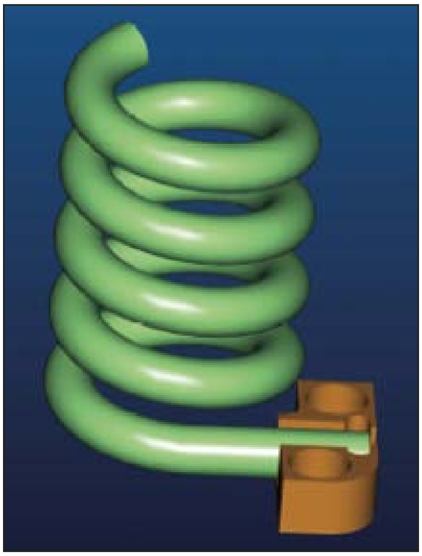
A HELICAL RESONATOR-BASED FILTER WITH IMPROVED SKIRT SELECTIVITY

Helical type resonators are widely used for frequencies below 0.5 GHz, mainly for mass and dimensional considerations. Replacing the more traditional TEM combline types or dielectric resonators by helical resonators significantly reduces the size and mass of the filters at the expense of the insertion loss. The rather complicated mechanical structure of the helical resonator sometimes impedes the practical implementation of the cross-couplings necessary for an improved passband response.[1] Achieving a reasonably high resonator Q-factor (above 1000) is another design challenge.

A five-element UHF band (370 MHz) bandpass filter using helical type resonators has been developed. A relatively high resonator Q-factor of over 1200 allowed a low insertion loss filter even with a relatively small (for this frequency) size housing. In the process of the filter development several approaches were undertaken in order to improve the skirt selectivity by placing additional transmission zeroes on both sides of the passband. All the approaches were modeled with an Eagleware circuit simulator and experimentally tested. In this article, the circuit models and the theoretical and experimental response characteristics of the filter are presented.

Fig. 1 A helical resonator.



HIGH Q HELICAL RESONATOR EXPERIMENTAL DEVELOPMENT

The structure of the helical resonator is shown in ***Figure 1***. The terminology and definitions used for the helical resonator are as follows:

- Resonator diameter, D (center-to-center wire diameter of the loop)
- Conductor diameter, d_0 (diameter of the wire from which the resonator is constructed)
- Pitch, α (wire center-to-center distance between turns)
- Number of turns, n
- Conductor length, L (the overall length of the wire if straightened)
- Resonator height, H
- Square cavity width, B
- Conductor impedance, Z_0

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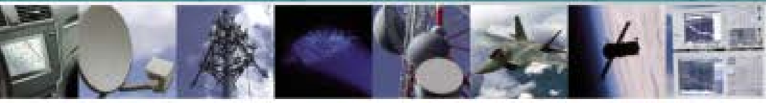
NEW SILICON PRODUCT LINES



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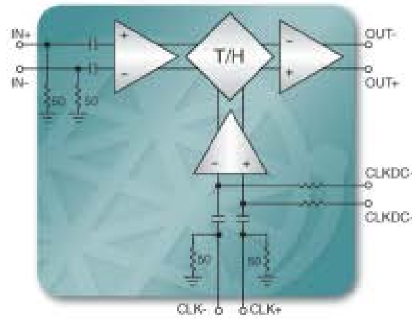
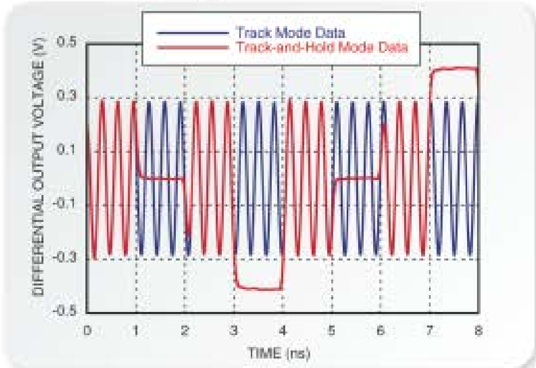
Wideband Track-and-Hold Amplifier



HMC660LC4B

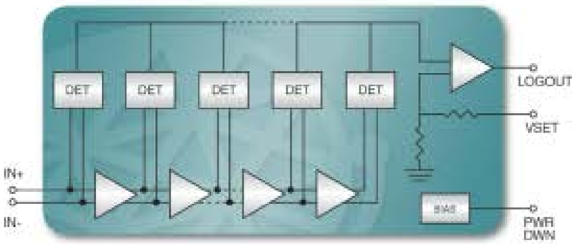
- 4.5 GHz Input Bandwidth (1 Vpp Full Scale)
- Single Tone THD/SFDR: -66/67 dB
- Maximum Clock Rate: 3 GS/s
- 4x4mm SMT Package

Extends High Speed ADC Performance!



Measured time-domain output waveforms with a 3.125 GHz sinewave input signal sampled at 500 MS/s

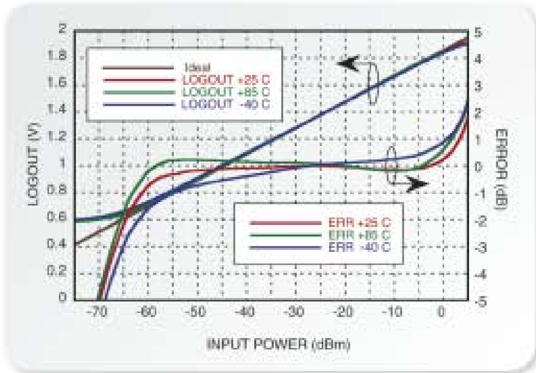
Logarithmic Power Detector / Controller



HMC600LP4

- 50 - 4000 MHz Wide Bandwidth
- Wide Dynamic Range: >70 dB
- Excellent Stability vs. Temperature
- 4x4mm SMT Package

Ideal for AGC & RSSI Applications!



Output Voltage and RSSI Error as a function of Input Power & Temperature (at 3.3 VDC) measured at 900 MHz

13 Product Lines Covering RF, Microwave & Millimeterwave Applications

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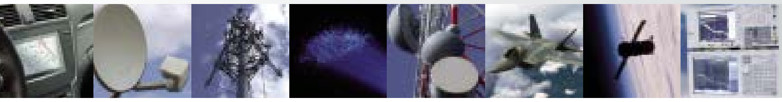

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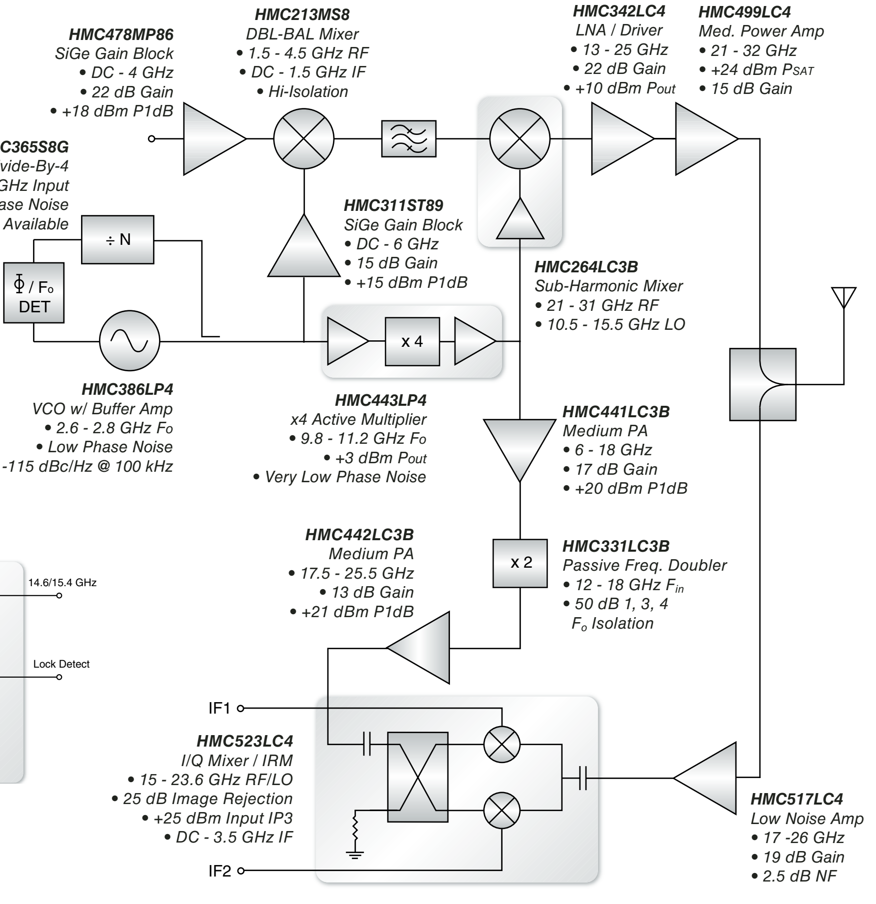
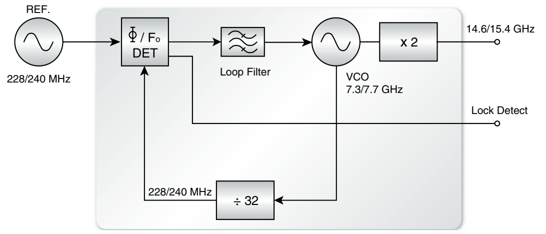
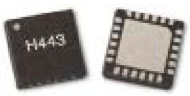
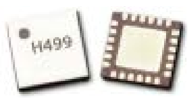






All SMT products are available in RoHS compliant packages.



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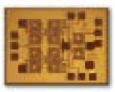
MT SOLUTIONS COVERING 7 TO 38 GHz!

A SELECTION OF HITTITE TRANSCEIVER COMPONENTS FOR STANDARD MICROWAVE RADIO BANDS

Function	7 / 8 GHz	11 GHz	13 GHz	15 GHz	18 GHz	23 GHz	26 GHz	28 GHz	32 / 38 GHz
LNA	HMC564 HMC564LC4 HMC565 HMC565LC5	HMC516LC5 HMC564 HMC564LC4 HMC565 HMC565LC5	HMC516LC5 HMC565 HMC565LC5	HMC516LC5 HMC565 HMC565LC5	HMC517LC4 HMC565 HMC565LC5	HMC341LC3B HMC517LC4	HMC341LC3B HMC517LC4	HMC341LC3B HMC518	HMC263 HMC566
Driver Amplifier	HMC441LP3 HMC451LC3 HMC516LC5	HMC441LP3 HMC451LC3 HMC516LC5	HMC441LC3B HMC451LC3 HMC490LP5	HMC441LC3B HMC451LC3 HMC490LP5	HMC383LC4 HMC442LC3B HMC498LC4	HMC383LC4 HMC442LC3B HMC498LC4	HMC383LC4 HMC283LM1 HMC499LC4	HMC383LC4 HMC283LM1 HMC499LC4	HMC283LM1 HMC300LM1 HMC383LC4
Power Amplifier	HMC486LP5	HMC487LP5	HMC489LP5	HMC489LP5	HMC498LC4	HMC498LC4	HMC499LC4	HMC499LC4	HMC283LM1
Attenuator: Analog	HMC346LP3	HMC346LP3	HMC346LP3	HMC346LC3B	HMC346LC3B				
Divide-by-2	HMC361S8G	HMC364S8G	HMC492LP3	HMC492LP3	HMC492LP3				
Divide-by-4	HMC362S8G	HMC365S8G	HMC493LP3	HMC493LP3	HMC447LC3	HMC447LC3	HMC447LC3		
Divide-by-8	HMC363S8G	HMC363S8G	HMC494LP3	HMC494LP3					
Multiplier: Active X2	HMC368LP4 HMC575LP4	HMC368LP4 HMC573LC3B	HMC368LP4 HMC573LC3B	HMC368LP4 HMC573LC3B	HMC448LC3B HMC576 HMC576LC3B	HMC448LC3B HMC576 HMC576LC3B	HMC448LC3B HMC578 HMC578LC3B	HMC449LC3B HMC577LC4B HMC578LC3B	HMC449LC3B HMC578LC3B HMC579
Multiplier: Active X4		HMC443LP4	HMC370LP4	HMC370LP4					
Multiplier: Passive X2	HMC189MS8	HMC189MS8	HMC204MS8G	HMC204MS8G	HMC204MS8G	HMC205	HMC205	HMC331	HMC331
I/Q Receiver	HMC567LC5	HMC568LC5	HMC569LC5	HMC570 HMC570LC5	HMC571 HMC571LC5	HMC572 HMC572LC5	HMC572 HMC572LC5		
I/Q Mixer / IRM	HMC520LC4 HMC525LC4	HMC521LC4 HMC527LC4	HMC521LC4 HMC527LC4	HMC522LC4 HMC528LC4	HMC523LC4	HMC523LC4	HMC524LC4	HMC524LC4	HMC404 HMC524 HMC555 HMC556
Mixer: Fundamental	HMC129LC4 HMC144LC4 HMC219MS8 HMC220MS8	HMC144LC4 HMC411MS8G HMC412MS8G	HMC144LC4 HMC411MS8G HMC412MS8G	HMC144LC4 HMC260LC3B HMC412MS8G	HMC144LC4 HMC260LC3B HMC292LC3B	HMC260LC3B HMC292LC3B	HMC292LC3B HMC329LC3B	HMC292LC3B HMC329LC3B	HMC294 HMC329LM3
Mixer: Sub-Harmonic				HMC258LM3	HMC258LM3	HMC264LC3B	HMC264LC3B	HMC265LM3	HMC338 HMC339
Switch	HMC547LP3	HMC547LP3	HMC547LP3	HHMC547LP3	HMC547LP3				
VCO & PLO: *Requires X2 or X4	HMC466LP4 HMC505LP4 HMC506LP4 HMC532LP4 HMC587LC4B	HMC513LP4 HMC515LP5 HMC588LC4B	HMC513LP4 HMC529LP4	HMC529LP4 HMC531LP5	HMC429LP4	HMC431LP4	HMC515LP5	HMC531LP5	HMC505LP4 HMC512LP4



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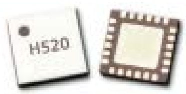

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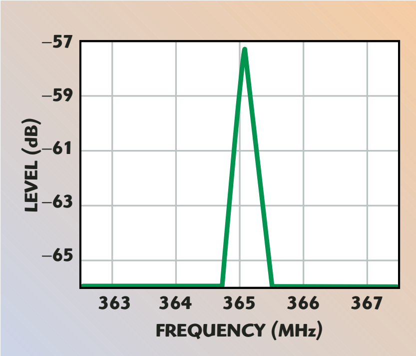
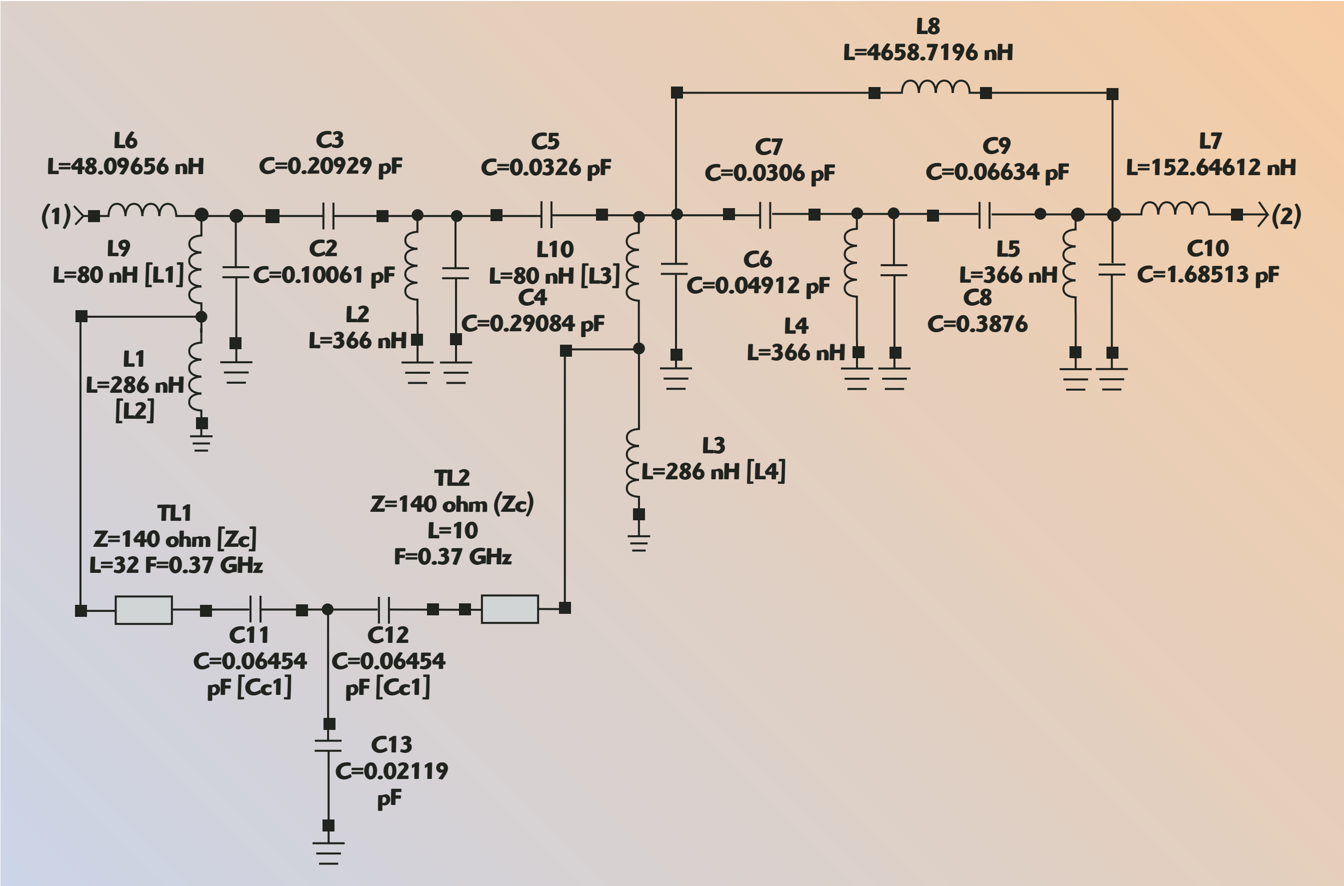


▲ *Fig. 2 Single resonator response, Q-factor measurement.*

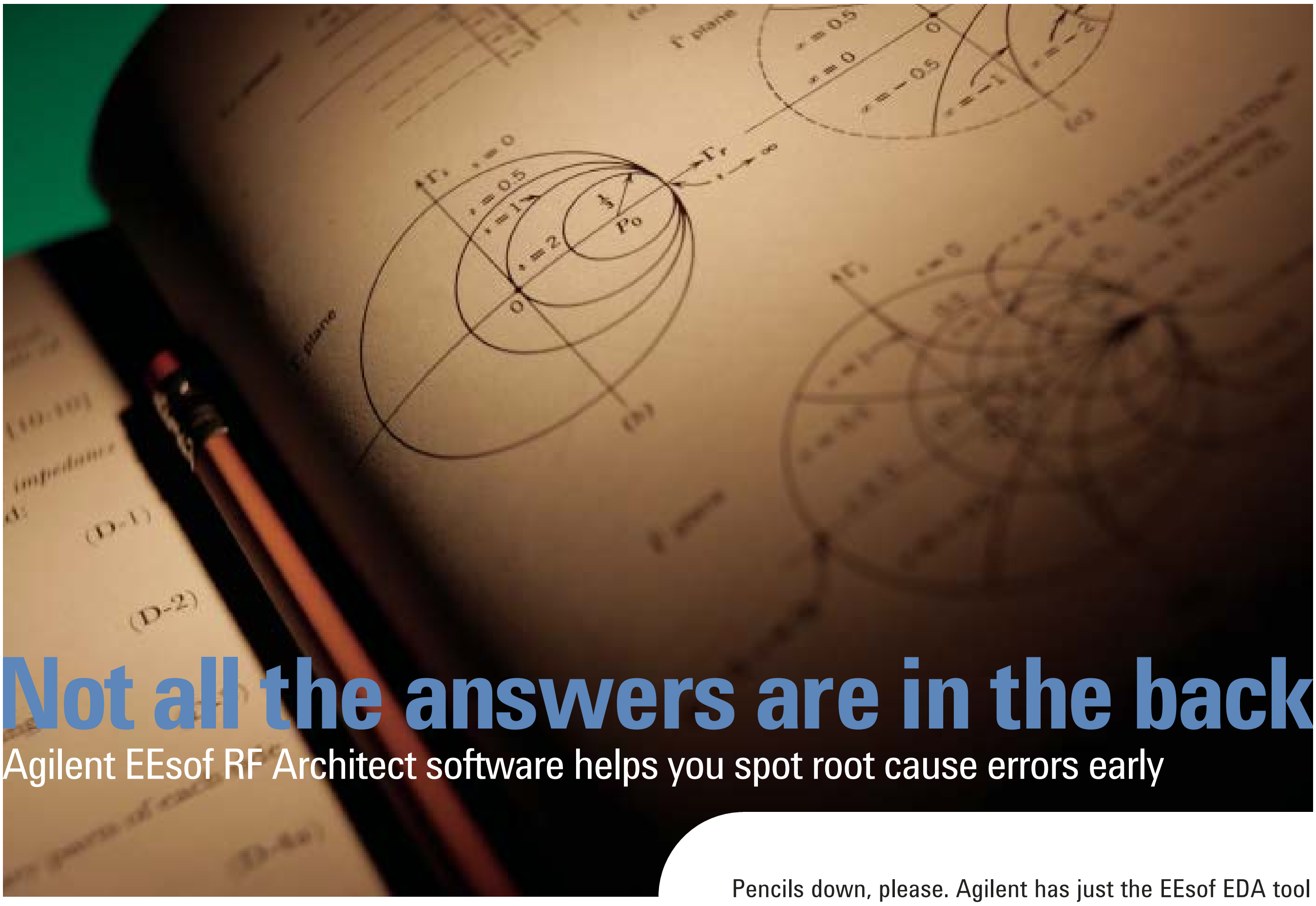
The development and investigation of the frequency and Q-factor of a single helical resonator were chosen based on experimental results rather than on well-known formulas.[2] A few resonators made of various copper conductor diameters and having D of approximately 0.75" and α of approximately 0.32" were tested inside a rectangular silver-plated test cavity of 1.5" × 1.5" × 1.7", determined by the overall filter size requirement. A (approximately) four-turn helix resonated in the desired frequency range. The unloaded Q-factor, measured with less than –50 dB coupling, demonstrated some improvement with increasing conductor diameter. In particular, resonators with conductor diameter d_0 = 0.1", 0.141" and 0.185" gave Qs of 1025, 1121 and 1250, respectively, as shown in ***Figure 2*** for the latter. A tuning screw at the top of the cavity has a significant effect on the resonant frequency, decreasing it (as with the TEM combline resonator), and also degrading the Q-factor. It should be mentioned that firm grounding of the resonator greatly improves the Q-factor.

It was found, that in spite of the fact that a helical resonator is a quarter-wavelength type resonator,[2] due to the inter-capacitance between turns, its actual electrical length, determined by the physical length of the conductor, is about 100° to 115°, and depends on the pitch and the diameters D and d_0. Further conductor diameter increase was deemed unnecessary because of two factors, the physical difficulty of bending the conductor to the given diameter D and, more importantly, the insignificant Q improvement that could be achieved. Since the conductor diameter determines both the current density and the transmission line impedance Z_0 (which is usually greater than 100 Ω[2]), an increase in d_0 will reduce both the current density (losses) over the conductor circumference and Z_0. The decrease in Z_0 will cause a conductor current increase (as well as losses), so assuming that the Q-factor is mainly determined by losses in the wire, the Q-factor as a function of d_0 has a maximum point at a certain conductor diameter for a given cavity size. Based on the experimental results, it is safe to say that a conductor diameter of 0.185" provides a nearly maximum Q-factor for the cavity used.

It is interesting to compare the Q-factor measured experimentally with the empirical relation known in the literature. For the helical resonator dimensional ratios shown, where H = 1.16", and falling within the limits set in Reference 2



▲ *Fig. 3 Initial circuit model.*



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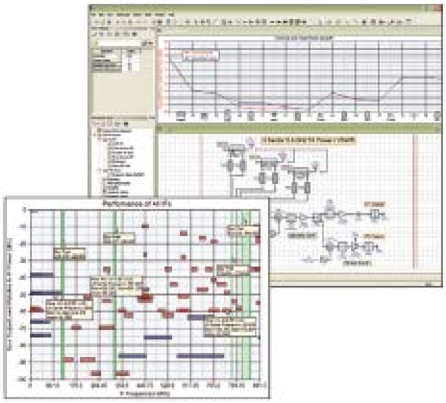

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$$1.0 < (H/D = 1.55) < 4.0$$
$$0.45 < (1.2\ D/B = 0.6) \le 0.6$$
$$0.4 < (d_0/\alpha = 0.58) < 0.6$$
$$\alpha < D/2 \quad (1)$$

The theoretical Q-factor is

$$Q = 60\ B\sqrt{f_0(\text{MHz})} = 1719 \quad (2)$$

and according to formulas of Reference 3

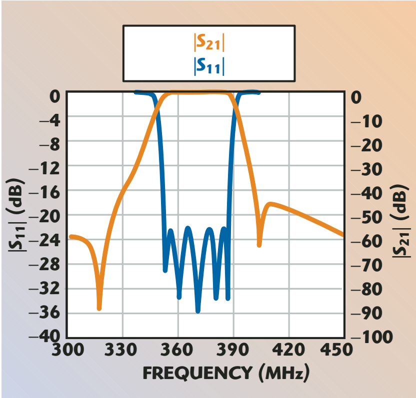
$$Q = 88 \bullet 2.54 \bullet D/2 \bullet \sqrt{f_0(\text{MHz})} = 1601 \quad (3)$$

$$Q = 44 \bullet 2.54 \bullet B/2 \bullet \sqrt{f_0(\text{MHz})} = 1601 \quad (4)$$

which is higher than the measured value. In any case, it is prudent for engineers to start the development of a helical resonator-based filter with an experimental investigation of a single helical resonator for both Q and frequency consideration.

CIRCUIT MODELING, PROTOTYPE DEVELOPMENT AND COUPLING MECHANISM

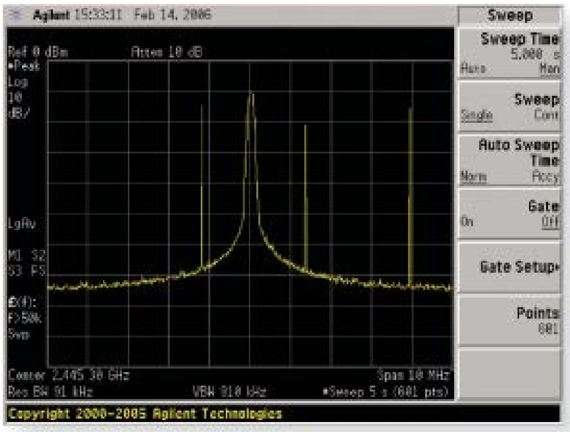
The initial circuit model and response of the five-element helical resonator filter with two triplet cross-couplings are shown in ***Figures 3*** and ***4***. The initial circuit model was based on the widely accepted representation of a helical resonator filter as a number of capacitively coupled L/C loops.[2] At this point, it is assumed that the capacitive coupling results in an asymmetric passband re-



▲ *Fig. 4 Initial circuit response.*

▲ *Fig. 5 Capacitive cross-coupling.*

▲ *Fig. 6 Helical resonator filter with capacitive (through-the-opening) cross-coupling and a trap resonator.*



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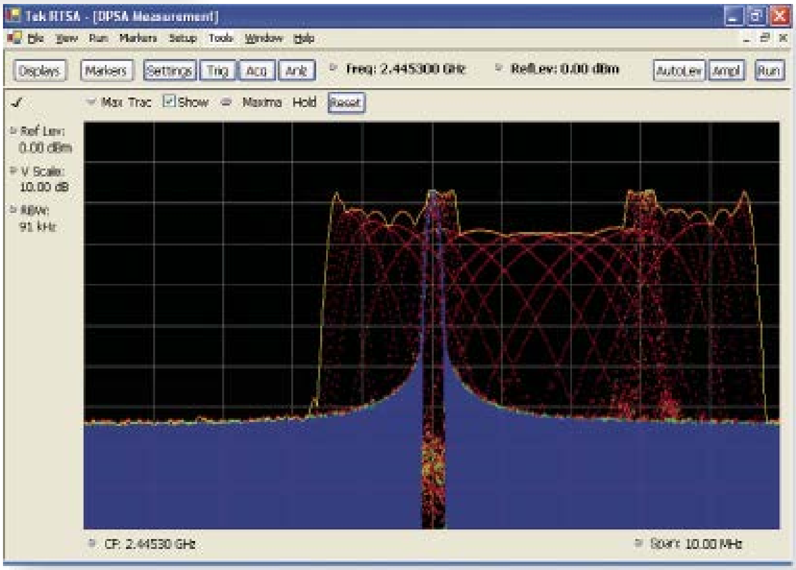

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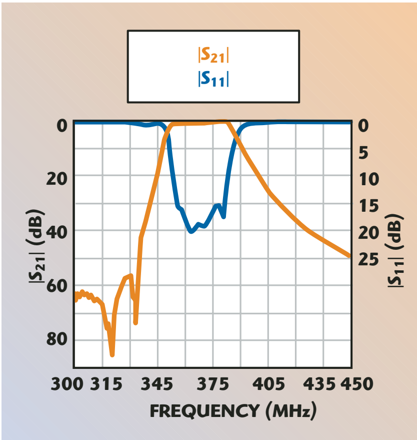
sponse of the helical resonator filter with a non-abrupt high side skirt. The same type of theoretical response could be obtained with shunt inductances as a coupling means between L/C loops. This model allows the coupling coefficients between resonators as well as external Q-factors of the input/output resonators to be determined. A more detailed assessment of the coupling between helical resonators based on both experimental results and EM simulation will be given below. The inductive elements of each loop shown in the model correspond to an almost quarter-wavelength resonator at the center passband frequency. The capacitive cross-coupling delivering a low side real frequency[1] transmission zero (TZ) is modeled as a "real world" lumped capacitive element connected to the first and third filter elements by wires of a certain electrical length (high impedance transmission lines), directly tapped to the resonators, as shown in ***Figure 5***. It seems to be the only way to realize capacitive cross-coupling in the case of the in-line resonator topology (electrically non-adjacent resonators). Due to the fact that each helical resonator has a close to 90° electrical length, its resonant frequency is very sensitive to a small capacitive load change at the top, which makes it impossible to attach the wires at the top of the resonators to be cross-coupled as well as using wires of lower impedance for this purpose. Violation of both requirements results in a severe resonator detuning, which was demonstrated experimentally. It should be noted that a triplet requires rather strong cross-coupling value in order to deliver a transmission zero (TZ) close to the passband.[1] Another option for the cross-coupling implementation is a direct opening between the third and fifth resonators configured as a meander. Surprisingly, a full height opening, as shown in ***Figure 6***, resulted in a real frequency TZ on the low side of the passband. Further investigation, based on the HFSS 3D simulation, revealed that capacitive coupling dominates the full height iris opening between two helical resonators. ***Figure 7*** shows a five-element helical resonator filter prototype response with two capacitively cross-coupled triplets, implemented with both a lumped capacitive element between resonators 1 and 3 and through an iris opening (quasi-static electrical field



▲ *Fig. 7 Response of a five-element helical resonator filter with two capacitive cross-coupling triplets.*

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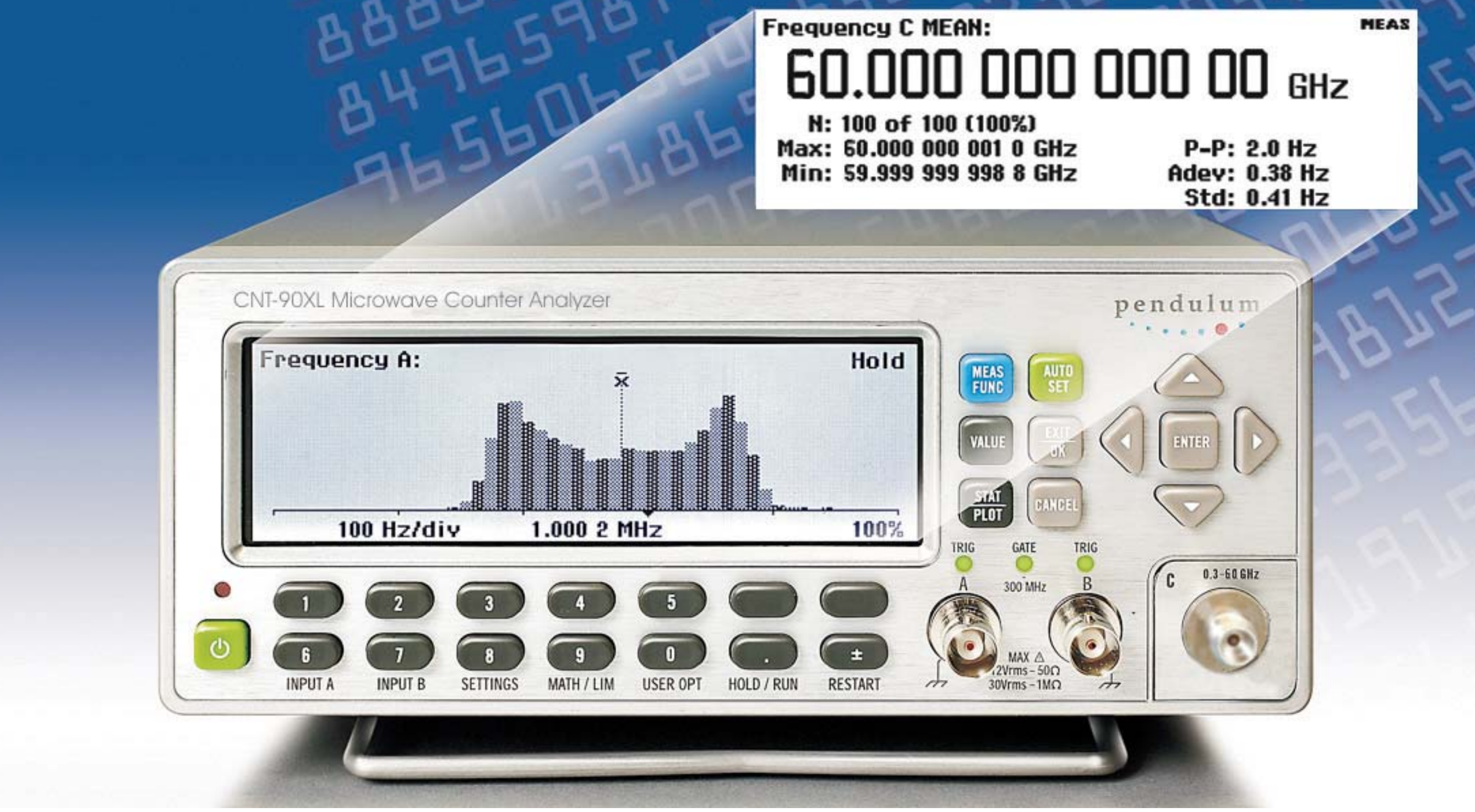

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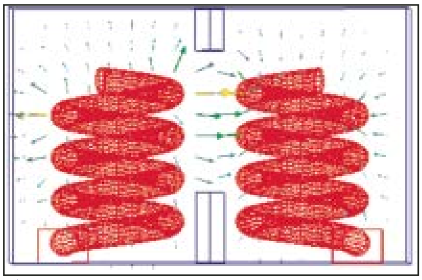
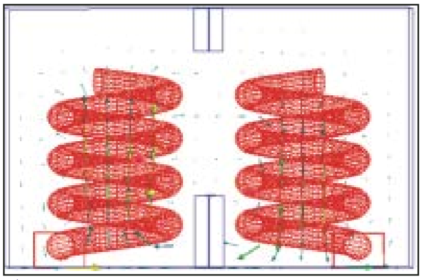
coupling) between resonators 3 and 5. ***Figure 8*** illustrates the electrical field between two resonators, simulated with HFSS. The electrical field is shown to be strong in the space between the resonators, increasing towards the top. It is interesting to mention that the vertical tuning screws shown between helical resonators decrease the electrical coupling as in combline filters.[4] ***Figure 9*** shows the HFSS simulated magnetic field between two resonators. The magnetic field lines are mainly concentrated inside the resonators with increased density at the bottom. The outside magnetic field between resonators is weak and provides minimal coupling, which was also proved experimentally. In particular, any attempts to deliver magnetic coupling and, as a result, a right side TZ, via a bottom iris opening[2] or via a phase reversing magnetic loop, did not succeed due to the insufficiency of the magnetic field outside the resonator, even at the bottom, and a stronger cross-coupling required for the triplet.[1] This observation questions the possibility of the quasi-static magnetic (inductive) coupling between two helical resonators in general. A solution for the inductive cross-coupling as well as proof of the latter statement can be found in Yu and Dokas.[5] The eight-element filter described employs a folded structure with two cross-coupling delivering enhanced skirt selectivity (two TZ on each side of the passband) with a flattened group delay response. A direct wire coupling between resonators 2 and 7 delivers the necessary inductive coupling, which produces pairs of real frequency and equalization transmission zeroes, while a slight capacitive coupling between resonators 1 and 8 (iris opening at the top) contributes to the additional real frequency TZ on each side of the passband. The circuit analysis performed for the topology presented in Yu and Dokas[5] proved the fact that such a response is possible only with a 270° phase shift (capacitive coupling) between main path resonators.

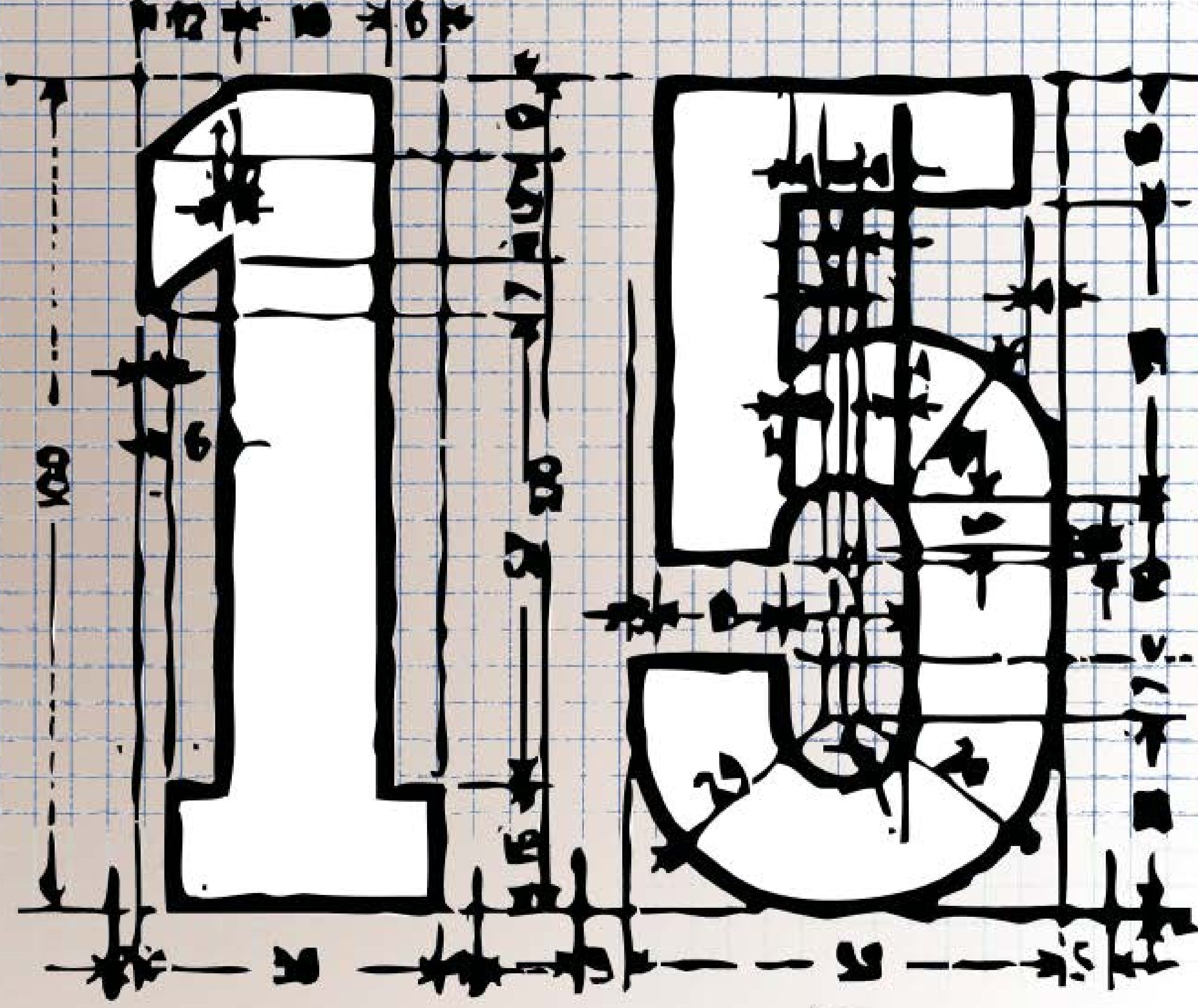
Figures 10 and ***11*** illustrate the circuit model and theoretical response for the inductive wire coupling approach. Shown in ***Figures 12***

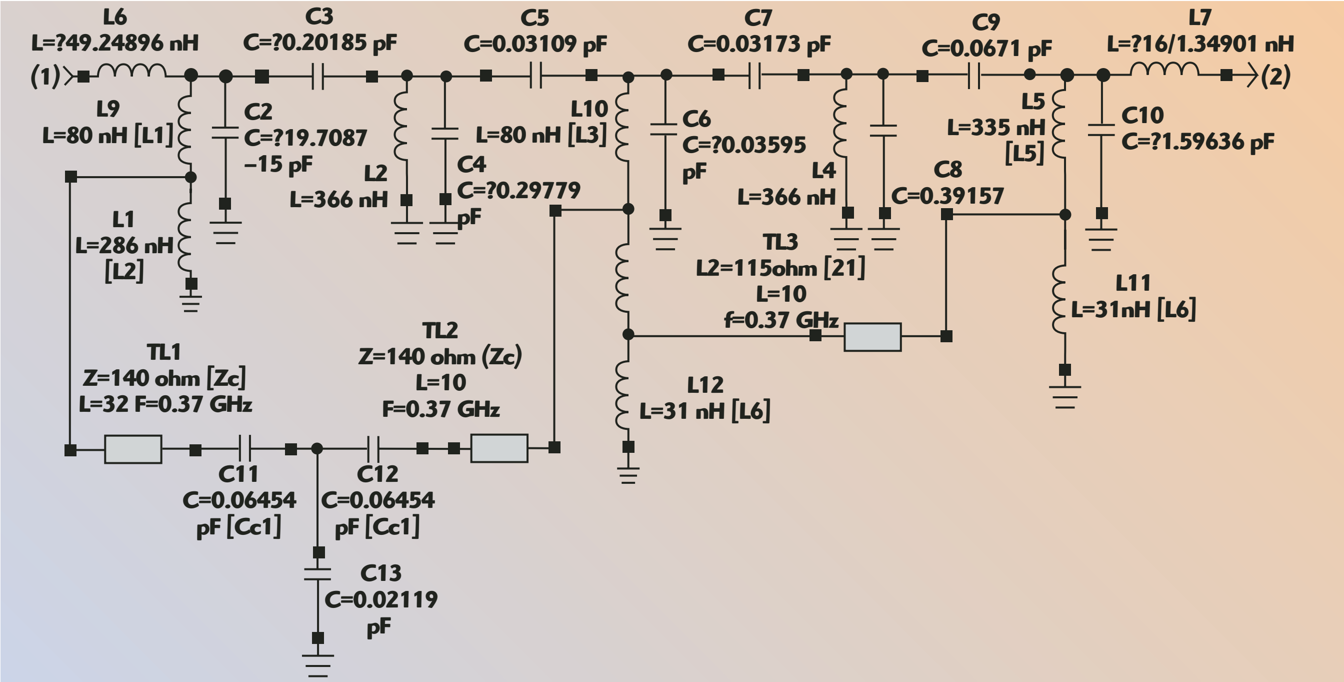


▲ *Fig. 8 Electrical field between the resonators (HFSS simulation).*

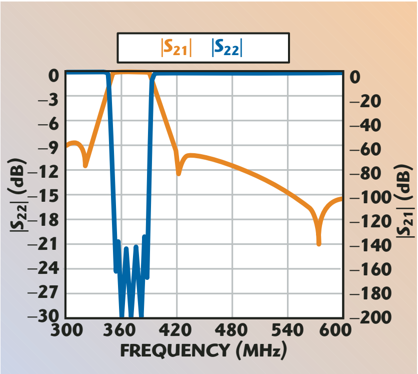


▲ *Fig. 9 Magnetic field between the resonators (HFSS simulation).*



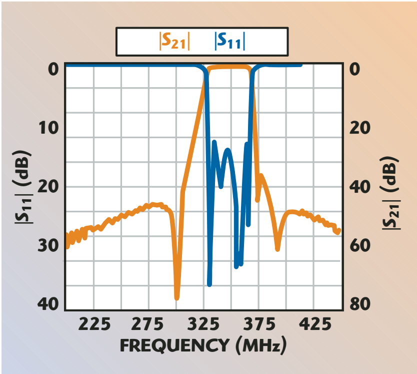


▲ *Fig. 10 Circuit model with wire cross-coupling.*

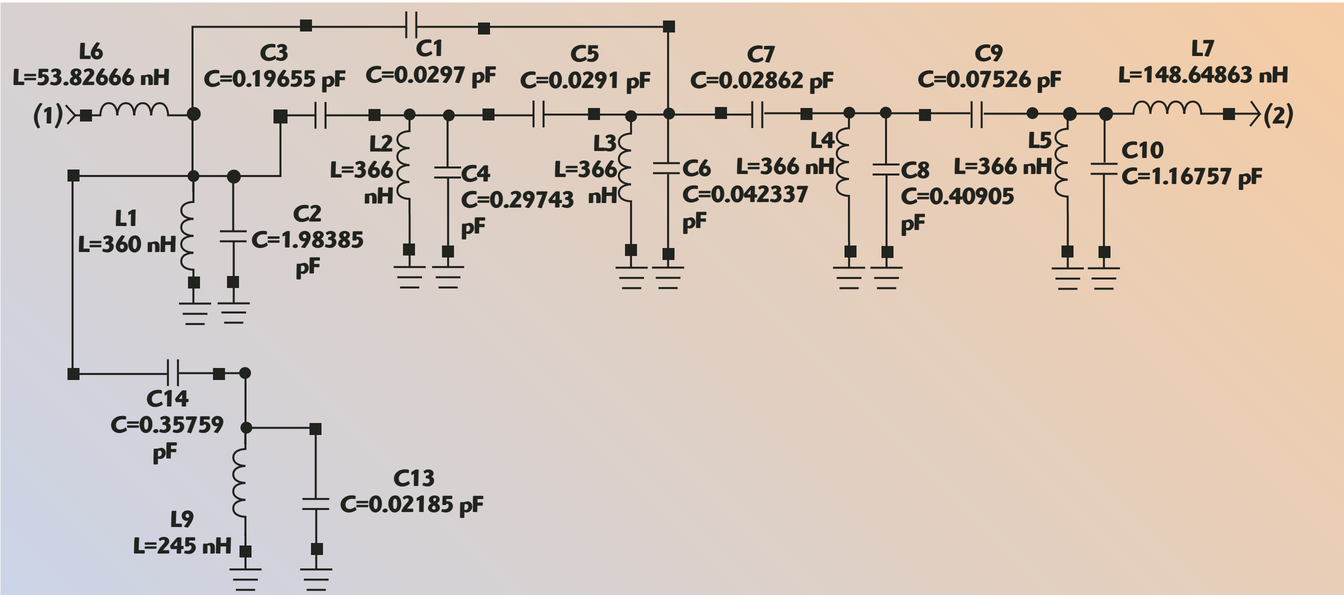


▲ *Fig. 11 Theoretical response of the circuit with inductive wire cross-coupling.*

▲ *Fig. 12 Filter with 3rd and 5th resonators inductively coupled with wire and capacitively coupled resonators 1 and 3.*



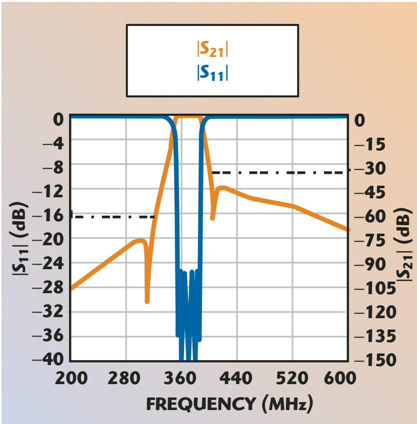
▲ *Fig. 13 Filter response with both capacitive and inductive cross-coupling.*



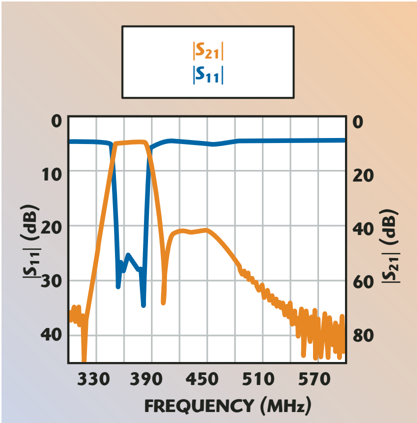
▲ *Fig. 14 Filter circuit model with the trap resonator.*

and **13** are a photograph and the response of the prototype unit with the third and fifth resonators inductively coupled by the wire in addition to capacitively coupled resonators 1 and 3. Both TZs on the higher frequency side are contributed by the cross-coupling inductive wire. The first high side TZ is determined by the inductive triplet cross-coupling[1] and the second, far out of band TZ seen on both simulated and prototype responses, is caused by the resonance properties of the wire, directly related to the wire length and tap points on the coupled resonators. Obviously, due to the resonant properties of the coupling wire by itself, the phase of the cross-coupled path gains an increased phase slope (dΨ/df), which results in the additional out-of-phase condition met on the skirt.[1] It should be mentioned that tuning of a filter with direct wired cross-coupled triplet is rather complex, sometimes resulting in erratic moves of both high side TZs from out-of-band to inside the band frequency region. The physical configuration of helical resonators by itself makes adjustment of the wire physical length and tap point difficult.

A more successful approach to placing a high side real frequency TZ was based on the addition of a helical trap resonator coupled to the number 5 resonator. ***Figures 14***, ***15*** and ***16*** show the circuit model, the simulated and prototype responses, respectively. Therefore, in order to deliver a quasi-symmetrical performance with enhanced skirt selectivity on both sides, this approach employs one capacitive through-the-opening triplet cross-coupling (resonators 3 to 5) and a coupled trap resonator. The advantages of such an approach are obvious. First, there is no need for additional parts and soldering joints (lumped capacitance, wires) placed



▲ *Fig. 15 Theoretical response of the circuit with the trap resonator.*



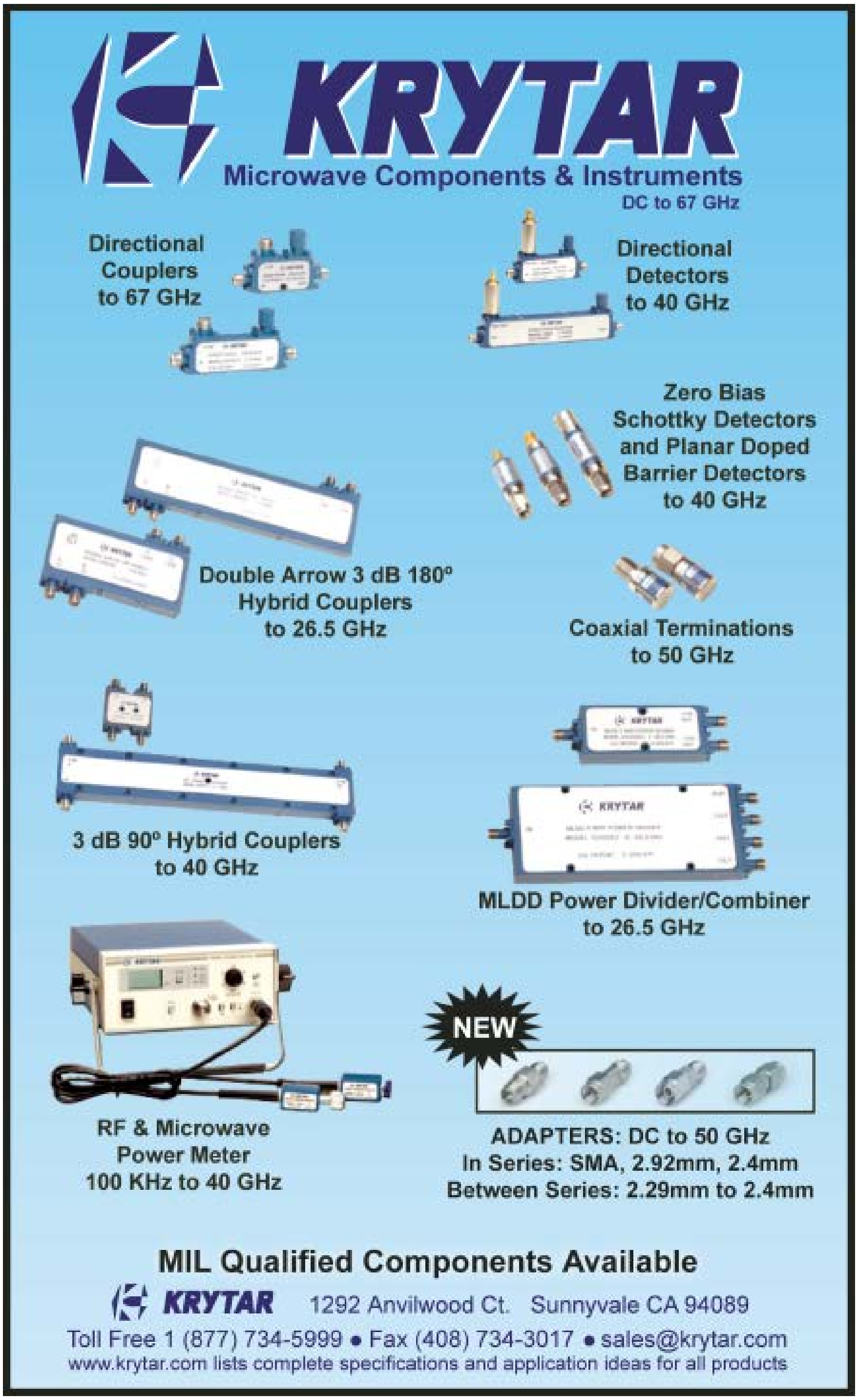
▲ *Fig. 16 Final prototype response.*

TABLE Ia

TWO PATH PHASE SHIFT FOR HELICAL RESONATOR FILTERS WITH VARIOUS CROSS-COUPLING TOPOLOGIES

Topology	Two Path Phase Balance (°)	Phase Difference at the Center Frequency (°)	Resulting TZ and Response
Triplet with capacitive CC: main path	–270 –270 = –540		
cross-coupling path	–270	–90	single left skirt TZ
Triplet with inductive CC: main path	–270 –270 = –540		
cross-coupling path	–90	90	single right skirt TZ

Table 1b on page 74



inside the filter cavity, which also may cause parasitic coupling. Second, the tuning is made easier because the location of the high side TZ is determined by the trap resonator frequency only and not by the out-of-phase conditions between two signal paths. Since the Q-factor of the trap resonator is not a critical parameter, its functional dimensions D and d_0 can be significantly reduced in order to minimize the effect on the overall filter size.

CROSS-COUPLING CONSIDERATIONS IN HELICAL RESONATOR FILTERS AND CONCLUSIONS

Helical resonator-based filters deliver a high output performance in the UHF frequency band with minimized weight/size of the package, if designed with carefully developed maximized Q-factor resonators. The critical dimensions of the helical resonators should be experimentally verified during the prototype stage in a single cavity of predetermined size. The cross-coupling implementation targeting either skirt selectivity enhancement or group delay flattening (or both) involves a phase computation for signal paths.[1,4] Capacitive coupling delivers a 270° phase shift between helical resonators at the center frequency, which makes the implementation aspect of cross-coupling different from the widely used combline and DR-based filters. In particular, in a number of cases, in order to achieve the same cross-coupling effect, for example, for quadruplet (4 to 1) or sextuplet (6 to 1), the coupling between corresponding helical resonators should be inversed (see ***Table 1***) for cross-couplings in a variety of topologies. For the sake of simplicity and best results, the right side skirt selectivity en-

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TABLE Ib

TWO PATH PHASE SHIFT FOR HELICAL RESONATOR FILTERS WITH VARIOUS CROSS-COUPLING TOPOLOGIES

Topology	Two Path Phase Balance (°)	Phase Difference at the Center Frequency (°)	Resulting TZ and Response
Quadruplet with one capacitive CC main path cross-coupling path	3 × –270 = –810 –270	out-of-phase	pair of equalization TZ at the center frequency, flattened GD
Quadruplet with one inductive CC: main path cross-coupling path	3 × –270 = –810 –90	in-phase	two TZ on the right and left skirts
Six-element folded filter with one inductive CC main path cross-coupling path	5 × 270 = –1350 –90	out-of-phase	two TZ on the right and left skirts, pair of equalization TZ at the center frequency, flattened GD

hancement can be achieved with the addition of a single trap resonator coupled to the input or output element. ■

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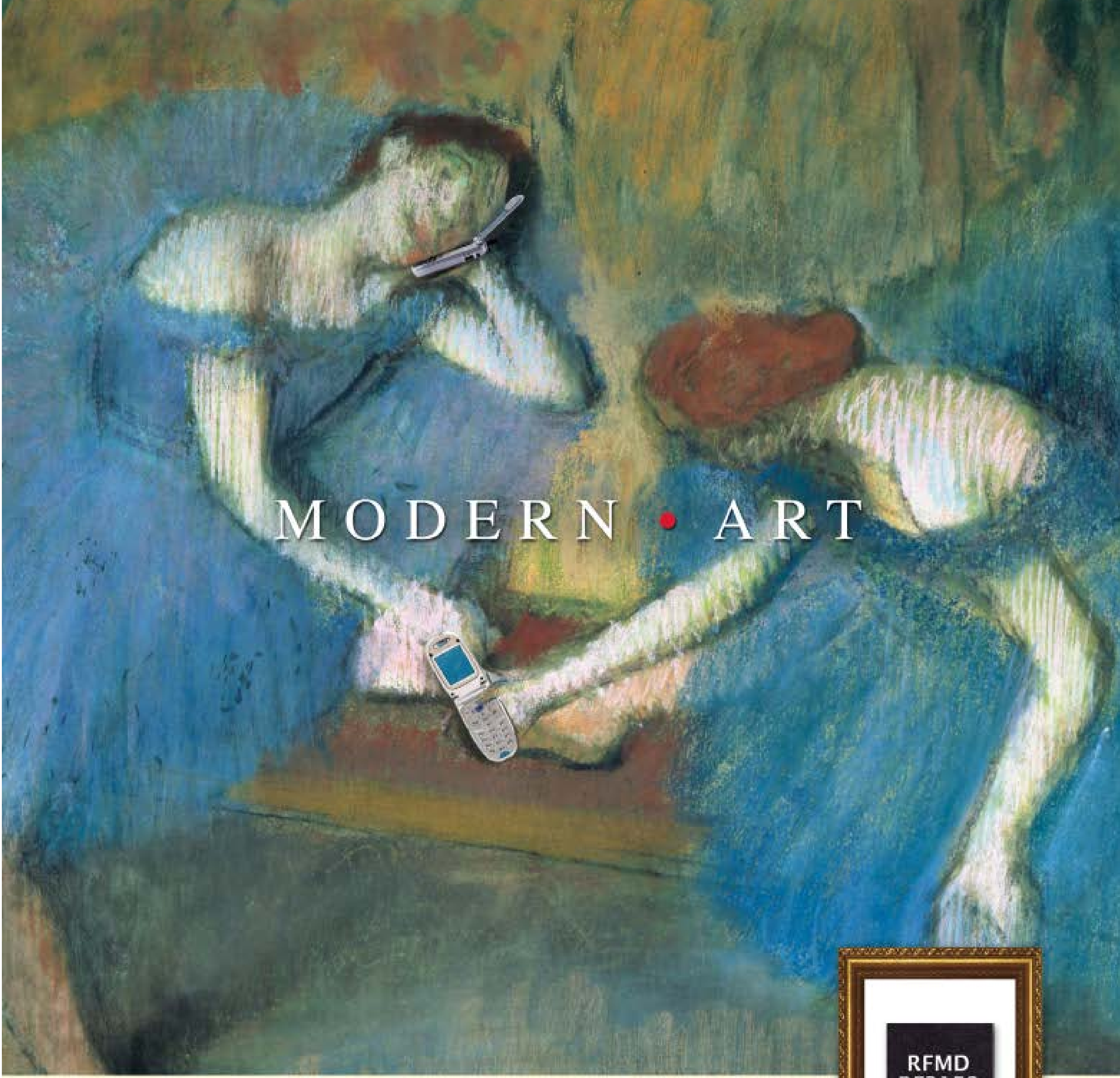

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POWER AMPLIFIER LINEARIZATION USING AN INDIRECT-LEARNING-BASED INVERSE TDNN MODEL

In this article, an effective digital predistortion procedure of data acquisition, analysis, modeling and linearization for high power amplifiers is presented, based on tapped delay neural networks (TDNN). Memory effects of high power RF amplifiers were identified and modeled using baseband signal analysis. The output RF signal of the amplifier was converted down to the baseband in-phase (I) and quadrature (Q) signals, which were sampled for modeling and linearization in the digital domain. Behavioral modeling was carried out using a well-known neural network algorithm including delay taps in order to consider the memory effects of high power amplifiers. Based on the behavioral model of the power amplifier, an indirect learning process for linearization was constructed, using an inverse TDNN model. Compared to the memoryless predistortion process without tapped delay lines, the proposed predistortion method showed an approximately 15 dB better adjacent-channel leakage ratio (ACLR), which was about 60 dBc for a WCDMA downlink signal.

Current research studies are drawing more and more attention on the memory effects of high power amplifier linearization, especially for cellular base transceiver system applications.[1,2] Although many studies on power amplifier linearization have been conducted, linearization of strongly nonlinear systems with large memory, which exacerbates the performance of the linearizer, still gives rise to many challenging issues related to the complex nonlinear distortions caused by the memory.[3–9]

There are two kinds of predistortion techniques: one is based on analog circuits and the other on digital circuits. The analog predistortion methods, when applied to WCDMA systems, have a limited linearization ability (5 to 10 dB) due to their poor flexibility on functional representations and their insufficient capability in the memory effect compensation, while the cost of the circuits is relatively low. Therefore, it has been difficult to make a high power amplifier with an analog predistorter meeting the 3GPP system's linearity specifications.[9] On the other hand, the digital predistortion method has been regarded as a promising candidate for a low cost linearization method, thanks to its more precise compensation capability for the complex nonlinear

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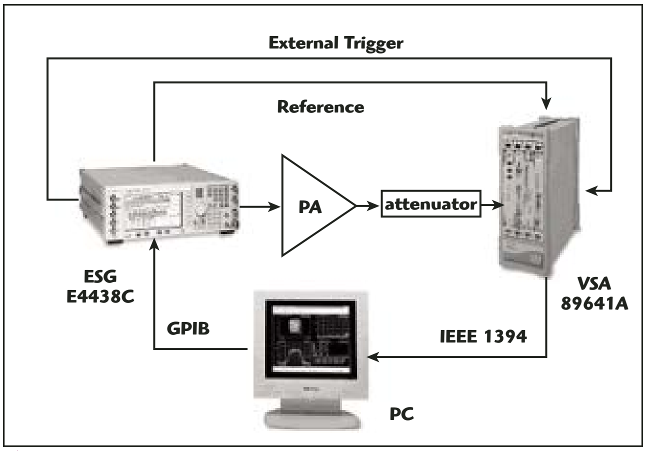
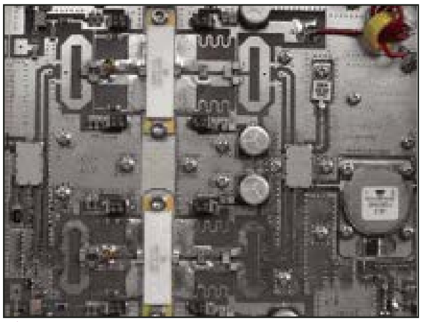


▲ *Fig. 1 Test set-up used to obtain the input and output baseband I/Q signals.*

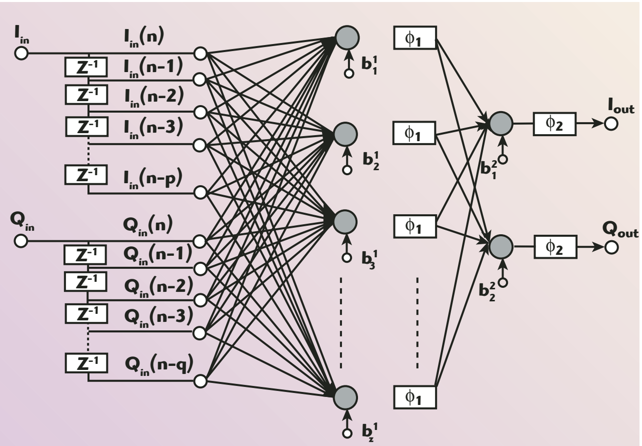
behavior of the high power amplifiers. Furthermore, as the resolution and the sampling speed of analog-to-digital converters (ADC) and digital-to-analog converters (DAC) get higher and faster,[10,11] digital predistortion methods gain greater value for commercial use.

Various behavioral modeling methods for RF power amplifiers have been developed using many different functions or algorithms, such as a Volterra filter, Weiner filter, memory polynomial, auto-correlation and various types of neural networks.[10–20] They have been mainly used for communication system simulation. Recently, researchers have begun to apply artificial neural networks to baseband behavioral modeling of RF high power amplifiers and even to digital predistortion techniques, due to advantages such as the fast nonlinear analysis, high reusability and the versatility for arbitrarily nonlinear systems.[21,22] Since the basic neural network structure is not sufficient to reflect the memory effects in modeling, reinforced neural network methods with delay taps (that is tapped delay neural networks or TDNN) have been introduced.[22] Because the algorithm for digital predistortion requires a very accurate baseband equivalent model for the power amplifier, an exact behavioral model, including memory effects, should be developed as the first step in the power amplifier linearization procedure. Time and effort can be saved if a standardized procedure for the digital predistorter construction is available as well as an outstanding linearization algorithm.



▲ *Fig. 2 The amplifier final stage.*

In this article, an effective linearization procedure is developed, adopting TDNN for accurate behavioral modeling and the linearization process of the power amplifier. An indirect learning process was selected to extract an inverse model of the power amplifier as well, using the same TDNN structure. The inverse TDNN model is directly used as a predistorter for the power amplifier. The linearization results with and without delay taps were compared and analyzed for a downlink WCDMA signal. The validity of the model structure and linearizer was proven by linearization testing, using a downlink CDMA2000 signal.



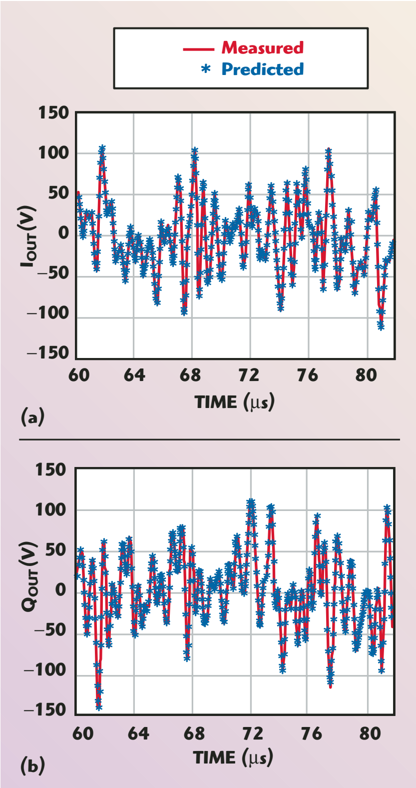
▲ *Fig. 3 TDNN structure of the power amplifier behavioral model.*

HARDWARE SET-UP FOR THE MEASUREMENTS

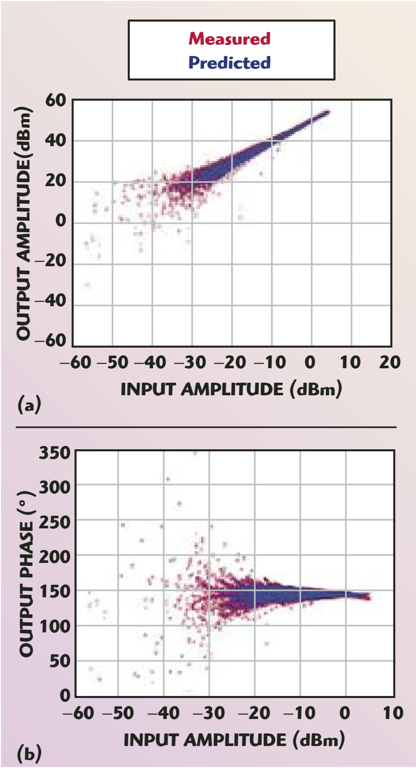
To obtain the dynamic AM-to-AM and AM-to-PM characteristics of the power amplifier, the test set-up shown in ***Figure 1*** was assembled using Agilent Technology's Electronic Signal Generator (ESG) model E4438C, Vector Signal Analyzer (VSA) hardware/software model 89641A and simulation software from Advanced Design Systems (ADS). A WCDMA signal was generated by the ESG and applied to the amplifier under test. After down-converting the output WCDMA signal of the power amplifier, the VSA collected the baseband I and Q signals. The dynamic baseband AM-to-AM and AM-to-PM characteristics can be identified by comparing the output I/Q signals with the input. The ADS digital package controlled the measurement system using GPIB and IEEE-1394 interfaces. The ESG provided an external trigger and reference signals to the VSA for synchronization.[23] The final stage of the power amplifier was implemented to have 340 W-PEP, using a parallel combination of two push-pull amplifiers made of Freescale's 170 W-PEP LDMOSFETs. ***Figure 2*** shows a photograph of the amplifier final stage, including an isolator at the output and bias networks. An MRF9045, 45 W-PEP LDMOSFET drives the final stage. The overall amplifier chain has a power gain of 49 dB and a saturated output power of 54 dBm.

MODELING OF THE POWER AMPLIFIER USING TDNN

The configuration of the real valued TDNN was used and optimized as a modeling method for the power amplifier. Parts of the baseband input and output I and Q signals were used as the training data of the TDNN. ***Figure 3*** shows the specific structure of the TDNN, which has an input layer, a hidden layer, an output layer and delay taps. The output I and Q signals can be expressed using the input I/Q signals, their previous signals having different time delays with multiple taps, and the activation functions. The output I and Q signals are formulated as



▲ *Fig. 4 Measured and predicted I (a) and Q (b) signals versus time.*



▲ *Fig. 5 Measured and predicted AM-to-AM (a) and AM-to-PM (b) characteristics.*

$$I_{out}(n) = \phi_2\left(\sum_{j=1}^{z} w_j^2 \phi_1\left(\sum_{i=0}^{p} w_{ij}^1 I_{in}(n-i) + \sum_{i=0}^{q} w_{ij}^1 Q_{in}(n-i) + b_j^1\right) + b_1^2\right) \quad (1)$$

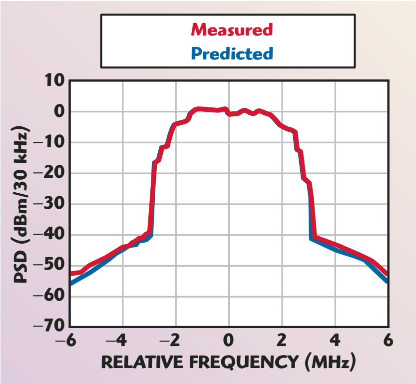
$$Q_{out}(n) = \phi_2\left(\sum_{j=1}^{z} w_j^2 \phi_1\left(\sum_{i=0}^{p} w_{ij}^1 I_{in}(n-i) + \sum_{i=0}^{q} w_{ij}^1 Q_{in}(n-i) + b_j^1\right) + b_2^2\right) \quad (2)$$

where $\phi_1(x)$ and $\phi_2(x)$ are the activation functions, which have the following functional representations in this experiment

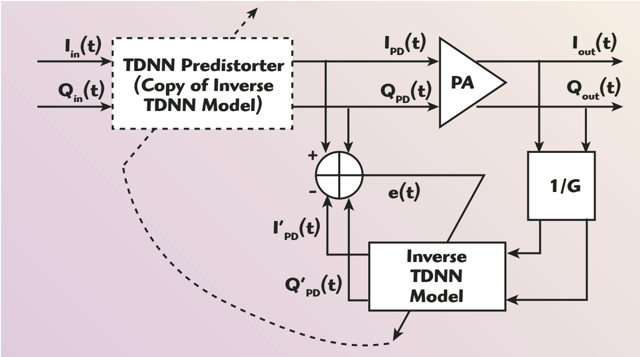
$$\phi_1(x) = \tanh(x) = \frac{1-e^{-2x}}{1+e^{-2x}} \quad (3)$$

$$\phi_2(x) = \begin{cases} 1, & x \geq +\frac{1}{2} \\ x, & +\frac{1}{2} > x - \frac{1}{2} \\ 0, & x \leq -\frac{1}{2} \end{cases} \quad (4)$$

The nonlinear characteristics of the power amplifier, that is AM-to-AM and AM-to-PM, were initially modeled using memory-less neural networks (without tapped delay lines). Subsequently, the tapped delay lines were added one by one to accurately model the nonlinear behavior of the power amplifier with memory effects. The training process adopts the well-known back-propagation algorithm, which minimizes the mean square error of the training data sets as the epochs increase. The number of delay taps for the I and Q signal paths were sequentially increased and the optimum number of taps was determined to be five. When the number of delay taps exceeds five, the modeling results improve only marginally despite a drastic increase in computational load. In similar fashion, five input neurons and two output neurons were selected in this experiment. The number of layers was optimized in the same way. Because the multi-layer structure did not exhibit much better performance than



▲ *Fig. 6 Measured and predicted power spectral densities.*



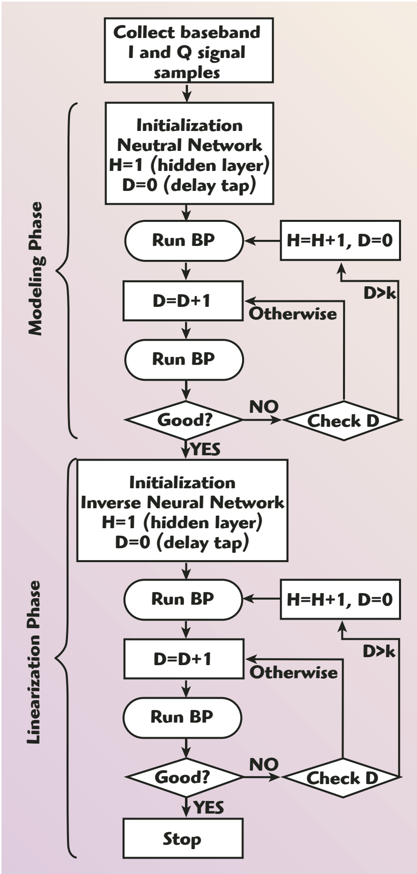
▲ *Fig. 7 Diagram of the digital predistortion scheme using an inverse TDNN modeling based on the indirect learning process.*

the simple single-layer structure, a very simple single-layer structure was chosen. Ten thousand samples of data were used for the training and 1000 epochs of simulation were conducted for one training event. After the training session, the model was tested with another 80,000 samples to see if the model predicts the nonlinear behavior of the amplifier well enough. The time-domain signals for the 80,000 measured samples and the predicted samples using the model are compared in ***Figure 4***. ***Figure 5*** also shows the dynamic AM-to-AM (a) and AM-to-PM (b) characteristics for the measured and predicted samples. An almost exact match between the measured and predicted data is demonstrated.

In particular, a significant scattering of the measured data due to memory effects can be seen, but the TDNN-based behavioral model tracks those variations well. The predicted power spectral density (PSD) matches well with the measured results, as shown in ***Figure 6***. A slight mismatch in the spectral level could be observed, not because of inaccuracy of the model but because of a long-term memory effect possibly caused by a thermal accumulation or other environmental deviation during the measurements. Hence, the outstanding capability to model the nonlinear behavior of the power amplifiers in the presence of considerable memory effects is validated using the TDNN structure.

PREDISTORTION PROCEDURE WITH AN INVERSE TDNN MODEL

As with behavioral modeling, inverse training using a TDNN structure was performed to build a linearizer. The output I/Q signals of the power amplifier model, after extracting the linear gain of the amplifier, are used for



▲ *Fig. 8 Flow chart for the modeling and linearization procedure.*

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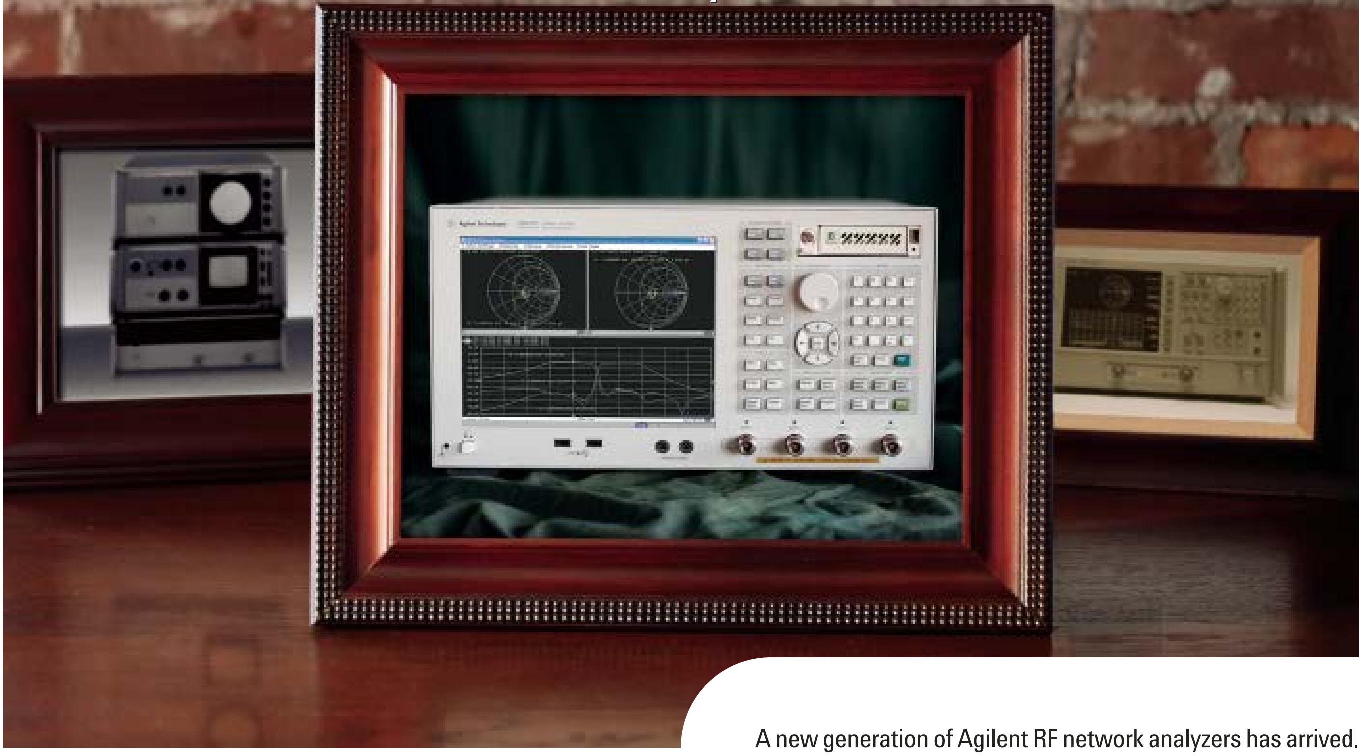

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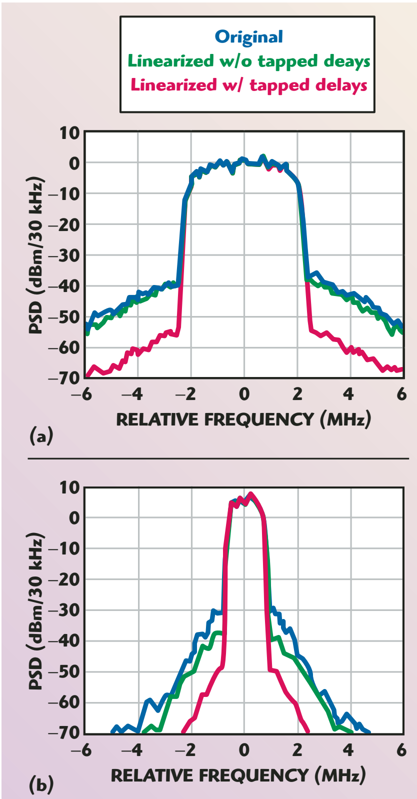
the TDNN as the input I/Q data of the inverse model. The inverse TDNN model is also trained to minimize the mean square error between the output and the input data of the power amplifier. The well-trained neural network is copied to the front of the power amplifier in order to pre-distort the I/Q signals and eventually linearize the power amplifier. This procedure is called indirect learning.[24] It is presented schematically in ***Figure 7***. The overall modeling and linearization procedures are summarized in the flow chart shown in ***Figure 8***. Using parts of the measured baseband I and Q signal samples, a neural network is initially set up with one hidden layer and no delay tap, and then a back propagation algorithm, abbreviated as BP in the flow chart, is run to extract the initial parameters of the model. After the initial run, one delay tap is added and the BP run again. This routine is repeated until very good modeling results are obtained or the number of iterations becomes more than an arbitrary constant k (five in these experiments). If the number of iterations becomes greater than k, the number of hidden layers is increased. The modeling routine ends and the linearization phase starts when a good modeling result is obtained; that is a good match between the measured and modeled data.

A very similar procedure is performed to optimize the inverse TDNN model as a predistorter, shown in the lower part of the chart. Five delay taps, five input neurons and two output neurons were used for the training, which is the same as with the power amplifier modeling. The training was continued for 1000 epochs. To validate the training process, 80,000 samples of the baseband I/Q signals were applied to the trained neural network. In order to verify the superior performance of the TDNN, the same indirect learning procedure was conducted with the conventional neural network without delay taps, which does not have the ability to compensate for nonlinearities associated with memory effects. PSDs using the neural network predistorters with and without delay taps are plotted and compared to each other in ***Figure 9***. For a downlink WCDMA signal, more than 15 dB compensation is observed for the tapped delay neural network predistortion, while only 2 to 3 dB is observed for the neural network predistortion without delay tap. About 65 dBc of ACLR was achieved at 5 MHz offset. For a CDMA2000 signal, the improvements were approximately 20 dB and less than 10 dB, with and without tapped delay lines, respectively.

CONCLUSION

The power amplifier behavioral model, using an artificial tapped delay neural network, was built to effectively predict the complex nonlinear behavior of the power amplifier in the presence of strong memory effects. Using this behavioral model and modeling technique, a digital predistortion linearizer, using an indirect learning process, was developed and tested in order to linearize the 3GPP base station power amplifiers. Overall procedures of modeling and linearization were efficiently organized and described. The systematic flow of linearization, including behavioral modeling, model verification and building of a predistorter using an indirect learning process, were developed. Com-



▲ *Fig. 9 PSDs for the downlink WCDMA (a) and CDMA 2000 (b) signals.*

pared with the linearizer using a conventional neural network, the TDNN-based linearizer showed better results, due to its ability to handle memory effects. When the TDNN predistorter was used, more than 15 dB compensation was obtained for a downlink WCDMA signal. Otherwise, for the predistorter without tapped delay, merely 2 to 3 dB improvements were observed, which verifies that the TDNN predistorter has an excellent performance on the linearization of the high power amplifiers for 3GPP systems and that memory effect compensation is very important for modeling and linearization of power amplifiers. ■

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INTERMODULATION DISTORTION IN MEDIUM-POWER DROP-IN FERRITE ISOLATORS AND CIRCULATORS

One of the major applications for ferrite junction components is in base station amplifiers. Each amplifier module may include several isolators, which typically provide mismatch protection. In the case of the isolator placed between the power amplifier and the antenna, the primary purpose is protection against high levels of reflected power. The form factor of these isolators is a drop-in, in which the large termination chips attached to the isolator base plate are capable of absorbing up to 200 W average power. Situated after the power amplifier, the isolator must handle the full RF power of about 100 W or more. Since each base station amplifier may have several channels, nonlinear distortion will present a problem. Various linearization methods are used to limit distortion in the amplifier, but they do not help reduce distortion in the isolator (except perhaps crest factor reduction). The ferrite materials used in isolators are fairly linear up to a few watts. Above this level, the most significant nonlinear effect is third-order intermodulation distortion (IMD). This is the result of two (or more) signals of different frequencies (F_1 and F_2) interacting in a region with nonlinear transmission properties.[1] The third-order distortion products that may interfere in the receiver pass band are the difference frequencies $2F_1–F_2$ and $2F_2–F_1$. Higher order distortion products are usually several decibels lower in amplitude. If third-order products are reduced, the higher order products should also drop by a similar amount. IMD is measured as the ratio in power levels between the distortion signal and the input signal, in units of dBc. Typical IMD levels for isolators are approximately –80 dBc for two signal tones of 20 W each. Usually ferrite isolators obey the theoretical behavior for varying the input signals, that is, for each 1 dB change of input level, the IMD level changes by 2 dBc.

ANALYSIS

The generation and behavior of distortion signals can be worked out mathematically by assuming that a nonlinear medium causes an output, which can be expressed as a power series

$$V_{out} = aV_{in} + b(V_{in})^2 + c(V_{in})^3 + d(V_{in})^4 + \ldots \tag{1}$$

where a, b, c and d are constants, V_{in} is the input voltage, which in the case of two input fre-

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quencies is equal to $V_1 \cos(\omega_1 t) + V_2 \cos(\omega_2 t)$. The phase can be ignored for this purpose, and inserting this expression for V_{in} into Equation 1 yields

$$V_{out} = a(V_1 \cos\omega_1 t + V_2 \cos\omega_2 t) + b(V_1 \cos\omega_1 t + V_2 \cos\omega_2 t)^2 + c(V_1 \cos\omega_1 t + V_2 \cos\omega_2 t)^3 + d(V_1 \cos\omega_1 t + V_2 \cos\omega_2 t)^4 + \ldots \quad (2)$$

When the individual terms are multiplied out, the third-order output is given by

$$V_{out3} = (c/4)\left\{V_1^3(3\cos\omega_1 t + \cos 3\omega_1 t) + V_2^3(3\cos\omega_2 t + \cos 3\omega_2 t)\right\} + (3c/2)\left\{V_1V_2^2 \cos\omega_1 t + V_1^2V_2 \cos\omega_2 t\right\} + (3c/4)V_1V_2^2\left\{\cos(\omega_1 + 2\omega_2)t + \cos(\omega_1 - 2\omega_2)t\right\}(3c/4)V_1^2V_2\left\{\cos(2\omega_1 + \omega_2)t + \cos(2\omega_1 - \omega_2)t\right\} \quad (3)$$

Collecting only the difference terms for the third-order intermodulation distortion yields

$$V_{im3} = (3c/4)\left\{V_1V_2^2 \cos(\omega_1 - 2\omega_2)t + V_1^2V_2 \cos(2\omega_1 - \omega_2)t\right\} \quad (4)$$

When the input signals have the same amplitude V

$$V_{im3} = (3c/4)V^3\left\{\cos(\omega_1 - 2\omega_2)t + \cos(2\omega_1 - \omega_2)t\right\} \quad (5)$$

Since the distortion level is proportional to V^3, increasing the input signal by 6 dB will cause an 18 dB increase in the distortion level. Since the desired output signal also increases by 6 dB as a result of the input increasing by 6 dB, the increase in distortion level relative to the output is only 12 dB. Similarly, a 3 dB change in the input power causes the relative distortion power level to change by 6 dB. For example, if two 100 W tones cause IMD levels of 0.001 mW, this is equivalent to a –80 dB ratio between output and input, that is –80 dBc. If the input levels were changed to 50 W, the IMD level would become –86 dBc. Referring to Equation 4, in which the amplitudes are different, a 3 dB change in power level of the higher frequency (F_2) will cause the higher IMD frequency ($2F_2–F_1$) to change by 3 dBc, and the lower IMD frequency to remain at the same relative level with respect to the input.

In practice, there are typically more than two input signals, causing many more intermodulation frequencies.[2] With only four channels, the number of third-order difference frequencies is 12, compared to 2 for the two-channel condition. However, there are 27 three-tone products of the type $F_1+F_2–F_3$. These may have four times the power of the two-tone products. Not all of these will cause interference, of course, but as the number of channels increases, the combination of in-band IMD gives rise to "spectral regrowth."[3] The actual IMD level at any given frequency depends on the instantaneous phase and amplitude of the many individual distortion product frequencies. Since testing with more than two tones requires an expensive test system, a rule-of-thumb conversion may be used to convert two-tone IMD levels to multi-tone IMD levels. For example, eight signals combine to give IMD levels that may be 10 dB worse than for the equivalent two-tone measurements. Measurements tend to confirm that IMD signal levels change by 3 dB (that is 2 dBc) for each 1 dB change of input signal over the normal operating power and temperature ranges. The IMD level can be related to the third-order intercept point (IP_3), where extrapolated lines of drive power (at 1 dB/1 dB) and third-order IMD (at 3 dB/dB) would theoretically meet. To convert from third-order intercept point to IMD values in dBc, the following formula applies on the assumption that the 3 dB/dB law holds sufficiently well

$$IMD = 2[IP_3 - P_{out}] \quad (6)$$

where IP_3 and P_{out} are in dB (dBm or dBW).

CAUSES OF IMD IN FERRITE DEVICES

The theory of operation of junction circulators was established decades ago for above- and below-resonance conditions.[4,5] From these and other considerations, the major

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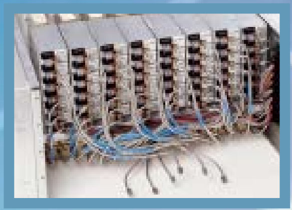

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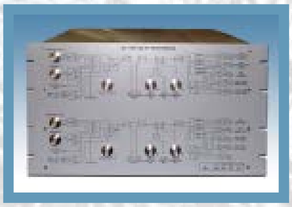

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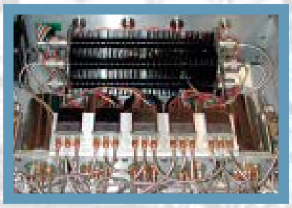

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contributors to ferrite device nonlinearity are:

- **Proximity to Ferrimagnetic Resonance in Above-resonance Devices**[6,7]

The same mechanism that causes circulation in the junction (κ/μ, the ratio of off-diagonal to diagonal elements in the permeability tensor) also causes IMD. To a certain extent, the IMD level can be traded-off against bandwidth. In general, a higher applied magnetic field brings a better IMD performance, as the ferrimagnetic resonance is moved further away from the operating band. This reduces κ/μ and bandwidth, but often reduces the loss and improves the temperature stability of the junction. Material porosity or cracked ferrite also contributes to IMD. Various methods are used to process the ferrite materials to obtain small and uniform particle size to avoid local hotspots. However, there does not appear to be any advantage for IMD in going beyond currently available materials. For similar reasons the applied magnetic field should be as uniform as possible in the ferrite region. The linewidth (ΔH) is not significant for IMD in the above-resonance operation.

- **Excitation of Spin Waves in Below-resonance Devices**[8]

This should not really create problems for IMD because spin waves are avoided for another reason: they cause high losses in the ferrite junction. It can be controlled by selection of junction design parameters, including bias field, ferrite properties such as linewidth (ΔH) and the use of rare-earth doped ferrite material. When not excited, the junction is quite linear. In estimating the spin-wave threshold, allowance must be made for worst-case peak power. If n channels are multiplexed, the CW power of each must be multiplied by n^2 to estimate worst-case peak power (where all voltages add in phase). For CDMA applications, the effective peak power is normally taken as 12 or 13 dB higher than the CW power.

Unlike below-resonance devices, above-resonance devices do not exhibit spin-wave peak power limiting.

- **Junction Design**

Since IMD is strongly affected by the strength of the RF field, methods to minimize fields in the junction should be addressed.

- **Presence of Ferrous Metals**[9]

The hysteresis associated with permeable materials and a nonlinear B-H curve produce IMD. Steel, Invar and (to a lesser extent) nickel are typical offenders. Silver or gold plating over such ferrous-type materials does not resolve the IMD effects due to the RF magnetic fields not being constrained within the plating.

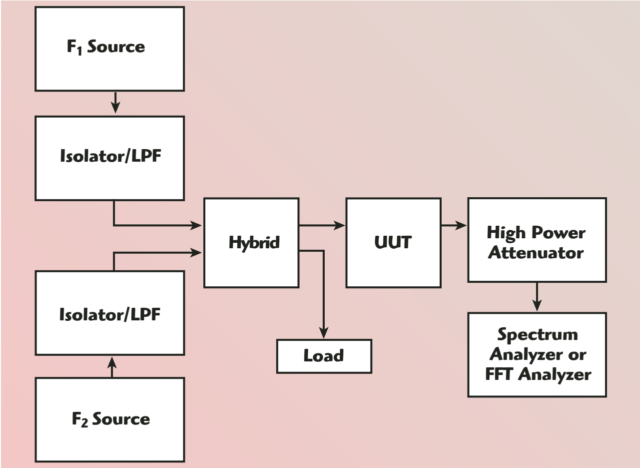
- **Metal Surfaces and Contacts**[10,11]

Metallic junctions that have become oxidized can form inefficient rectifiers. Aluminum is commonly used in microwave components and readily forms oxides that can cause IMD. Also, nonlinear tunneling can be introduced when metal junctions do not have sufficient contact pressure. IMD is produced through the mechanism of "conductivity modulation."

A starting point in the design of isolators is to avoid the assembly methods and materials listed above that cause IMD (other than the inherently nonlinear ferrite material). The remaining parameters that can affect IMD are the ferrite 4πMs, the applied magnetic field, and the circuit size and shape. Isolators can operate over a range of 4πMs values. Selecting higher 4πMs values in turn requires a higher applied magnetic field, and also larger circuit geometry than for a lower applied magnetic field. These parameter relationships are well known, but for good IMD performance the values of these parameters should all be kept as large as possible. Higher Q circuits also produce better IMD, but the exact circuit shape is usually a proprietary matter. Isolators that are designed for best IMD performance will have somewhat less bandwidth and higher insertion loss, compared to isolators designed for high bandwidth and low insertion loss.

IMD TESTING

The simplest IMD test is done with two CW signals, though some specifications call for a more complex setup that mimics IMD performance in the overall system. Generally, results from two-tone measurements can be converted to equivalent multi-tone levels to assure compliance with a multi-channel or spectral regrowth requirement since the physical causality is identical. This allows the component manufacturer to keep a



▲ *Fig. 1 F_1 and F_2 common feed.*

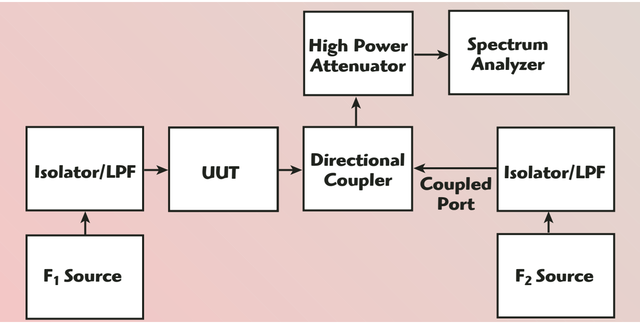
less expensive and more flexible IMD test bench.

Various schemes[1] exist for combining signals from sources F_1 and F_2 for the two-tone IMD test. Two methods are shown in ***Figures 1*** and **2**. In the first method, the two input signals are combined in the forward direction, as in a multi-carrier system. In the second method, the second signal is applied to the output of the ferrite component. This occurs typically in a transmitter combiner or where energy enters a transmitter from a co-located antenna and produces an IMD product. The IMD produced by the second method will generally differ by the isolation of the unit under test (UUT) isolator, from a common feed scheme having identical power levels. Since the two methods often use isolators/circulators in the test bench that are of the same type as those being measured for IMD distortion, some care is required to assure accurate results. Critical considerations are: the isolation between the sources must be sufficient to avoid mixing to occur in the sources. Isolators or circulators other than the UUT must not see full power at both frequencies.

High level mixing must not occur in the spectrum analyzer. The noise floor must be 6 to 10 dB below the IMD level being measured. No spurious response must be visible above the noise floor of the setup when the UUT is replaced by a through connection. If a residual spur is seen that cannot be removed, a sharp filter can be used to reduce the level of F_1 or F_2, which will reduce the level of the spurious signal. In general, the IMD level is not a strong function of the frequency separation.

The signals F_1 and F_2 must be kept separate until they enter the UUT so that mixing does not occur external to the UUT. This is accomplished by using a hybrid combiner in the methods discussed here. The disadvantage is that half the input power is lost. However, the hybrid combiner allows arbitrarily small frequency separation and also provides a source match at the IMD frequencies. It is important to maintain source match at IMD frequencies, since the ferrite junction acts more or less as an isotropic source for IMD production, that is, a significant quantity of IMD is emitted from the input port, and if there are sufficient reflections due to a poor source match, it adds vectorially to the IMD emitted from the output port. The result is unequal IMD amplitude levels, even when the input power levels are equal at the two source frequencies. The length of the input cables can also affect the relative IMD amplitudes.

An identified IMD product should be verified by switching off one source at a time, making sure its signal and the IMD signal both disappear on the spectrum analyzer. IMD frequencies must be an integral multiple of the frequency difference be-



▲ *Fig. 2 F_1 and F_2 opposed feed.*

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tween F_1 and F_2. The spectrum analyzer should be adjusted to have a minimum noise floor 6 to 10 dB below the expected IMD level. When an IMD signal is lost below the noise floor, it may be necessary to slow the sweep, narrow the scan, and/or use averaging. If the sources and the spectrum analyzer are synthesized, synchronizing all three instruments to one of the synthesizer 10 MHz clocks will further lower the noise floor.

RESULTS

Above-resonance drop-in isolators, fed with two +43 dBm common feed carriers, produce third-order IMD between –65 and –95 dBc, depending on the bandwidth, junction size and packaging techniques employed. Production isolators are available with IMDs of –85 dBc over wide temperature ranges for frequencies between 800 and 2200 MHz. Typically these devices are somewhat larger than conventional isolators since they have larger and stronger magnets and bigger circuit geometries. Because of the higher 4πMs and higher fields used at higher frequencies, isolators in the 2200 MHz range have slightly better IMD (a few dB) than those in the 800 MHz range. ■

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NOVEL MICROSTRIP BAND-STOP FILTERS BASED ON COMPLEMENTARY SPLIT RING RESONATORS

In this article, the stop-band characteristics of complementary split ring resonators (CSRR) and their applications to microstrip band-stop filters are proposed. The equivalent circuit model of a unit CSRR is applied to explain its characteristics and the parameters of a circuit model are extracted from EM simulation and circuit theory. Two types of novel compact microstrip band-stop filters based on CSRRs are proposed and their frequency responses are simulated and measured. The measurements are in agreement with the simulations.

In recent years, there has been a growing interest in electromagnetic bandgap structures (EBG), which exhibit the properties of rejecting electromagnetic waves at certain frequencies. The most interesting applications for these structures are the filtering of frequency bands or the suppression of undesired spurious passbands and harmonics in microwave or millimeter-wave circuits. However, traditional Bragg-effected-related EBGs require several periods to provide a significant stop-band.[1] These structures may therefore be relatively large for certain microwave circuit applications. Moreover, the parameters of EBGs cannot be easily controlled for a fixed stop-band.

The split ring resonator (SRR) is an alternative to traditional EBGs for tailoring certain frequency responses of microwave devices. This structure, originally proposed by Pendry, et al.,[2] consists of a pair of concentric metallic rings with splits etched on opposite sides. SRRs are able to inhibit signal propagation in the vicinity of the resonant frequency, which can be interpreted as corresponding to a frequency band with a negative permeability ($-\mu$) provided by the SRR structure. Compared with conventional ring resonators, SRRs exhibit a quasi-static resonance by virtue of the distributed capacitance between concentric rings and the rings' over all inductance. Essentially, a unit SRR structure behaves as a LC resonant circuit that can be excited by a time-varying magnetic field applied parallel to the rings' axis. The potential of SRRs to reduce circuit dimensions relies on the fact that the structures can be designed with dimensions much smaller than the wavelengths at their resonant frequencies. A complementary split ring resonator (CSRR) was recently proposed,[3–7] which is the negative image of an SRR. According to the duality and complementary concepts, CSRR exhibits dual characteristics of an SRR. CSRRs are subwavelength structures, which are about only one-tenth of the guided wavelength.

One- and two-dimensional CSRRs, etched in the ground plane of microstrip lines, have been proposed.[5–7] Because of leakage, the enclosure problems should be considered when using these kinds of microstrip lines to design practical microwave circuits. In contrast with

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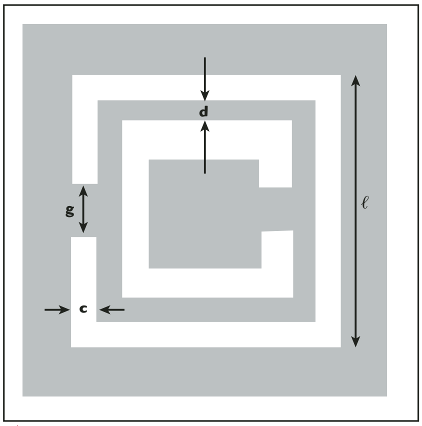
Shanghai, China

CSRRs etched in the ground plane, one-dimensional CSRRs etched in the conductor strip are presented in this article, showing better stop-band characteristics. A simple circuit model of a unit CSRR is used to study its characteristics, based on EM simulation results, and lumped elements of this model are extracted according to circuit theory. In order to show the effectiveness of the proposed scheme, two types of microstrip band-stop filters are designed, using CSRRs to improve the stop-band characteristics. The experimental results agree well with the simulation.

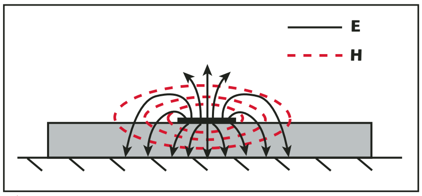
STUDY ON COMPLEMENTARY SPLIT RING RESONATOR

The layout of the square-shaped CSRR (also called dielectric split ring resonator) is shown in ***Figure 1***, where the metal regions are shown in gray. It is well known that the CSRR can be obtained by replacing the metal parts of the original split ring resonator with apertures, and the apertures with a metal plate. In the case of a microstrip line, the magnetic field loops around the line (as shown in ***Figure 2***) and the SRRs are not very well excited since the magnetic field does not penetrate through the rings. In order to best excite these rings, and considering the duality theory, the electric field of the microstrip are used. If the one- and two-dimensional CSRRs are etched in the ground plane, the electric field is found to be perpendicular to the CSRRs.[5–7] If the CSRRs are etched in the center conductor, there will be no leakage through the ground plane, and this structure can be integrated more easily with other microwave circuits. Simultaneously, for the microstrip line, the electromagnetic field is concentrated around the conductor strip, so the CSRRs etched in conductor strip can be more efficiently excited by a time-varying electric field than when etched in the ground plane.

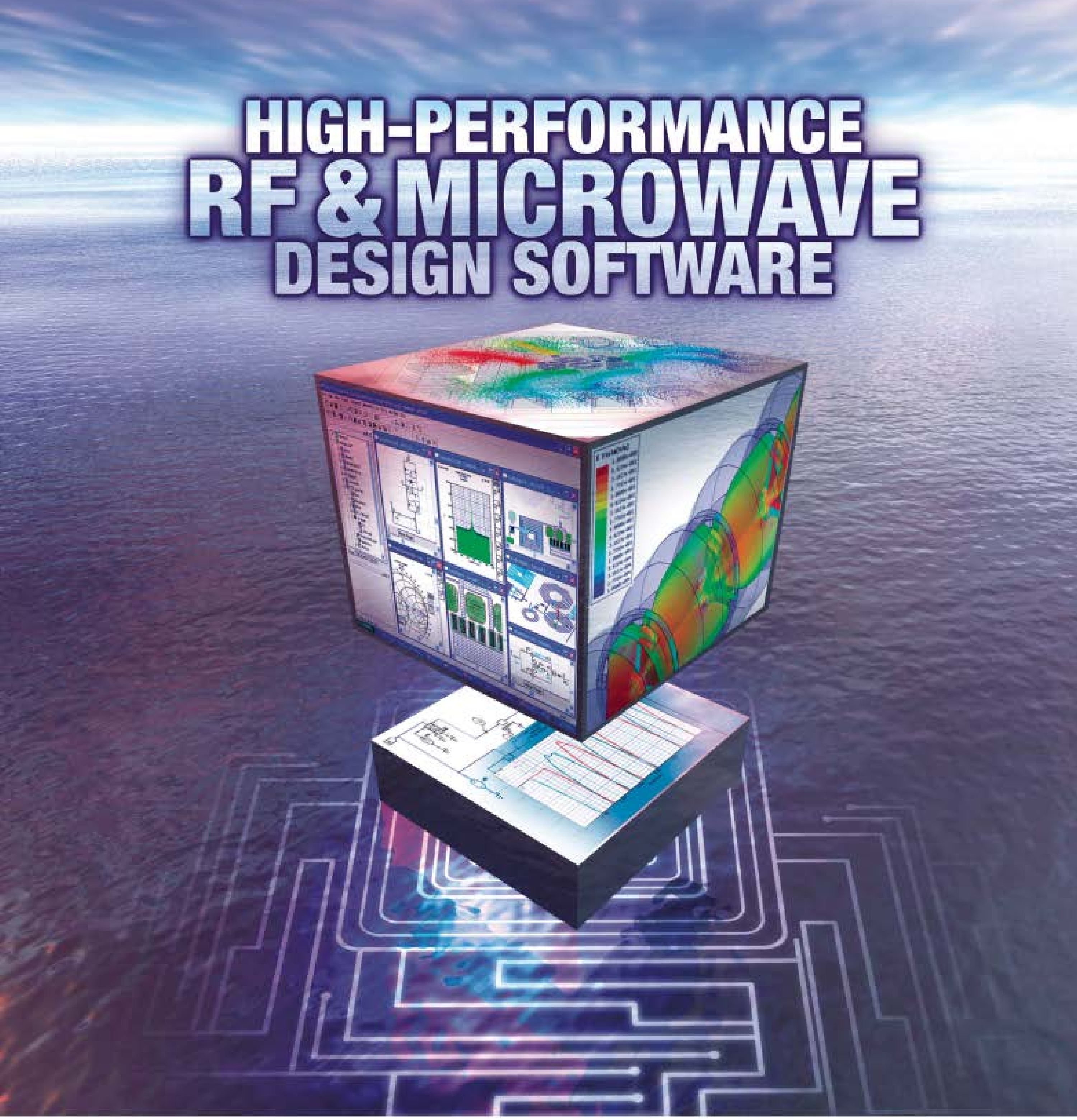
To show this fact, unit CSRRs of the same dimensions are etched in 50 Ω microstrip lines. One CSRR is etched in the center conductor and the other in the ground plane right under the strip. The dimensions of the CSRR cell are l = 3 mm, c = 0.2 mm, g = 0.2 mm and d = 0.2 mm.



▲ *Fig. 1 Layout of the unit CSRR.*



▲ *Fig. 2 Electric and magnetic field in a microstrip line.*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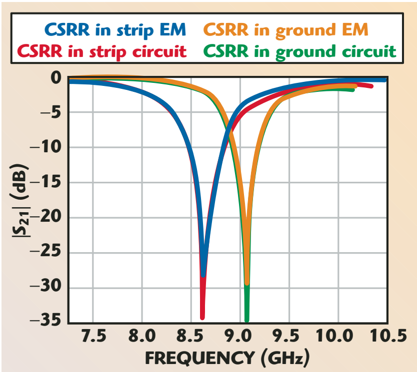
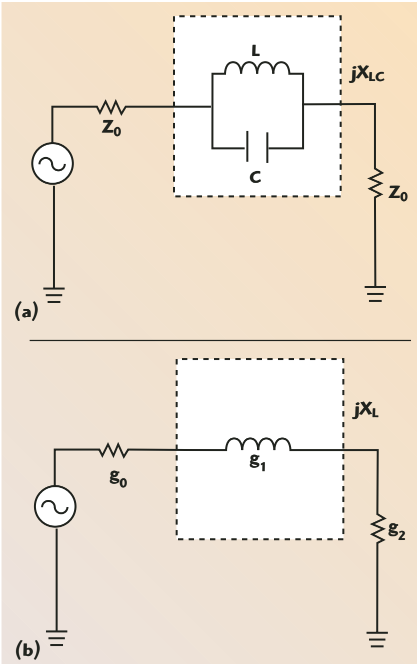
The 50 Ω microstrip line, with a substrate relative dielectric constant ε_r= 2.2, a substrate height h = 1.2 mm and a strip width w = 3.8 mm, are chosen for all the simulations. The transmission losses S_{21} of the two microstrip lines, with unit CSRR etched in the ground plane and the center conductor, have been simulated with an EM simulator and the results are shown in ***Figure 3***. The attenuation pole frequency f_c of the microstrip with unit CSRR etched in conductor strip (approximately 8.62 GHz) is lower than when etched in the ground plane (approximately 9.06 GHz). The –3 dB bandwidth of the CSRR etched in the strip is nearly 1.15 GHz, while the –3 dB bandwidth of CSRR etched in ground is only 0.67 GHz. The dimensions of the CSRR determine the resonant frequency. For the same resonant frequency, the dimensions of CSRR etched in conductor strip are smaller than etched in the ground plane.

As previously mentioned, the electrical characteristics of the stop-band for a CSRR can be simply represented as a parallel LC resonant circuit, as shown in ***Figure 4***. The lumped L-C parameters of the CRSS have been investigated in recent years, but their calculation methods are complicated for practical microwave circuit designs.[3–4] However, the equivalent parameters of the parallel LC circuit of a CSRR can be extracted from EM simulation results, and the equivalent circuit of the CSRR is matched to the one-pole Butterworth low pass filter (LPF) response. The reactance of CSRR can be expressed as



▲ *Fig. 3 Simulated S_{21} parameter of a 50 Ω microstrip line with unit CSRR etched in the center strip and ground plane.*



▲ *Fig. 4 Equivalent circuit of the microstrip line with unit CSRR (a) and Butterworth prototype of the one-pole LPF (b).*

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VLF-80	DC-80	145	200	VLF-1450	DC-1450	1825	2025
VLF-95	DC-95	165	220	VLF-1500	DC-1500	1825	2100
VLF-105	DC-105	180	250	VLF-1525	DC-1525	1750	2040
VLF-120	DC-120	195	280	VLF-1575	DC-1575	1875	2175
VLF-225	DC-225	350	460	VLF-1700	DC-1700	2050	2375
VLF-320	DC-320	460	560	VLF-1800	DC-1800	2125	2425
VLF-400	DC-400	560	660	VLF-2250	DC-2250	2575	2900
VLF-490	DC-490	650	800	VLF-2500	DC-2500	3075	3675
VLF-530	DC-530	700	820	VLF-2600	DC-2600	3125	3750
VLF-575	DC-575	770	900	VLF-2750	DC-2750	3150	4000
VLF-630	DC-630	830	1000	VLF-2850	DC-2800	3300	4000
VLF-800	DC-800	1075	1275	VLF-3000	DC-3000	3600	4550
VLF-1000	DC-1000	1300	1550	VLF-5000	DC-5000	5580	6850
VLF-1200	DC-1200	1530	1865	VLF-6000	DC-6000	6800	8500
VLF-1400	DC-1400	1700	2015	VLF-6700	DC-6700	7600	9300

U.S. Patent Numbers 6,790,049 & 6,943,646

Model	Passband (MHz)	fco, Nom. Loss 3dB (MHz) Typ.	Stopband Loss >20dB (MHz) Min.	Model	Passband (MHz)	fco, Nom. Loss 3dB (MHz) Typ.	Stopband Loss >20dB (MHz) Min.
High Pass *VHF Models $24.95 ea. (1-9)*							
VHF-650	710-2490	650	480	VHF-1810	1900-4750	1810	1480
VHF-740	780-2800	740	550	VHF-1910	2000-5200	1910	1400
VHF-880	950-3200	880	640	VHF-2000	2260-6250	2000	1530
VHF-1200	1220-4600	1180	940	VHF-2100	2200-6000	2100	1530
VHF-1300	1400-5000	1300	930	VHF-2275	2450-7000	2275	1770
VHF-1320	1400-5000	1320	1060	VHF-2700	2650-6500	2500	1800
VHF-1500	1600-5500	1550	1250	VHF-3800	4250-10000	3800	3200
VHF-1600	1650-5000	1600	1290	VHF-5500	6000-11500	5500	4500
VHF-1760	1900-5500	1760	1230	VHF-8400	9000-13000	8400	6000

U.S. Patent Number 6,790,049

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TABLE I

STOP-BAND CHARACTERISTICS AND EXTRACTED EQUIVALENT CIRCUIT PARAMETERS OF THE CSRR USING A 50 Ω MICROSTRIP LINE

CSRR Dimensions	c = 0.2 mm, d = 0.2 mm, g = 0.2 mm			
L (mm)	3.10	3.00	2.90	2.80
f_c (GHz)	7.71	8.15	8.50	8.88
f_0 (GHz)	8.19	8.62	8.97	9.36
–3 dB bandwidth (GHz)	1.20	1.15	1.12	1.08
L (nH)	0.2349	0.2066	0.1911	0.1791
C (pF)	1.6078	1.6479	1.6476	1.6142

$$X_{LC} = \left[\omega_0 C\left(\frac{\omega_0}{\omega} - \frac{\omega}{\omega_0}\right)\right]^{-1} \quad (1)$$

where

ω_0 = angular resonance frequency of the parallel LC resonator

The series inductance of the one-pole Butterworth LPF can be written as

$$X_L = \omega' Z_0 g_1 \quad (2)$$

where

ω' = normalized angular frequency
Z_0 = characteristic impedance
g_1 = normalized parameter of a one-pole Butterworth LPF

According to circuit theory, the two reactance values must be equal at ω_c

$$X_{LC} = \Big|_{\omega=\omega_c} = X_L\Big|_{\omega'=1} \quad (3)$$

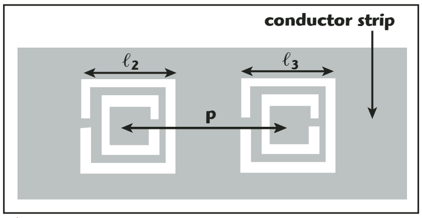
where

ω_c = cut-off angular frequency of the parallel LC resonator

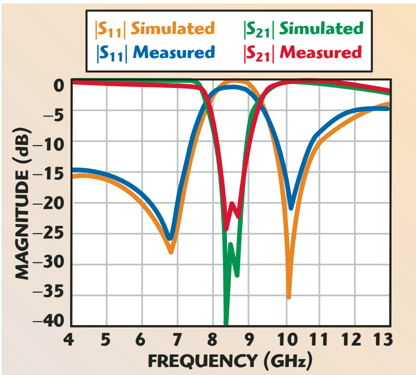
From Equations 1 to 3, the inductance L and capacitance C can be obtained as

$$C = \frac{\omega_c}{Z_0 g_1}\frac{1}{\omega_0^2 - \omega_c^2} \quad (4)$$

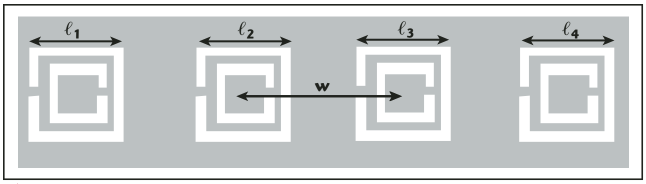
$$L = \frac{1}{4\pi^2 f_0^2 C} \quad (5)$$



▲ *Fig. 5 Double CSRRs etched in the conductor strip.*



▲ *Fig. 6 Simulated and measured S-parameters of a double CSRR band-stop filter.*



▲ *Fig. 7 Quadruple CSRRs etched in the conductor strip.*

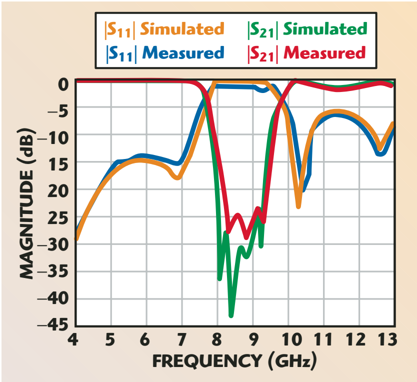
where

f_0 = resonant frequency, which can be obtained from EM simulation results

The equivalent-circuit parameters can be calculated from Equations 4 and 5. The simulated frequency responses using the extracted equivalent-circuit parameters for a 50 Ω microstrip line with unit CSRR are compared with the EM simulation results and show excellent agreement. The equivalent C and L of the unit CSRR in the conductor strip are calculated as 1.6479 pF and 0.2066 nH, respectively, while the equivalent C and L of the unit CSRR in ground plane are 2.5424 pF and 0.1212 nH. A small discrepancy between the EM and circuit simulations still exists because the LC parallel circuit is an ideal simple model, and the resistive loss of the radiation are not considered.

SIMULATIONS AND MEASUREMENTS

In order to demonstrate the stop-band validity of the CSRR, microstrip lines with double cells and quadruple cells etched in conductor strips are designed, respectively. The dimensions of the CSRRs are shown in ***Table 1***. The layout of the double CSRR cells in the conductor strip is shown in ***Figure 5***. The lengths of the CSRRs are l_2 = 3.00 and l_3 = 2.9 mm, respectively. The distance between the two CSRR centers is p = 6 mm. The simulated and measured results are shown in ***Figure 6***. For the stop-band characteristics, the maximum insertion losses S_{21} are better than –20 dB, and the –3 dB relative bandwidth is approximately 16.8 percent. In order to improve the insertion loss performance and widen the band-width of the stop-band, a quadruple cells filter, etched in the conductor strip, is proposed, as shown in ***Figure 7***. The dimensions of the CSRRs are shown in Table 1, and the period between adjacent CSRRs is w = 6 mm. ***Figure 8*** shows the simulated and measured S_{11} and S_{21} responses of this filter. The maximum S_{21} is greater than –23 dB and low return loss ripples are obtained in the stop-band; the –3 dB bandwidth of the filter is approximately 2.15 GHz (the relative bandwidth is



▲ *Fig. 8 Simulated and measured S-parameters of a quadruple CSRR band-stop filter.*

nearly 25 percent). The measured S-parameters compare well with the ones obtained from EM simulators in the two cases. The small discrepancies may be attributed to fabrication tolerances and radiation losses. The measurements of the band-stop filters were obtained with a HP8510 vector network analyzer.

CONCLUSION

In this article, a CSRR etched in the conductor strip of a microstrip line and its equivalent circuit are studied. Compared with the CSRR etched in the ground plane, it can be excited more efficiently by a time-varying electric field and there are no enclosure problems. Two compact microstrip band-stop filters based on CSRRs etched in conductor strips are proposed and their S-parameters are calculated and measured. Deep and wide bandgap characteristics are shown in the proposed filters. ■

ACKNOWLEDGMENTS

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A NOVEL WIDEBAND TRANSITION BETWEEN A CONDUCTOR-BACKED FINITE GROUND CPW AND A MICROSTRIP LINE

This article describes a transition between a conductor-backed coplanar waveguide (CPW) and a microstrip line, which provides a very low loss alternative to a standard microstrip-to-coplanar line transition at higher frequencies. This simple topology is easy to incorporate in a monolithic circuit. The introduction of slots, along with the elimination of parasitic parallel plate modes and parasitic losses, are the main features of this transition. This MIC transition is designed for a center frequency of 20.5 GHz. The simulated and measured results of the transition, along with the design procedure, are detailed in the article.

Microstrips (MS) and coplanar waveguides (CPW) are two of the main waveguide structures used in higher frequency applications, because of their compatibility with monolithic fabrication and solid-state devices. In CPW, the signal lines and ground planes are placed on one side of the substrate, permitting a circuit consisting of passive components and active devices to be implemented with relative ease. However, the most widely used lines are microstrips, which have the ground plane placed on the backside of the substrate. Consequently, a circuit element has to be connected through via holes for grounding.[1] In many systems, it is necessary to use both type of lines simultaneously. A transition is required to connect them with minimum loss. This necessitates a common ground reference. At millimeter-wave frequencies, the presence of a backside metallization excites parallel plate waveguide modes. This problem leads to complex and costly solutions such as wafer thinning and backside processing in MMICs. In the case of CPW lines, the elimination of parallel plate modes requires a large number of vias, which introduce additional parasitic effects, increasing the circuit complexity. Therefore, the concept of a conductor-backed CPW[2] is introduced, having the inherent advantage of lower radiation loss and higher power handling capability. The circuit can be viewed and analyzed as a system of three coupled slot lines.

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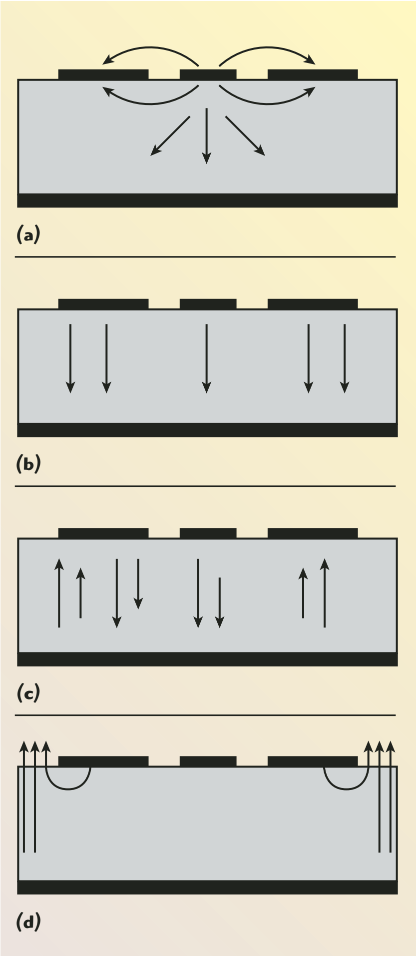
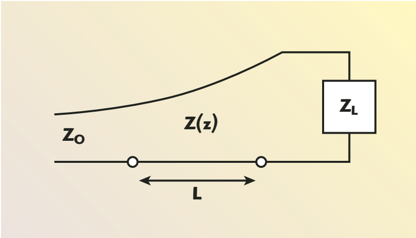


▲ *Fig. 1 Symmetric modes in CB-CPW lines; (a) CPW mode, (b) MSL mode, (c) first higher order MSL mode and (d) image guide-like mode.*

The transitions reported so far are limited by their length. This article introduces the concept of wideband, finite ground conductor-backed CPW (FG-CBCPW) lines, working from 19.5 to 22.0 GHz. This transition can be easily implemented in a monolithic configuration.

MODES IN CBCPW LINES

The backside metallization, in CPW lines, launches a microstrip-like mode. The dielectric thickness cannot be increased arbitrarily to minimize the effect of the backside metallization. In MMIC technology, the process limits the thickness, while the limitation in MICs comes from mechanical strength. Shih and Itoh have shown that the influence of the ground plane on the propagation characteristics can be significant when the substrate thickness becomes comparable to the slot width.[3] Furthermore, the short circuit and



▲ *Fig. 2 Tapered transmission line matching.*

discontinuities may cause parasitic modes, such as space waves and surface waves. Besides the parasitic radiation effect, the conductor backing may result in power leakage into the dielectric-filled parallel plates at all frequencies. The modes, which can exist in the metallized backside circuit, are the CPW mode, MSL (microstrip mode), first higher order microstrip mode and image guide-like mode, as shown in ***Figure 1***.

The MSL mode can occur in a CPW with side planes of finite width, with or without conductor backing. The TM0 parallel plate mode, or surface mode, excited by discontinuities, may be converted into a bounded MSL mode. Thus, a CPW structure is overmoded. In this case, mode conversion among incident, transmitted and reflected waves takes place. The discontinuity between CBCPW and MS gives rise to the mode conversion process. In this mode, the electromagnetic energy is no longer confined in the vicinity of the CPW slot-surfaces; rather it may be carried by the microstrip-like mode, leaky wave, or other higher order modes, depending on the frequency of operation and the wave-guiding structures. Such non-CPW type of energy can couple to the neighborhood circuits and produces cross talk in the CPW circuit. The MSL mode, resembling the parallel plate transmission line mode, inherently exists in FW-CBCPW if no other means of mode suppression is applied. The next higher order MSL mode may exist if the side planes are too wide. The image guide-like mode exists if the substrate protrudes far from the side planes. It exhibits a zero cut-off frequency propagation characteristic.

The prevention of higher order modes in FG-CBCPW can be done by connecting the bottom ground to the side ground periodically with conducting posts. This configuration requires the conducting posts be placed near the conducting strips to form a quasi-rectangular waveguide beneath the strip operating below the cut-off frequency. However, this approach increases the circuit complexity. This article presents a novel transition structure, which eliminates the use of vias and ribbon bonds in addition to having a common ground reference. This makes the circuit simpler for ease of fabrication, along with a balanced configuration.

BROADBANDING TECHNIQUE

The bandwidth of a multi-section transformer can be increased by either having a binomial matching transformer for a flat response or a Chebyshev multi-section transformer to have further bandwidth improvement. A tapered line section has been used here, instead of a discrete line section to eliminate the effect of discontinuities.[4] ***Figure 2*** shows the tapering concept.

$$Z(z) = Z_0 e^{\alpha z} \qquad 0 < z < L$$

where

$\alpha = (\ln Z_L/Z_0)/L$

Using the theory of small reflections,

$$\Gamma = (\ln Z_L/Z_0)\, e^{-j\beta L} \sin \beta L/\beta L$$

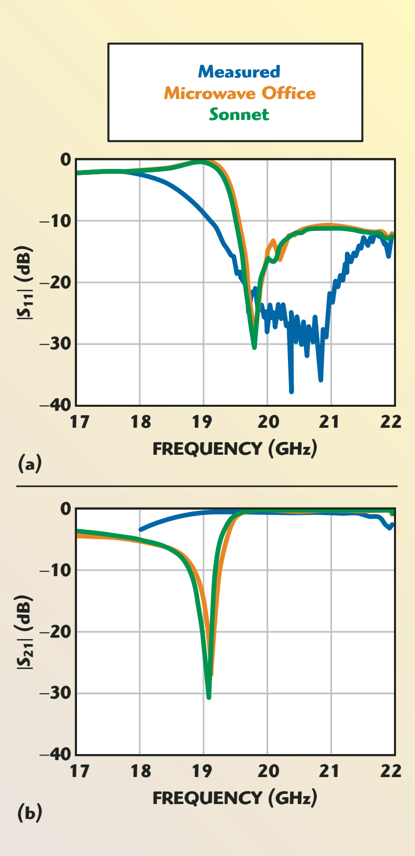
where

L = length of the taper
β = propagation constant

Furthermore, radial slots have been incorporated in the ground planes within the tapered section and further optimized. These slots present a very wideband open circuit, which forces the electrical field to be mainly in the microstrip line.

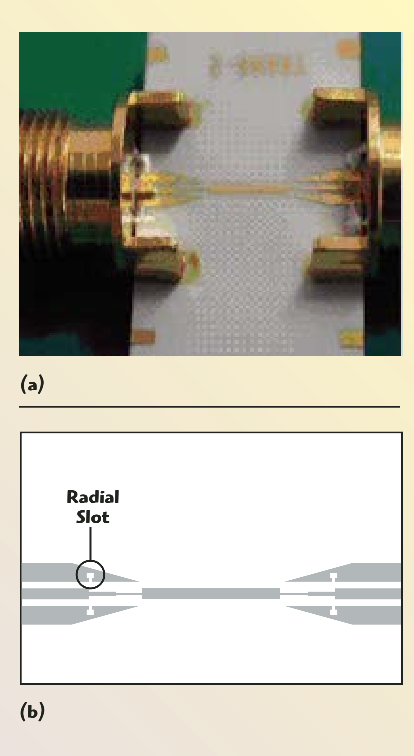
DESIGN ASPECTS

The approach presented in this article combines the advantage of a single ground plane along with finite grounded coplanar (FGC) lines. The FGC lines provide the capability to control the cut-off frequency of the higher order modes, thus allowing higher operating frequencies. The finite size of the ground planes and the capability to change their size for controlling the performance is an added advantage of these lines. The ground plane is tapered in tune with the transition tapering. The width of the ground reference is chosen so



▲ *Fig. 3 Comparison between the simulated and measured performance of the transition.*

that the lateral size of the structure is less than half the lowest operating wavelength. A common ground plane is chosen for the CPW and microstrip line, which is provided through the connectors. The single ground plane eases the circuit complexity as well as reduces the loss. In MIC fabrication, a single photolithography step is required for etching of the circuit. Radial slots, with an optimized angle of 45°, are incorporated for a wider bandwidth. The optimal width of the CPW is kept 2.5 times the distance between the two ground planes.[3] The tapering section is designed to match 67 to 50 Ω. The widths of the CPW are kept as 24 μm for the signal line and 106 μm for the grounds. The spacing between the signal line and ground is kept at approximately 40 μm. These dimensions have been obtained after optimization of the transition length, spacing, width of the ground reference, tapering of ground reference along with slot length to achieve a wider bandwidth. The microstrip line width is kept at 0.24 mm.



▲ *Fig. 4 Back-to-back transition's; (a) photograph and (b) layout.*

EXPERIMENTAL RESULTS

The circuit was simulated using the Microwave Office EM tool along with Sonnet. The circuit was fabricated as a back-to-back transition on a 10-mil alumina substrate. The connections are made with SMA connectors, using solder and conducting epoxy. A Rohde & Schwarz SZV series network analyzer is used for the measurement. It was properly calibrated to remove measurement related errors. ***Figure 3*** shows the agreement between the measured and simulated results within the band of interest, 19.5 to 22 GHz. The resonance spike shown in the simulated S_{21} is caused by the finite dimensional limits used in the calculations. ***Figure 4*** shows the layout and a photograph of the back-to-back transitions. The maximum loss in the band of back-to-back transitions is 0.8 dB with a return loss greater than 10 dB.

CONCLUSION

A simple wideband transition from a conductor-backed finite ground CPW line to microstrip has been realized. It can easily be incorporated directly in monolithic form. The result shows good agreement with the measured results. The losses can be further reduced by decreasing the lengths of the microstrip and CPW line, which in turn reduce the conductor losses. ■

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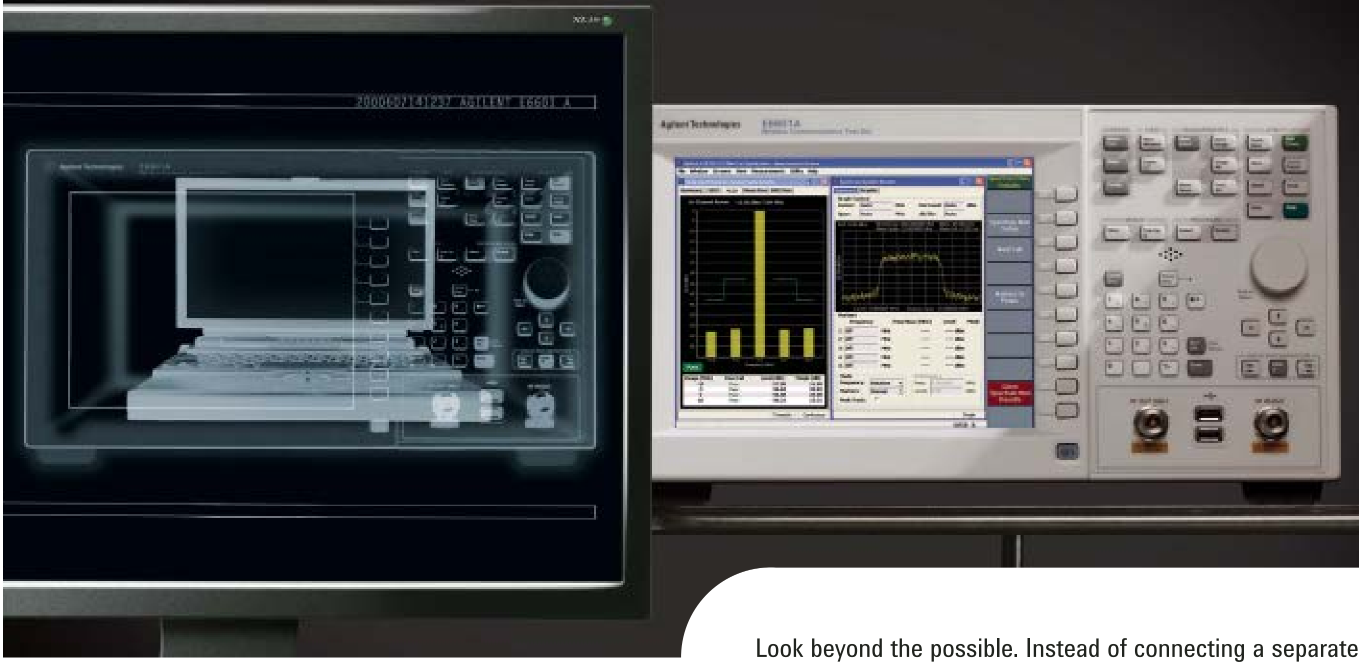

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EuMW 2006: Regenerating Interest

Manchester, UK, has been a major port and trading centre since the 1700s and the tradition continued in September when European Microwave Week (EuMW) visited the city for the first time and set out its stall at the G-MEX/MICC Complex. Exhibitors not only traded new and innovative products at the European Microwave Exhibition but visitors to the six-day event also traded ideas and opinions at the four major conferences, workshops and short courses.

Dr. Ulrich L. Rohde, president of Synergy Microwave Corp., presents at a conference (photo courtesy of Shmuel Auster, EuMA/EuMW Steering Committee Member).

Just as the historical city of Manchester has profited from regeneration, the established conferences received a makeover too with the introduction of the European Microwave Integrated Circuits Conference EuMIC (formerly the GAAS® Symposium), which is the product of close collaboration between the GAAS Association and the European Microwave Association. The new format enabled it to dovetail well and complement the established 36th European Microwave Conference (EuMC 2006), the European Conference on Wireless Technology (ECWT 2006) and the European Radar Conference (EuRAD 2006).

THE CONFERENCES

EuMC 2006

In what is an increase from 2005, the European Microwave Conference featured 60 regular oral sessions, including several focused

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AND JENNIFER DIMARCO
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sessions on specific topics, and two poster sessions. The concept of EuMW favours the integration of the four component conferences, uniting their respective communities and, in this spirit, EuMC featured nine joint sessions with its sister conferences. In addition, there were various workshops designed to encourage technical exchanges on certain topics.

ECWT 2006

This is not only Europe's premier meeting on wireless technology but also a growing international event, demonstrated by the fact that the conference received a record number of papers from over 50 countries with a significant proportion of contributors from North America and the Asia Pacific region. As well as established ECWT topics like antennas and integrated modules, the conference incorporated growing areas such as UWB, WiMAX and HSDPA through to fledgling topics like Cognitive Radio and Ad Hoc Networks.

EuMIC

The GAAS Association and the European Microwave Association worked together to produce this new conference. As the name suggests it focused on all monolithic microwave integrated circuits whether they are fabricated using silicon, silicon germanium, gallium arsenide, gallium nitride or any other semiconductor material. The global involvement and interest in the subjects covered was illustrated by the fact that the technical programme, which consisted of 85 papers selected from 189 submitted, represented the work of over 20 countries.

EuRAD 2006

Right from its inception EuMW has involved radar activities, with the number of radar related papers increasing year by year. That growth continued with EuRAD 2006 seeing a substantial conference programme consisting of 55 papers for oral presentation and 35 poster papers. Contributions were received from authors from many countries around the world covering a wide range of topics. Among them were presentations on sparse antenna arrays, remote sensing of the atmosphere, ultra-wideband radar, real-time signal processing, novel antennas, SAR, new transmitter techniques, millimetre-wave radar and netted radars.

Audience members listen at the Opening Ceremony held on Monday (photo courtesy of Shmuel Auster, EuMA/EuMW Steering Committee Member).

THE EXHIBITION

Central to European Microwave Week is the three-day European Microwave Exhibition, which was fittingly staged in the Central Hall of the G-MEX Centre. The venue, a transformed former train station, is an example of Manchester's historical and industrial past and a symbol of regeneration and growth. The European Microwave Exhibition has grown too and was the largest to date, with more than 300 exhibiting companies, taking up 7500 m^2 of gross exhibition. It has also grown in status with many exhibitors using it as a platform for launching new products and making major announcements.

It attracted international players, not just from Europe but also from across the globe with strong representation from the US and Asia who recognise the significance of the exhibition to showcase their wares to a wide and focussed audience. As always, it provided a stage for companies, large and small, established or new start-ups, to spotlight their latest introductions, discuss possible future developments and get feedback from customers. To give *Microwave Journal* readers feedback from the exhibition floor, a selection of new and innovative products showcased at the exhibition follows. Apologies to those companies that have not been mentioned due to space constraints.

Agilent Technologies specifically targeted EuMW as a platform to launch two brand new products. The first is the MXG signal generators with key manufacturing benefits for wireless communications applications. They are said to offer industry-best adjacent channel power ratio (ACPR) performance and switching speeds, coupled with simplified self-maintenance to maximize uptime. These new analogue and vector signal generators are ideal for manufacturing teams producing components and receivers for communications systems.

The second announcement regarded the availability of the MXA signal analysis platform, heralding the arrival of the next generation in signal analysis. It is claimed to be the industry's fastest signal analyzer with the highest accuracy and performance of any mid-range analyzer. Its measurement speed enables dramatically improved throughput and yields in manufacturing, enabling engineers to solve design challenges for current and emerging applications quickly and with few iterations.

Keeping it simple and practical, **Anritsu** introduced the VNA Master MS2034A and MS2036A that offer inte-

The Industry Exhibition.


Attendees walk the show floor.

Another aid to engineers is the RFA™ from **Applied Wave Research**, which is a system-level architectural planning tool that provides an advanced radio frequency budget analysis feature and 'frequency heritage inspection' capabilities for next-generation communication design. This new entry-level product is the latest addition to the company's Visual System Simulator™ (VSS) design suite.

Moving on to materials, **Arlon** announced the availability of the CLTE-XT microwave laminate. It represents the eXtended Technology of the existing CLTE product line and offers low insertion loss and loss tangent (0.0012 at 10 GHz). The laminate is a micro dispersed ceramic PTFE composite utilizing a woven fibreglass reinforcement to provide the highest degree of dimensional stability, which is critical in multi-layer designs.

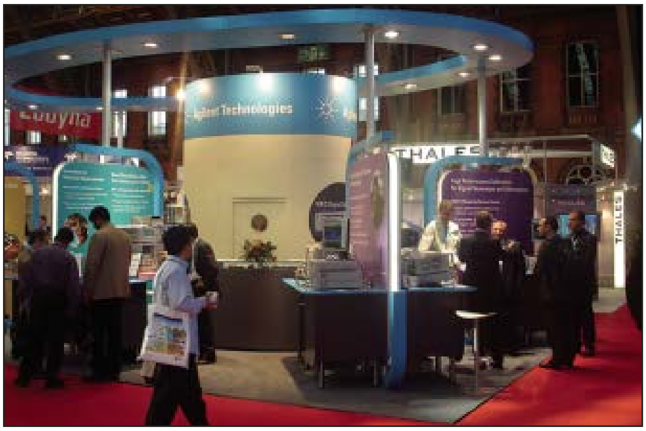
Chronos Technology launched new RoHS-compliant power amplifiers, low noise amplifiers and multipliers from Cernex. They feature benefits such as solid-state class A design, 50 Ω in/out impedance and rugged construction. The power amplifiers also have the additional benefit of instantaneous broadband. The company also announced the release of the CW85 GPS 'Broadcaster' from NavSync, which incorporates NavSync's high sensitivity GPS receiver with an 802.11b transmitter to provide location information when in the vicinity of a WiFi hotspot.

Similarly, **CompoTRON** announced the release of Pletronics' new high frequency, crystal-controlled oscillator. It combines the latest advancements in IC and crystal technology to provide frequencies ranging from 10 MHz to 1.25 GHz with jitter as low as 0.16 ps RMS from 10 Hz to 20 MHz. The 5x7 mm ceramic, surface-mount oscillator is currently available in PECL output, 3.30 V, with LVDS output units to be introduced in the near future.

grated vector network analyzer, spectrum analyzer and power meter capability in a single handheld, battery-operated, rugged instrument. Their multi-function capability enables them to serve as single-instrument solutions for phase matching cables, identifying sources of interference and troubleshooting transmitters in a variety of aerospace, defence and general-purpose systems.

The company also introduced a 70 GHz model and a series of options for its MG3690B family that not only extends the frequency range of the RF/microwave signal generators but also adds flexibility and cost of ownership advantages. The options—a 10 dB low phase noise and high power—are available for all six models, which cover 2 to 70 GHz and deliver high purity signals for accurate analysis.

Staying with the test, measurement and design theme, **Ansoft** displayed new technologies developed specifically for the needs of high performance electronic designers. Among the products showcased were a preview of the upcoming release of Nexxim and Ansoft Designer v3.5. It features Circuit Envelope, Monte Carlo and Loadpull analyses as well as Verilog AMS model support (compiled and interpreted) to both the Ansoft Designer and Cadence ADE environments. Other products featured included a new Distributed Analysis option for HFSS and Q3D Extractor that applies parallel computation to parametric design variations and ePhysics v2—a product that enables the company's electromagnetic field simulation products to couple with thermal and stress analyses.



Looking in at the Agilent booth.

Dielectric Laboratories featured its XtremeQ™ series of microwave filters and resonators, which is now available from prototype to high volume manufacturing. XtremeQ filters and resonators can be ordered from the company's extensive catalogue, *Resonators, Filters and Custom Ceramic Components*. Or they can be manufactured to customer's specification utilizing proprietary or patented ceramic formulation to deliver the unique combination of compact footprint, unsurpassed temperature stability and excellent RF performance.

A new launch for EuMW from **Elisra** was the instantaneous frequency measurement (IFM) assembly, which is a digital frequency discriminator that measures the frequency of the RF input signal. Compact in size, the standard frequency range is 2 to 18 GHz, with the option of extension to 0.5 to 18 GHz. The frequency accuracy is 2 MHz as is the frequency resolution. It has internal or external triggering, a high dynamic range of –50 to +10 dBm, a pulsed width range of 50 ns to CW and a SNR of 3 dB.

A new name at EuMW was **Emerson Network Power** with, for the very first time, **Vitelec Electronics**, **Johnson Components**, **Midwest Microwave** and **Thunderline-Z** appearing at a trade event under the company's Connectivity Solutions banner.

Endwave Defense Systems announced the release of a series of custom multi-function assemblies (MFA) for RF power distribution applications. These particular MFAs provide input filtering, amplification using GaAs MMIC devices, digitally controlled attenuation and temperature-compensated power distribution of incoming RF signals among eight output ports.

A key announcement from **Filtronic Compound Semiconductors** was that it is now sampling a new family of packaged MMICs targeting the Wireless Infrastructure and WiMAX market segments. The FMA3017QFN, FMA3018QFN and FMA3019QFN MMICs are balanced low noise amplifiers packaged in industry standard, cost-effective RoHS-compliant outlines. Each MMIC is designed for optimum performance over the 1.7 to 2 GHz frequency range, making them suitable for first, second and third stage front-end base station LNAs. By integrating the input and output couplers on chip, these LNAs reduce both board space and component count.

Hittite Microwave Corp. showcased four new active ×2 frequency multiplier modules that provide output frequency coverage from 6 to 46 GHz. Each of these active ×2 frequency multipliers provide high output power, and excellent fundamental and subharmonic suppression for microwave communications, RADAR, test equipment and general laboratory applications. The models HMC-C031, HMC-C032, HMC-C033 and HMC-C034 are broadband active ×2 multipliers that utilize GaAs PHEMT technology and are packaged in miniature hermetic 41.66 × 27.59 × 8.50 mm connectorized modules.

The new Empire XCcel™ 3D EM field solver that was showcased by **IMST** has been further optimized for speed. Utilizing modern processor architectures (for example, smart cache management), a speed-up of about 200 percent has been reported. Extra speed has also been obtained by using dual-core, single-CPU machines; the performance is an additional 60 percent, using dual-core, dual-CPUs; and performance values of at least 350 Mcells/s have been achieved. When utilizing Empire XCcel, there

is neither a need for special hardware set-ups nor a limit for the application size to the memory space.

The leading range of SMA plugs from **Johnson Components** is now available in Europe through **Vitelec Electronics**. The devices quickly and easily mate to standard, threaded SMA jack receptacles allowing rapid test connections without compromising electrical performance. Retaining all the benefits of a threaded coaxial coupling, Johnson SMA Quick-Connect plugs deliver high performance coupled with superior ease-of-use.

Keithley Instruments introduced an innovative line of RF test instruments, combining high performance, speed, flexibility, ease of use and compact size. To achieve this, these instruments employ new approaches to test and measurement that enable users to save time, effort and money. These new products can be used throughout the design, development and manufacturing processes, and complement the company's existing solutions sold in this market such as battery simulation sources, semiconductor characterization systems and source-measure units.

LPKF showcased the ProtoLaser 200, a versatile state-of-the-art laser system, combining advanced laser technology, optics and table mechanisms, resulting in superior quality, speed and accuracy. This rapid PCB prototyping solution is suitable for the precision geometries demanded by RF, microwave, RFID, antennas and filters. Laser structuring applies to nearly any substrate, such as FR4, flexible materials, ceramics, PTFE and Al_2O_3 (alumina).

Analog Devices on display.

The development of amplifiers was a major topic at the EuMW conferences and also at the exhibition, where **M/A-COM** announced new low cost two-stage driver amplifiers. They are the MAAMSS0072 and MAAMSS0073, which extend the company's successful family of broadband, high linearity driver amplifiers. The broad frequency range, high linearity and reliability make this product family ideally suited for a variety of wireless applications such as WiMAX, WiBro and UMTS/WCDMA base stations. The company also announced the MASW-007107, a new DC to 8 GHz SPDT RoHS-compliant switch for applications that require low insertion loss and fast settling times over a wide frequency range in an ultra small size.

MicroMetrics has taken advantage of its newly expanded facility in Londonderry, NH, US, which now includes seven Gemini Epi reactors, to announce the expansion of its epitaxial growth and coating services for the semiconductor fabrication market.

Always keen to show off its new developments, the **Microwave Innovation Group** (MIG) demonstrated the latest version of WASP-NET®, the fast hybrid EM CAD and optimization engine that utilizes the advantages of all four common EM solvers (MM/FE/MoM/FD) in one tool. Its high speed is of particular benefit, especially when full-wave optimizations are required to meet given specifications. New features include 64-bit capability utilizing enhanced memory handling performance, extended slot array library with direct feed optimization capability for very large arrays, dielectric resonator and combline filter library with full 3D flexibility, and improved efficiency.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SMA 18GHZ 5W
SA6S5W $43.00
SMA 6GHZ 5W
SA6S10W $88.00
SMA 6GHZ 10W
SA18S10W $122.00
SMA 18GHZ 10W
SA3T $29.00
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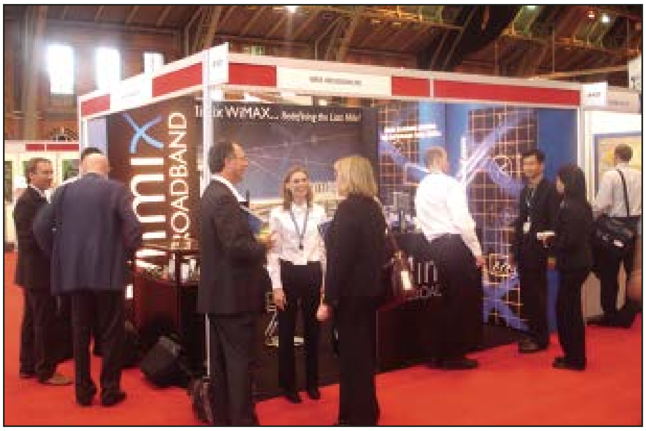

Mimix Broadband meets and greets attendees.

The new **MILMEGA** 2.5 to 6 GHz range of amplifiers is designed to address the recently released edition 3 of IEC 61000-4-3 that outlines a new requirement for testing up to 6 GHz. The requirement presents those EMC labs with an existing amplifier capability up to 3 GHz with a procurement challenge of how best to fill this gap. In addition, this new range of amplifiers provides the perfect solution for testing against WiMAX requirements.

Antenna development is always of interest and **MTI Wireless Edge** announced the availability of its new ultra low cost omni directional antennas in the ISM bands. The development of these antennas was specially designed to support mesh architecture networks.

The NM100 VNA+ from **NMDG Engineering** is a combination of software and hardware, running on top of a VNA and allows the characterization of the harmonic behaviour of high frequency components, including diodes, transistors and power amplifiers. On top of the regular capabilities of the VNA, the NM100 measures, in a calibrated way, the incident and reflected waves or voltages and currents at the ports of a component. During measurements, it is submitted to 'realistic conditions,' via a periodic harmonic-related stimulus, possibly in combination with tuners. The software includes a user-friendly graphical interface that allows visualization of data in time as well as in the frequency domain. The NM100 supports a frequency range from 600 MHz up to 20 GHz.

On the **OMMIC** stand, the company announced the introduction of two new circuits in its family of products of control functions for military, civil and telecommunication applications. The CGY2176AUH is a 6-bit digital attenuator with good performance from 4.5 to 6.5 GHz. The CGY2177AUH is a 6-bit digital phase shifter with good performance from 4.5 to 6.5 GHz.

Pascall Electronics showcased the OCXO series, which is designed to meet the increasing demand for high performance reference oscillators. Oven-controlled SC-cut crystals are used to give good temperature stability combined with the lowest possible phase noise. The oscillators are available with either mechanical or electrical tuning, with the option of a low noise reference voltage output to allow the oscillator to be tuned using an external potentiometer. The frequency range is 50 to 130 MHz, tuning range is $\pm 4 \times 10^{-6}$ and output power is 13 dBm ±2 dBm, 50 Ω.

RADIALL featured an extension to its coaxial microwave switching product range with the new DP3T-SPDT Platinum series and 40 GHz SPnT terminated switch. New test and measurement RF microwave cable assemblies; coaxial connectors: SMP, R3C, QMA, QN, IMP 18 GHz; RF micro and power switches, antennas for military applications (wideband and broadband) and civil applications (combined antennas) were also on display.

Several products were showcased by **Remcom**, including its latest version of XFDTD, version 6.4, with the emphasis placed on antenna calculations to answer a need in the market. One of the major applications for XFDTD is in the area of antenna design and analysis. Also announced was XSTREAM-hardware acceleration for the well-established XFDTD electromagnetic analysis software package. This hardware option is said to improve performance by factors of 10, 20 or more. The company also featured version 2.3 of Wireless Insite and Varipose v1.2, a modelling tool for repositioning biological modes for use with XFDTD software.

Rogers Corp. used EuMW to introduce its new RO4450B™-dx Bondply, a high fill/flow version of the RO4450B high frequency circuit material. The RO4450B material is a glass-reinforced hydrocarbon/ceramic thermoset bondply designed for performance-sensitive, multilayer printed circuit boards. These bondplys are designed to offer superior high frequency performance and low cost circuit fabrication. The result is low loss material, which can be fabricated using standard epoxy/glass (FR4) processes. The new RO4450B-dx is a high fill/flow version, designed to fill those high density designs while still offering thin dielectric spacing.

As usual, **Rohde & Schwarz** set out to demonstrate its expertise in all aspects of microwave measurement technology. The new R&S ZVA40 vector network analyzer is the flagship member of the well established family of network analyzers and now allows measurements on pulsed signals, up to a frequency of 40 GHz. Further highlights included the R&S FSUP signal source analyzer, an all-in-one spectrum analyzer up to 50 GHz and a phase noise tester in a single instrument, the high end R&S SMA100A signal generator with a frequency range up to 6 GHz and the new R&S ESU EMI test receiver offering measurement speeds up to 100 times higher than with comparable receivers. Last but not least, the company presented reliable and standard-compliant measurement solutions for WiMAX applications in addition to its R&S AFQ100A I/Q modulation generator with extended memory space up to 1 GSample and I/Q bandwidth of up to 100 MHz.

Rosenberger featured its new series of QN connectors that are based on the N connectors' interface and operate in a frequency range up to 11 GHz. The quick lock coupling mechanism allows fast, easy and reliable connections in the tightest spaces. The manufacturer's current product spectrum covers straight and right angle plugs as well as panel jacks for various cables (UT 141, RG 58, RG 213, RG 214, RG 223). The product range is completed by N (female) - QN (male) adapters. QN and standard N connectors are not intermateable.

New from **Schmid & Partner Engineering** (SPEAG) is SEMCAD X V11.0 Mönch, the latest release of the powerful EM TCAD package and another major breakthrough

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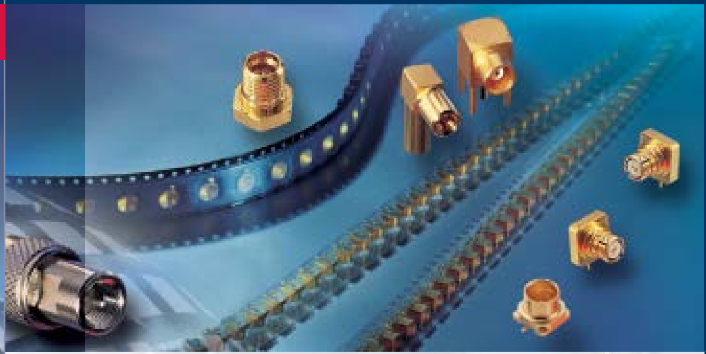

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Sonnet Software showcased its new Sonnet® Suites Professional™ Release 11. This release introduces a new type of internally calibrated port, which exhibits exceptional dynamic range. These ports can be used as accurate attachment points for transistors, diodes or other active components enabling full co-simulation of surface-mount parts and packages with planar EM analysis. Release 11 also introduces a redesigned seamless interface to the Agilent EEsof EDA's ADS Suite. The re-design, including an intuitive, easy-to-use GUI interface, runs entirely in the ADS environment, which greatly simplifies the translation process. Users can produce layout look-alike schematic symbols for using and sharing Sonnet models in ADS schematics.

Taking centre stage on the **SUSS MicroTec** stand was the company's recently released version of wafer-level, high frequency calibration software, SussCal Professional, which simplifies the wafer-level calibration process and significantly increases the accuracy of on-wafer measurements.

Tektronix announced the RSA6100A series of real-time spectrum analyzers that provides an unmatched combination of real-time performance, capture bandwidth and dynamic range to meet the needs of a broad range of digital RF applications. DPX™ waveform image processor technology transforms volumes of real-time data to produce a live RF spectrum presentation that reveals previously unseen RF signals and signal anomalies. Live RF is achieved by improving the spectrum measurement rate nearly 1000 times compared to the fastest swept spectrum and vector signal analyzers.

An RF MEMS switch technology was spotlighted at the **TeraVicta Technologies** stand. It features a wide frequency range that operates from DC to 20 GHz, high isolation of 21 dB at 20 GHz and high linearity of IP3 > 65 dBm. These switches are used in high performance RF switching, automated test equipment and instrumentation.

Thunderline-Z announced the posting of two new engineering tools to its web site. The first is an advanced search engine of the company's entire database of previously designed feedthroughs. This tool allows users to search over 2000 models of RF/50 Ω, DC and capacitor/filter feedthroughs to find the model that most closely resembles their application. The second tool is a new impedance reference calculator, which allows engineers to calculate the opposing dimension of glass to pin, or pin to glass that will achieve optimal impedance from their package.

Two new high output third order intercept (OTOI) gallium arsenide

MILLIMETER WAVE MIXER ASSEMBLIES

From Stock

MIXERS

Model Number	Frequency (GHz) RF	LO	IF	LO Power (dBm)	Conversion Loss (dB Typ.)	LO-RF Isolation (dB, Typ.)
TB0440LW1	4–40	4–42	.5–20	10–15	10	20
DB0440LW1	4–40	4–40	DC–2	10–15	9	25
SBE0440LW1	4–40	2–20**	DC–1.5	10–15	10	20
IR2640L17*	26–40	26–40	Note 1	15	10	15
M2640W1	26–40	26–40	DC–12	10–12	10	20
TB2640LW1	26–40	26–40	.5–20	10–15	10	20

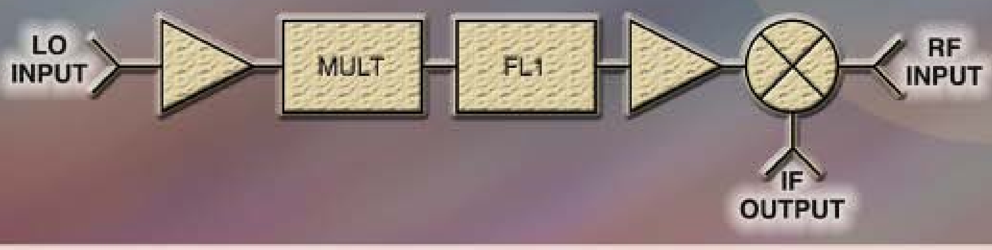
* Image Rejection typically 15 dB. ** Sub Harmonic

Note 1: IF Option A: 20–40 MHz, B: 40–80 MHz, C: 100–200 MHz, Q: DC–1000 MHz

MULTIPLIERS

Model Number	Frequency (GHz) Input	Output	Input Power (dBm)	Output Power (dBm, Typ.)	Fundamental Leakage (dBc, Typ.)
SYS2X1428	14	28	+12	+12	-50
SYS2X1734	16–17.5	32–35	+12	+12	-50
SYS3X1442	14	42	+12	+12	-50
SYS4X1146	11	46	+12	+15	-60
SYS2X2040	10–20	20–40	+12	+15	-15
TD0040LA2	2–20	4–40	+10	-5	-20

MIXER/MULTIPLIER ASSEMBLIES



Model Number	Frequency (GHz) RF	LO	IF	LO Power (dBm)	Conversion Loss (dB, Typ.)	Input IP3 (dBm, Typ.)	Fundamental LO-RF Isolation (dB, Typ.)
SYSMM2X2335	23.67–35.33	11.385–17.665	.04–.230	13–15	12	+15	50
SYSMM3X2640	26.5–40	8.8–13.3	DC–.5	10	10	+15	40

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amplifiers were the star attraction for **TriQuint Semiconductor**. These advanced design amplifiers are part of the company's continuing commitment to meet customers' market-specific high frequency signal amplification needs while also providing smaller, lower cost alternatives compared to previous-generation products.

A new thin film innovation has been announced by **UltraSource**. By eliminating the need for a wirebond, or an air bridge, this consistent, reliable, cost-effective solution called UltraBridge is a useful design option for circuit designers at high frequencies.

Universal Microwave Corp. announced its new RoHS-compliant, octave-band oscillator (model UMZ-1601-A16-G) that operates in a frequency range from 800 to 1600 MHz and features low phase noise performance of –100 dBc/Hz at 10 kHz offset from the carrier over the 800 MHz bandwidth. Operating with a 10 VDC supply while drawing 25 mA (typical) over the temperature range of –40° to 85°C, model UMZ-1601-A16-G is suited for applications requiring signal stability, tuning linearity and low phase noise performance across a wide frequency range.

Vector Fields introduced a new variant of Concerto,™ its advanced RF and microwave design software. ConcertoES™ offers 3D Finite Difference Time Domain (FDTD) analysis at a fraction of the cost of the full version, but with no compromise to performance or accuracy.

The availability of a leading range of connectors that meet or exceed MIL-PRF-39012 performance requirements was announced by **Vitelec**. The company also announced that it is making a range of high performance SMK connectors, specifically designed for demanding applications, available throughout Europe. The range includes hermetically sealed, field replaceable components and is ideally suited to, among others, military and aerospace applications.

W.L. Gore & Associates has extended on-line capabilities building on the success of last year's launch of the cable configurator. Newly available is the GORE™ Microwave/RF Assembly Builder, an online interactive design guide that provides simple step-by-step instructions for configuring GORE microwave/RF cable assemblies.

Last alphabetically, but not least, **Z-Communications** announced the introduction of a high linearity power amplifier (5 W average) for emerging 802.16 WiMAX base station applications. The first in the series of power amplifier products for WiMAX, model ZPA3436-5W operates over the 3.4 to 3.6 GHz band with a typical gain of 46 dB and 37 dBm OFDM output power for 64 QAM, 3/4 coding, 3.5 MHz channel bandwidth, 256 carriers.

SOCIAL EVENTS

The organisers of European Microwave Week always endeavour to create a balance between business and pleasure through a wide variety of social events and Manchester was no exception. On Monday, EuMIC celebrated its inception with a Reception and Dinner sponsored by Filtronic Compound Semiconductors at the magnificent Manchester Town Hall, with the Lord Mayor of Manchester as honoured guest. The Town Hall was again the venue for the QinetiQ sponsored EuRAD Conference Dinner in the magnificent neo-gothic Banqueting Room on Thursday.

It was more sporting than historical on the Tuesday when the EuMW Gala Dinner was held against a background of football legends and memorabilia at Old Trafford Stadium, the home of Manchester United. Not quite legendary but going that way is the EuMW 2006 Welcome Reception, sponsored by Agilent Technologies, EuMA and Horizon House Publications. Held on Wednesday evening it presented the registered conference delegates and the exhibitors participating in the show with the unique opportunity to network and interact.

SPONSORS

The conferences, exhibition and social events would not have been so extensive, varied and successful without the support and encouragement of commercial sponsors, many of which have made specific features their very own in recent years. That is the case with Platinum Sponsors Agilent whose contribution to the Welcome Reception has made it a social highlight. Thanks also to Filtronic for the delegate bags, complete with pens sponsored by Tony Chapman Electronics, WIN Semiconductors for the badge cords and Mician for the visitor bags. The very welcome coffee breaks were sponsored by Mimix Broadband, Avago, Impulse Technologies, MicroMetrics, UltraSource, Emerson Networks and Endwave, while the ever popular Cyber Café sponsored by CST provided a mental caffeine boost and the opportunity to visit (among others) the EuMW web site with its Rohde & Schwarz sponsored banner. Rohde & Schwarz also played a vital part in the conference preparations with its all-important support of the TPC Dinner.

MUNICH 2007

To celebrate its first decade the 10th European Microwave Week returns to the ICM, the International Congress Centre in Munich, Germany, from 8 to 12 October 2007. And where better to celebrate such a milestone than the home of the Oktoberfest, especially as EuMW 2007 follows immediately on from the world famous beer festival. But what have the organisers brewed up for the Week itself? Every effort is being made to provide an intoxicating mix of relevant, incisive and challenging conferences, a strong international exhibition and social events worthy of the EuMW's 10th Anniversary. The Call for Papers has gone out, so if you would like to contribute or just find out more about EuMW 2007, visit www.eumweek.com. ■

THE 37TH EUROPEAN MICROWAVE CONFERENCE (EUMC), 9–12 OCTOBER, MUNICH, GERMANY, IS THE CORE OF EUROPEAN MICROWAVE WEEK 2007, THE LARGEST EVENT IN EUROPE DEDICATED TO MICROWAVE ELECTRONICS. VISIT WWW.EUMWEEK.COM FOR MORE INFORMATION.

RF & MICROWAVES IN ASIA: TECHNOLOGIES AND MARKETS

Asia grabs the headlines when it comes to technological and economic development, but what is the reality? Is the continent an innovative leader or low cost mass producer? And what is its role and influence on the global RF and microwave market? This article attempts to offer some answers.

The rapid growth and hunger for information technology and electronic media has created a 'global village,' as mass communication, combined with a need and willingness to exchange ideas, has 'shrunk' the modern world so that knowledge, expertise, investment and new markets are more easily accessible. Inhabiting a particularly vibrant and fast developing sector of this technological global community is Asia, which is a hub of activity. Here, the more established countries have been innovators and models for commercial development, while the emerging regions offer competition through low cost and large scale mass production. What's more, they also nurture booming home consumer markets eager to gorge themselves on the latest technologies.

The RF and microwave industry has a role to play in satisfying that appetite and the Asia Pacific Microwave Conference (APMC) 2006 in Japan (12 to 15 December) is the perfect platform for it to demonstrate state-of-the-art research and development, and showcase its latest products. Key areas of interest covered include metamaterials engineering, packaging technology, integrated circuit development, millimetre-wave and ultra-wideband technology, mobile communications and wireless applications.

These are the technologies being developed. Where is the innovation coming from in Asia? What are the region's particular strengths and what does the future hold?

This article does not attempt to be a comprehensive market overview but, by considering the commercial and technological environment in which the Asian RF and microwave industry is operating, takes a snapshot of the current status of academic and industrial development and identifies the main trends influencing it. It also provides a commercial perspective as executives from a cross-section of companies operating in the Asian RF and microwave industry contribute to a 'company survey.'

Asia is a vast continent, which is diverse in terms of technological advancement and economic development. Therefore, this article concentrates particularly on the Asia Pacific region and aims to highlight its diversity by contrasting the relatively established countries

RICHARD MUMFORD
Microwave Journal *European Editor*

such as Japan, South Korea and Taiwan with emerging nations like China.

High-tech, state-of-the-art electronics is most synonymous with Asian industry. After the 2001 downturn, a significant portion of electronic manufacturing shifted from the US and Europe to low cost regions of Asia, making it a dominant force. In the RF and microwave field mobile communications and wireless technologies are key areas of activity and product development.

SEMICONDUCTORS

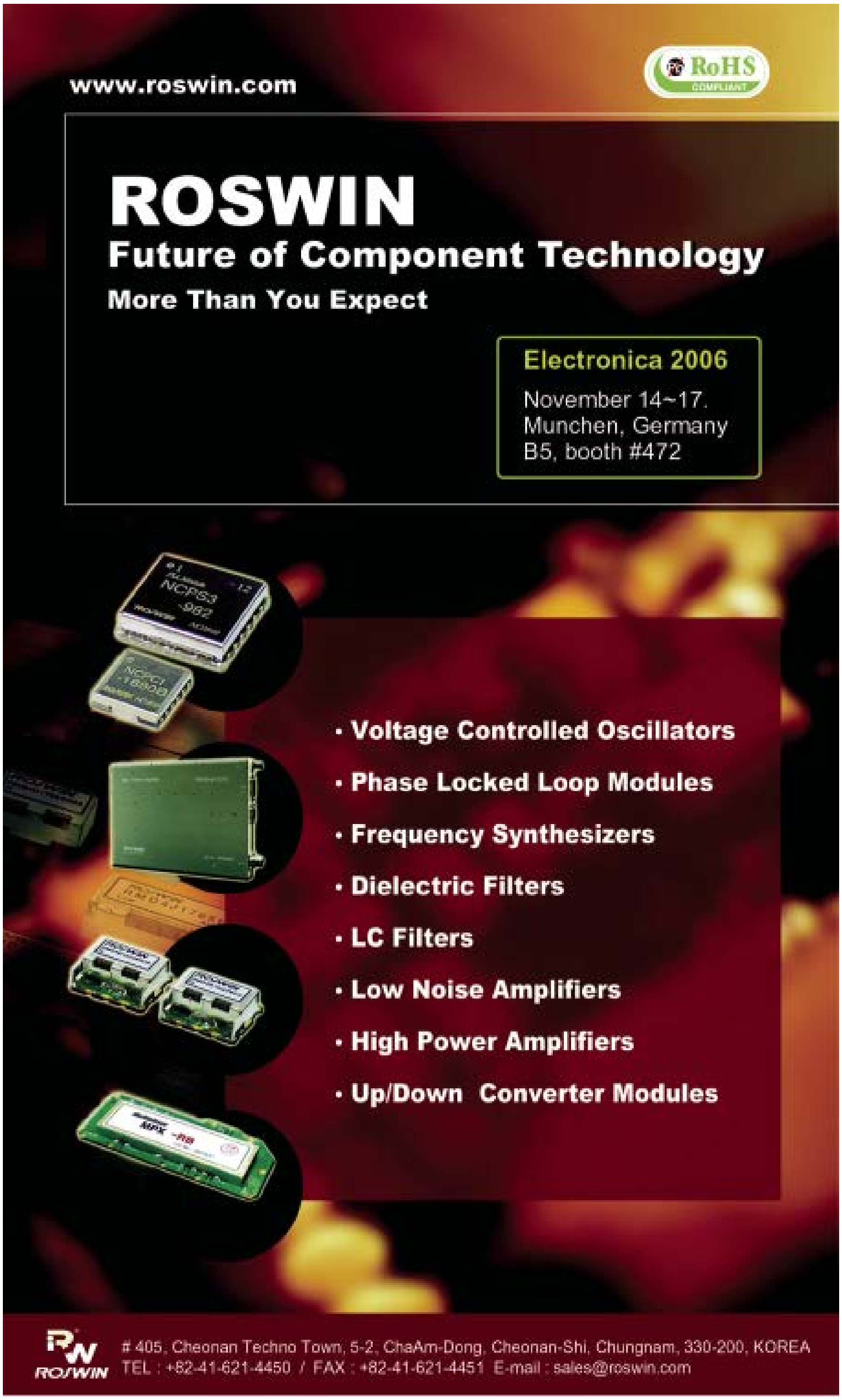
Essential to these sectors is the semiconductor market, an industry where developmental and price pressures have brought about changes in structure, geographical activity and areas of application. According to the 2006 spring forecast of the World Semiconductor Trade Statistics (WSTS), the global semiconductor market is expected to grow 10.1 percent on an annualized basis to \$250 B in 2006, with projected growth accelerating to 11.0 percent in 2007 and 12.8 percent in 2008. Significantly, Asia Pacific is forecast to be the largest and fastest growing regional market, not so much because of a continuing shift in manufacturing due to low manufacturing costs but more in response to rising domestic demand. And with the demand for increasing semiconductor content in electronic products for mobile communications, telecom infrastructures and consumer applications, that growth is set to continue.

It will not surprise many to identify China as the number one growth area globally for both semiconductor manufacturing and consumption as it becomes a prime location for IC design and production. According to a recent In-Stat report, China consumed about 20 percent of total global semiconductor products in 2004, and by 2010 will consume one-third, making it the world's largest semiconductor consumer. Other Asian countries such as India and Thailand are growing rapidly, but not nearly on the same scale as China.

FOUNDRIES

A key determinant of the success of the Asian semiconductor manufacturing market is the strength of the region's semiconductor foundry industry. Technical expertise and production costs are key factors, of course, but global issues have also had an effect with the ITAR export restrictions having helped to accelerate the investment and development of the region's semiconductor foundries. Now, In-Stat reports that of the \$18.24 B global revenue in 2005, \$16.56 B (nearly 91 percent) was contributed by the Asian foundry industry, which itself is dominated by Taiwan. The country has built up foundry capacity to become the world's highest fab density area.

As for Japan, although it was one of the first countries in the region to provide foundry services, the country's well-established semiconductor industry is dominated by major integrated device manufacturers (IDM) that have their own wafer fabs. South



Korea is emerging as a foundry source to serve its well-developed semiconductor manufacturing infrastructure and is in a strong position to reduce the cost of logistics and improve supply chain management by offering a complete turnkey manufacturing solution.

China too has proved that it has serious intentions to be a leading force, having established foundries whose aggressive technology development and pricing is putting pressure on more established foundries. The country's IDM and foundry players are expanding their production capacities, with price advantages and emerging domestic fabless companies having an impact.

WIRELESS TECHNOLOGIES

The Asia Pacific wireless telecom industry is set to grow from $159.97 B in annual revenue in 2005 to $242.42 B by the end of 2010, reports In-Stat. In 2005, there were over 859.4 million wireless service subscribers in the region, a total that is expected to reach 1.57 billion in 2010. The overall subscriber penetration rate for the region was about 25 percent in 2005, varying from 6.8 percent (India) to 115 percent (Hong Kong).

The region has been the flagship for 3G roll out with Japan and South Korea being ahead of the rest of the world in introducing new handset and service capabilities. They were the first markets to launch 3G services and are currently the only countries to have achieved mainstream adoption of 3G. In Japan, in 2005, about 40 percent of subscribers used 3G networks only and it is expected that 2006 will see the transition from 2G to 3G be largely completed. South Korea is not far behind.

3G is one area where China has been slow off the mark with 3G licenses, for which foreign carriers will not be allowed to apply, and are not expected be issued until late 2006 or early 2007. However, both Chinese officials and industry executives have stated they want 3G in place in time for the Beijing Olympic Games in August 2008.

The Asia Pacific region has always been an active test bed and open market for new technologies and it is taking the lead in WiMAX development where it has the largest number of WiMAX subscribers. However, most WiMAX deployments are still in a trial phase providing only high speed Internet service, although in the future the largest markets for WiMAX will be for mobile applications. At present South Korea and Taiwan are particularly active in this sector.

Moving on to infrastructure, in relation to the point-to-point business, there is significant activity in Asia Pacific where cellular infrastructure is the optimum solution to interconnect mobile base stations. This is due to minimal existing fibre optic/leased line infrastructure and also the large distances that often need to be covered.

AUTOMOTIVE

In the RF and microwave field, the mobile handset sector may be the largest single product market for semiconductors outside the PC market, but others are significant too. For instance, the automotive semiconductor market is creeping up to 10 percent of the total semiconductor market. Growth in this sector is forecast to continue as technological advances are made with regards to telematics, infotainment, vehicle networking and inter-vehicle networking. Another key area of development is in automotive radar systems, particularly at 77 GHz with the aim of dramatically reducing road injuries and fatalities.

The automotive electronics market in Asian countries is booming, as consumers demand everything from vehicle entertainment to on-board navigation systems. In China alone, the domestic market for vehicle entertainment and navigation systems will be worth at least $4 B by 2013, according to a report by Strategy Analytics.

It states that for international automotive infotainment system suppliers, China offers opportunities to reduce component and system production costs, to increase access to international Chinese vehicle OEM joint ventures, and to respond to the growing domestic Chinese OE market. There are also significant cost containment opportunities for any international electronics system vendors willing to invest locally. Interestingly, Japanese vendors are currently leading this field.

COMPANY SURVEYS

Technologically and economically, the above briefly sets the context in which the Asian RF and microwave industry is currently operating, but how are the different technology sectors and individual companies faring in this environment? To provide insight into current market conditions and technological development, a commercial perspective is offered via a 'company survey' of executives from companies representing a wide cross-section of the Asian RF and microwave industry. The format is generally a brief overview of the company's activity, followed by comments on technological and market initiatives.

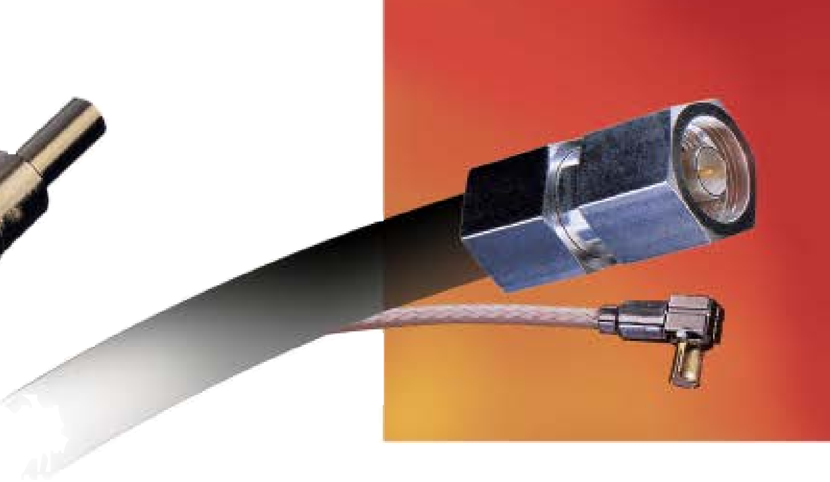
JAPAN

Kyocera

Part of the Kyocera Group's stated philosophy is to "Create. Change. Grow. Think creatively; execute logically. Innovate consistently and grow steadily. By building on creative thinking, we can create value for society."

That thinking is evident in the RF and microwave field, where the company manufactures and supplies custom-design ceramic packages (aluminium oxide, aluminium nitride and low temperature co-fired ceramics). Its current activity is vast, focussing on: ceramic packages for SAW filters, crystal oscillators, duplexers, power amplifier modules, front-end modules, Bluetooth® modules, wireless LAN modules, TV tuner modules, satellite communication devices, point-to-multipoint radio communication devices, 24 GHz security devices and LDMOS/GaAs RF power devices. The company also develops ceramic packages for millimetre-wave applications such as 60 GHz wireless LAN and 77 GHz automotive radar applications.

Its approach is a worldwide one, manufacturing and supplying custom-design devices to fit the specific need and application rather than developing products for different geographical markets. It believes in capitalising on its strengths and sees Asian manufacturers in general doing the same, being particularly strong in the field



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of miniaturization of RF modules for mobile phone applications.

Kyocera is currently seeing significant activity in the development of wireless LAN modules, TV tuner modules, 77 GHz automotive radar and GaN RF power devices. The company envisages that the technologies that will fuel the growth of the RF and microwave industry in the future will be ultra-wideband (UWB) and RF-MEMS.

SOUTH KOREA

RFHIC

In the RF and microwave sector, RFHIC's main activities are making multi-chip module (MCM) components for 3G, 4G, base transceiver station (BTS) and repeater markets, with the aim of providing a total solution for customers. A particular highlight of current activity is the company's use of GaN technology to develop high power amplifiers that are two-stage hybrid or pallet for wide bandwidth applications. Significantly, this development will help to minimize the number of base transceiver stations, since one power amplifier covers several frequencies, that is, DCS, PCS and UMTS all in one PA.

The company takes a worldwide approach to product development. However, because each geographical region has its own priorities and technological emphasis, the company has a network of representatives globally whose job it is to cater to the needs of their particular region.

For instance, in Europe, the main emphasis is on companies focussing on base station development. In Korea, Japan and other Asian countries, companies develop products based on the custom-made module due to the highly successful repeater market. In the US, however, the focus is on the development of the low noise amplifier (LNA), up-down phase-locked loop (PLL) synthesizer, divider and power amplifier used for WiMAX systems.

Today's telecommunication market requires fast paced development, production/manufacturing and mass production. RFHIC believes that Asian companies have the ability to react to this rapidly changing market and quickly move from development to production. Also, Asian companies have the resources that make it possible for customized multi-chip module (MCM) products to be developed and manufactured at low production costs.

From a technological point of view, the company sees its market sector being stimulated by the introduction of the GaN device. In particular, it will lead to the reduction in the size of the wideband, WiMAX (PCS + WCDMA or cellular + UMTS), base transceiver station (BTS) and repeater, the lowering of maintenance costs and the realisation of high speed data communication, which opens up new market possibilities.

In the next few years, the company predicts the development of simple devices, with MMIC technology becoming easily available. It sees partners having to work closely together to develop products at a pace that reflects the practicality of new technology adoption. In particular, RFHIC

sees the future expectation of the RF market to be in custom-made MCM technology and hybrid power amplifiers using GaN devices.

TAIWAN

Chin Nan Precision Electronics

As an ISO 9001 registered manufacturer, Chin Nan has been providing interconnect products to the RF and microwave industry since 1965 and its main operating principles are clarity and stability. Its key areas of activity are RF connectors and cable assembly products. Quality and reliability are built into each product by design and the company maintains the integrity of the design with strict process controls from initial procurement and machining of raw stock through assembly, final test and packaging.

Chin Nan can provide products in the frequency range from DC to 40 GHz, due to the utilisation of precision equipment and microwave network analysers that can operate at up to 60 GHz.

The company operates worldwide but attempts to adapt to the specific requirements of each region according to customer needs and market demands. It is continually on the lookout for partners and distributors outside Asia. Chin Nan recognises that in today's competitive global marketplace, quality, on-time delivery and overall value is vital to its diversified customer base. In general, the company's view is that the strengths that Asian manufacturers bring to the market place include design capability, quality, price and short lead times.

In its specific field of operation, Chin Nan is seeing technological development of wireless communications and the RF measurement moving at a rapid pace. It believes that the move towards higher frequencies will be significant in the future.

RFIC

In 2001 the RF Integrated Corporation (RFIC) established its Asia Pacific operation site with a well equipped R&D centre in Taiwan. This was followed in 2004 by the opening of an R&D and marketing coordinating centre in Beijing, China, with the aim of combining the Taiwan and China development resources to enable the company to speed up market and product integration in South Asia.

Based on advanced HBT/PHEMT, RF COMS and SiGe technologies, the company develops its own products and in particular is a pioneer in proprietary RFIC design and manufacturing for wireless communication applications such as WLANs, cellular, PCS mobile handsets and base stations. Currently, the company has introduced a full line of power amplifiers for WLAN 802.11a/b/g and Bluetooth applications as well as the new product lines for CDMA, GSM/GPRS, PHS handset and optical fibre communication components.

The company offers its products globally and its approach to marketing does not vary for different geographical markets. There is no need as the product is a wireless communication component that is used in everyday life in such devices as cell phones and PCI, so the method for developing the product is the same worldwide. The only geographical consideration is that technological requirements might differ because of the frequency and or power required in a specific band or the input/output power, which results in some product adjustment for specific regions.

Looking at Asian manufacturing as a whole, RFIC sees its specific strength as being its price competitiveness, which is enabling it to make significant inroads into global markets. As for the company itself, it has distributors outside Asia but is still looking for more in order to stimulate further growth.

CHINA

HT Microwave

The company was established in 1992 and is a leading manufacturer of RF components, specializing in digital cellular telecommunication systems. As an independent, privately owned, high technology enterprise, HT Microwave has unique technical strengths in microwave technology research and RF and microwave components. It employs high level technologists and prides itself on its research links with major universities.

The company offers active and passive components for radar and communications. It manufactures its own products and also others under licence. It can design and, if required, supply custom components, products and complete system solutions to specific customer requirements.

HT Microwave operates worldwide with its philosophy to work closely with customers to supply products that specifically meet their requirements. It believes in strong alliances and is looking for partners and distributors that it can work with globally.

The company also sees it as important to get its message and products to a wide audience in a focussed way. Therefore, its strategy is to target key exhibitions, particularly in the microwave industry, including the annual IEEE MTT-S and European Microwave Week, as well as specific International Telecommunications Union (ITU) events.

Tiger Micro-Electronics Institute

Tiger manufactures passive and active RF and microwave components. The company's passive components include power dividers/combiners, directional couplers and 90°/180° hybrids, circulators/isolators and filters. Active components include frequency synthesizers, mixers, DROs and amplifiers. Using these components, the company also manufactures and assembles subsystems.

The passive components are the company's mainstay. Tiger is able to take advantage of China's basic industrial base and the low cost of technical labour to produce high performance, reliable products at low prices. It is also forging partnerships and has recently joined Ericsson's global business chain.

The company operates its business worldwide, with North America and Europe being the main areas of activity and its philosophy is to adapt to specific regional and customer requirements. Particularly in Europe, Tiger believes it needs to consider trends and statistics to be able to forecast and develop products that can satisfy the market in large quantities. Up until now, the company has been developing its own products, but in the future may well manufacture under license from Europe.

When considering the specific strengths that Asian manufacturers bring to the marketplace, Tiger believes that technical expertise and

good quality control leading to good reliability combined with low prices, offer a competitive edge in the global marketplace. Also, due to cooperation with Europe and America, the appearance and packaging of Asian products now meet the required international standards.

As far as new developments are concerned, Tiger identifies high density MIC technology as being an area of growth. It also sees the expansion of wireless communications systems such as 3G, WLAN and WiMAX fuelling the development of the RF and microwave industry over the next few years.

CONCLUSION

Asia Pacific has become a strong and influential force in the electronics market. For the RF and microwave industry, it is the mobile communications and wireless technologies sectors that are seeing the most benefit and growth, particularly in the efforts to achieve greater capacity and larger bandwidths. Based on a foundation of strong foundry businesses, the region's semiconductor manufacturing industry dominates the global market, which, in turn, benefits the region's component, system and subsystem developers. 3G technologies are at the forefront of global development, while WiMAX is potentially a growth development area as is the automotive sector. Millimetre-wave, ultra-wideband and RF-MEMS are technologies to keep an eye on as well.

The established industries of Japan, South Korea and Taiwan profit from high levels of technical expertise, strategic investment and rapid times to market. Emerging nations, particularly China, offer competition through low cost and large scale mass production. Additionally, the region's home markets have a ravenous appetite for the latest technologies and the economic conditions to feed it. China is a prime example, with an industry that is rising at a meteoric rate, helped by governmental support. They are becoming more open but have received some criticism for protectionism.

The Asia Pacific market is one that the rest of the world is also eager to exploit. Foreign companies in North America and Europe in particular have identified the potential and have acted by forging alliances and setting up joint venture manufacturing and marketing ventures, all of which is adding to the mix of a vibrant region. ■

ACKNOWLEDGMENTS

The author would like to thank the company executives who shared their in-depth knowledge and expertise. Their contributions have given a rare insight into the Asia Pacific RF and microwave industry. Thanks also to the companies below for sharing their statistics on the market:

WSTS (www.wsts.org); In-Stat (www.instat.com); Strategy Analytics (www.strategyanalytics.net).

NEW DESIGN METHODOLOGIES FOR HIGH PERFORMANCE RF CMOS

CMOS technology continues to gain market acceptance for high performance applications due to the combination of low cost, high level integration and availability. As a result, more engineers are experimenting with CMOS processes and customizing new methodologies to integrate RF, analog and digital circuits in a single chip. The ability to integrate more functionality in CMOS leads to larger transistor counts and more complex circuit topologies. These larger, mixed-signal circuits can cause traditional simulators to experience convergence failures and/or reach practical limitations based on simulation speed. Design success is further complicated by the need to accurately characterize critical on-chip passive components fabricated on lossy semiconductor substrates operating at higher frequencies. Therefore, new simulation tools and methodologies must be adapted in order to successfully implement RF designs in CMOS for today's wireless standards. This article examines these challenges as applied to high performance CMOS RFICs, specifically addressing electrical modeling, circuit simulation and specific design flow requirements.

PASSIVE COMPONENT MODELING AND SYNTHESIS CHALLENGES

Given the lossy nature of the silicon substrates used in CMOS processes, a sizable engineering effort is focused on reducing the substrate coupling which causes poor electrical performance. Due to their relatively large substrate area, on-chip inductors are particularly prone to substrate coupling. Inductor reactance and Q are critical in establishing the overall performance of low noise amplifiers, oscillators and other impedance-tuned circuits. By reducing substrate coupling, higher Q inductors can be obtained. Substrate coupling is reduced through a variety of novel structures and processing techniques, including pattern ground shields, deep trenches, and suspended and vertical trace metal construction. In addition to these various structure types, inductor performance is also

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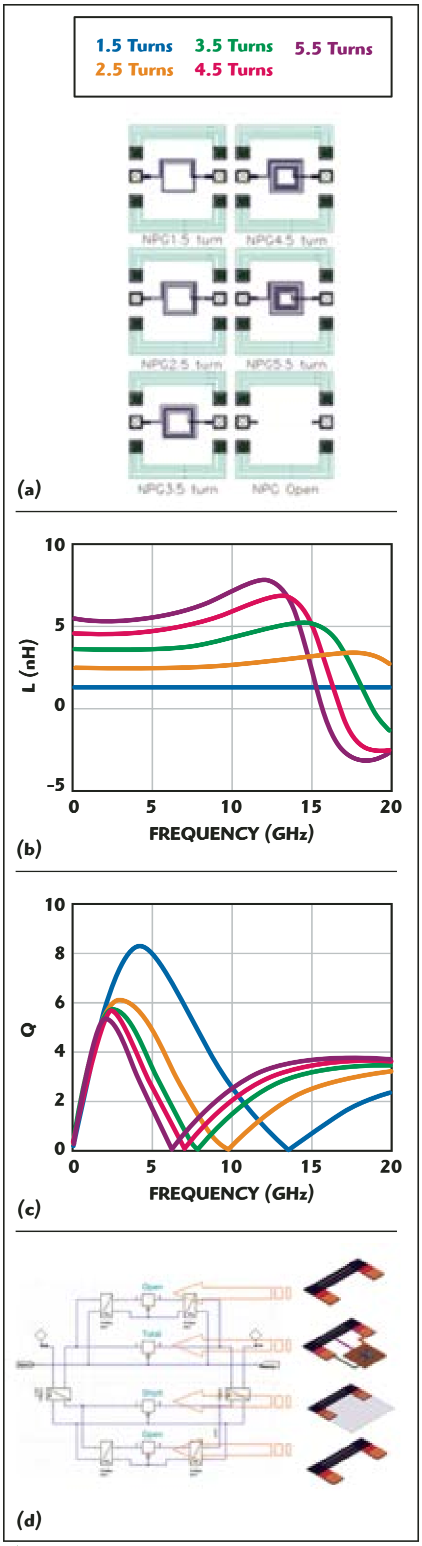

▲ *Fig. 1 Spiral test patterns with ground rings (a); inductance per number of turns (b); Q per number of turns (c); and a de-embedding technique to remove ground ring effects (d).*

determined by line width, spacing, outer radius, number of turns, shape (square, hexagonal, octagonal, circular...), metal layer material, etc. The potential number of geometric variations is too large to implement a component model library database practically through fabrication and measurement-based characterization. The lack of accurate and scalable models for on-chip spiral inductors presents a challenging problem for RFIC designers. Fortunately, 3D electromagnetic (EM) simulation provides a proven method for characterizing any arbitrarily shaped on- or off-chip structures.

Ansoft's full-wave 3D EM simulator, HFSS, was used to characterize a series of square spiral inductors that had been fabricated for use as test patterns. The inductor shape, outer diameter, line width and spacing were held fixed while the number of turns was varied from 1.5 to 5.5 turns, in one-turn increments. To reduce the amount of engineering time required to draw these inductor variations, it is common practice to develop a parameterized component footprint or P-cell using the layout tool of choice and the appropriate scripting language. Three independent methods were employed for generating a parameterized HFSS inductor in order to demonstrate design flow flexibility.

The first approach implemented the structure directly in HFSS using the 3D modeler, parameterization of geometric properties and user-defined primitives. The HFSS parameterized inductor was then used to generate S-parameters imported back into the circuit simulator of choice. With this approach the EM simulator and layout structures are independent and the user must work to ensure faithful representation. The second method applied Ansoft Designer's footprint editor and scripting capability to create a parameterized layout structure and stack-up that could be automatically exported into an extruded 3D HFSS object. The parameterized HFSS structure can then be dynamically linked back into the circuit simulation, saving manual effort. The third approach used Ansoft Designer to import a GDSII file from a single instance of P-cell that was generated using the Cadence Virtuoso IC layout tool along with the corresponding layer map file containing the stack-up information. Ansoft Designer then exported the extruded structure into HFSS and the resulting S-parameters were used in the circuit simulator of choice. This approach takes advantage of existing design tools and scripted P-cells but is generally more manually intensive, especially when numerous parametric permutations are to be applied. ***Figure 1*** shows the spiral inductor test patterns, which include the inductor, a ground ring and wafer probe launch pad. The values of inductance and Q are plotted as a function of frequency and number of turns. As the number of turns increases so does the substrate coupling, leading to a decrease in the value of maximum Q. The simulation also shows the inductance value increasing with the number of turns except at higher frequencies where a parasitic capacitance begins to dominate the structure's overall reactance. Much of this parasitic behavior is related to the capacitive coupling between the ground ring and the actual inductor. Since the ground ring is only present for performing measurements with test probes and would not be present in the actual circuit, it is advisable to characterize the ground ring separately and de-embed its behavior from the measured results. When comparing EM simulation to measurements, it is imperative that the measured and simulated structures are faithfully replicated. Therefore, the effect of the ground ring must be removed from both the measured and simulated results. This is accomplished by using an Ansoft Designer schematic to de-embed the S-parameters obtained for the open-circuited ground ring from those obtained for the entire structure. After de-embedding the effects of the ground ring on the spiral inductance, the measured versus EM simulated results for inductance, Q and impedance of a 3.5 turn spiral shows excellent agreement, as shown in ***Figure 2***. The agreement between the measurement and EM simulation validates the representation of the CMOS physical structure in HFSS and allows the engineer to perform additional electrical modeling for any geometric variation without the need for physical prototyping. In fact, the reliability, efficiency and cost savings of EM simulation in RF, microwave and high speed design over a manufacture and test approach has led to its widespread adoption. Recent de-

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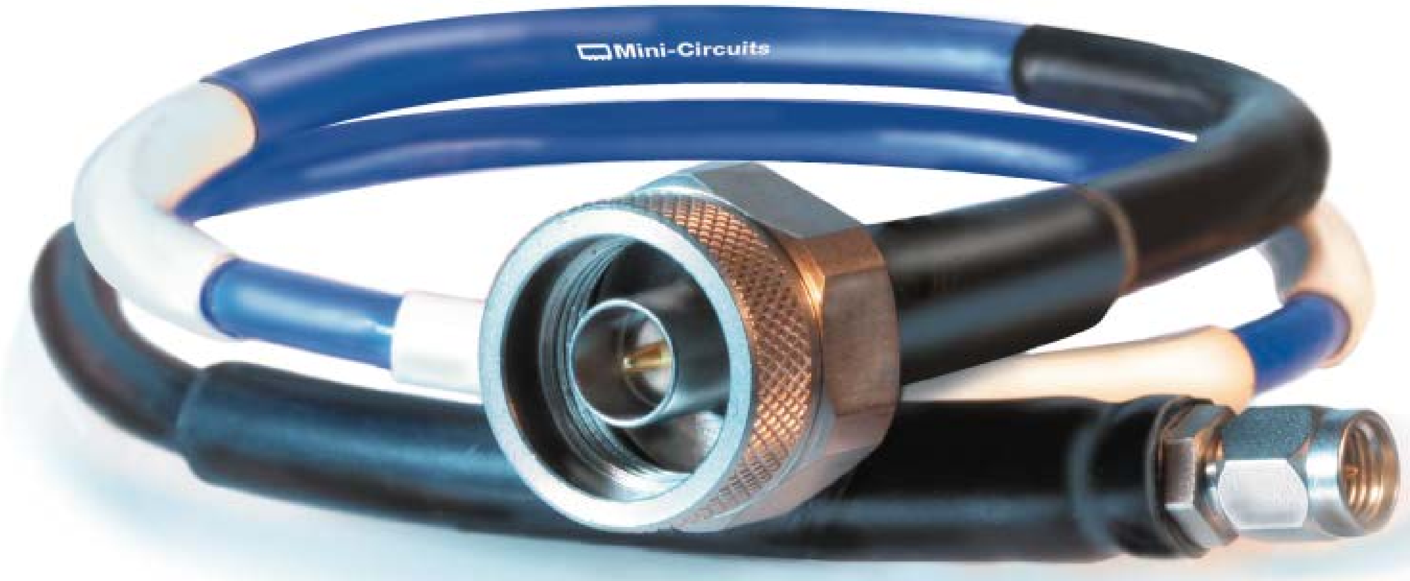

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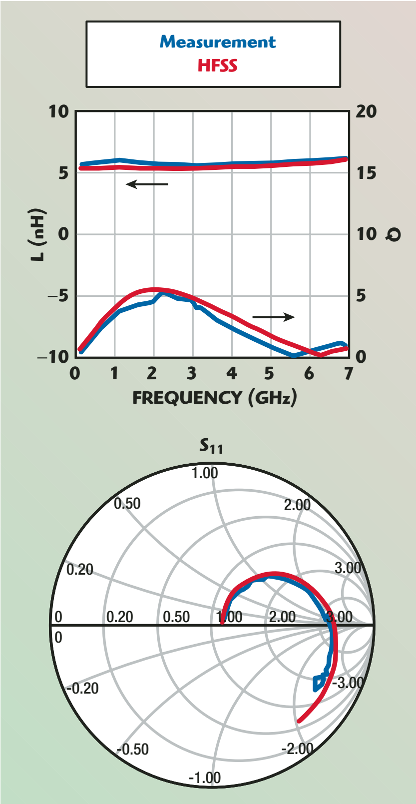
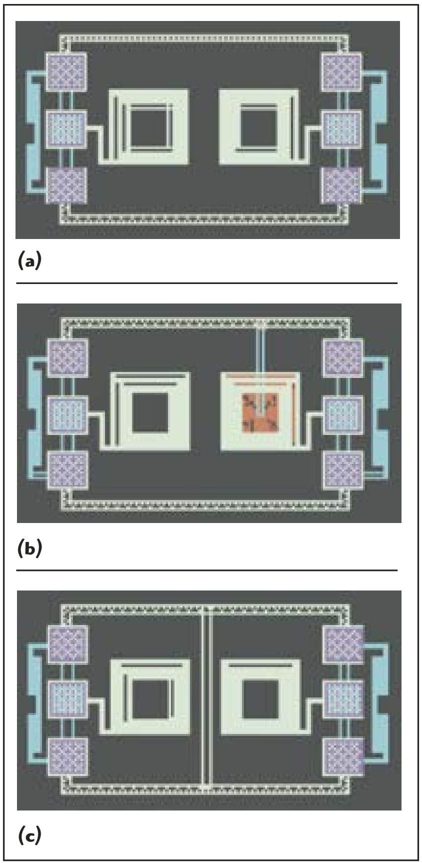


▲ *Fig. 2 Comparison between HFSS simulated and measured results for a 3.5 turn inductor.*

sign automation, exemplified by the implementation of an EM-based design flow, specifically addresses the need for scalable passive models. EM simulation combined with parameterization and distributed computation of parametric analysis helps design teams generate a practical IC passive component library quickly and efficiently. Alternatively, engineers can modify and characterize passive components "on-the-fly" via dynamic co-simulation. With the resulting electrical models incorporated into the circuit simulation via dynamic co-simulation, designers can parametrically "tweak" components for more flexible and accurate "what if" analyses of the overall design.

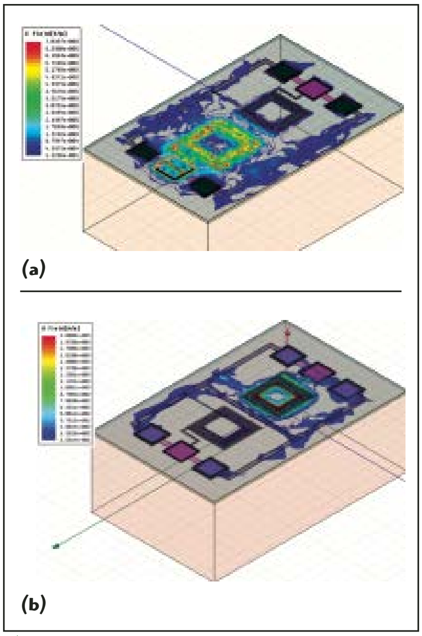
ON-CHIP COMPONENT COUPLING

The next consideration for RF design on CMOS involves the electromagnetic coupling (or isolation) between basic structures, namely metal pads, traces and spiral inductors implemented with a CMOS process. Electromagnetic simulation was again used to characterize the IC performance and to develop design guidelines regarding minimum passive component spacing in order to avoid proximity effects. Through EM analysis, the isolation characteristics of guard rings and pattern ground shield (PGS) layers for cross-talk suppression between RF blocks was investigated. This particular study examined the coupling between two planar spiral inductors when no isolating structure was used (a) and when either a PGS layer (b) or ground guide (c) isolation design was employed. The layout of the test patterns for the three cases is shown in ***Figure 3***.

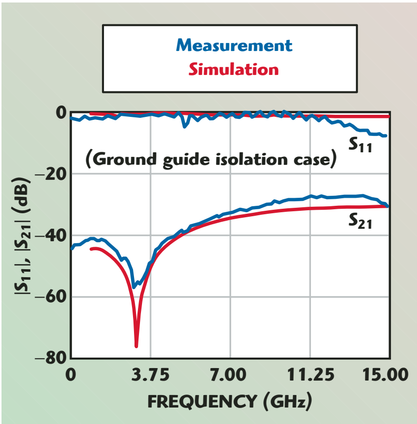


▲ *Fig. 3 Test patterns for coupled spiral inductor investigation.*

Field visualization of the structure in HFSS reveals how the E and H fields couple (at a sample frequency of 5 GHz) inside the silicon dioxide layer and the silicon substrate layer. From the field intensity plots, one quickly recognizes that the ground guide isolation has a profound effect on reducing the energy that is coupled from one inductor to a neighboring one, as shown in ***Figure 4***. Comparing the S-parameters from the three different configurations confirms the improved isolation offered by the ground guide (outside of the 6.75 GHz resonance observed with the non-isolated and PGS layer structures). A designer's guide would use this information to target improved isolation between passive components and recommend the inclusion of a grounded guide or minimum component spacing. Again, measurements of the ground guided inductor pair shows excellent agreement with the EM simulation, as shown in ***Figure 5***.



▲ *Fig. 4 Study of coupling between adjacent spiral inductors; (a) no isolating structure and (b) ground guide isolation.*



▲ *Fig. 5 Isolation (S_{21}) and return loss (S_{11}) of the measured and simulated coupled spiral inductors with ground guide isolation.*

HIGH PERFORMANCE RF DESIGN IN CMOS

At this point, further tool requirements for RF design in CMOS are examined with a specific circuit block example. The architectures employed

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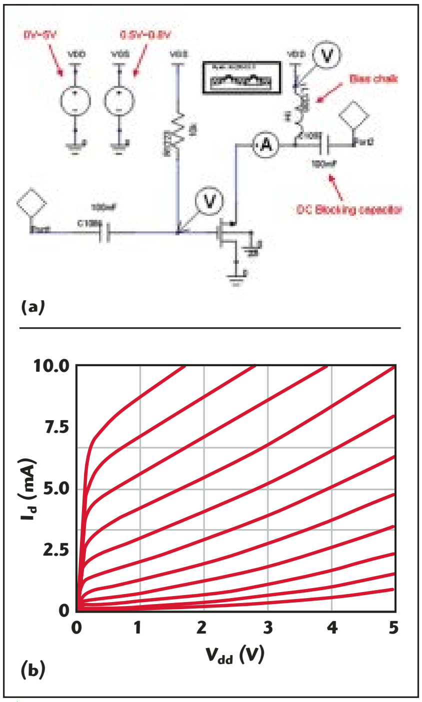
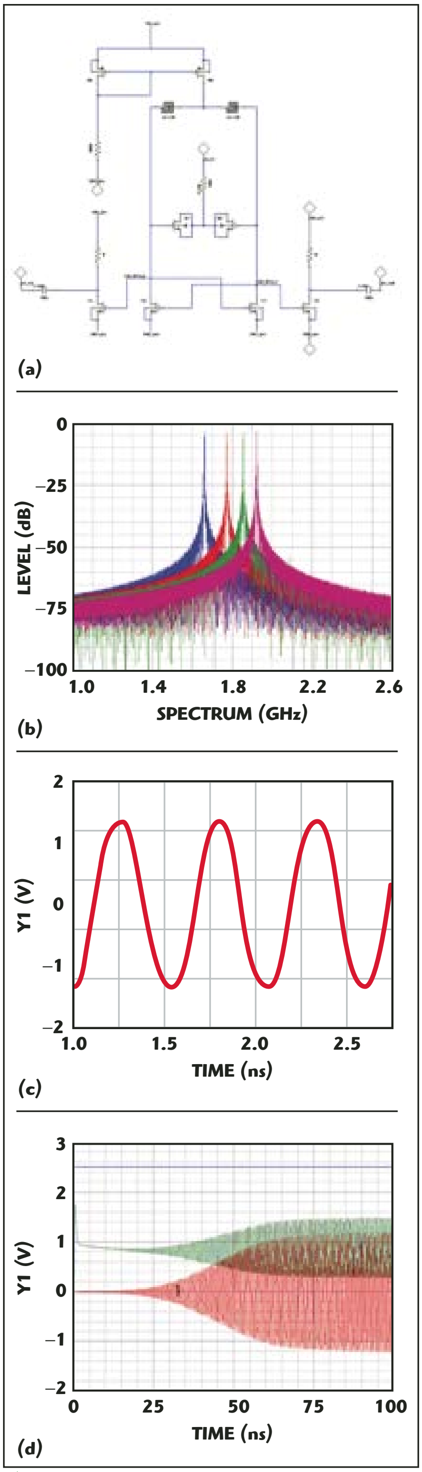


▲ *Fig. 6 Schematic for biasing the test MOSFET (a) and IV characteristics (b) of a 10 μm by 40 finger MOSFET with a 0.25 μm channel length.*

in today's communication systems often require sources with fast settling times and low phase noise in order to provide the agile, high quality signal fidelity called for by the latest wireless standards. These RF sources are being addressed by a new generation of frequency synthesizers. At the heart of these frequency synthesizers and phase-locked loops is a voltage-controlled oscillator (VCO). Implementing a VCO in CMOS allows a single chip solution and the potential to save millions of dollars during large-scale production. New simulation, modeling and design automation technologies are utilized in the following CMOS-based VCO. The VCO will be fabricated with a standard 0.25 μm CMOS process. A circuit schematic for a single MOSFET biasing circuit is created in order to determine the I-V characteristics of the transistors that will be used in this design (see ***Figure 6***). The actual VCO circuit topology is shown in the schematic of ***Figure 7***. Note that in this phase of the design, the circuit is represented only by foundry models for the RF-MOSFETS as well as ideal models for the MIM capacitors, spiral inductors and thin-film resistors. Components are connected with ideal "wires," initially disregarding



▲ *Fig. 7 Time and frequency domain simulation of an ideal VCO; (a) schematic; (b) spectral plot of fundamental frequency outputs; (c) voltage output waveform and (d) start-up performance.*

the contribution of interconnecting trace metals (transmission lines) on circuit behavior. The "ideal" circuit will guide engineering decisions concerning proper device scaling, biasing and tuning for the desired output frequency, phase noise and other key

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Output options:	
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Divider Option	5.5 - 1050 MHz
Bandwidth:	700 MHz
Step Size: 1 Hz	
Internal Reference	
Options:	
TCXO Specifications	12.8 MHz
Temperature Stability	±1.5 x 10^{-6}
Aging first year	±2 x 10^{-6}
Operating Temp. Range	-10 to +60 °C
(With freq. adjustment through voltage control pin)	
OCXO Specifications	13 MHz
Temperature Stability	±2.0 x10^{-8}
Aging first year	±1 x 10^{-7}
Operating Temp. Range	-10 to +70°C
Warm-Up Time:	10 min.
Additional Current Consumption	500 mA (warm-up)
After warm-up	200 mA (continuous)
External Reference Input:	10, 12.8, 13, 19.44 MHz and multiples thereof
Bias Voltage:	VCC: +13 VDC (±3 V)
Supply Current:	<800 mA @ 13 V
Bias Voltage Ripple:	100 mV p-p (Max)
RF Output Power:	(w/amp. option) +10 dBm (Min)
When Unlocked:	≤20 dBm
Spurious Suppression:	-65 dBc (Max)
Harmonic Suppression:	
Amplifier/Filter option	15 dBc (Min)
Divider option (Full range model)	8 dBc (Min)
(Octave band in divider range)	15 dBc (Min)

Maximum Phase Noise

Offset	Frequency: 350 MHz (dBc/Hz)	Frequency: 1050 MHz (dBc/Hz)
100 Hz	-108	-100
1 kHz	-110	-102
10 kHz	-115	-110
100 kHz	-115	-115
1 MHz	-140	-140

Switching Speed:	
Per programming step:	≤8 mSec
After Turn-on	<1 Sec
Output Impedance:	50 Ohms (Nom)
Operating Temp. Range:	(See reference option)
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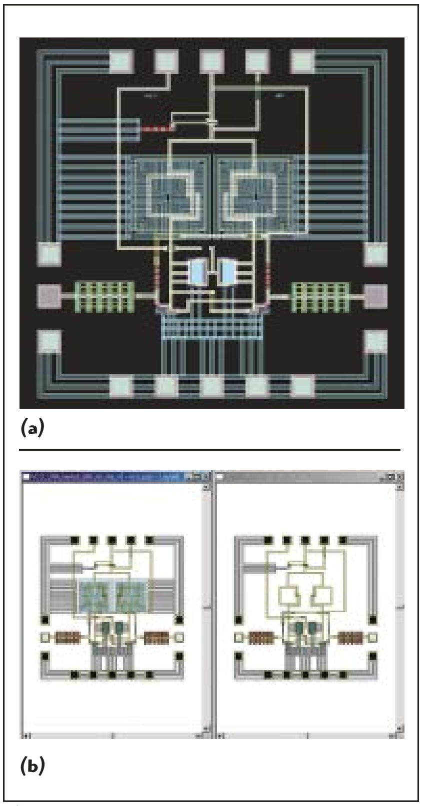
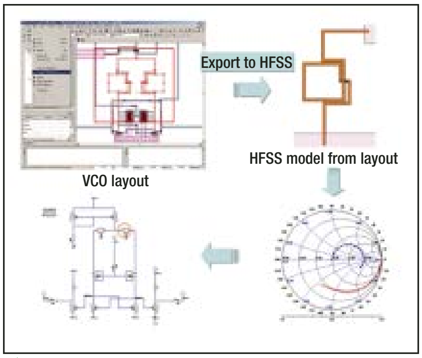
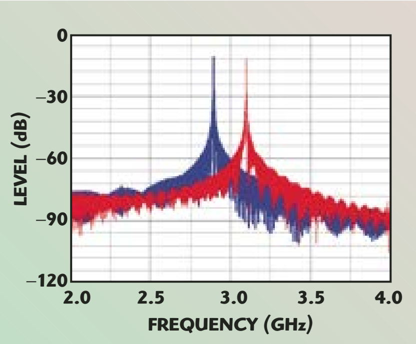


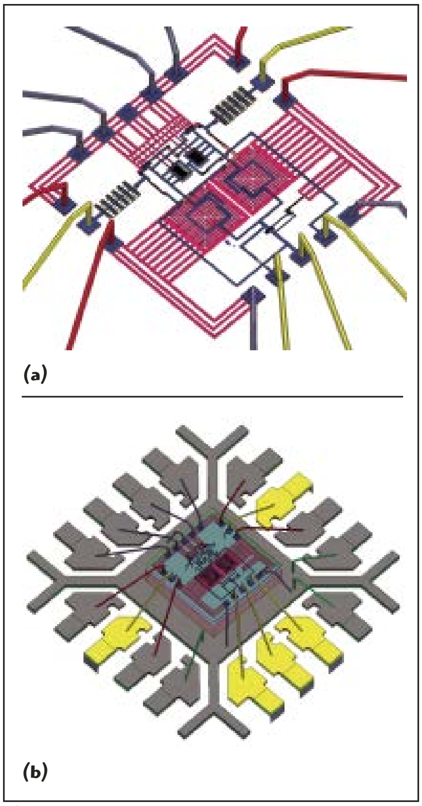
▲ *Fig. 8 VCO layout in (a) Cadence Virtuoso and (b) Ansoft Designer.*



▲ *Fig. 9 Incorporating HFSS spiral inductor into the VCO design.*



▲ *Fig. 10 Spectral response of the VCO, highlighting the frequency shift due to the spiral inductor parasites.*



▲ *Fig. 11 3D view of the IC layout in HFSS (a) and the IC and package in HFSS (b).*

performance metrics. Prior to fabrication, it will be critical to replace the ideal models with the more accurate EM-based models and make the fine adjustments to the circuit design that are needed to compensate for performance shifts attributed to device parasitics. Several key results from the preliminary design are shown in the figure. Using the Nexxim circuit simulator from Ansoft, the spectral response of the VCO can be simulated and plotted, capturing the output frequency and power level at four different tuning voltages, the steady-state voltage-wave output as well as the transient start-up behavior. Nexxim's harmonic balance simulator provides a faster, more efficient broad spectrum analysis of spurious harmonic output than is possible with a traditional time domain or periodic steady-state (PSS) simulation, which would have to sample fine time steps over a long period in order to capture the full-spectral response. With the initial design providing the desired performance, the ideal components are replaced with their EM counterparts and the circuit layout is performed. Several tool choices are available to the design team when it comes to generating the layout. Considerations include tool availability and the existence of a foundry process design kit (PDK) including component P-cells. This particular design was implemented in the Cadence Virtuoso IC layout editor as well as in the Ansoft Designer layout editor (see ***Figure 8***), the former providing an advantage when subsequent EM co-simulation is required for design verification. It is recognized that the spiral inductors in the LC-tank circuitry will have a sizable impact on performance; therefore, the performance shift due to the inductor behavior is first examined. Several different methods for incorporating the spiral model data into the circuit are available to the designer. While the HFSS generated spiral inductor model could be imported into any circuit simulator which supports S-parameters or Ansoft's Full-wave SPICE model, this example took advantage of the dynamic co-simulation between HFSS and Nexxim. The full-parameterized HFSS project containing the spiral was inserted into the Ansoft Designer schematic (see ***Figure 9***) and Nexxim was used to simulate the shifted performance, as shown in ***Figure 10***. The two 1.5-turn inductors led to a 200 MHz shift in oscillation frequency.

DESIGN VERIFICATION AND MEASURED RESULTS

Verification of the entire IC requires the simulation of all critical performance metrics, operating conditions and process variations using a circuit model that includes all critical parasitics. For this final stage of analysis, Nexxim, Ansoft Designer and HFSS were used together to perform swept parametric time and frequency domain analyses. Integration between these three tools allows the entire passive portion of the VCO layout to be characterized by HFSS and embedded into the Nexxim nonlinear circuit simulation (see ***Figure 11***). The non-negligible parasitics of the IC package were also investigated and included as part of the circuit model. With a fully verified circuit performing as required, the design was fabricated and tested. Through precise modeling of the passive on-chip components and interconnects, excellent correlation between the simulated and measured results was

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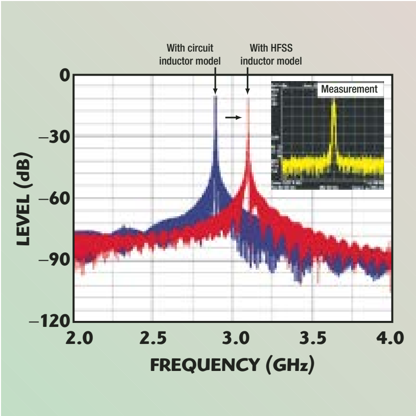
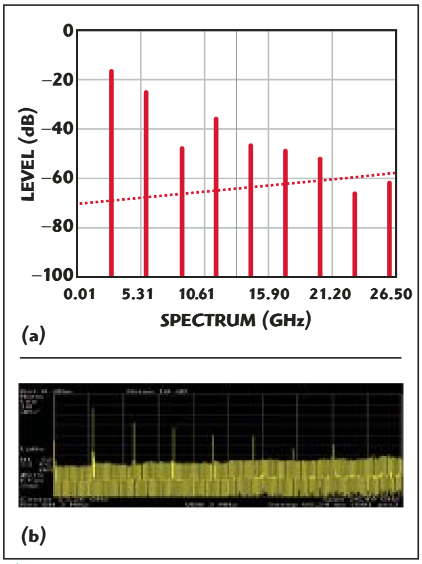
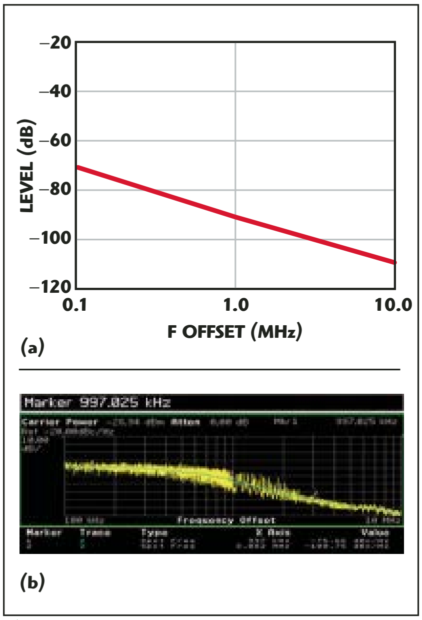


▲ *Fig. 12 VCO simulated and measured frequency response for a tuning voltage of 2.5 V.*



▲ *Fig. 13 Broadband simulated (a) and measured (b) output spectrum.*



▲ *Fig. 14 Simulated (a) and measured (b) phase noise.*

achieved. The inclusion of the HFSS-based spiral inductor led to a considerable shift in the simulated oscillation frequency. The new simulated value of –11.49 dBm output power at 3.0975 GHz was virtually identical to the measured result of –12.15 dBm at 3.094 GHz, as shown in ***Figure 12***. The harmonic balance oscillator analysis in Nexxim accurately simulated the output spectrum of this autonomous-source circuit, faithfully capturing the harmonically-related spurious output tones up to the measurement range limit of 26.5 GHz (see ***Figure 13***). The measured versus simulated phase noise results are shown in ***Figure 14***. The simulated result showed a phase noise of –99 dBc/Hz at a 3 MHz carrier offset. The measured result showed good correlation with a phase noise of –100.7 dBc/Hz at a 3 MHz carrier offset.

CONCLUSION

The economical advantages of implementing wireless designs in CMOS are evident by the number of electronic RF devices targeting this process. The lossy nature of the silicon substrate dictates the use of novel IC structures to minimize substrate coupling as well as the use of new analysis tools to capture the uncertain electrical behavior of these new structures. It is also imperative to simulate all critical performance metrics by which the commercial product is specified. This calls for parametric analyses in the time and frequency domains. These extraction and circuit simulation technologies must be coupled to a design flow that facilitates schematic and layout editing with parameterized layout cells (preferably organized into a process design kit) for manufacturing as well as to an EM simulator that will make the simulation results more reliable. Advances in EM modeling, circuit simulation and design flow automation are making first-pass design success possible, as is evident by the correlation between measured and simulated results in the example presented. ■

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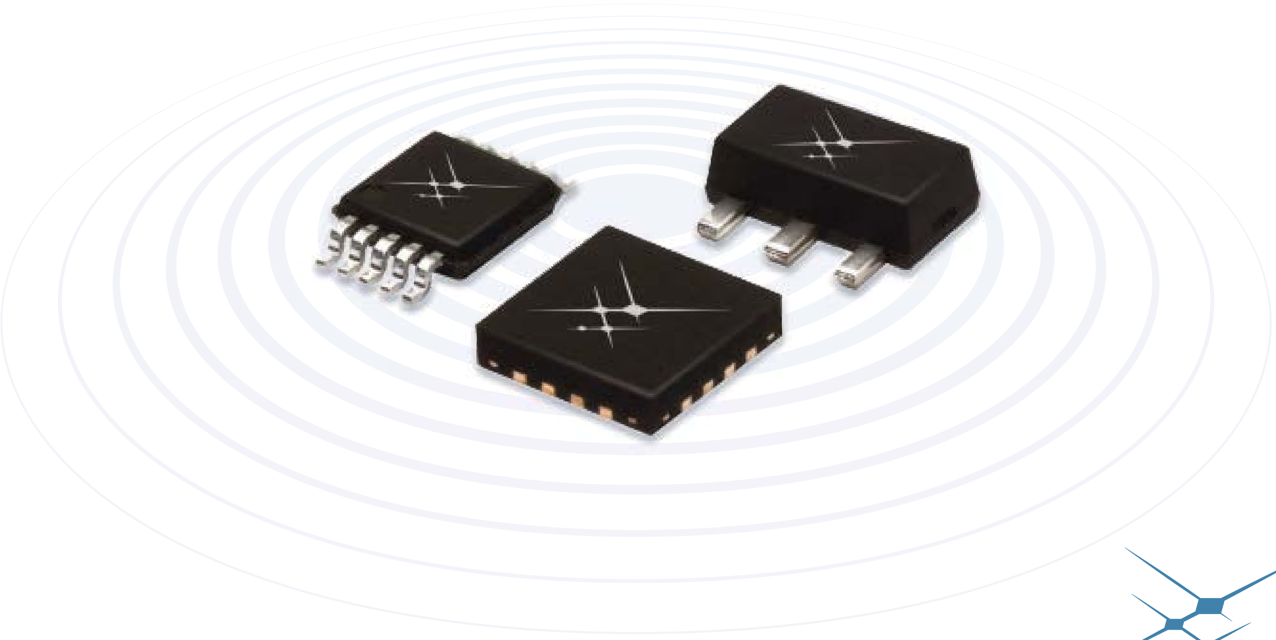

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A DUAL-BAND HF-VHF/UHF SWITCH MATRIX

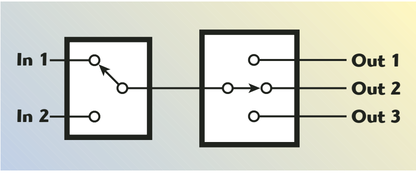
Switch matrices are vital for applications where large numbers of signals received from various antennas and other sources are routed to receivers. The Crane Electronics Microwave Systems Model 1517 switch matrix is an ideal solution for installations where a number of antennas are being shared by numerous broadband receivers.

SWITCH MATRIX BASICS

Switch matrices are manufactured in a variety of configurations and sizes. Devices can range from very simple cross-point matrices to very large, multi-level units. The following is an explanation of various matrix configurations.

The simplest of switch matrix types is the blocking matrix. This type of matrix has a single or limited number of paths through the matrix, causing some inputs or outputs to be "blocked" in their ability to transfer signals. A simplified blocking matrix is illustrated in ***Figure 1***. These offer the most economic and efficient approach as well as eliminating issues related to high frequency operation due to system impedances.

Fig. 1 Simplified blocking matrix.



A block diagram illustrating a simple cross-point matrix is shown in ***Figure 2***. This matrix provides the ability to connect each input to the three respective outputs. This type of matrix operates well at low frequencies. However, as the frequencies increase to RF and

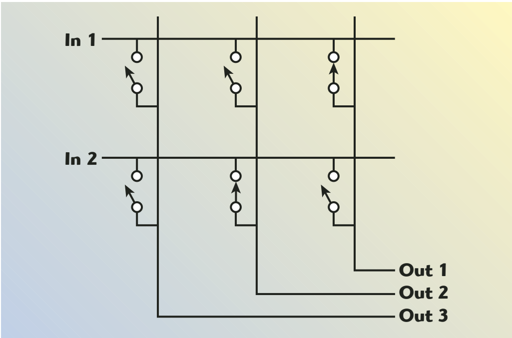


Fig. 2 Non-blocking X-Y matrix (cross-point).

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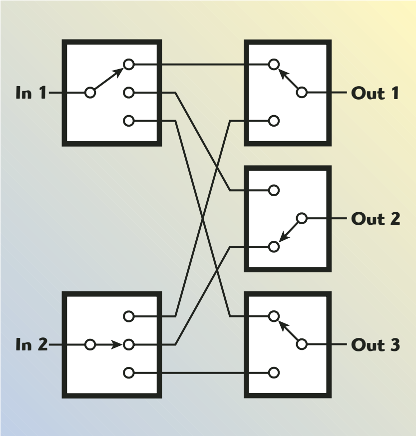
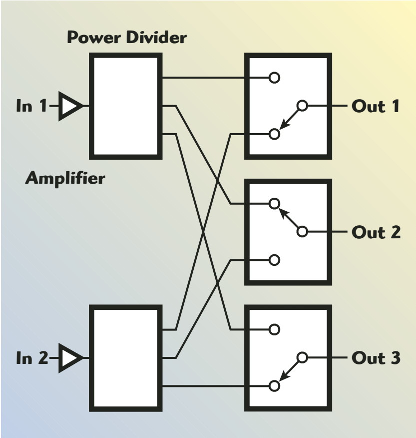
microwave ranges, maintaining proper impedances when different input/output combinations are selected, as well as configuring the matrices into larger units, becomes a challenge.

Adding complexity and additional through-paths, the matrix can be configured as a non-blocking distributed matrix, as illustrated in ***Figure 3***. This configuration offers the ability to have a constant impedance and minimal unit insertion loss. The penalty is one additional switch crosspoint.



▲ *Fig. 3 Non-blocking distributed switch matrix.*

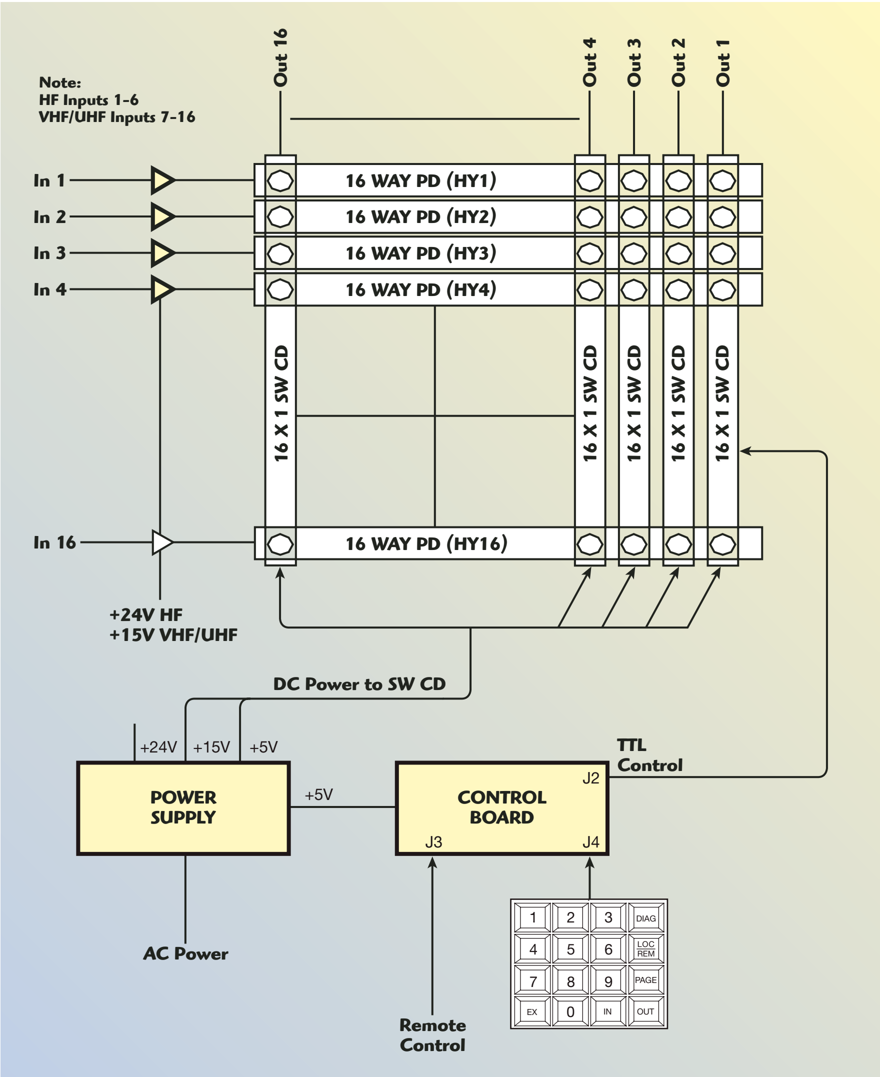


▲ *Fig. 4 Full fanout non-blocking switch matrix.*

Adding more complexity in the form of power dividers, the switch matrix can be made a full fanout type. This type of matrix is illustrated in ***Figure 4***. The advantage of this configuration is that any input can be simultaneously routed to all outputs. Introducing the power dividers adds loss in the signal path due to the signal split. In this case, amplifiers are usually added so that the loss can be overcome. The addition of the amplifiers further complicates the device and degrades the ability to maintain the ultimate signal purity. Compromises of compression point and signal intercept point are usually a trade off of size, power consumption and cost. The frequency response of this type of matrix becomes more of a challenge as the signal is now routed through more than just the passive switch. The power divider and amplifier characteristics significantly impact the frequency response and other characteristic performance of the matrix.

Most switch matrices built by Crane Electronics Microwave Systems are non-blocking, full fanout types. Non-blocking refers to the fact that when connecting multiple inputs there are enough internal signal paths so that all inputs can be connected to all outputs. Full fanout means that any one input can be connected to any or all outputs, simultaneously, without degrading the signal on another output.

The model 1517 switch matrix is a full fanout non-blocking type of matrix. It contains power dividers and amplifiers, as illustrated in Figure 4.



▲ *Fig. 5 Model 1517 switch matrix block diagram.*

TECHNICAL IMPLEMENTATION

The 1517 matrix offers a full fanout architecture. In addition, the unit provides exceptionally wide operating bandwidth with coverage as low as 1.5 MHz and as high as 1000 MHz. In order to achieve this wideband performance, the unit is actually separated into two separate operating bands. Since antennas do not usually cover this entire frequency spectrum, this unit is internally separated into an HF operating band (covering 1.5 to 32 MHz) and a VHF/UHF band (covering 30 to 1000 MHz). Amplifiers and power dividers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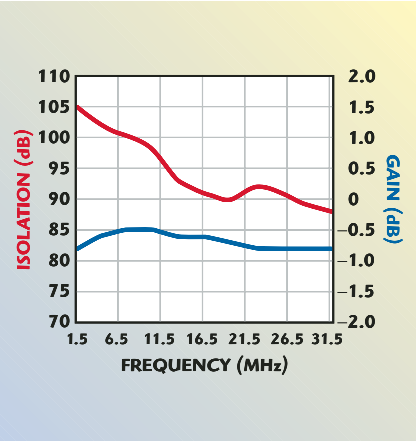
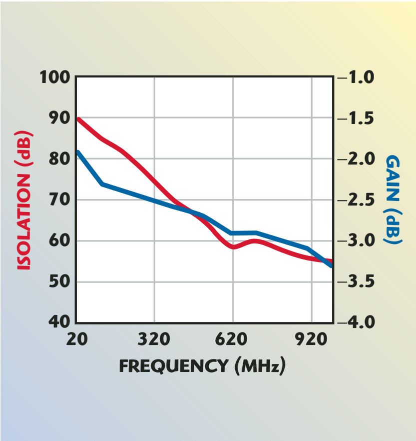


▲ *Fig. 6 HF band gain and isolation performance.*



▲ *Fig. 7 VHF/UHF band gain and isolation performance.*

optimized for each respective band are used as the input structure of the unit. At the output, wideband solid-state switches, covering the entire frequency range, are used. A block diagram illustrating the configuration is shown in ***Figure 5***.

The design implementation for the model 1517 matrix uses a modular approach. The signal inputs are routed to amplifiers, which set the noise figure and overcome the losses of the subsequent power division and switch loss. The gain is set such that the overall gain of the unit is nominally zero in the HF band and –3 dB in the VHF/UHF band. The amplifiers used can either be for the HF band or of the VHF/UHF type. In the fully configured matrix with 16 inputs and 16 outputs, there are 256 switch crosspoints within the unit.

Following the input amplifiers, the signals are routed to the power dividers. These are 16-way Wilkinson power dividers, offering constant impedance for the inputs and outputs. The power dividers are fabricated using toroid transformer technology. Being 16-way dividers, these units have an inherent loss due to their 12 dB signal division. The HF divider is specified to have an additional signal loss of 1.5 dB above the 12 dB making a total of 13.5 dB loss. Similarly the VHF/UHF divider has 14.5 dB maximum total loss. The power dividers are configured with blind-mate SMB male connectors. The output connectors are configured such that they mate directly with the switch assemblies once installed in the unit chassis. They are arranged orthogonally such that the switches are fed in the arrangement indicated in the diagram.

The switches are fabricated using conventional printed-circuit technology using PIN diodes as the signal control elements. Signal isolation is achieved using multiple sections of diode switching in a series-parallel configuration. This approach allows the unit to achieve 45 dB minimum isolation at the maximum operating frequency of 1000 MHz and 50 dB minimum at the HF operating range.

The unit is controlled using an embedded PC-based control architecture. The controller is based on an Intel Pentium MMX processor and utilizes a disk-on-a-chip for managing the operating system and executable instruction set. Control can be executed through the unit front panel or through a variety of remote control options, including RS-232 and 10/100 TCIP LAN. The commands are executed through establishment of a communications session with the matrix over the communications path. The connections are made through a series of strings that are transmitted to the unit. The command protocol is simple, commanding that a particular output be connected to a specified input. An established connection can also be broken by commanding the unit output to connect to input zero.

The controller is set such that when power is lost to the unit and the controller reboots, the last connection state will be restored. Additionally, the unit controller has a diagnostic mode in which power supplies and internal logic interfaces are evaluated. Upon completion of the diagnostic test, a report is returned indicating whether any faults are present.

UNIT PERFORMANCE

The Model 1517 achieves good RF performance over the operating bandwidth. RF gain is maintained within ±1 dB for the HF band. Additionally, over the HF band, the isolation is guaranteed to be 50 dB minimum. These performance points are illustrated in ***Figure 6***.

Similarly, for the VHF/UHF band, the gain is specified at –1 ±2 dB and the isolation at 45 dB minimum. This performance is illustrated in ***Figure 7***.

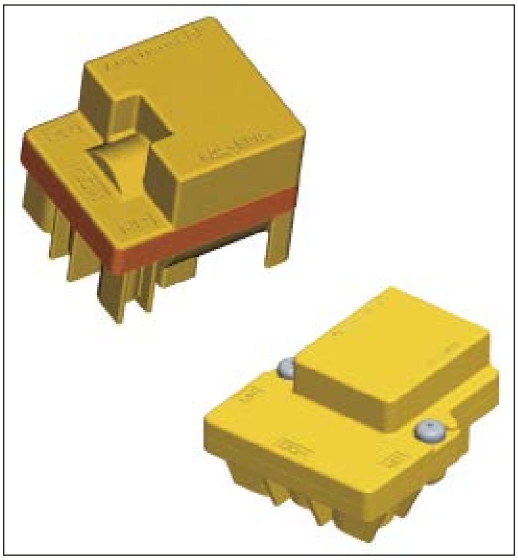
Noise figure for the unit is 8 dB maximum for the HF band and 10 dB maximum for the VHF/UHF band. Output intercept points are +18 dBm for the third-order and +40 dBm for the second-order. The unit is contained in a 4U, 19-inch rack chassis, 23 inches deep. It operates on a flexible 120 or 230 VAC with an auto-switching internal power supply. The unit is designed to operate in environmental temperatures from 0° to +50°C.

CONCLUSION

This new, highly flexible switch matrix unit is ideal for smaller signal reception installations. The model 1517 matrix offers the flexibility of having both HF band and VHF/UHF band input signals within the same unit. The inputs can be flexibly configured allowing for a different number of HF and VHF/UHF inputs depending upon the specifics of the location into which this unit is installed. Economies are achieved by allowing broadband receivers to be used covering both the HF and VHF/UHF bands, while maintaining band-specific antennas and therefore not compromising signal reception performance. The model 1517 switch matrix is a unique solution for reception site challenges.

Crane Aerospace & Electronics, Microwave Systems, Beverly, MA (978) 524-7200, www.craneae.com.

RS No. 301



SURFACE-MOUNT COAXIAL RELAYS

Amphenol RF has developed several high power microwave relays for applying directly to a printed circuit board (PCB) utilizing the SMT process. These designs enable the user to move from a frame-mounted package design necessitating a labor-intensive final assembly into the supporting product. In addition to the physical mounting of these earlier designs, hand soldering of the solenoid power leads was required as well as cabling of the NC/C/NO contacts to the main PCB.

The new surface-mount coaxial relays feature a nominal characteristic impedance of 50 or 75 Ω depending on the cavity where internal switching occurs and based on the users' application. The product can be supplied as either a single pole-double throw (SPDT) or single pole-single throw (SPST) design with fail-safe operation.

The SMT relays are designed for operation up to 3 GHz and feature maximum VSWRs of 1.15 from DC to 1 GHz, 1.2 from 1 to 2 GHz and 1.25 from 2 to 3 GHz. Insertion loss is 0.10, 0.15 and 0.20 dB maximum for the same frequency ranges, respectively, and isolation is 65, 60 and 50 minimum. The relays operate with a wide range of DV voltages and a power consumption of 2 to 3 W typical. They are designed to operate over a temperature range of –25° to +85°C and can operate for a minimum of 10,000 life cycles. Switching time for these mechanical relays is 10 ms maximum.

Using a gold-plated zinc die cast body and gold-plated beryllium copper or brass PC contacts, the construction of these relays allows for a SMT leaded or lead-free solder re-flow

AMPHENOL RF
Danbury, CT

RoHS COMPLIANT

from **$1.29** ea. *(Qty. 1,000)* IN STOCK

- *Absorptive*
- *High IP3 Performance*
- *Low Insertion Loss*
- *Immune to Latch-Up*
- *Very Linear Performance*

Mini-Circuits HSWA2-30DR+ SPDT absorptive switches with internal CMOS control driver deliver a giant leap in performance by giving you exceptionally high isolation, very low insertion loss, and high input IP3 over the *entire* DC-3000MHz band! Operating from a single positive 3V supply voltage, these RoHS compliant switches are totally immune to latch-up so they always work, incorporate our unique design-simultaneous switch-off of RF1 & RF2, and provide super low DC power consumption, essential for today's portable battery operated wireless devices. They're also great solutions for base station infrastructure, CATV, DBS, MMDS, Wireless WLAN, band switching, and more. So resolve your switching needs now and get the most competitive prices in the industry using Mini-Circuits HSWA2-30DR+ high performance switches!

Mini-Circuits…we're redefining what VALUE is all about!

Specifications, Typical (50Ω)

Model	Freq. (MHz)	Isolation (dB)	Ins. Loss (dB)	IP3 (dBm)	Volt (V)	Current (μA)	Price $ea. (Qty.10)
HSWA2-30DR+	DC-3000	50	0.95	+52	+3	8	2.95

Small 4x4mm Package

Detailed Performance Specs and Shopping Online at: **www.minicircuits.com/HSWA2-30DR.pdf**

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P.O. Box 350166, Brooklyn, New York 11235-0003 (718) 934-4500 Fax (718) 332-4661 For quick access to product information see MINI-CIRCUITS CATALOG & WEB SITE

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RF/IF MICROWAVE COMPONENTS

414 Rev Org

temperature of 260°C maximum for 10 seconds. In addition, there is a silicone rubber dust seal to protect the contact area.

Various FEA tools are utilized to optimize performance through analysis and then validate through extensive testing. Power handling is optimized by employing Ansoft ePhysics to accurately predict the thermal characteristics of the products and identify the ideal materials and configuration for each component. Currently offered products are rated for 50, 100 or 200 W continuous at up to 2 GHz.

With an understanding of the PCB characteristics, Amphenol RF can work with the user to develop a PCB footprint capable of optimizing RF performance at the launch area of the signals. These characteristics include PCB material, thicknesses and knowledge as to whether the PCB design represents a microstrip, coplanar or stripline configuration.

Special considerations have been taken to minimize overall package size and the comparative size benefit demonstrates a 50 percent savings of available real estate. This allows for denser packaging in all applications.

Each relay contains several features to withstand environmental conditioning. Highlights include a sealed construction with an IEC 529 rating of IP50 to ensure the RF switching cavity remains clean for error free operation in controlled office environments for extended lifecycles. A robust internal design ensures protection against industry standard vibration and mechanical and thermal shock conditions.

Strict quality control procedures are applied to production including 100 percent functional screening. Dedicated work cells and processes are configured to ensure cleanliness is maintained on critical switching components.

The products implement the latest technologies for cost reduction including zinc die casting, progressive die stamping, molding and selective plating. The product can be supplied in tape-and-reel for pick and place equipment resulting in significant total installed cost reduction. All internal components are designed to consider the necessary process temperatures for no-lead processes.

These products are backed by Amphenol's global service and support team. A local representative is available to discuss specific applications.

Amphenol RF,
Danbury, CT (203) 743-9272,
www.amphenolrf.com.

RS No. 300

 Visit http://mwj.hotims.com/7965-29

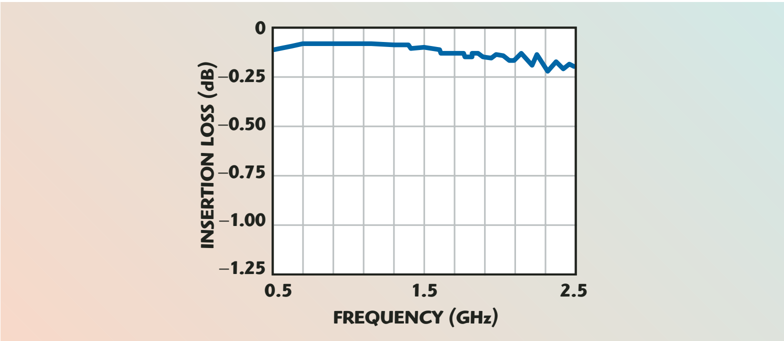
RoHS Compliant Bias Tees

High Power, Weatherproof

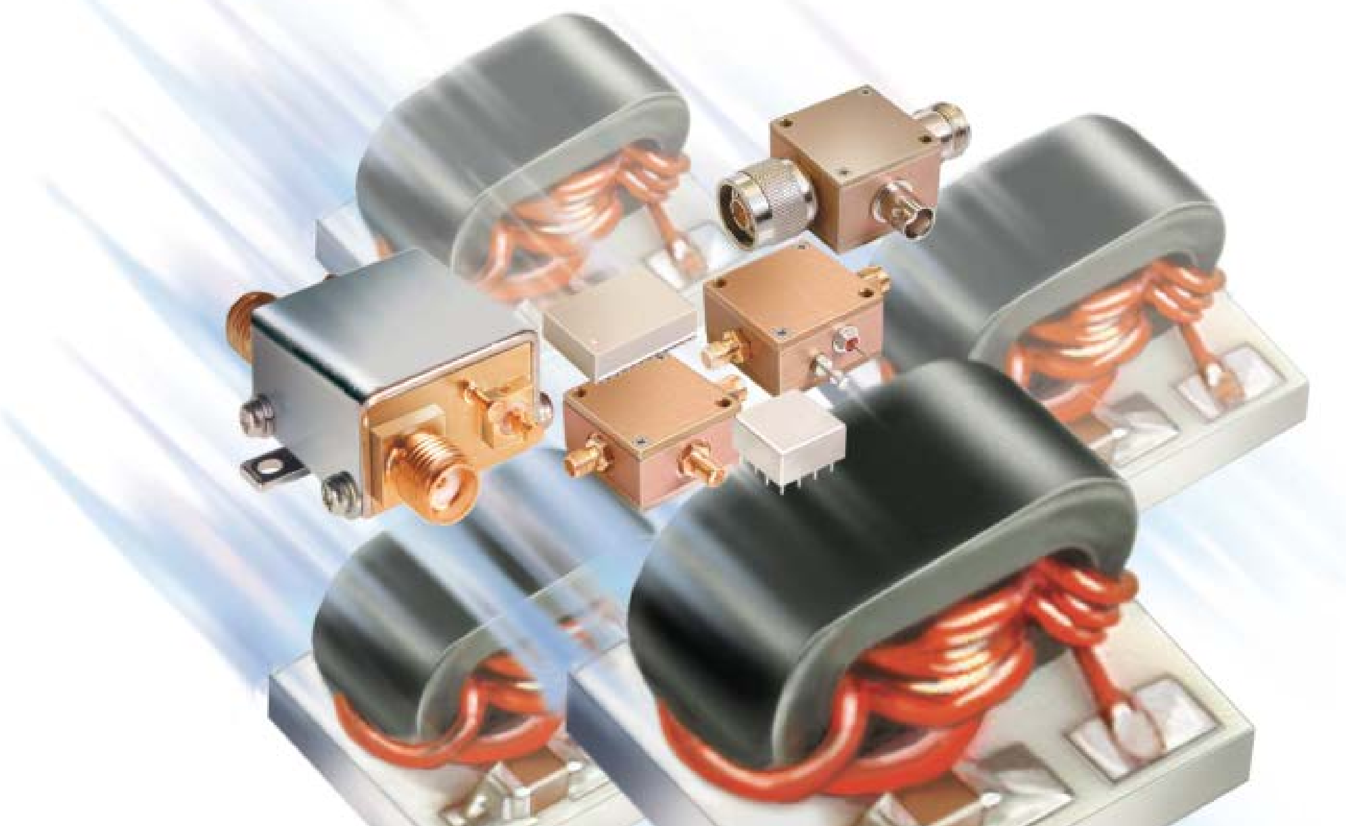
What can possibly be new with bias tees? This seemingly simple product has been used forever to inject DC currents or voltages in RF circuits without affecting the RF signal through the main transmission path. In today's growing wireless marketplace, however, the need for these simple devices seems to be everywhere. They find uses in remote base station systems, repeater installations and tower-top amplifiers to mention just a few areas. Hence, this relatively simple device must be able to be used with many different interfaces and in many different locations and environments, and handle high levels of RF power.

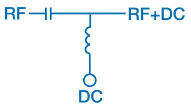
Meca bias tees and their DC block counterparts offer a unique design construction that provides maximum flexibility at any port. The same model can be specified with any connector configuration on any port and still comply to the IP65 rating against direct exposure to outdoor elements (weatherproof). They are available in 7/16 DIN, SMA, N, BNC and TNC connector configurations with power ratings to 300 W (3 kW peak) and maximum DC levels of 100 VDC and 7 amps. In addition, they are now being supplied as RoHS compliant products, so as to meet many of the no-lead requirements currently being imposed.

Fig. 1 Insertion loss vs. frequency.



MECA ELECTRONICS INC.
Denville, NJ





BIAS-TEES

$3.95* IN STOCK from ea. Qty.1000

Now up to 500mA DC current 100kHz-12GHz

Mini-Circuits is your complete source for Bias-Tees, covering from 100kHz to 12GHz and handling up to 500mA DC in a variety of coaxial, plug-in, and surface mount packages. All of our Bias-Tees boast low insertion loss and VSWR. Our TCBT LTCC ceramic designs are the smallest in the world and are ready for your projects where very low price, space limitation, and temperature stability are a must. Our ultra-wideband ZX85 Bias-Tees use our patented Unibody construction to give you small size and high repeatability. Whether your applications call for biasing amplifiers, laser diodes, or active antennas, DC blocking, DC return, satellite communications, test, or if you have custom requirements, just contact Mini-Circuits and let us fit your needs to a "TEE"!

ZX85+ RoHS compliant.

TYPICAL SPECIFICATIONS

Model	Freq (MHz)	Insertion Loss (dB)	Isolation (dB)	VSWR (:1)	Price $ea. Qty.10
TCBT-2R5G	20-2500	0.35	44	1.10	6.95*
TCBT-6G	50-6000	0.7	28	1.20	9.95
TCBT: LTCC, Actual Size .15"x.15", Patent Pending.					
					Qty.1-9
JEBT-4R2G	10-4200	0.6	40	1.10	39.95
JEBT-4R2GW	0.1-4200	0.6	40	1.10	59.95
PBTC-1G	10-1000	0.3	33	1.10	25.95
PBTC-3G	10-3000	0.3	30	1.13	35.95
PBTC-1GW	0.1-1000	0.3	33	1.10	35.95
PBTC-3GW	0.1-3000	0.3	30	1.13	46.95
ZFBT-4R2G	10-4200	0.6	40	1.13	59.95
ZFBT-6G	10-6000	0.6	40	1.13	79.95
ZFBT-4R2GW	0.1-4200	0.6	40	1.13	79.95
ZFBT-6GW	0.1-6000	0.6	40	1.13	89.95
ZFBT-4R2G-FT	10-4200	0.6	N/A	1.13	59.95
ZFBT-6G-FT	10-6000	0.6	N/A	1.13	79.95
ZFBT-4R2GW-FT	0.1-4200	0.6	N/A	1.13	79.95
ZFBT-6GW-FT	0.1-6000	0.6	N/A	1.13	89.95
ZNBT-60-1W	2.5-6000	0.6	45	1.10	82.95
ZX85-12G+ NEW	0.2-12000	0.6	N/A	1.20	99.95

NOTE: Isolation dB applies to DC to (RF) and DC to (RF+DC) ports

ZX85 Protected By U.S. Patent 6,790,049. Add'l Patent Pending.

Detailed Performance Specs and Shopping Online at: ***www.minicircuits.com/bias.shtml***

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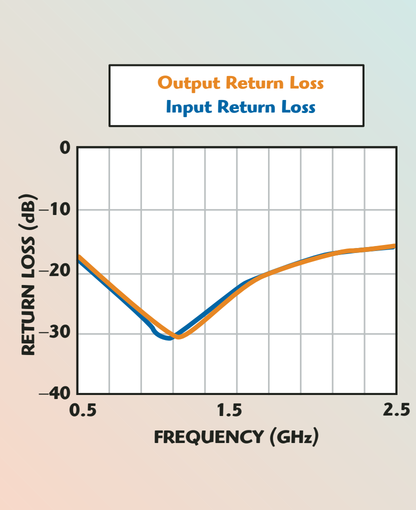
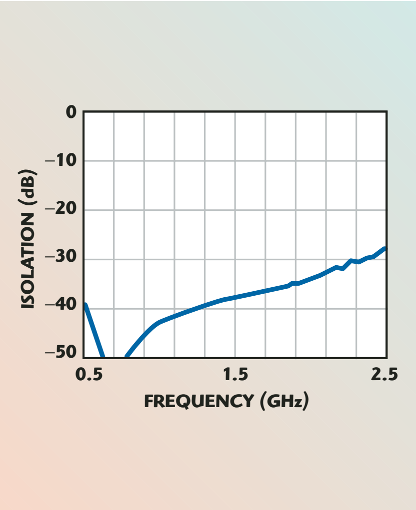


▲ *Fig. 2 Input and output return loss vs. frequency.*



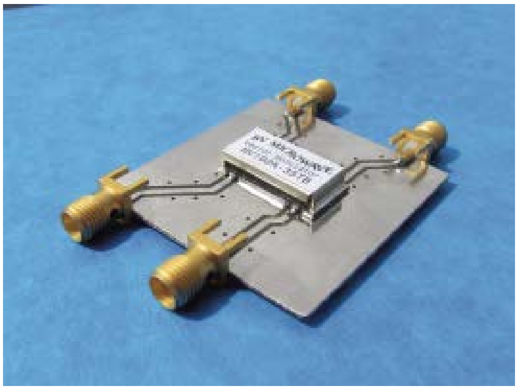
▲ *Fig. 3 Isolation vs. frequency.*

The current family of Meca bias tees covers wireless band applications from 500 to 2500 MHz and features typical insertion loss of 0.25 dB (0.5 max), isolation of 30 dB (25 dB min) and typical input and output VSWRs of 1.25 (1.40 max). ***Figure 1*** displays measured insertion loss vs. frequency, ***Figure 2*** input and output return loss and ***Figure 3*** isolation vs. frequency.

Additional product specifications on Meca RoHS compliant bias tees may be found on the company's web site. Bias tees are currently available to ship from stock two weeks after receipt of order.

Meca Electronics Inc., Denville, NJ (866) 444-6322, www.e-meca.com.

RS No. 303



SURFACE-MOUNT MONOTONIC VECTOR MODULATORS

SV Microwave has introduced a family of surface-mount vector modulators with monotonic phase and attenuation response. These devices offer design engineers the benefits of modulating the phase and amplitude by applying a variable voltage and maintaining an always-increasing response of these parameters. In addition, these vector modulators offer minimum amplitude ripple and linear phase balance in their frequency ranges.

The new family of vector modulators is available with center frequencies in the 800 MHz to 2.5 GHz frequency range. Models are offered with 360° of phase shift and 35 dB of attenuation. In addition, the third-order intercept point (IP3) performance is exceptional with a guaranteed minimum of 40 dBm.

By utilizing state-of-the-art engineering techniques and Lean Six Sigma manufacturing practices, SV Microwave is able to provide vector modulators with outstanding performance at a competitive price. This product can also be supplied as RoHS compliant (lead-free), if requested.

THE VECTOR MODULATOR PRINCIPLE

The functional principle of vector modulators occurs when the input signal is divided into at least two signals and a phase difference is produced between these signals. Internal variable attenuators process these signals and a power combiner is added to obtain a phase-dependent vector sum.

There are two voltage-controlled bias signals required to control the phase and amplitude of the vector modulator. In these monotonic vector modulators, the amplitude and phase have a direct relationship with an increase in the control voltage. In standard vector modulators, this feature may not be controlled and, at certain voltage levels, the amplitude or phase may not increase.

In many applications, where errors in modulation must be controlled, it is imperative

SV MICROWAVE INC.,
AN AMPHENOL COMPANY
West Palm Beach, FL

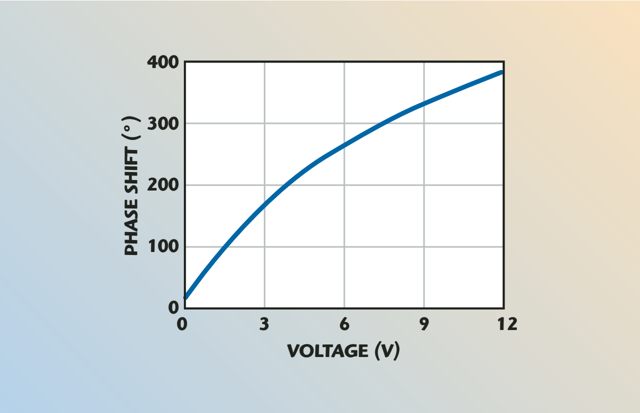


Fig. 1 Phase shift performance of the model MV152A-77ER7 vector modulator.

TABLE I
KEY FEATURES

Center frequency ranges	800 MHz to 2.5 GHz
Insertion loss (dB)	2.5
Phase shift	90° to 360°
Attenuation (dB)	10 to 35
IP3 (dBm)	+42 typ., +40 min.
Phase and attenuation response vs. control voltage	monotonic
Operating temperature (°C)	–25 to +85
Storage temperature (°C)	–40 to +85

that the phase and amplitude are increasing consistently. If the polarity changes with a voltage increase, this could have major effects in the logic of the system and it will make it very difficult for system designers to track and monitor modulating errors. ***Figure 1*** shows the typical phase shift vs. control voltage performance of a model MV152A-77ER7 vector modulator.

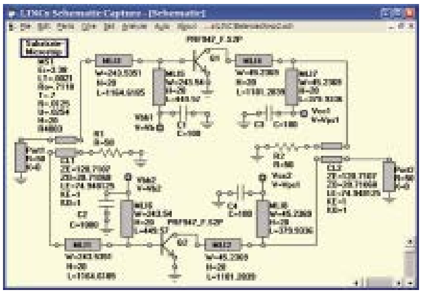
In addition to the monotonic response, these vector modulators have excellent phase and amplitude variation as well as low insertion loss. ***Table 1*** summarizes some of the key features of these devices.

VECTOR MODULATOR APPLICATIONS

Vector modulators are used in many applications, both military and commercial. They are typically used in radars, adaptive antenna combining, measurement, feed-forward amplifier systems and phased-array active architectures. The monotonic vector modulators are ideal for signal processing applications and very cost-effective solutions for commercial wireless networks.

SV Microwave Inc., an Amphenol company, West Palm Beach, FL (561) 840-1800, www.svmicrowave.com.

RS No. 302



AMPLIFIER SYNTHESIS SOFTWARE

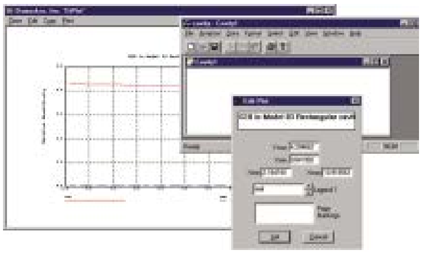
ACS has recently added new amplifier synthesis software to its line of circuit synthesis products. The wizard-like GUI quickly and effortlessly guides the user through the process of entering the specifications for the automatic synthesis of a wide variety of amplifier circuits, including single or multistage amplifiers, balanced amplifiers, differential (push-pull) amplifiers and low noise amplifiers. The LINC2 Pro RF and microwave circuit design and analysis software combines circuit synthesis, simulation, optimization and statistical yield analysis into a single integrated design environment.

Applied Computational Sciences,
Escondido, CA (760) 612-6988,
www.appliedmicrowave.com.
RS No. 310

EMC TEST SOFTWARE

The model SW1006 is the latest version of the company's radiated susceptibility, conducted immunity and pre-compliance emissions software. Model SW1006 automatically performs both calibration and immunity testing in full compliance with IEC 61000-4-3, 4-6, MIL-STD 461/462 RS103, CS114, RTCA/DO160 Section 20 specifications. The software also supplies the user with selectable test parameters and a "thresholding" mode for pre-compliance investigation of equipment susceptibility, as well as closed loop leveling. Pre-compliance emission testing can be done with the use of a spectrum analyzer and either a pre-amp or LISN. The SW1006 software is designed for use with the supplied NI PCI-GPIB interface card for instrument communication.

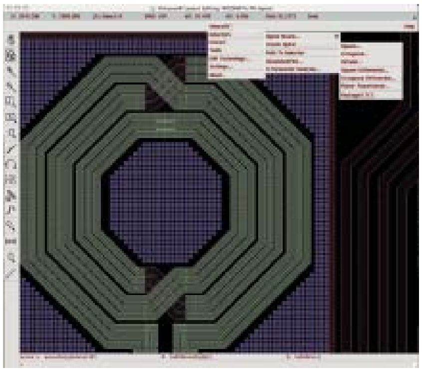
AR Worldwide RF/Microwave Instrumentation,
Souderton, PA (215) 723-8181, www.ar-worldwide.com.
RS No. 311



INSTRUMENT CONTROL SOFTWARE

The CAVITY™ software packages for Microsoft Windows and Macintosh OS X are versatile programs that perform all of the instrument control, calibration and data processing for measuring complex permittivity and permeability using a wide variety of resonators. The software supports thin sheet testers, open resonators, circular cavities, harmonic stripline cavities and Courtney resonators. The software controls common vector network analyzers made by Agilent, Anritsu, and Rohde and Schwarz. The programs are automated, and lead the user through all steps required to perform measurement and calibration. In most instances the measurements require no direct user interaction with the network analyzer.

Damaskos Inc.,
Concordville, PA (610) 358-0200, www.damaskosinc.com.
RS No. 312



ENHANCED EDA TOOL

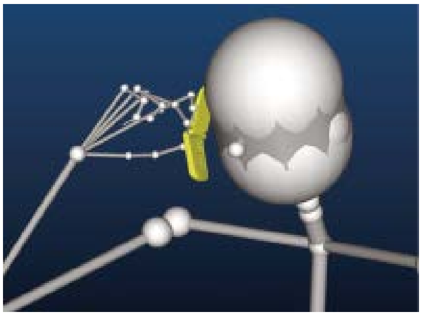
The VeloceRF™ v1.5 features an enhanced Spiral Wizard™ inductor synthesizer, several improvements in its rapid RLCK modeling engine and new features addressing Design for Manufacturability for 90 nm and 65 nm RFICs. The synthesis engine now supports the creation of patterned shields that enhance inductor Q-factor and improve substrate isolation. Version 1.5 efficiently addresses DFM requirements emerging for RF CMOS at the 90 nm process node and below. Features such as conductor track slotting to mitigate metal stress, geometry resizing under current density constraints and the use of dummy fill patterns are now programmed into the VeloceRF inductor library and are consistently supported by the Spiral Wizard, the modeling engine, and the layout and LVS modules.

Helic,
Athens, Greece +30 210 9949390, www.helic.com.
RS No. 313

PARAMETRIC PRODUCT SEARCH TOOL

The parametric product search tool is designed for the RF engineer to specify important product parameters and view the company's products that match a specific requirement in a specification-compliance format. Unlike conventional search engines that eliminate products that narrowly fall outside of specification, the parametric product search tool can show these products allowing the engineer to make intelligent design trade-off decisions to "fine tune" the requirement to specific needs. View this and other product software support tools including Product Cross Reference, PLL Phase Noise and Mixer Spur Chart Calculators on the company's site.

Hittite Microwave Corp.,
Chelmsford, MA (978) 250-3343, www.hittite.com.
RS No. 314



ELECTROMAGNETIC ANALYSIS SOFTWARE

The company announced a number of new products and enhancements to its electromagnetic analysis software, XSTREAM, the hardware acceleration package for XFDTD, a full-wave 3-D electromagnetic (EM) solver. It provides much faster calculation speeds than using a CPU alone. A parallel/multiprocessing version of Wireless InSite v2.3 is now available. This multiprocessor and cluster-based version enhances the well-established propagation prediction tool. VariPose v1.2 is also now available. It provides for repositioning of the Male Visible Human mesh including internal anatomical structures. One new feature is that VariPose now has an enhanced skeleton head, allowing precise positioning of hands and cell phone near the head.

Remcom Inc.,
State College, PA (814) 861-1299, www.remcom.com.
RS No. 315

Thick Film Attenuator

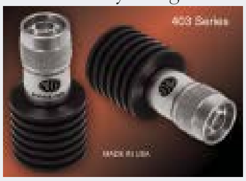
The model IMA2391 is a surface-mount thick film 1206 attenuator especially suited to RF/microwave applications and communications-oriented circuitry. This thick film attenuator is operational to 15 GHz in a properly matched continuous 50 Ω system. It is available from 1 to 70 dB in 1 dB increments with a tolerance as low as ±0.2 dB. Input power handling is 1 W (using proper thermal management techniques).

International Manufacturing Services Inc., Portsmouth, RI (401) 683-9700, www.ims-resistors.com.

RS No. 216

15 W Load Terminations

These medium power, 50 Ω load terminations are efficiently designed for high performance, cost-effective solutions. Rated for 15 W average power (2 kW peak) with VSWR of 1:10 to 2 GHz, 1.20 to 6 GHz and 1.30 to 12 GHz. Made in the US and available from stock in Type-N, SMA, BNC and TNC connector styles (male/female).



MECA Electronics Inc., Denville, NJ (973) 625-0661, www.e-meca.com.

RS No. 217

Wireless Band Splitters

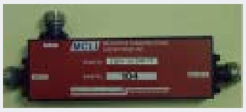
These two-, three- and four-way wideband reactive power splitters operate in a frequency range from 380 to 2500 MHz. The model Dx-88FD series of power splitters is ideal for designing passive in-building wireless distributed antenna systems (DAS) now being required to meet homeland security issues. The extremely low loss of reactive components such as the D2-88FD help make the passive design realizable without recourse to amplifiers or other active components. Such a passive approach enhances reliability, cuts installation cost and has a high communications survival potential in an emergency situation. Insertion loss is < 0.05 dB and PIM is guaranteed to be < –150 dBc.

Microlab/FXR, Parsippany, NJ (973) 386-9696, www.microlab.fxr.com.

RS No. 218

Directional Couplers

The model CB59-10-200/NF is a directional coupler that offers 200 CW at a frequency range of 0.8 to 2.5 GHz. The model shown is a 10 dB component, but 20 and 30 dB are also available. Since this model is a stock item, immediate delivery is available.



Microwave Communications Laboratories Inc., Saint Petersburg, FL (727) 344-6254, www.mcli.com.

RS No. 219

10 to 1000 MHz Mixers

This series of ADEX level 3, 7 and 17 (LO) mixers are designed to provide high isolation of greater than 50 dB typical with flat conversion loss of ±0.2 dB typical over the entire 10 to 1000 MHz band. LO and RF have good matching, typically 15 to 20 dB return loss, and the low profile 0.112" package is ideal for high density designs. Price: $2.95 each (10).

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

RS No. 220

Ultra-light Filter/Limiter Assembly

These ultra-light filter/limiter assemblies operate in a frequency range from 10 to 3000 MHz for military and space applications. These assemblies combine roofing and narrowband filters with an integrated limiter to handle high input power and package weight is < 1 oz. Custom designs and package options are available (SMT, GPO, GPPO and SMA interfaces).

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

RS No. 221

Single-chip Switch

These two single-chip solutions support USB 1.1, USB 2.0 full speed, USB 2.0 high speed and high fidelity audio signals, captured on tiny 3.5 × 1.5 mm TDFN packaging. The devices are ideal for handheld applications including mobile phones and MP3 players. The PI3USB411 is used for switching two audio signals or USB data through a single socket, while the PI3USB412 is used for switching two audio signals from two different sources, or USB data through a single socket.

Pericom Semiconductor Corp., San Jose, CA (408) 435-0800, www.pericom.com.

RS No. 222

2 to 18 GHz Power Divider

The model ADP-2-218-M-BB is a miniature power divider designed to operate in a frequency range from 2 to 18 GHz. This model offers an insertion loss of 2.2 dB maximum, isolation of 16 dB minimum and a VSWR of 2.0 maximum. The power handling is 1.5 W at 2.0 VSWR and 2 W at 1.2 VSWR. Size: 0.779" × 1.026" × 0.300" with the connector shrouds removed.

Planar Monolithics Industries Inc., Frederick, MD (301) 631-2029, www.planarmonolithics.com.

RS No. 223

Two-way Power Divider

The part number PS2-53-450/15S is a two-way power divider that operates in a frequency range from 15 to 40 GHz. This power divider offers 1.2 dB insertion loss, 13 dB isolation, amplitude balance of 0.8 dB, phase balance of 10° and 1.80 VSWR. Outline dimensions are 1" × 0.6" × 0.4" with 2.92 mm female connectors.

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

RS No. 224

Cavity Notch Filter

The part number 16R7-1270.86-X73.5S11 is a highly selective cavity notch filter. This unit is centered at 1270.86 MHz and offers a nominal 3 dB bandwidth of 73.5 MHz. The notch depth is greater than 45 dB across the frequency band of CF ±25 MHz. The passbands are 1200 to 1234 and 1307 to 1500 MHz, with insertion loss measuring less than 2 dB.

Reactel Inc., Gaithersburg, MD (301) 519-3660, www.reactel.com.

RS No. 225

Surface-mount Circulators/Isolators

The SMC series of surface-mount coplanar circulators and isolators is designed for high power applications and operates in a frequency range from 800 to 2500 MHz. These circulators are distinguished by good high power

performance in congested multi-carrier environments. Models are available in typical bandwidths of 10 to 15 percent with isolation > 22 dB and insertion loss < 0.35 dB.
Renaissance Electronics Corp.,
Harvard, MA (978) 772-7774,
www.rec-usa.com.

RS No. 226

3 dB Quadrature Combiner/Divider

The company's newly patented 3 dB quad coupler technology provides low loss and exceptional amplitude balance. This bonded structure removes any air gaps within the circuit, insuring consistent unit to unit performance. The model QH7741 operates in a frequency range from 800 to 3000 MHz and offers a 50+ W CW unit with insertion loss of 0.5 dB maximum, VSWR of 1.35 maximum, isolation of 18 dB minimum, phase balance of 90° ±5° and amplitude balance of ±0.4 dB maximum. Size: 1.35" × 0.65" × 0.08".

Werlatone Inc.,
Brewster, NY (845) 279-6187,
www.werlatone.com.

RS No. 230

Schottky Detector

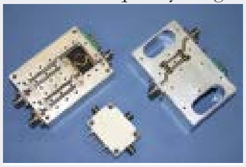
The model CR-455-R is a zero-bias Schottky detector designed to operate over the 43.5 to 45.5 GHz frequency range. This rugged, miniature design is suitable for a wide range of environmental conditions. The detector is supplied with a 2.4 mm input connector and an SMA output connector. Other types of output connectors are available. The VSWR is 2.0 maximum and the flatness is ±0.5 dB. Typical low-level sensitivity is 0.4 millivolts per microwatt. Negative or positive output polarity is available.

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

RS No. 227

PIN Diode Switches and Attenuators

These PIN diode switches and attenuators operate in a frequency range from 0.5 to 18 GHz. Switches are available in 0.5 to 18 GHz with isolation of greater than 60 dB and switching speeds of less than 30 ns. PIN diode attenuators are available in bands that cover 2 to 4 GHz, 4 to 8 GHz and 8 to 18 GHz with either digital or voltage control.



Rodelco Electronics Corp.,
Ronkonkoma, NY
(631) 981-0900,
www.rodelcocorp.com.

RS No. 228

WiMAX Bandpass Filter

This high performance bandpass filter was designed for use in WiMAX base stations filtering broadband information in the 2.5 GHz band. This model offers a maximum 0.7 dB of insertion loss and provides over 30 dB of band rejection at DC to 2.45 GHz and at 2.74 GHz during operation. Also this bandpass filter is compact in size with 120 × 90 × 40 mm. In addition, the bandpass filter is also available with the 3.5 GHz frequency band.

Universal Microwave Technology Inc.,
Taipei, Taiwan
+886 2 2698 9969,
www.umt-tw.com.

RS No. 229

COMPONENTS

PCB Mount Switch

The 409 switch is a compact PCB mount switch that operates in a frequency range from DC to 3 GHz. This switch is specially designed for mounting directly on a PCB and is ideal for military, ATE and commercial applications that require high power handling and resistance to severe environmental conditions. This switch is a high quality alternative to solid-state devices.

Dow-Key Microwave Corp.,
Ventura, CA (805) 650-0260,
www.dowkey.com.

RS No. 231

Active Mixers

The model SKY42068 is a 400 to 1000 MHz active mixer focused on CDMA, EDGE, GSM,

TETRA, WCDMA, WiMAX and WLL devices, and model SKY42070 is a 1700 to 2200 MHz active mixer aimed at DCS, PCS and UMTS communications. These models are integrated, high dynamic range, low noise receiver down converters. They include a double-balanced active mixer, local oscillator (LO) amplifiers and dual LO inputs selected by an external switch interface. The LO switch function is managed using an externally controlled complementary metal oxide semiconductor (CMOS) compatible interface. Price: $5.50 (10,000).

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

RS No. 233

High Vacuum Sub D Connectors

The high vacuum Sub D 5000 series of hermetic feedthroughs provides a solution for

users needing more robust, more compact Sub Ds that are fully compatible with standard, off-the-shelf non-hermetic mating connectors. New hermetic connectors are available in double-ended pin configurations. The connectors provide higher pin densities by utilizing double density MIL-C-24308 arrangements; plug to plug and plug to receptacle versions are available. These connectors operate from –269° to +450°C and offer robust ceramic seals utilizing Ceramax dielectric.

SRI Hermetics Inc.,
Melbourne, FL (904) 323-0662,
www.srihermetics.com.

RS No. 234

Push-on Connectors

The MCX and MMCX low cost miniature and micro miniature push-on connectors have been

recently added to the company's broad connector family. The MMCX connector series is rated up to 6 GHz, is designed for 75 and 50 Ω impedances, and have reliable coupling methods. The connectors are designed for use in applications where space and weight considerations are crucial.

Tensolite,
Long Beach, CA (866) 282-4708,
www.tensolite.com.

RS No. 235

Hex/Round Attenuator

The model 2082-6446-XX is a 2 W SMA Hex/Round attenuator that operates in a fre-

quency range from DC to 6 GHz. This attenuator features a lightweight, passivated stainless steel body and coupling nut, along with a gold plated, beryllium copper center contact. This, coupled with solid electrical performance and attractive prices starting at just $11.99 for quantities 1–99, make this an outstanding value. This product is ideal for volume production applications that require superior long-term performance and low cost.

XMA Corp.,
Manchester, NH (603) 222-2256,
www.xmacorp.com.

RS No. 236

Thin Film Chip Resistor

The MSMR series is a miniature, thin film chip resistor that provides electrical characteristics consisting of value ranges from 2 Ω to 75 kΩ, TCRs available to ±5 ppm/C and tolerances starting at 0.01 percent. Size: 0.012" × 0.009". Sizes such as 0.015" × 0.015" and 0.020" × 0.010" are available along with the industry standards.

Mini-Systems Inc.,
North Attleboro, MA (508) 695-0203,
www.mini-systemsinc.com.

RS No. 232

AMPLIFIERS

Detector Log Video Amplifier

The model DLA-218CWI-SK45 is a small detector log video amplifier (DLVA) with a dy-

namic range of 45 dB and integral CW-immunity circuitry. The logging range is –40 to +5 dBm, the TSS is –40 dBm and the CW-immunity is to –10 dBm. The DC power is +12 VDC at 120 mA maximum and –12 VDC at 80 mA. The rise time is 20 ns typical and the fall time is 150 ns typical. Size: 2.52" × 1.97" × 0.40".

American Microwave Corp.,
Frederick, MD (301) 662-4938,
www.americanmicrowavecorp.com.

RS No. 237

Automatic Gain Control Amplifier

The model AMP6G18-22-AGC is a broadband automatic gain control (AGC) amplifier that

covers the frequency range from 6 to 18 GHz with a minimum of 20 dB gain. Gain flatness is better than ±1.75 dB with typical values of ±0.75 dB. This amplifier features a P1dB of at least +18 dBm. Noise figure is less than 4 dB with 2.5 dB typical. The AMP6G18-22-AGC features a gain adjust of greater than 20 dB via the AGC control pin. This unit utilizes the latest in microwave semiconductor technology, which results in an economical and high performance solution.

Amplical Corp.,
Verona, NJ (201) 919-2088,
www.amplical.com.

RS No. 238

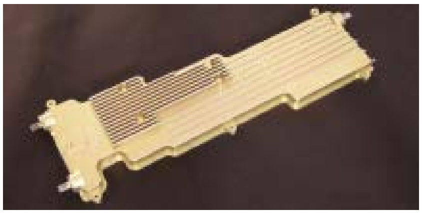
Satellite Communication Amplifiers

This range of 'turn-key' line amplifiers in 1U × 19 inch rack units is designed for fast installation and hook-up in satellite communication bands from L to Ku. Typical gain of standard units is in the 20 to 25 dB range, while the output power of +20 dBm at 1 dB gain compression is selected to provide an adequate drive level for a high power TWT or solid-state amplifier. All the usual transmit and receive bands are covered from 3.6 to 31 GHz while some models will encompass multi-band applications such as C, X and Ku in a single unit.

Atlantic Microwave Ltd.,
Braintree, UK, +44 1376 550220,
www.amrf.co.uk.

RS No. 239

Dual High Power Amplifier

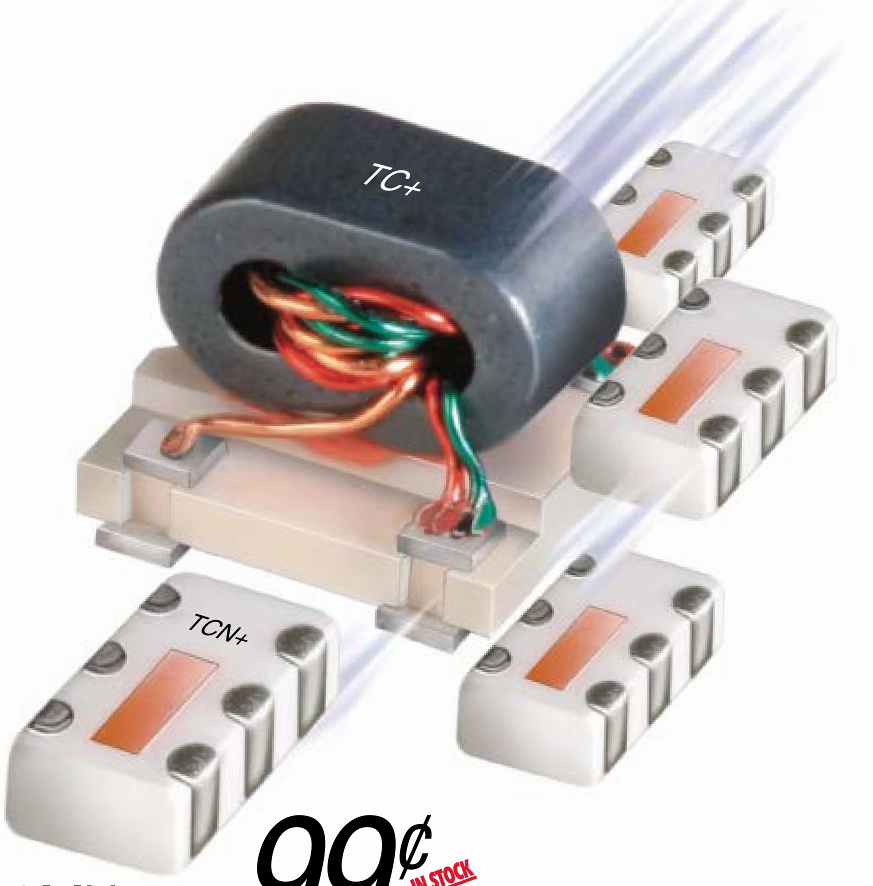


The LS2598 amplifier provides dual 75 W phase and gain matched outputs from a single input across the 1215 to 1390 MHz frequency range. A multi-technology architecture allows this unit to offer constant output power over a 12 dB input range, operational efficiencies exceeding 40 percent and standby power dissipation of less than 3 mW. Packaged in an ultra lightweight package weighing less than eight ounces, yet robust enough to withstand harsh environments, this amplifier has applications in long and short pulse L-band radars. In alternative packaging the unit will operate CW.

CAP Wireless Inc.,
Newbury Park, CA (805) 499-1818,
www.capwireless.com.

RS No. 240

RF & MICROWAVE
TRANSFORMERS



.3-3000MHz as low as 99¢ IN STOCK each (qty. 100)

Quickly find and get the transformers you need from Mini-Circuits wide selection of RoHS compliant broadband models that give you very good return loss, impedance ratios ranging from 1:1 up to 16:1 ohms, and also accommodate your need for small size! Our mini Low Temperature Co-fired Ceramic TCN+ transformers deliver superior thermal stability, improved reliability, and permit fast, high volume manufacturing. Our compact TC+ models are constructed with high strength plastic base, all welded, and come equipped with solder plated leads for solderability and reliability. And with small quantity prices starting from under a dollar each, these low cost transformers are one of the best price/performance buys in the business!

Mini-Circuits...we're redefining what VALUE is all about!

Model	Ω Ratio	Elec. Config.	Freq. (MHz)	Price $ea. (qty. 100)
TC1-1+	1	C	1.5-500	1.19
TC1-1-13M+	1	G	4.5-3000	.99
TC1-15 +	1	G	350-1500	1.29
TC1-1T+	1	A	0.4-500	1.19
TCL1-11+	1	G	600-1100	1.09
TCL1-19+	1	G	800-1900	1.09
TC1.5-1+	1.5	D	0.5-2200	1.59
TC2-1T+	2	A	3-300	1.29
TC3-1T+	3	A	5-300	1.29
TC4-14+	4	A	200-1400	1.29
TC4-19+	4	H	10-1900	1.09
TC4-1T+	4	A	0.5-300	1.19
TC4-1W+	4	A	3-800	1.19
TC4-25+	4	H	500-2500	1.09
TC4-6T+	4	A	1.5-600	1.19
TC8-1+	8	A	2-500	1.19
TC9-1+	9	A	2-200	1.29
TC16-1T+	16	A	20-300	1.59
*TC4-11+	50/12.5	D	2-1100	1.59
*TC9-1-75+	75/8	D	0.3-475	1.59

*Step down transformer.

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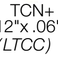
Model	Ω Ratio	Elec. Config.	Freq. (MHz)	Price $ea. (qty. 100)
TCN1-10+	1	G	680-1050	1.69
TCN1-23+	1	G	1300-2300	1.69
TCN2-14+	2	G	700-1400	1.69
TCN3-11+	3	G	600-1100	1.69
TCN4-13+	4	G	650-1250	1.69
TCN4-22+	4	J	1200-2200	1.69



TCN+
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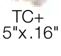
(LTCC)



TC+
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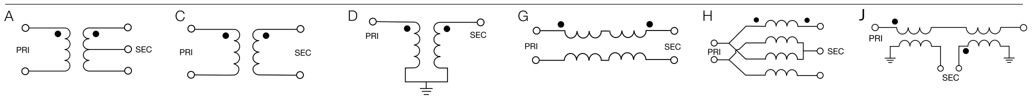
ELECTRICAL CONFIGURATIONS



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RF/IF MICROWAVE COMPONENTS

377 Rev H

Bi-directional 802.11 Amplifier

The model SMTR1719-48LD is an LDMOS FET amplifier designed for multi-purpose use in military and commercial markets. The unit operates from 1.7 to 1.9 GHz with a Tx P1dB of 48 dBm. Transmit gain is 29 dB with a flatness of ±0.75 dB across the band. Standard features include a single +28 VDC supply, thermal protection with auto reset and over/reverse voltage protection. In module form, the unit measures 6.7" × 4" × 0.8".

Stealth Microwave Inc., Trenton, NJ (609) 538-8586, www.stealthmicrowave.com.

RS No. 241

ANTENNAS

Omni-directional Antenna

The 2.4 GHz PCNLP series is a low profile 3 dBi gain omni-directional antenna. This antenna provides a discrete antenna for wireless inventory analysis or any other meter-reading application. Rugged UV-stable radomes with many connector configurations make the PCNLP the ideal choice for any application that requires omni performance.

Astron Wireless Technologies Inc., Sterling, VA (703) 450-5517, www.astronwireless.com.

RS No. 242

Rotary Joint

The WR28 in-line waveguide rotary joint operates in a frequency range from 27.5 to 31 GHz with a VSWR of less than 1.30 and insertion loss less than 0.30 dB. The waveguide channel is capable of handling 500 W of average power. The material is aluminum with iridite finish. The overall length is 3.00". Waveguide flanges, mounting flanges and pressurization are optional.

Microwave Development Labs Inc., Needham Heights, MA (781) 292-6600, www.mdllab.com.

RS No. 243

Rotary Joint

This coaxial rotary joint focuses on facilitating antenna rotation on maritime radar applications. The unit operates from DC to 12 GHz and offers VSWR of 1.15, insertion loss of 0.3 dB maximum, WOW of 1.05 and power handling of 100 W average. The unit measures 2.8" × 1.5", plus 1.97" diameter mounting flange with four 0.157" thru holes. The in-line configuration utilizes a hex body and a removable flange for ease of mounting. Product is offered with Type-N male and female connector options. Housing is nickel-plated brass.

Response Microwave Inc., Framingham, MA (978) 456-9184, www.responsemicrowave.com.

RS No. 244

DEVICES

MOSFET Devices

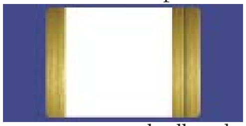
These MicroFET™ MOSFET products are thermally enhanced ultra-compact, low profile (2 × 2 × 0.8 mm) devices that target low power applications in the < 30 and < 20 V ranges. MicroFET power switches combine the company's advanced PowerTrench® technology with an industry-standard molded leadless package. This approach allows the MicroFET to deliver significant thermal and space improvements over conventionally used power MOSFETs in larger packages.

Fairchild Semiconductor Corp., South Portland, ME (207) 775-8100, www.fairchildsemi.com.

RS No. 245

Noise Diode

The model NW402 is a broadband microwave noise diode that operates in a frequency range from 10 MHz to 40 GHz with a 25 to 30 excess noise ratio (ENR). The diode is packaged in an economical pill package, 50 mil in length and diameter. The NW402 requires a bias current of only 15 mA with a diode voltage of 8 to 12 V, making it convenient for most microwave and built-in test applications.



NoiseWave Corp., East Hanover, NJ (973) 386-1119, www.noisewave.com.

RS No. 246

MATERIALS

GEN 2 RFID Tags

The company has developed solutions for three new Generation 2 RFID Tags. ECCOPAD® isolators are now available for the Avery Dennison AD-220 Runway, UPM Rafsec Short Dipole and the KSW Excalibur, all used at the UHF (915 MHz) frequency. ECCOPAD isolators are thin, flexible, rugged elastomers, which, when placed between the metal surface and the RFID tag, enable tag operation. ECCOPAD isolators are available with an integral pressure sensitive adhesive on one side, both sides or neither side.

Emerson & Cuming Microwave Products Inc., Randolph, MA (781) 961-9600, www.eccosorb.com.

RS No. 248

Metal Matrix Composites

The metal matrix composites are designed for thermal management products of high heat applications. These thermal management products for LDMOS packages, base plates and spreaders are for military electronics, telecommunications, aerospace and aviation uses involving extreme temperatures, including radar and weapons systems, and integrated circuits. The copper-clad molybdenum copper, molybdenum copper, aluminum silicon carbide and tungsten copper are used to dissipate heat in high temperature semiconductor chip applications.

AMETEK Specialty Metal Products, Eighty Four, PA (724) 250-5182, www.ametekmetals.com.

RS No. 247

SOURCES

YIG Oscillators

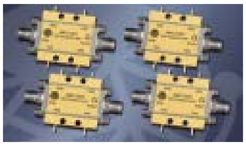
These Yttrium Iron Garnet (YIG) frequency sources feature high spectral purity that is needed for FMCW radar, microwave point-to-point radio and instrumentation applications. The YIGs are available up through Ku-band, and these high fundamental frequencies also minimize spurious signals in advanced radars. Proprietary shock-mounting techniques minimize microphonics. The YIGs are available in two configurations, Micro-YIG and Mini-YIG, to address a range of packaging and operating parameters. These YIG oscillators can be operated in an unlocked free-running mode, providing phase noise better than –105 dBc/Hz at 10 kHz offset and –128 dBc/Hz at 100 kHz offset.

Endwave Defense Systems, Sunnyvale, CA (408) 522-3180, www.endwave.com.

RS No. 249

Active ×2 Multipliers

Models HMC-C031, HMC-C032, HMC-C033 and HMC-C034 are broadband active ×2 frequency multipliers that provide output frequency coverage from 6 to 46 GHz. These multipliers utilize GaAs PHEMT technology and are packaged in miniature hermetic 41.66 × 27.59 × 8.50 mm connectorized modules. When driven with a +3 dBm signal, these active ×2 frequency multipliers deliver between +13 and +17 dBm of output power, with F_o and $3F_o$ isolations from 12 to 30 dBc with respect to the output signal level.

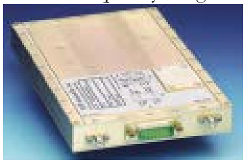


Hittite Microwave Corp., Chelmsford, MA (978) 250-3343, www.hittite.com.

RS No. 250

8 to 12 GHz Frequency Synthesizer

The TLSD/TLS2 frequency synthesizers operate in a frequency range from 8 to 12 GHz and provide good spectral quality; typically better than –85 dBc/Hz at 10 kHz off the carrier at 12 GHz. These units are system friendly, providing interface options of RS232, RS422 and RS485 within the unit. Features include: rugged EMI shielded enclosure on TLSD model, multi-drop bus configuration and low phase noise, low microphonics and no phase hits (over temperature).

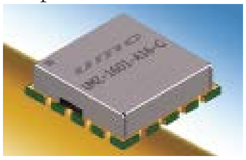


Luff Research Inc., Floral Park, NY (516) 358-2880, www.luffresearch.com.

RS No. 251

Octave-band Oscillator

The model UMZ-1601-A16-G is an RoHS-compliant, octave-band oscillator that operates in a frequency range from 800 to 1600 MHz. This model features low phase noise performance of –100 dBc/Hz at 10 kHz offset from the carrier over the 800 MHz bandwidth. Operating with a 10 VDC supply while drawing 25 mA (typical) over the temperature range of –40° to 85°C, UMZ-1601-A16-G is suited for applications requiring signal stability, tuning linearity and low phase noise performance across a wide frequency range. Size: 0.5" × 0.5" × 0.135".



Universal Microwave Corp., Tempe, AZ (480) 756-6070, www.vco1.com.

RS No. 252

Voltage-controlled Oscillator

The model SMV3417B-LF is a sub-miniature voltage-controlled oscillator (SMV) that operates in a frequency range from 3415 to 3420 MHz and is designed to meet the high performance requirements of portable radios and WLAN applications. This module offers phase noise performance of –85 dBc/Hz at 10 kHz away from the carrier. SMV3417-LF is a narrow band high performance model that provides good tuning linearity with a tuning sensitivity of 58 MHz/V (typical) and harmonic suppression of –20 dBc. Size: 0.30" × 0.30" × 0.08". Price: $15.95 (5 pcs min). Delivery: stock to four weeks.

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

RS No. 253

SUBSYSTEM

RFID Reader Module

The 1 W MPR7040 reader module operates over the specified Singapore UHF frequency band (923 to 925 MHz) and includes the RF, digital circuitry and embedded firmware required for EPC Class 0, EPC Class 1 Gen1 and 0+ Zuma, and ISO18000-6C (UHF Gen2) international standards operation. The MPR7040 leverages the common PCMCIA Type II package with 3.3 V CMOS levels (up to 5 V) serial communications.

WJ Communications Inc., San Jose, CA (408) 577-6200, www.wj.com.

RS No. 254

SYSTEM

Multi-band Satellite Ground Terminal

The MTT2400 2.4 m multi-band transportable satellite ground terminal is ultra compact and self-contained for easy transportation and set-up. With its rapid band switching capability it can be operated in any satellite network and it provides 34 RU free rack space for customized network functionality. The terminal can be monitored and controlled locally as well as remotely and a built-in power generator allows permanent stand-alone operation.

ND SatCom Defence GmbH, Friedrichshafen, Germany +49 7545 939 8759, www.ndsatcom.com.

RS No. 255

TEST EQUIPMENT

Portable Satellite Test Translators

This series of test translators is designed to translate the C-, X-, Ku- and Ka-band satellite communications frequency transmit bands to their respective receive bands. This series of test translators is available in single-, dual-, tri- and quad-band configurations. All translators are built in a convenient "suitcase" style package. Features include high frequency stability, minimum amplitude and delay distortion, and low phase noise contribution.

MITEQ Inc., Hauppauge, NY (631) 436-7400, www.miteq.com.

RS No. 256

Portable Test Bench

The model PTB-30-618-5R0-20-115VAC-SFF is a portable test bench that operates over the frequency range from 6 to 18 GHz. This unit provides 30 dB of minimum gain with an OP1dB of +20 dBm. An integrated 115 VAC, 60 Hz power supply is included in a self-contained sealed aluminum enclosure measuring 5" × 5" × 2.1". Input and output connectors are SMA female. This unit also features an on/off toggle switch and fuse protection. Other options are also available.

Planar Electronics Technology, Frederick, MD (301) 662-5019, www.planarelec.com.

RS No. 257

Arbitrary Waveform Generators

The AWG7000 series of arbitrary waveform generators (AWG) is designed to meet the test needs for high speed serial data buses and wide-band digital RF devices. With 5.8 GHz bandwidth, 10 bit resolution and sample rates up to 20 GS/s, the AWG7000 can produce high speed real-life waveforms with imperfections including noise, jitter, pre/de-emphasis and multi-level signaling up to 10 Gb/s. The AWG7000 is a fast, capable and versatile signal source for high speed serial and wideband RF signals. The series is available immediately for order. Price: starts at $60,000.

Tektronix Inc., Beaverton, OR (800) 835-9433, www.tektronix.com.

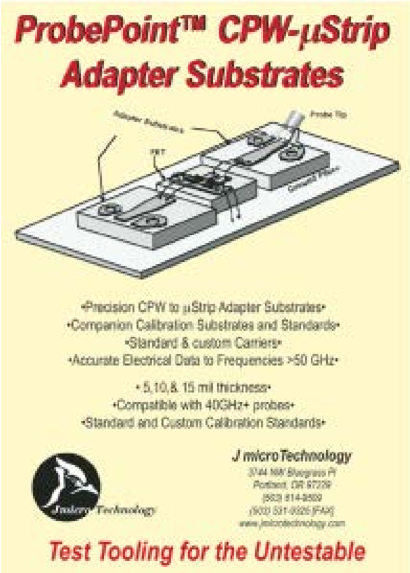
RS No. 258

RS 54

RS 34

RS 118

RS 31



RS 55

RS 142

RS 2

RS 72

RS 56

ERRATUM

In "UHF RFID and Tag Antenna Scattering, Part I: Experimental Results," a technical feature by Daniel M. Dobkin and Steven M. Weigand that appeared in the May issue of *Microwave Journal*, Equation 1 on page 174 contained an error. The correct equation is

$$A_{SC} = \frac{\lambda^2}{4\pi} G^2 \left| \frac{2R_a}{Z_L + Z_a} \right|^2$$

NEW LITERATURE

APPLICATION NOTE

"Selecting the Right Switch Technology for Your Application" is a free solid-state switch application note that helps in determining the right switch technology to accessorize and/or complement a system set-up. This application note provides a selection of products currently offered by Agilent to serve as a platform of comparisons for the technologies explained. To download a copy, visit http://cp.literature.agilent.com/litweb/pdf/5989-5189EN.pdf.

Agilent Technologies Inc., Palo Alto, CA (800) 829-4444, www.agilent.com.

RS No. 200

COMMUNICATIONS CD CATALOG

This comprehensive Fall 2006 Satellite Communication and Earth Station Equipment CD catalog features approximately 2000 pages of information, including the company's up/downconverters, test translators, IF/video equalizers, redundancy switchover units, video modulators and modems. Included also is a wide array of technical application notes, a full facility tour along with an explanation of the company's manufacturing and design capabilities.

MITEQ Inc., Hauppauge, NY (631) 436-7400, www.miteq.com.

RS No. 201

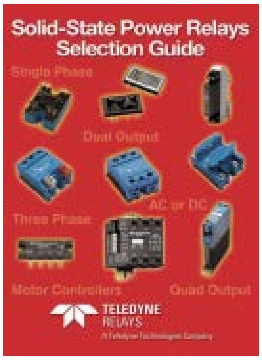
PRODUCT BROCHURE

The "Handset Solutions" product brochure showcases the company's wide range of specialty materials for handset applications. This literature features high performance foams, electroluminescent lighting and advanced circuit materials. These materials are used in a multitude of handheld device applications. For ease of use, each specialty material is color-coded to correspond to a table listing both its features and benefits.

Rogers Corp., Rogers, CT (860) 779-5597, www.rogerscorporation.com.

RS No. 202

SELECTION GUIDE



The solid-state power relays selection guide for industrial applications features 40 families of relays and motor controllers in a tabular format designed in an easy-to-use format to quickly assist engineers in choosing a product. The 24-page digest provides detailed information about the AC and DC relays and motor controllers, with output up to 125A, 690 VAC. The guide includes a comprehensive selection matrix and an appendix featuring thermal curves for single-phase hockey-puck relays and options such as heat sinks.

Teledyne Relays, Hawthorne, CA (800) 284-7007, www.teledynerelays.com.

RS No. 203

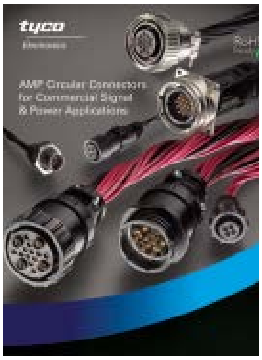
CD-ROM CATALOG

The 12th edition of this CD-ROM includes several new and updated brochures and catalogs including the newest edition of the LMR® Wireless Products Catalog with the latest updates to the LMR product line. The CD-ROM features an easy-to-use menu for navigation within each catalog. Also included are 'how-to' installation videos to assist users of LMR low loss coaxial cable products.

Times Microwave Systems, Wallingford, CT (203) 949-8400, www.timesmicrowave.com.

RS No. 204

CONNECTORS CATALOG



This newly updated circular plastic connector catalog provides the latest technical information and a comprehensive listing and cross reference of RoHS compliant part numbers. Included in the 84-page catalog are comprehensive electrical and mechanical specifications and technical information for connector housings, contacts and accessory items. To request a catalog, e-mail: newproducts@tycoelectronics.com.

Tyco Electronics Corp., Harrisburg, PA (800) 522-6752, www.tycoelectronics.com.

RS No. 205

2007 IEEE Radio Frequency Integrated Circuits Symposium
Honolulu, Hawaii
June 3-5, 2007

IEEE

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RFIC 2007 Call for Papers

The 2007 IEEE Radio Frequency Integrated Circuits Symposium (RFIC 2007) will be held in Honolulu, Hawaii on June 3-5, 2007. For the latest information, visit: **www.rfic2007.org**

Electronic Paper Submission/Communication: Technical papers must be submitted via the RFIC 2007 web site at www.rfic2007.org. Hard copies will not be accepted. Complete information on how and when to submit a paper will be posted on the RFIC 2007 web site.

Technical Areas: Papers are solicited describing original work in RFIC design, system engineering, system simulation, design methodology, RFIC circuits, fabrication, testing and packaging to support RF applications in areas such as, but not limited to:

- **Cellular System IC's and Architectures:** GSM, EDGE, TDMA, CDMA, 3G, WCDMA, GPS.
- **Wireless Data System IC's and Architectures:** WLAN, Bluetooth, 802.1x, Telemetry, RFID.
- **Wide Band System IC's:** UWB, MMDS, CATV, Optical System, Backplane.
- **Small-Signal Circuits:** LNA's, Mixer's, VGA's, Active Filters, Modulators.
- **Large-Signal Circuits:** Power Amplifiers, Drivers, Advanced TX circuits.
- **Frequency Generation Circuits:** VCO's, PLL's, Synthesizers.
- **Device Technologies and RFIC Testing:** Technologies, Packaging, Modules, Embedded Testing.
- **Modeling and CAD:** RFIC Modeling, Characterization of Active and Passive Devices.

Technical Format: The technical sessions will be held for three days from Sunday through Tuesday. Workshops will be on Sunday. Several invited sessions and talks will take place during the conference.

Microwave Week 2007: The RFIC 2007 will be in conjunction with the IEEE MTT-S International Microwave Symposium (IMS). Microwave Week 2007 will continue with the International Microwave Symposium and Exhibition, and the Microwave Historical Exhibit.

Guest Program: The Hawaiian Islands are a world-renowned visitor destination with many activities for you and your family to enjoy. Snorkel among tropical fish at Hanauma Bay. Learn to surf at Waikiki Beach. Golf at one of more than 80 courses and world-class resorts. Explore fiery lava flows on the Big Island. Hike through lush rainforests on Kauai. Cruise down a Maui volcano on a mountain bike. Many of these and other historical Hawaiian cultural activities will be part of our guest program. For more information in several languages, visit **www.gohawaii.com**

Electronic Submission Deadlines

Technical Paper Summaries in PDF format:	**8 January 2007**
Final Manuscripts for the Digest and CD-ROM:	**5 March 2007**
All submissions must be made through the RFIC2007 portal:	**www.rfic2007.org**

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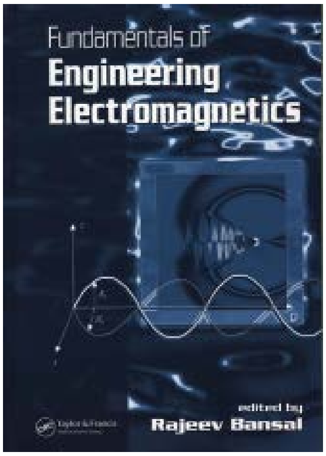
Fundamentals of Engineering Electromagnetics



Rajeev Bansal, Editor
CRC Press • 400 pages; $89.95, £49.99
ISBN: 0-8493-7360-3

This book is intended as a desk reference for the fundamentals of engineering electromagnetics. In Chapter 1, Fundamentals of Electromagnetics Revisited, the fundamental aspects of engineering electromagnetics are presented from the view of looking back in a reflective fashion at what has already been learned in undergraduate electromagnetics courses. Chapter 2, Applied Electrostatics, presents the fundamentals that one needs in order to understand electrostatics. The goals of Chapter 3, Magnetostatics, is to describe the fundamental theoretical foundations for magnetostatics, some simple and commonly encountered examples and a few common applications such as Hall elements sensors, magnetic storage and MRI imaging. Chapter 4, Electromagnetic Induction, is dedicated to the fundamental theoretical foundation of electromagnetic induction and its important consequences. In Chapter 5, Wave Propagation, the free-space propagation model, the path loss models and the empirical path loss formula are described. Chapter 6, Transmission Lines, provides a summary of the fundamental transmission-line theory and gives representative examples of important engineering applications. The specific properties of structures that transport electromagnetic waves are described in Chapter 7, Waveguides and Resonators. In Chapter 8, Antennas: Fundamentals, an overview of basic antenna terminology and antenna properties is given, including a discussion of concepts that are common to all antennas. In Chapter 9, Antennas: Representative Types, the discussion is focused on the specific properties of several representative classes of antennas that are commonly used. Chapter 10, Electromagnetic Compatibility, describes how EM concepts impact on practical design for EMC and thus assist engineers wishing to work in this area.

To order this book, contact:
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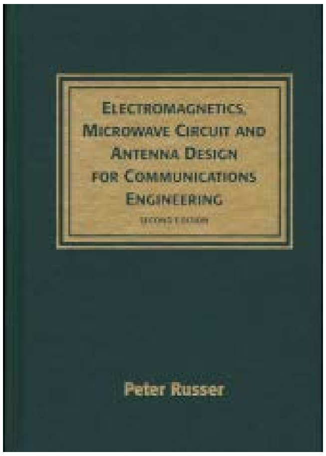
Electromagnetics, Microwave Circuits and Antenna Design for Communications Engineering: Second Edition



Peter Russer
Artech House • 749 pages; $139, £84
ISBN: 1-58053-907-6

This book is intended to provide the framework for engineers and students to attain the necessary background in electromagnetics for solving design problems in microwave circuits and antennas. This second edition is enlarged by more than 300 pages. Some of the added material is of advanced character and the reader or lecturer using the book may decide where to go in depth. Chapter 1 defines the topic and comments on the rationale and method of the book. Chapter 2 introduces the basic electromagnetic theory using exterior differential forms. In Chapter 3, scalar and vector potentials, as a power tool to solve Maxwell equations, are introduced. In Chapter 4, fundamental concepts, methods and theorems are introduced. Static and quasistatic fields are treated in Chapter 5. In Chapter 6, the surface wave propagation along a plane surface of finite conductivity is treated. The general principles of transmission lines and waveguides are discussed in Chapter 7. A unified presentation of transmission line theory for TEM transmission line modes and hollow waveguide modes is given. Resonant circuits and resonators are treated in Chapter 9. In Chapter 10, passive microwave circuits, their multiport representations and their analysis by signal flow graph are described. Chapter 11, on filters and periodic structures, far from giving a comprehensive treatment, is intended to introduce the fundamental concepts of the topic. In Chapter 12, the radiation of the Hertzian dipole is treated in the frequency and time domains. Antennas are treated in Chapter 13. The application of the integral equation method to the linear antenna for accurate computation of the antenna current distribution is demonstrated. Chapter 14 gives an overview of numerical methods for electromagnetic field computation.

To order this book, contact:
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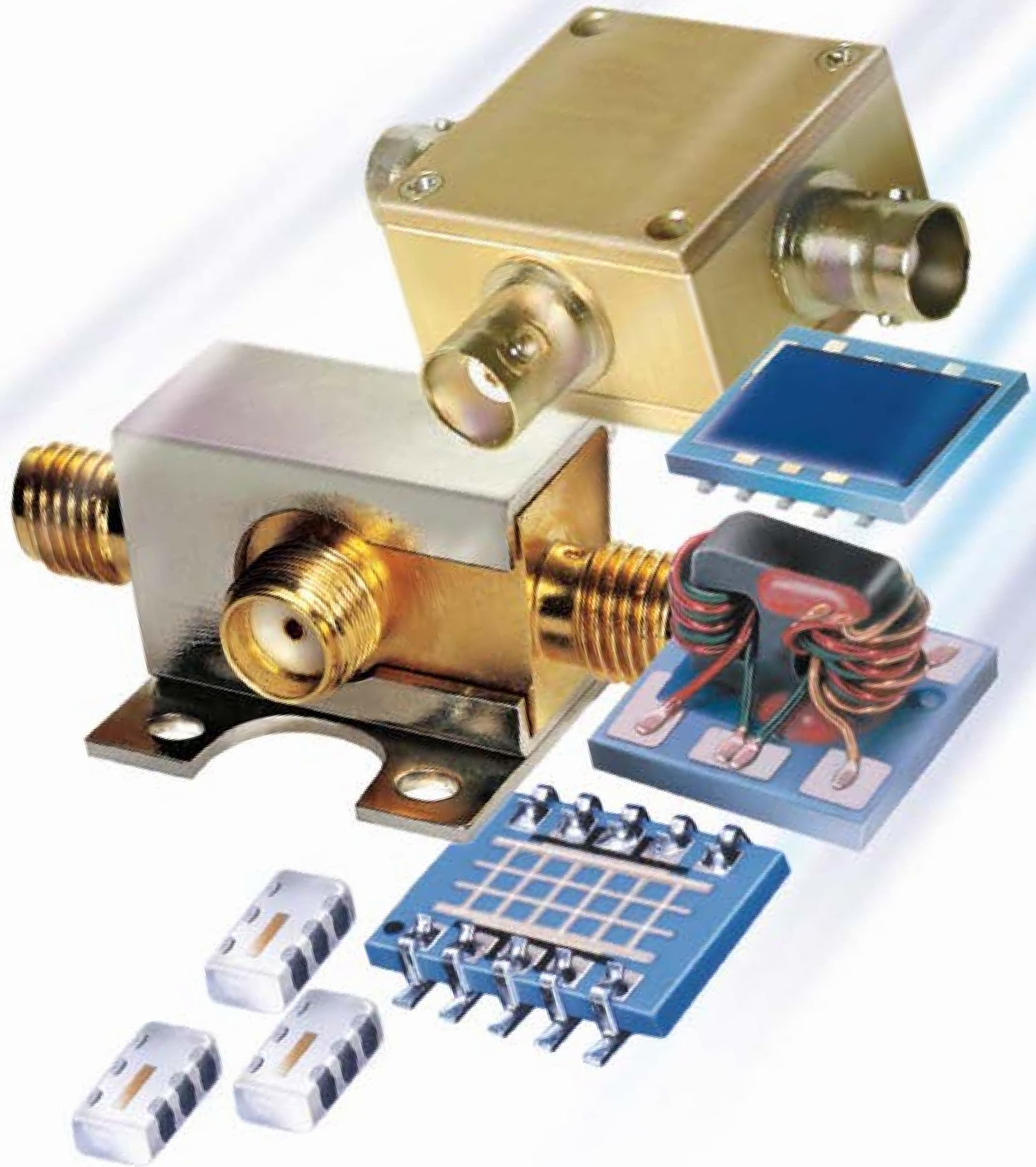

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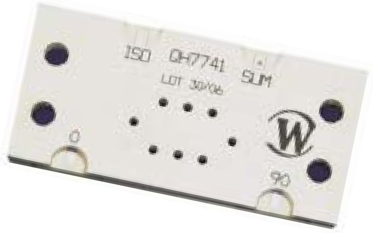

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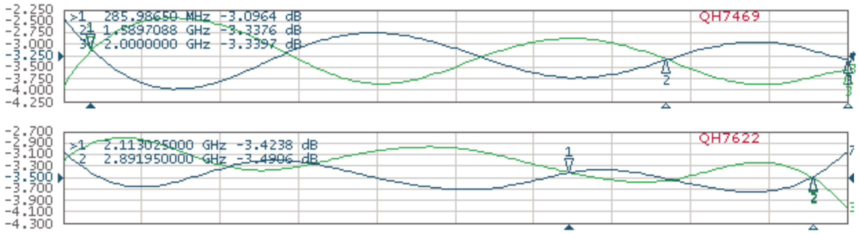

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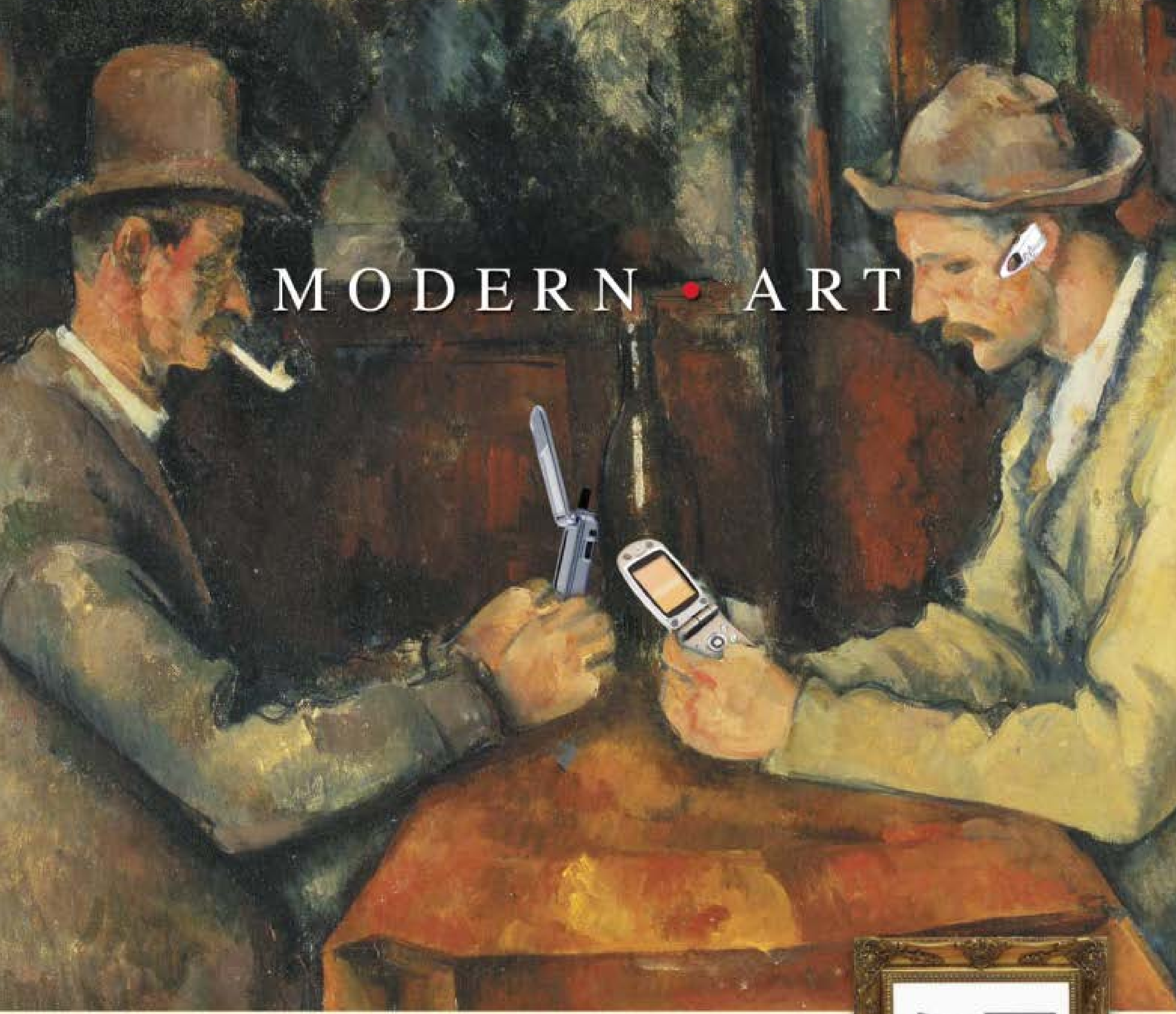
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Smart Partitioning for WiMAX Radios

Noman Rangwala and Rick Myers
Analog Devices Inc., Norwood, MA

The need for broadband wireless access (BWA) has long been acknowledged as the next step in the evolution of Internet access. Unfortunately, the lack of robust technology at a competitive price has been a barrier to its implementation. Today, though, momentum to cross the chasm is gathering—early adopters have endorsed the technology in under-served rural areas of the world, while standardization efforts have reduced costs enough that mainstream users can now consider WiMAX a viable alternative for broadband access with a future promise of mobile access.

WiMAX, based on IEEE 802.16 specifications, supports operation in multiple frequencies and multiple air standards. To ensure interoperability between multiple WiMAX solutions, the WiMAX Forum, an industry consortium, has developed profiles that specify the operating frequency, bandwidths, air-interface and medium access protocols. These profiles are based on a 256-carrier orthogonal frequency division multiplexing (OFDM) air interface for fixed/nomadic operation, and scalable-OFDM-access (S-OFDMA) air interface for portable/mobile applications.

Figure 1 shows a block diagram of a traditional WiMAX system. An RF transceiver is connected through a power amplifier (PA) and RF switches to the antenna on one side, and to a digital baseband (DBB) on the other. The interface between the RF transceiver and the DBB is composed of analog signals, which can be at intermediate frequency (IF) or baseband. Note that the ADCs and DACs in this architecture can be discrete devices, or can be integrated on an ASIC.

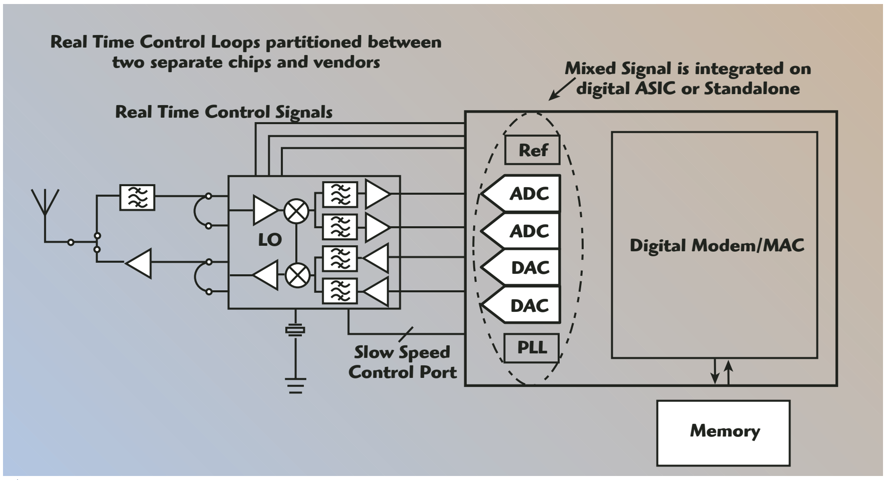
In some applications, a two-chip solution may have higher performance and lower cost than a single-chip solution. The key is to know how to divide the functions between the two chips to best exploit both the circuit topology and the available manufacturing technologies. Smart partitioning does just this, allowing an RF system-on-a-chip (SoC) to provide a complete RF-to-bits solution including all required automatic gain control, transmit power control and RF calibration loops. Including control loops on the radio front end enhances ease of use, provides for an easier mix-and-match capability with different DBB modems and improves performance. The accompanying reduction of real-time software control results in simpler system design. All analog and RF specific controls are integrated on the RF front-end IC. This is smart partitioning. ***Figure 2*** illustrates a block diagram for a system using smart partitioning.

COST BENEFITS ENABLED BY SMART PARTITIONING

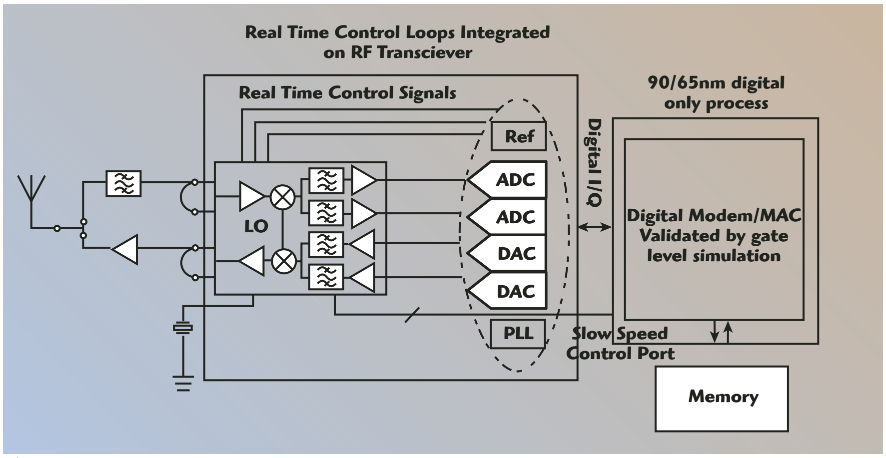
For communication systems such as WiMAX and BWA, consumer prices less than $100 are essential. In CPE equipment for asymmetric digital subscriber loop (ADSL) and 802.11g Wi-Fi ($20 to $30), for example, volumes increased dramatically as prices declined. Emerging markets such as WiMAX are also experiencing similar price pressures. End-user CPE prices are expected to be less than $100 by mid-2007. To achieve these targets, chipset pricing must fall to $20 or $25. Much lower than the current cost, this reduction will require significant improvements for market prices to yield an acceptable profit.

Smart partitioning offers the opportunity to dramatically reduce the total cost of a WiMAX system. Today's traditional DBBs are mixed-signal ASICs, with over 90 percent of their area occupied by digital gates and 5 to 10 percent used for data converters. The cost to manufacture such a mixed-signal device is over 1.5 times the cost of manufacturing a digital-only IC. The major contributors include higher wafer price (1.2 times), higher test cost (1.1 times), higher yield cost (1.1 times) and larger die size (1.05 times), totaling a 1.5 times increase in cost.

In addition to the tangible cost, there is a large opportunity cost incurred. Data converters typically lag behind by one generation of the process, and proven cores for 90 nm or 65 nm are not available for integration on today's fine-line digital processes. The opportunity cost for using a 130-nm process for the digital baseband instead of a state-of-the-art 90-nm process can be up to twice. Data converters integrated on a DBB constrain the cost, keeping the IC from taking advantage of Moore's law.



▲ *Fig. 1 Block diagram of a traditionally partitioned WiMAX system.*



▲ *Fig. 2 Block diagram of a WiMAX system using smart partitioning.*

EASE OF USE ENABLED BY SMART PARTITIONING

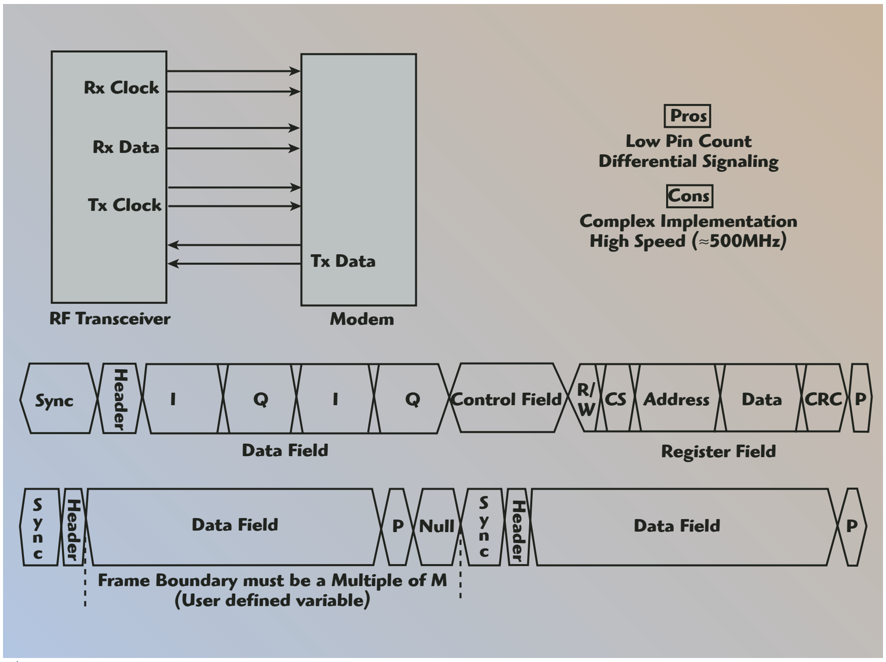
By itself, the integration of data converters is not sufficient for smart partitioning. The data converters required for WiMAX are typically over-sampled, so handling the raw data rate in and out of the transceiver would present implementation challenges. However, integrating decimation and interpolation filters on the transceiver allows the interface speed to be reduced. The availability of mature fine-line RF CMOS processes, coupled with advances in analog and RF modeling capabilities, have now made it possible to move data converters and other mixed-signal blocks to the RFIC in WiMAX radio designs. For cost and power efficient implementation of the digital blocks, fine-line CMOS is a definite plus. This article explores the choice of digital interface and the ease of use advantages introduced by simple RF drivers for receivers and transmitters.

DIGITAL INTERFACE: CHOICES, ISSUES AND CHALLENGES

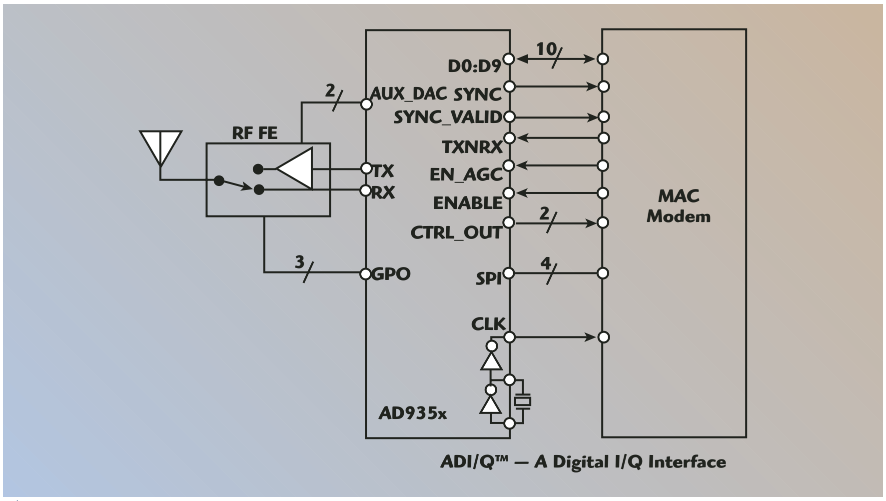
The evaluation board design and layout has a critical impact on the performance of the mixed-signal component of the DBB. The analog I/O on the reference board is sensitive to external noise, and the supply routes to the mixed-signal portion of the design require high isolation. Eliminating the analog I/O minimizes these noise-coupling issues, and solves the problem of interfacing analog cores from different vendors (such as RF chip and mixed-signal converter cores). For example, some ADC cores require a discrete 5 V driver op-amp to obtain specified data sheet performance. Modems using smaller processes, such as 130 nm or 90 nm, must reduce the signal swing and match the common-mode level to that of the RFIC. These considerations require valuable engineering resources. For systems using smart partitioning, the boundary between the transceiver and the DBB is digital, simplifying these issues.

Two basic options for selecting a digital interface are a high speed serial data stream using low voltage digital swing (LVDS) signaling, or a slower speed parallel bit stream. Variations of these schemes include embedded clock, synchronous clocking, or nibble transfers. Each approach has its advantages and disadvantages.

High speed serial links (see ***Figure 3***) have a lower pin count, reduced switching noise due to the differential signaling and larger separation (between DBB and RF transceiver). However, the high speed circuit design risk is one of the biggest implementation challenges. Implementation of the serializer and de-serializer is complex and requires clock recovery circuits and other custom design blocks that are not readily available in standard digital libraries.



▲ *Fig. 3 Digital interface — Serial interface option.*



▲ *Fig. 4 Parallel interface example from the AD935x family of smart partitioned transceivers.*

The parallel bit stream approach offers lower data rates and a standard CMOS I/O, but increases the pin count. To reduce the pin count to a manageable number, the data bus can use time duplexing to multiplex between receive and transmit data. Additionally, the I/O can be single-ended if the switching and high frequency noise are carefully managed and isolated from the highly sensitive RF circuitry. The design on the DBB is straightforward, and can be implemented with a standard hardware description language (HDL)-based design flow.

The JEDEC Committee (JC-61), formed in 2002, was chartered to create an open standard for digital interface, enabling smart partitioning and multi-vendor solutions. The published standard, JESD96, offers the high speed LVDS approach. A proposal and basic configuration for the parallel interface have also been accepted. ***Figure 4*** shows an example of a parallel interface implemented on Analog Devices' AD935x family of smart partitioned transceivers. The ADI/Q™ digital I/Q interface provides the basis of the JC-61 parallel standard.

AUTONOMOUS AUTOMATIC GAIN CONTROL (AGC)

In addition to ADCs and decimation filters, smart partitioned transceivers also integrate the automatic gain control (AGC) circuitry on the transceiver. The AGC adjusts the gain of the receiver path such that the input signal to the ADC is maximized in scenarios with and without interference. The AD935x receiver signal chain is illustrated in ***Figure 5***.

Time division duplexing (TDD), the preferred system for the future, supports framed waveforms (bursts). The media access controller (MAC) at the base station generates a downlink frame, which starts with a preamble, and follows with a frame control header and multiple data frames. The duration of each frame is short (1 to 2 ms). The input power during the burst varies by 3 dB

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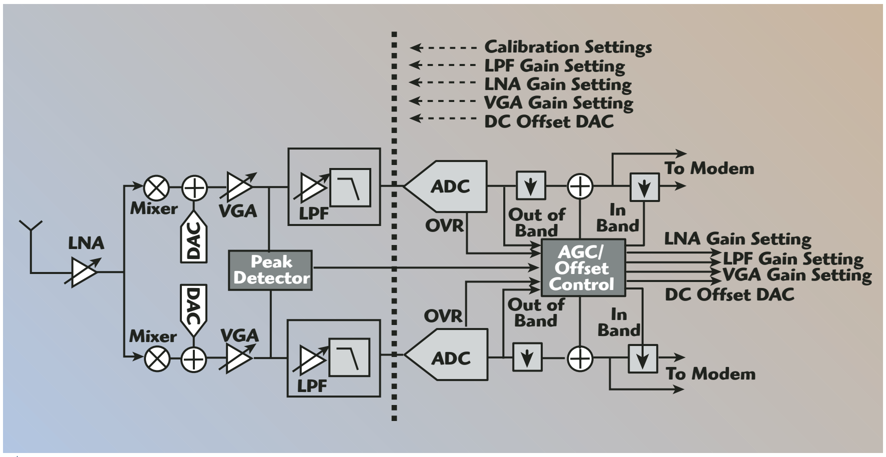
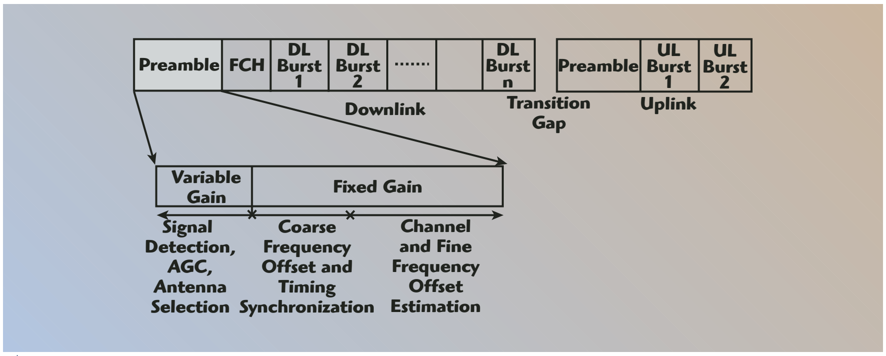


▲ *Fig. 5 Receiver architecture on the AD935x family of smart partitioned transceivers.*



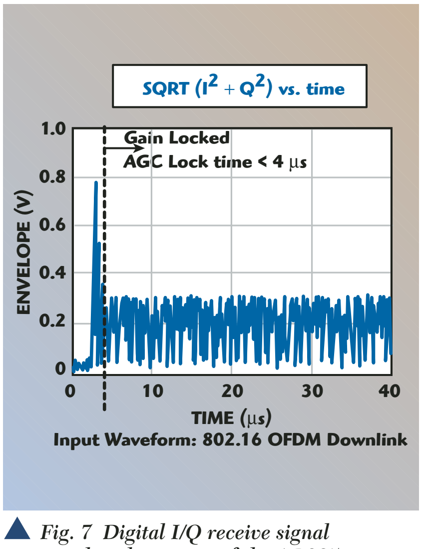
▲ *Fig. 6 The 802.16 OFDM waveform.*

for fixed systems and 10 to 12 dB for mobile systems.

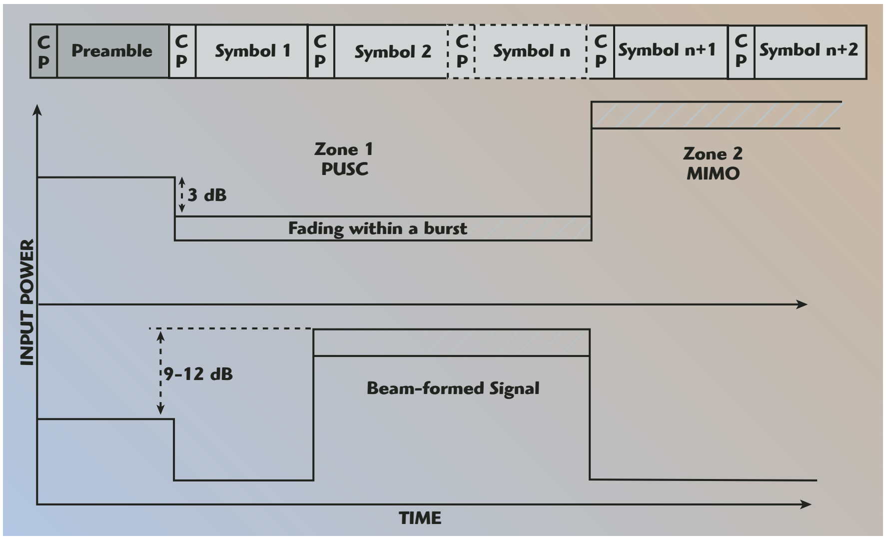
The transceiver uses the frame preamble to lock the gain of the receiver (see ***Figure 6***). The preamble is one or two OFDM symbols consisting of multiple tones whose phases are aligned to create a waveform with a small peak-to-average power ratio. The tones are also distributed such that the waveform is repetitive in the time domain.

To detect the minimum desired signal, the receiver gain is set to maximum. The in-channel received power is measured at the outputs of the ADCs and decimation filters. The peak detectors distributed along the receiver chain and the ADCs are also monitored for over-ranging. If detected, the receiver gain is reduced depending on the type of over-ranging. If the baseband peak detector before filters indicates clipping, for example, then the LNA gain is stepped down. The AGC algorithm cycles through these iterations and converges on an optimum gain setting. The system then freezes the gain for the remainder of the frame. For the modem to synchronize and correlate to the signal, the receiver gain must be fixed. A fast AGC lock time allows the modem more time to synchronize and make accurate channel estimates, reducing the implementation loss and improving the system performance.

Traditional systems achieve this by distributing the AGC function on both modem and transceiver. The dotted line in the receiver architecture indicates the functional partitioning. In this approach, the DBB must monitor the gain, detect peaks and set a new gain. The algorithm is generally implemented in the RF software driver. Every time the gain is changed, the transceiver must be recalibrated and the DC-offsets must be removed. The RF driver must maintain accurate timing and must respond to interrupts generated from the transceiver, making optimization a tedious, time-consuming task. In the case of multiple vendors, each RF driver must be customized for a specific transceiver.



▲ *Fig. 7 Digital I/Q receive signal measured at the output of the AD935x.*



▲ *Fig. 8 Power variations in a burst for advanced MIMO and beam-formed signals.*

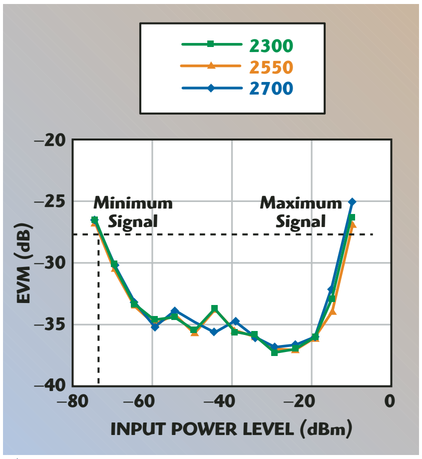
In multiple instances, vendors have struggled to achieve 64QAM operation on their reference designs because of these complex interactions.

A transceiver using smart partitioning integrates the complete control loop including monitoring and control algorithms on a single device. The basic process to lock the gain remains the same, but the responsibility for control is transferred to the RF transceiver. From the modem's perspective, the loop is autonomous and does not require any dynamic interactions. The modem can still accurately start and stop the loop, and can still monitor the received signal strength indicator (RSSI) and gain settings. All internal calibrations are now self-contained.

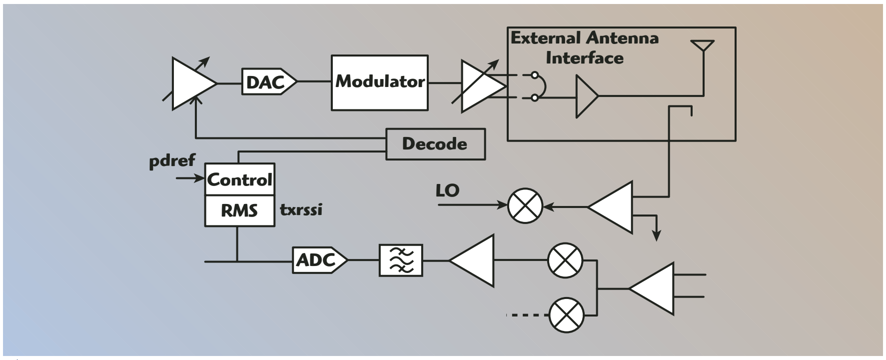
With well-managed timing constraints, this smart partitioning approach results in two advantages: a simpler RF driver and shorter AGC locking time. ***Figure 7*** shows that the AGC lock time, when using the autonomous AGC loop on the AD935x, is of the order of four microseconds for an 802.16 waveform. Further advanced techniques such as stronger signal detection, radar detection and interference back-offs can also be easily implemented.

Advanced systems, operating in mobile environments with fading channels, multiple antennas and beam-formed signals, require new techniques such as symbol-to-symbol AGC. The power variation within a burst in this scenario is 9 to 12 dB. A typical power variation versus time for a beam-formed or space-time coded waveform is shown in ***Figure 8***. To accommodate this power step, one option is to increase the ADC dynamic range and pay the corresponding cost of increasing a bit in performance. Another option is to reacquire lock on a symbol-by-symbol basis. A fast AGC with short lock times, coupled with accurate timing control for starting and stopping the AGC loop, could enable symbol-to-symbol AGC.

Figure 9 shows a plot of receiver input vs. measured receiver error vector magnitude (EVM) for a WiMAX transceiver, using



▲ *Fig. 9 Receiver performance of a smart partitioned receiver implemented on the AD935x.*



▲ *Fig. 10 Smart partitioned transmitter block diagram.*

smart partitioning along with a software modem implemented with Agilent VSA software. The performance curve exemplifies the ease of implementation achieved using the smart partitioning approach. For low input power, the receiver gain is automatically adjusted to accommodate the small input signal; the gain is then backed off automatically until the EVM is limited by the linearity of the transceiver.

TRANSMITTER POWER CONTROL

The 802.16 standard specifies a ranging process that determines the correct output power radiated by the terminal. This process ensures that transmissions from multiple terminals arrive at the base station at the desired power level (within a certain range that can be handled by the base station). The standard specifies a transmit power control range of 50 dB for the terminal. This will allow terminals to be distributed around the cell site to meet the equal power criteria at the base station.

During the ranging process, the base station requests the terminal to send out a ranging signal. The base station will then command the terminal to increase or decrease its transmit power. The WiMAX Forum is currently discussing requirements for accuracy and number of iterations.

In traditional architectures, external attenuators and true rms power detectors can be used to achieve the system specifications. Using smart partitioning, the integrated ADCs and DACs offer the transmitter the ability to rapidly measure highly accurate burst output power. ***Figure 10*** shows the components of the unique transmit power control scheme implemented on the AD935x transceiver. To utilize the power detector, the transmitted signal is sensed from an external coupler. It is then fed back to the receiver, where it is down-converted to baseband. The receive ADCs digitize the signal, which is then processed by a digital rms power meter block. This takes advantage of the half-duplex nature of the system to make an accurate measurement using the idle calibrated receiver path. The detector is capable of measuring power on a TX burst-by-burst basis, providing the modem with near-real-time power information. The front-end mixer is designed to be temperature and frequency independent, and thus requires only a one-point factory calibration. This feature saves test time and reduces calibration complexity.

The ease of use advantage is equally applicable to the transmitter. The modem can vary the power on a burst-by-burst basis by simply writing to the register before the burst. The transmit power is automatically adjusted to the open loop accuracy specification of the device. If greater accuracy is required, the transmit power control loop can be initiated and a correction factor can be applied to the next burst. Other novel techniques such as self-generated short test signals can be transmitted before the actual burst to calibrate the device in close loop. These techniques can be explored as emissions requirements and system requirements evolve.

SUMMARY

The smart partitioning of a WiMAX system enables the lowest system cost and reduces the dependence of real-time control from the DBB. Integration of the ADCs and DACs by itself is not sufficient to achieve these advantages. To reduce the speed of the digital interface, decimation and interpolation filters are also integrated in the transceiver. These stages also include the channel filters. A large portion of the RF driver complexity is managing the real-time signaling between the modem and transceiver to achieve fast and accurate AGC and TPC. To reduce the processing load on the modem, the AGC and TPC algorithm blocks are integrated on the transceiver. Other smart features can be integrated on the transceiver such as auxiliary ADCs and DACs, RF general-purpose outputs for RF switch and PA control. The AD935x family of transceivers exemplifies the RF system-on-chip features that can be implemented. ■

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Richard H. "Rick" Myers *received his BS degree from Old Dominion University in 1983. He is a senior applications engineer focused on wireless applications for the High Speed Signal Processing division of Analog Devices Inc. (ADI) and is based in Raleigh, NC. Before joining ADI, he was CDMA hardware development manager for handsets at Ericsson in Research Triangle Park, NC, and principal electrical engineer of RF and receivers at E-Systems (Raytheon) in Falls Church, VA.*

WiMedia UWB PHY Design and Testing

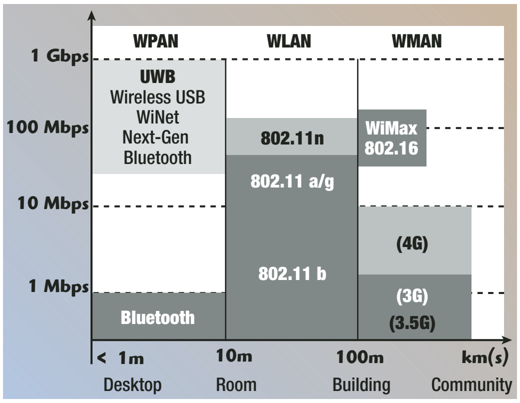
New wireless networking standards commonly present design challenges in the physical layer, which in turn present circuit simulation and testing challenges. The WiMedia MB-OFDM UWB signal with its low power, hopped, 528 MHz wide OFDM format is a current example, which will have broad impact as the base technology for certified wireless USB and next-generation Bluetooth for personal computer, consumer electronics and mobile devices. This article reviews WiMedia's MB-OFDM PHY layer structure and discusses various MB-OFDM testing topics, including transmitter analysis, receiver simulation and evaluation, and using simulations during circuit design to improve device immunity to interference. Finally, simulated and measured results from industry leading solutions are presented.

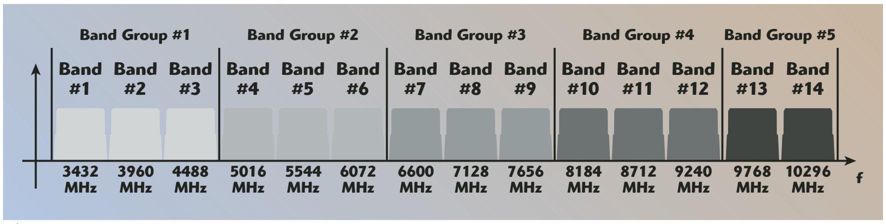
AMOLAK SINGH BADESHA
Agilent Technologies, EEsof, Santa Rosa, CA

With the blessing of the WiMedia Alliance, the stage is set for widespread implementation of certified wireless USB and next-generation Bluetooth 3.0 products, using multi-band orthogonal division modulation (MB-OFDM)-based ultra-wideband (UWB) physical layer (PHY). Wireless USB supports data rates of 53.3, 80, 106.7, 160, 200, 320, 400 and 480 Mb/s. Support for transmitting and receiving data rates of 53.3, 106.7 and 200 Mb/s is mandatory (see ***Figure 1***). The UWB spectrum is divided into 14 bands, each with a bandwidth of 528 MHz (see ***Figure 2***). The first-generation products are focusing on the first three bands (3.1 to 4.8 GHz), also known as Band Group no. 1, for simplification in the design of radio and analog front-end circuitry. The WiMedia standard specifies a MB-OFDM scheme to transmit information. A total of 110 sub-carriers (100 data carriers and 10 guard carriers) are used per band to transmit the data. In addition, 12 pilot sub-carriers allow for coherent detection. Frequency-domain spreading, time-domain spreading and forward error correction (FEC) coding are used to vary the data rates. The coded data is then spread using a time-frequency code (TFC).

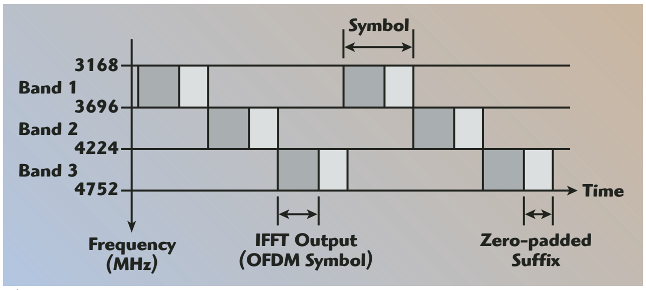
The standard specifies two types of time-frequency codes:

Fig. 1 Wireless services matrix showing where UWB fits in the picture.





▲ *Fig. 2 UWB spectrum divided into 14 bands.*



▲ *Fig. 3 Time versus frequency plot showing frequency hopping, TFC1 as per WiMedia standard.*

- Time-frequency Interleaving (TFI): where the coded information is interleaved over three bands.
- Fixed Frequency Interleaving (FFI): where the coded information is transmitted on a single band.

Support for both TFI and FFI is mandatory in the WiMedia standard.

Figure 3 shows one possible realization of a transmitted RF signal using three frequency bands, where the first symbol is transmitted at a center frequency f_c = 3432 MHz, the second symbol at f_c = 3960 MHz, the third symbol at f_c = 4488 MHz, the fourth symbol at f_c = 3432 MHz and so on. A zero-padded suffix (ZPS) is appended to the OFDM symbol to provide a mechanism to mitigate multi-path effects and allow sufficient time for the transmitter and receiver to switch between different center frequencies. For data rates of 200 Mb/s and lower, the binary data is mapped onto a QPSK constellation. For data rates of 320 Mb/s and higher, the binary data shall be mapped onto a multi-dimensional constellation using a dual-carrier modulation (DCM) technique.

MB-OFDM BENEFITS

UWB channels are highly dispersive and therefore pose significant multi-path challenges. MB-OFDM receivers are much more efficient at capturing multi-path energy (over 90 percent). In addition to capturing energy more efficiently, a MB-OFDM system also possesses several other desirable properties: high spectral efficiency, inherent resilience to narrowband RF interference and spectral flexibility. With an OFDM system, the transmitted spectrum can easily be shaped by nulling out tones or turning off bands in order to protect sensitive or critical bands. Several aspects of MB-OFDM specification are chosen to reduce implementation complexity:

- Constellation size limited to QPSK; required precision of digital logic (specifically IFFT and FFT), as well as reduced ADC and DAC.
- Large sub-carrier spacing: Phase noise requirements on PLL relaxed and improved system robustness to synchronization errors.

TRANSMITTER

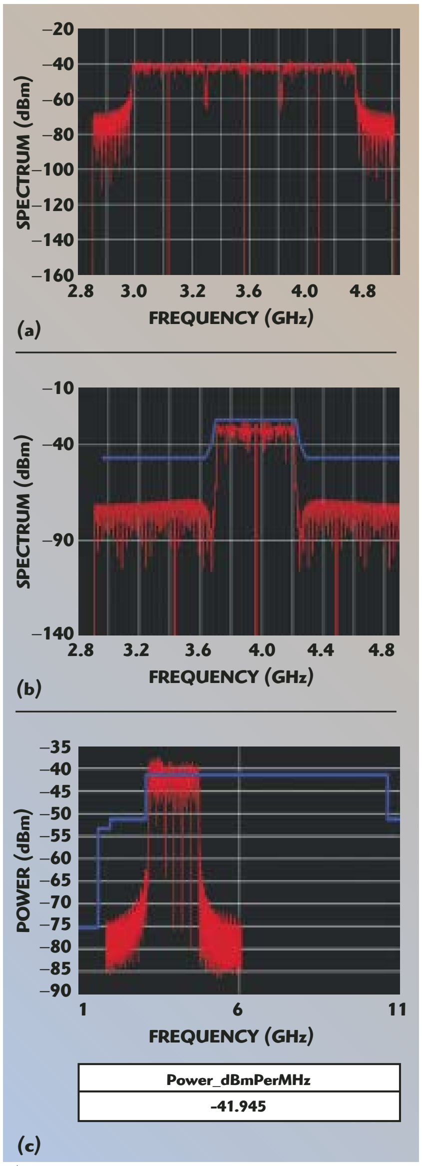
At the transmitter, the input bit stream is scrambled. A forward error correction (FEC) code (convolutional) is applied to provide resilience against transmission errors. The encoded sequence is then interleaved (TFI or FFI) and mapped to frequency bins of an OFDM symbol (QPSK or DCM). An IFFT is used to transform the frequency-domain information into a time-domain OFDM symbol. These are converted into continuous time-domain analog waveforms by a DAC, which is up-converted to the appropriate center frequency and transmitted. ***Figure 4*** shows the UWB spectrum, simulated in Agilent's Advanced Design System (ADS) WiMedia Library. What do the designers need to test in order to meet Federal Communications Commission (FCC) and WiMedia standard compliance for UWB transmitter? The most important tests are error vector magnitude (EVM), adjacent channel power ratio (ACPR), power control and packet error rate (PER).

The modulation measurements, such as EVM, provide great insight into the transmitter performance (much like doing an eye-diagram or eye-mask on digital data). EVM sheds light on "How is the overall system performing?" Starting at a system level with simulation tools, such as Agilent's Advanced Design System (ADS), allows the designer to simplify very complex designs. The WiMedia design library in ADS (supporting all bands) is used as a starting point to experiment with system and architectural tradeoffs. The design library provides a "Golden Radio" as a starting point. A designer can add radio impairments such as transmitter amplifier gain and compression characteristics, LO phase noise, fading channel and filtering effects. All these impairments affect EVM and simulations are used to predict the sensitivity of all impairments on the EVM. ***Figure 5*** compares some EVMs.

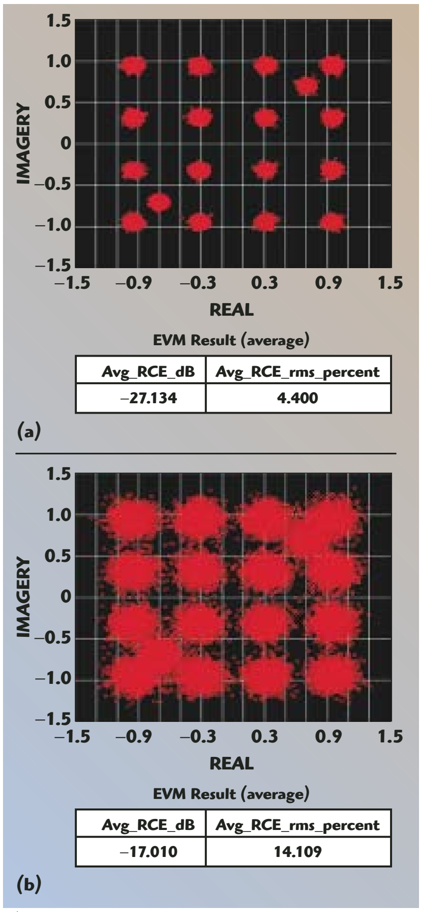
The primary purpose of the ACPR test is to guard against the possibility that in-band spurs may drive the 0 dBr level of the spectral mask test, which may hide potential failures. Therefore, it is desirable to construct a test that is insensitive to spurs, providing a good measurement of how much relative energy is leaking into the adjacent channel. The goal of the spectral mask test is essentially to measure how much interference is allowed to be transmitted into neighboring bands in a controlled way. The ACPR test measures the ratio of the in-band signal power to the out-of-band signal power and ensures that this ratio is at least 20 dB. ACPR can be simulated in ADS and measured with vector signal analyzer (VSA) software.

RECEIVER

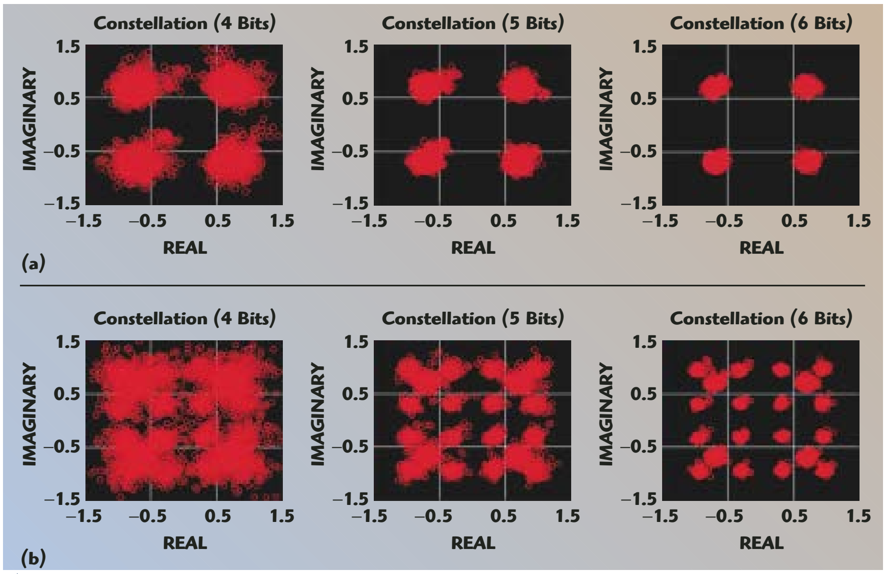
The received signal is amplified using an LNA and downconverted to the complex baseband using I and Q mixers. The time-frequency kernel provides the sequence of sub-band center frequencies based on appropriate TFC. Next, the complex baseband is low pass filtered to reject out-of-band interferers. The signal is then sampled and quantized using a 528 MHz ADC to obtain the complex digital baseband signal. Baseband processing begins with the packet detection and FFT operation follows to obtain the frequency-domain information. The output of the FFT is equalized using a frequency-domain equalizer (FEQ). A phase correction is applied to the output of the FEQ to undo the effect of carrier and timing mismatch between transmitter and receiver. The pilot tones in each OFDM symbol are used to drive the digital PLL. The output of the FEQ is demapped and deinterleaved before passing on the Viterbi decoder. The error-corrected bit sequence is now descrambled and passed on to the MAC. Two important considerations in WiMedia PHY receivers are receiver sensitivity and receiver PER. These results will vary depending on the receiver complexity. The challenge is to find the right balance between low cost (less complex receivers) and high end (more complex receivers). System-level simulations in ADS help quantify the trade-offs. For example, designers need to understand the effect of using low precision ADCs (4 bits) versus high precision ADCs (6 bits). High precision ADCs obviously increase the cost and complexity of the system. Most importantly, the bit precision of the ADC largely determines the power consumption of a UWB receiver. As shown in the simulation results, the requirement for the type of ADC used can vary depending on the data rates. ***Figure 6*** compares the simulated results (using ADS WiMedia Li-



▲ *Fig. 4 UWB spectrum simulated in Agilent ADS WiMedia Library; (a) UWB spectrum showing three frequency hopped bands (TFI), (b) Band 2 spectrum showing example of FFI (TFC6), (c) UWB spectrum and FCC mask.*



▲ *Fig. 5 Comparison of very good EVM (a) versus EVM barely meeting the WiMedia specification based on amplifier compression characteristics (b), simulated in ADS.*



▲ *Fig. 6 Looking at the effect of ADC precision on the constellation; (a) data rate = 80 Mb/s, TFC = 1(TFI), band group #1 = (3.1 to 4.7 GHz), modulation = QPSK, (b) data rate = 320 Mb/s, TFC = 1(TFI), band group #1 = (3.1 to 4.7 GHz), modulation = DCM.*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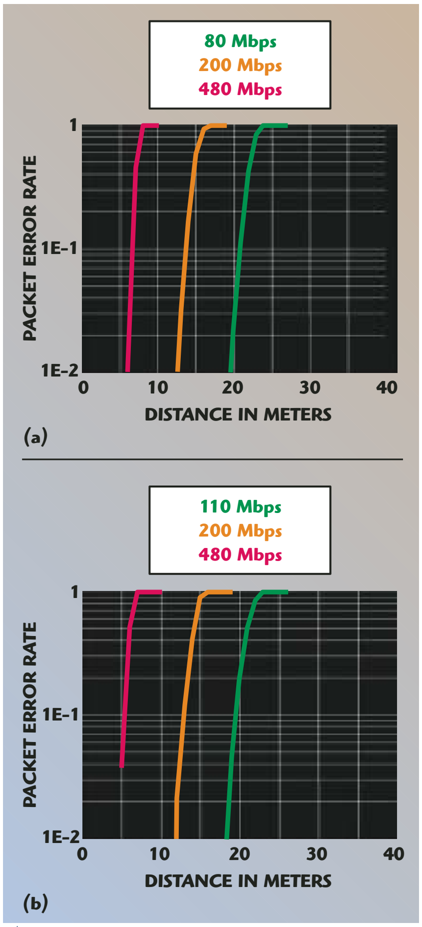
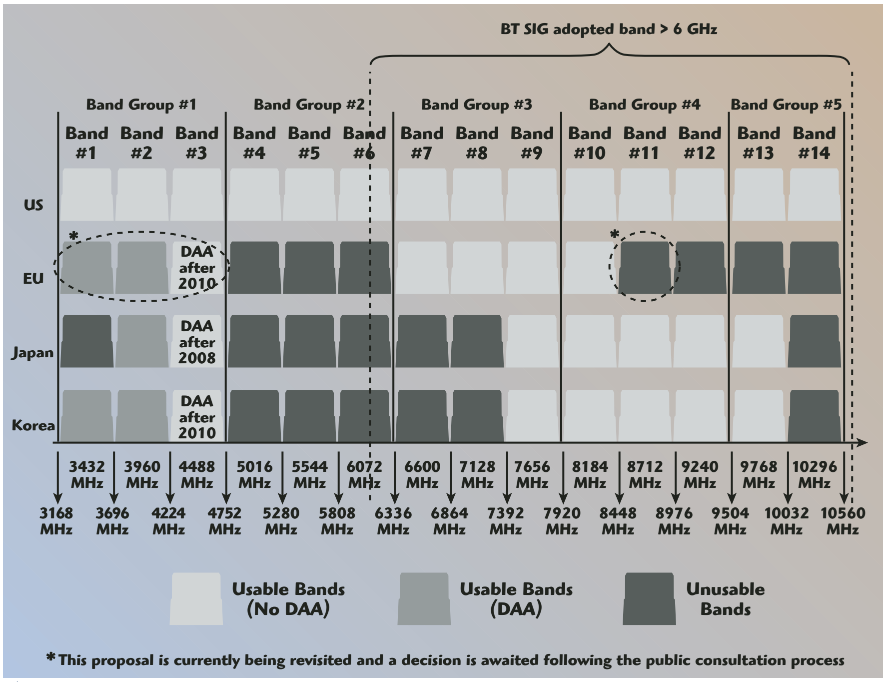
brary) of different precision ADCs for data rates of 80 and 320 Mb/s. Just looking at the constellation, it can be seen that whereas a 4-bit ADC can be used for lower data rate applications that use QPSK modulation, it will probably not meet the requirements of high data rate applications above 200 Mb/s, where system nonlinearities require higher precision to meet packet error rate (PER) specifications. Advanced Design System (ADS) design and simulation software, from Agilent Technologies, can also be used to simulate receiver PER versus range, using additive white Gaussian noise (AWGN) and fading channel models. A receiver PER measurement is required for the WiMedia Specification. ***Figure 7*** shows a comparison between simulations for PER of an AWGN channel and a simple fading channel. For very high data rate video services, multiple input multiple output (MIMO) techniques can be used to further enhance link reliability. The results shown in this article are all from Band Group no. 1, since most of the current developments are in this band. However, select companies are already looking at higher bands (Band Group no. 3 in particular) in order to develop radios that support international (Japan, Europe and Asia) regulatory standards. The ADS WiMedia library supports all bands. ***Figure 8*** shows the current status on regulatory activity around the world for UWB.



▲ *Fig. 7 PER versus range for an AWGN and fading channel at various data rates.*



▲ *Fig. 8 Current status of regulatory activity around the world.*

INTERFERENCE

Interference is an extremely important subject that will determine the technical and market acceptability of UWB systems, as shown in ***Figure 9***. FCC regulations require that UWB must not cause any harmful interference to licensed services. Specific interference mitigation techniques need to be used for in-band and out-of-band (OOB) interference.

There are two scenarios that need to be considered:

- UWB transmitter is an interferer and a licensed band receiver is a victim.
- UWB receiver is a victim and a licensed band transmitter is acting as an interferer.

A UWB transmitter can be prevented from interfering with licensed OOB services such as GPS, PCS, ISM and WLAN bands by meeting the FCC mask emission specifications (different mask requirements for Japan, Europe and Asia). If a possible victim is present in-band (for example, if a WiMAX signal at 3.5 GHz is present in the Band Group no. 1 UWB transmitter spectrum), the prominent technique used to mitigate interference is detect-and-avoid (DAA). This technique can be classified into two methods:

- Detect and Course Avoidance: the system will run the detection algorithm and effectively shut off the band containing the victim services and continue using the bands that are free of victim services. Going back to the WiMAX example, Band 1 (3.4 to 3.9 GHz) can be shut-off and the UWB transmitter can continue to transmit in Band 2 and Band 3.
- Detect and Fine Avoidance: specific avoidance is achieved by frequency notching (also known as tone-nulling) the narrowband signal and using the rest of the spectrum. This involves inserting zeros at the FFT stage to achieve notches in the transmit spectrum. Theoretically, a five-bit DAC

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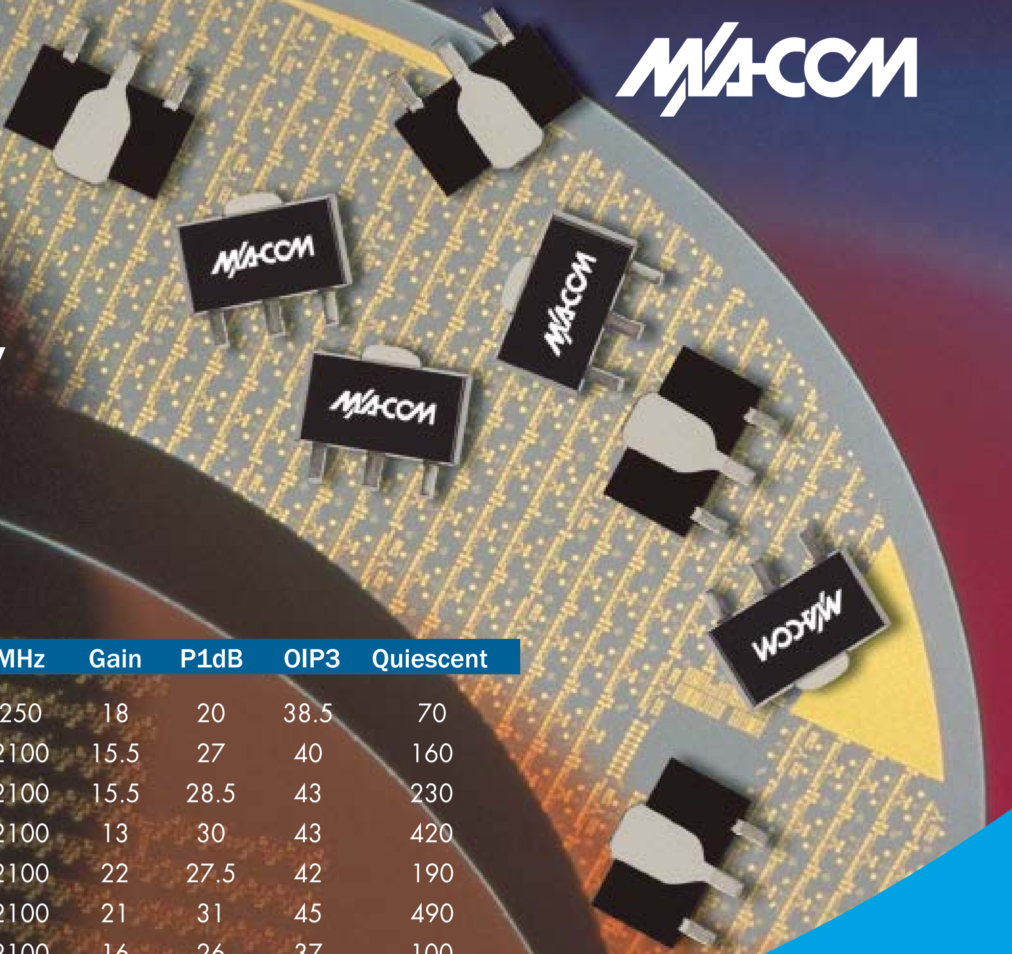

Product	Package	MHz	Gain	P1dB	OIP3	Quiescent
MAAMSS0046	SOT-89	250	18	20	38.5	70
MAAMSS0048	SOT-89	2100	15.5	27	40	160
MAAMSS0049	SOT-89	2100	15.5	28.5	43	230
MAAMSS0050	SOT-89	2100	13	30	43	420
MAAMSS0056	SOIC-8EP	2100	22	27.5	42	190
MAAMSS0057	SOIC-8EP	2100	21	31	45	490
MAAMSS0071	SOT-89	2100	16	26	37	100
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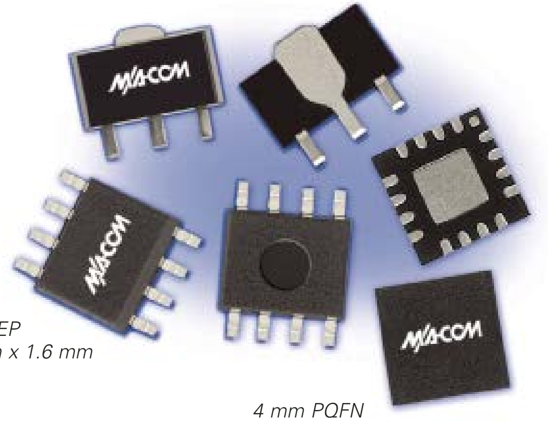

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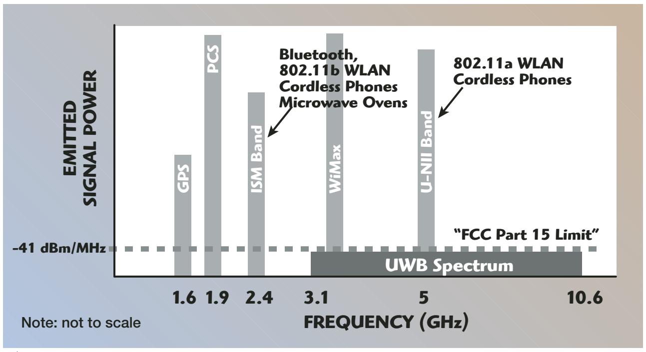
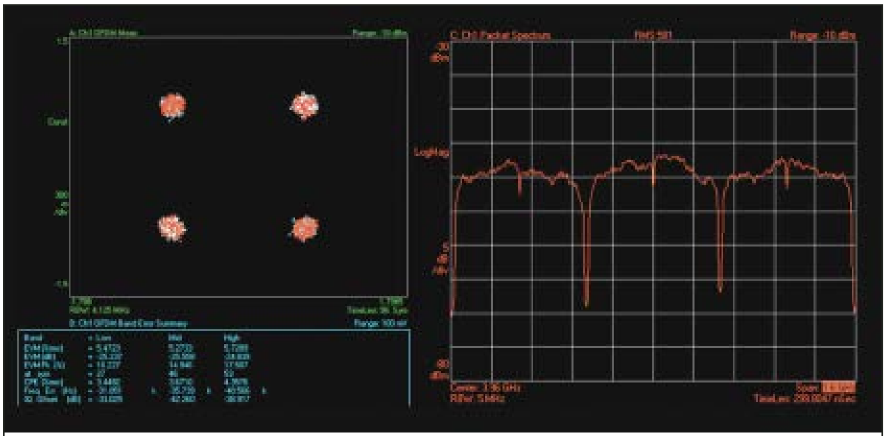
would achieve a 30 dB notch; practically, it is 15 to 20 dB, due to system nonlinearities. ADS can be used to simulate DAC precision versus notch depth, nonlinearities, etc. These techniques increase power consumption, add hardware complexity and cost, due to more computation at the transmitter.



▲ *Fig. 9 UWB spectrum and the presence of other licensed bands.*

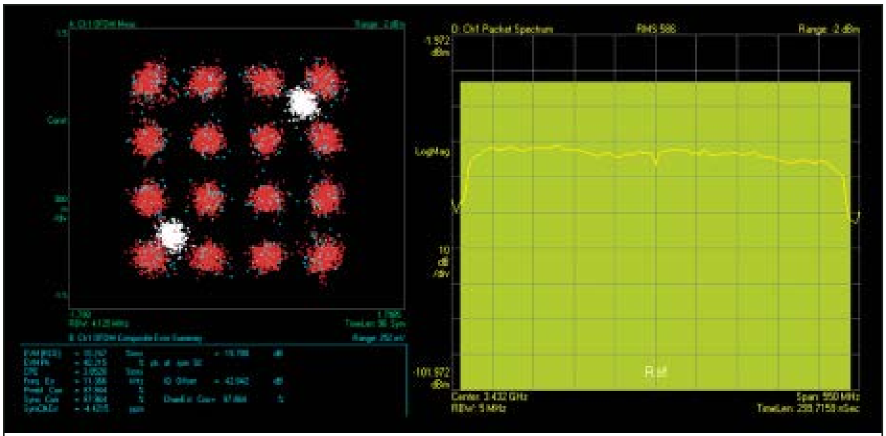
UWB receivers can reject OOB interferers by simply using an appropriate filter. For example, for a Band Group no. 1 receiver, a WLAN interferer at 5.19 GHz can be filtered out using a bandpass filter centered at 3.96 GHz, with an approximately 1.5 GHz bandwidth. UWB receivers are also likely to encounter in-band interference from narrowband systems such as WiMAX signals (interfering with Band Group no. 1) that may be quite powerful, operating in an uncontrolled manner and in close proximity. A recent article by David Leeper from Intel (available at www.wimedia.org) studied this very behavior using Agilent's SystemVue simulator. The results indicate that switching to fixed frequency interleaving TFC mode (TFC7 for Band 3, as per the WiMedia Standard) can provide protection against a powerful interferer like WiMAX. With FFI, the receiver performance will still degrade because of the interferer, but not "break" unless the interferer is so close (less than a meter) to the WiMAX receiver that front-end nonlinearities dominate the performance. The actual result will vary depending on the exact receiver implementation (ADC precision, etc). Other imperfections like LO leakage that may downconvert WiMAX interferer energy into UWB baseband can further limit receiver BER. Even then, additional filtering can be used to reduce the impact of WiMAX interferers. ***Figures 10*** and ***11*** give measured data for some example devices.

In conclusion, filtering techniques in conjunction with DAA mechanisms can be used to protect WiMAX and UWB receivers from possible interference and to meet emerging international regulations. ■



Data Rate = 200 Mb/s, TFC1, Measured Data from Wisair
[Note: Using Agilent 89600 Vector Signal Analyzer Software]

▲ *Fig. 10 Measured data from Wisair, TFC1 at 200 Mb/s, QPSK modulation, TFI.*



Data Rate = 480 Mb/s, TFC5, Measured Data from Staccato Communications
[Note: Using Agilent 89600 Vector Signal Analyzer Software]

▲ *Fig. 11 Measured data from Staccato Communications, TFC5 at 480 Mb/s, DCM modulation, FFI.*

ACKNOWLEDGMENT

The author would like to thank Staccato Communications and Wisair for their support in the writing of this article by providing valuable feedback and measured data from their UWB devices.

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Complete RFIC Design Flow Targeting Next Generation Wireless Front-ends

Besides the circuit design itself, a complete design flow based on a prescribed methodology is crucial for a successful implementation of next generation wireless front-ends. An integral part of this process is a scalable front-to-back solution that not only facilitates the job of the RFIC designer from the beginning, but also can be integrated with other domains such as analog/mixed-signal (AMS), digital and system design.

JÜRGEN HARTUNG
Cadence Design Systems Inc., Munich, Germany

The demand on mobile communications has grown over recent years. Today's mobile communication systems use sophisticated signal processing to achieve high transmission rates. The challenges for the next generation wireless systems will increase even further, when designs will need to meet multi-standards and achieve reconfigurability. Evaluations of various integration strategies will need to be performed to verify the feasibility of the proposed integration approach, where issues such as performance, cost and risk need to be considered. The requirements of the varying communication standards differ over a very wide range in terms of center frequency, signal bandwidth, signal-to-noise ratio, linearity, etc. This will have an impact on all radio front-end building blocks, and require comprehensive trade-off analysis to select the best appropriate architecture and derive the individual circuit block requirements.

The complexity of digital signal processing is also steadily growing, as can be seen from the block diagram of a dual-band transceiver IC shown in ***Figure 1***. The digital blocks offer the capability to compensate for some of the signal impairments caused by analog front-end blocks. To verify the complicated digital compensation algorithms, and the effect of analog nonidealities such as phase noise, nonlinearity and mismatch, the analog and digital blocks need to be simulated together. A key bottleneck to enable RF/baseband co-design is the

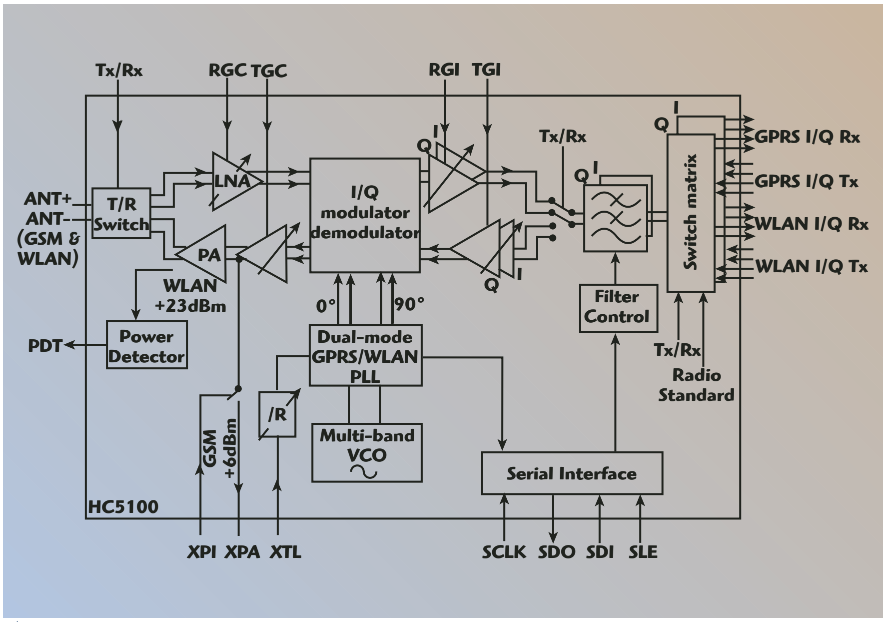


Fig. 1 Block diagram of a dual-mode transceiver IC from Helic.

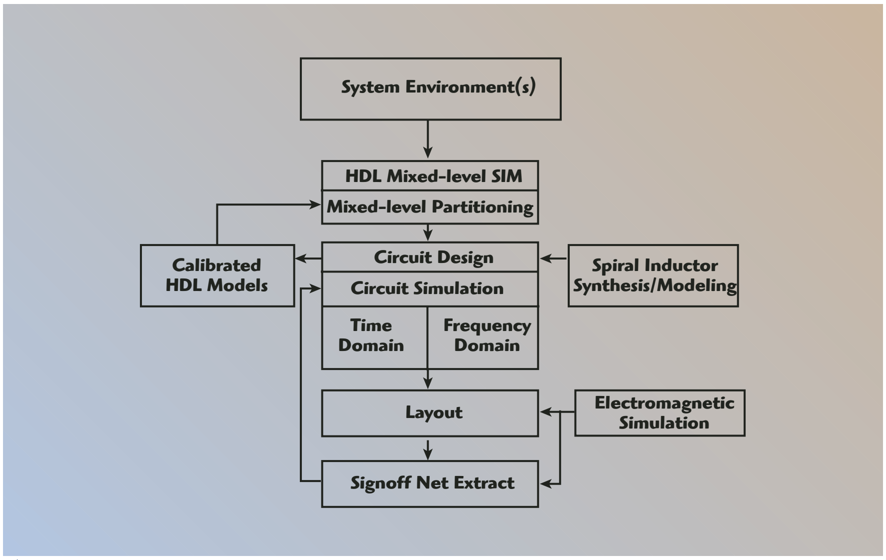


Fig. 2 Wireless RFIC flow.

presence of the RF carrier signal at several gigahertz in the RF front-end. To simulate the bit-error-rate (BER) or package-error-rate (PER) of a complete telecom link at the transistor-level and running thousands of cycles of the modulated signal is, at the very least, very expensive and often impractical.

Besides this performance verification, where the actual design is validated against specifications, another key requirement is the functional verification of the entire chip. Simple implementation errors at the interface between the digital control circuitry, which enable the various operating modes like power up, power down, receive, transmit and band selection, and the analog front-end, are often the cause of expensive re-iterations. IC designers typically overcompensate and stick to budget requirements passed down from the system designer. The IC designer may be able to prove that a more relaxed specification within the IC will still meet system-level requirements. Yet, with no way to prove theory, time is spent optimizing circuitry that may not be necessary.

Systems involving baseband and analog/RF portions have traditionally been designed, simulated and verified separately due to the different mindsets of the engineers and the tools of the two domains. The goal during system-level design is to find an algorithm and architecture that implement the required functionality while providing adequate performance at minimum cost. During the actual implementation phase, however, RFIC designers also face several significant challenges. Considering a large IC, such as a wireless transceiver, high speed requirements make circuits extremely sensitive to parasitics, including parasitic inductance, passive modeling, as well as noise. Thus, the essence of the RFIC flow is the ability to manage, replicate and control post-layout simulations and effects, and effectively use this information at timely points throughout the design process. RFIC design also requires specialized and unique analysis techniques, which are specific to RF design. These techniques cross between frequency domain and time domain analysis methods, which are chosen on the basis of circuit type, designer comfort level, circuit size, or designer preference. Ultimately, this requires a seamless environment that facilitates the choice of simulation method. Integration trends have also affected the RFIC world, which used to be viewed as a separate, almost stand-alone entity. Today, many RFICs contain at least ADC, DAC and PLL functions, as well as a digital synthesizer, which is created through the digital environment and integrated on-chip. In some cases, an RF content is added to large SoCs as some design groups attempt a single-chip solution, while others are integrating by using system in package (SIP) techniques, which leads to similar verification issues as RFIC and SoC methodologies.

These challenges need to be addressed by a complete solution that must:

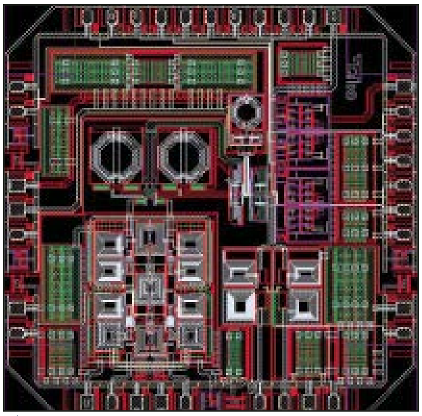
- Provide comprehensive links between system-level design and IC implementation
- Enable IC verification within a system-level context to leverage the existing wireless libraries, models and test benches
- Allow full-chip mixed-level simulation at different abstraction levels (language neutral)
- Allow for detailed analysis at the block and chip levels at an optimized simulation time
- Manage and facilitate simulation with full parasitics
- Contain layout automation that can be used at appropriate points in the design
- Allow for several levels of passive modeling throughout the design process

All of the above requirements must be met through a single environment, which not only facilitates the job of the RFIC designer from the begining, but also integrates with the other domains such as analog/mixed-signal (AMS) and digital. This must include both a chip and block-level perspective at multiple abstraction levels, where the same design collateral can be passed back and forth, facilitating verification/implementation from either environment point of view, independent of the physical integration strategies.

This article describes the Wireless RFIC reference flow as part of the RF Design Methodology Kit.[1] The flow was developed and verified based on a realistic reference design. Therefore, the design of the dual-band transceiver IC was ported to a generic CMOS 180 nm process, with the subsequent use of the whole design database in workshops and at customer sites. Instead of coming from a tool feature angle, the flow definition started from the challenges and difficulties of the application-specific design issues described earlier. The Wireless RFIC flow is depicted in ***Figure 2***. The flow is aimed at the RFIC designer and spans from the system design down to IC implementation, following the meet-in-the-middle approach described earlier.

LEVERAGING SYSTEM-LEVEL CONTENT

The design collateral from the system design process is used as the first, and highest, abstraction level. System-level descriptions become an executable test bench for the top-level chip. Models of the surrounding system can be combined with a high level model of the chip, producing an executable specification. System requirements serve as the first specification to drive the chip-level requirements and ultimately turn into repeatable test benches and regression simulations. Part of the leveraged system-level content is also the IP to determine the system relevant figures of merit, like EVM, BER and packet-error-rate (PER). Mixed-



▲ *Fig. 3 Layout of the underlying reference design.*

level simulation allows a natural sharing of information between the system and block designers. In order to enable the required links from the system environment to the IC environment, it is essential that the underlying multi-mode simulation solution is language neutral (from system models in C/C++, SystemC, SystemVerilog to digital/mixed-signal/analog behavioral HDL languages, down to Spice) and provides different engines and algorithms dedicated to the specific needs for a multi-domain circuit design.

DESIGN PLANNING AND SIMULATION

Successful execution on a complex design is contingent on the thoroughness of the planning upfront. No design can come together smoothly by accident. With a strong plan in the beginning that specifies top-level requirements, block-level requirements and the mixed-level strategies to use, a meet-in-the-middle approach can drive each block design to ensure full coverage of important design specifications and smoothly allow for blocks to have different schedule constraints. Therefore, the development of a comprehensive simulation strategy, which in turn leads to a modeling plan, is key.

After the realization of a first high level executable specification, the process continues by identifying particular areas of concern in the design. Plans are then developed for how each area of concern will be verified. The plans specify how the tests are performed, and which blocks are at the transistor level during the test. It is important to resist the temptation to specify and write models that are more complicated than necessary. Start with simple models and only model additional effects as needed. A formal planning process generally results in more efficient and more comprehensive verification, meaning that more flaws are caught early on, and there are fewer design iterations. The simulation and test plans are applied initially to the high level description of the system, where they can be quickly debugged. Once available, they can be applied during the mixed-level simulations of the blocks, reducing the chance that errors will be found late in the design cycle.

MULTI-MODE SIMULATION

The top-down process starts with HDL modeling for the entire RFIC added to the system-level test bench. This would include all RF blocks, along with any analog content and/or digital blocks. The first step is to behaviorally model the full chip within a top-level test bench, which would verify some system test such as EVM and BER. This at first verifies the partitioning, block functionality and ideal performance characteristics of the IC. This behavioral setup then serves as the basis to facilitate mixed-level simulations, where blocks can be inserted at transistor level and verified in a top-level context. This full chip and system setup can serve as the regression template to allow for continuous verification as blocks mature, allowing for a continuous evolution approach through the entire design. This is very important as any problems that are found can be detected at the earliest moment where time exists to fix the problem, and blocks can be designed in parallel to individual schedules.

Looking through the full simulation environment, several views of the same circuit will exist. This is likely to comprise a behavioral view, pre-layout transistor-level view and several views of parasitic information. As blocks mature, it may be required to add more transistor-level information to test RF/analog and RF/digital interfaces. This will require the use of a mixed-signal simulator capable of handling analog, digital and RF descriptions, and mix behavioral level with transistor-level abstractions. Picking the appropriate views of each block or sub-block, and managing the runtime versus accuracy trade-offs, can be made through simulation options such as sending the transistors to a fast Spice simulator or keep the transistors in a full Spice mode. This configuration is highly dependent on the circuit and sensitivity of the interfaces. The ability to manage these configurations effectively is key, as they must be repeatable. This provides an effective mechanism to set up the continuous regressions that support the ACD.

BLOCK CIRCUIT DESIGN

A preliminary circuit design then takes place, allowing for early circuit exploration and a first cut look at performance specifications. This early exploration leads to a top-level floor plan, which, for RFICs, is very sensitive to noise concerns and block-level interconnects.

At this stage, it is possible to synthesize passive components such as spiral inductors to specifications, and do their initial placement on the chip. This allows for two key activities: creating early models for spiral inductors that can be used in simulation before the block-level layouts are complete; and allowing for an initial analysis of mutual inductance between the spirals.

Component models of each inductor can be generated within this context for use in these simulations. Simulation is performed using the designer-preferred method, either in the frequency or time domain. This depends on the circuit, type of simulation, amount to be simulated and is a judgment call by the designer. A single process design kit and the associated environment allow for a smooth determination and selection of the simulation algorithm desired. The results are displayed through an appropriate display for the simulation type selected. As circuits are completed at block level, they are verified within the top-level context with behavioral stimulus and descriptions for the surrounding chip.

PHYSICAL IMPLEMENTATION

Layout automation (automated routing, connectivity driven layout, design rule driven layout, placement) can be used judiciously. The advantage to using layout automation is that it is tied to the schematic and DRC rules and allows for productivity gains. Analog capable routers can help with differential pairs and shielding wires, and allow for manual constraints per line. This allows for a physical design process that can also become repeatable just as the front-end process is. It may take some time and overhead to set up the initial tools, but this is made up as iterations are made through the design process. ECOs are more effectively performed if a repeatable layout process is in place. This is weighed against highly sensitive circuitry, which demands a manual approach.

PARASITIC EXTRACTION

As layouts are completed, electromagnetic simulation (EM) can be used to provide highly accurate models for passive components. For example, several spiral inductors may be selected as highly critical and are a target for EM simulation. These can be swapped in replacing the models that were created early in the design process, and mix and matched with the existing models. The designer then has full control over managing the spiral modeling process, again having the ability to trade off runtime versus accuracy at his/her choosing.

Net-based parasitic extraction becomes a key element of the process as layouts emerge. RF design is highly sensitive to parasitic effects. As such, the ability described above to manage different levels of parasitic information becomes paramount, as the designer can describe which areas, which lines and which blocks will have progressively more or less parasitic information associated with it. Less sensitive interconnects may require RC only, where more sensitive lines may require RLC. For lines with spirals attached, these can be extracted fully with RLC, plus the associated inductor component, even with substrate effects added for those lines that are the most sensitive, which are important to consider with respect to a compact layout (see ***Figure 3***, which shows a large number of partially closely spaced spiral inductors).

Again, these lines, which contain a 'full' extraction, can be mixed and matched with the component models for passive components that were created earlier.

Also, as the top-level layout emerges, analysis, especially substrate noise, is used to ensure that noisy circuits such as digital logic and perhaps PLLs are not affecting the highly sensitive RF circuits. The designer can check for this, and as areas of concern are flagged, either modify the floor plan accordingly or add guard bands around the noisy circuitry. However, it is often impractical to both simulate the entire design at the transistor level and include all the parasitic information. One approach is to extract calibrated behavioral models, using the extracted view of the design blocks. This, however, will not capture the effects of the parasitics on the interconnect between blocks. Therefore, hierarchical extraction capabilities to only extract parasitics of the interconnect between design blocks needs to be supported.

CALIBRATED HDL MODELS

Finally, as blocks are completed, the initial behavioral models can be back annotated for key circuit performance parameters, which can provide a more accurate HDL level simulation. While this will not account for every effect, it can add more realistic performance information at a very low runtime cost, allowing for faster level verification, and perhaps reduce the amount of full transistor-level verification required. In this way, the verification of a block by mixed-level simulation becomes a three-step process. First, the proposed block functionality is verified by including an idealized model of the block in system-level simulations. Then, the functionality of the block as implemented is verified by replacing the idealized model with the net list of the block. This also allows the effect of the block's imperfections on the system performance to be observed. Finally, the net list of the block is replaced by an extracted model.

By comparing the results achieved from simulations that involved the net list and extracted models, the functionality and accuracy of the extracted model can be verified. From then on, mixed-level simulations of other blocks are made more representative by using the extracted model of the block just verified rather than the idealized model. When done properly, bottom-up verification allows the detailed verification of very large systems. The behavioral simulation runs quickly because the details of the implementation are discarded while keeping the details of the behavior. Because the details of the implementation are discarded, the detailed behavioral models generated in a bottom-up verification process are useful as blocks mature, or for third-party IP evaluation and reuse. Especially for wireless systems including RF front-ends, bottom-up verification is absolutely essential when verifying the performance of large systems. As mentioned earlier, RF-system simulations at the transistor-level running thousands of cycles of the modulated signal are often impractical. The use of advanced envelope analysis techniques instead of traditional transient simulation would only speed-up the process by a factor of 10 to 20 times. In addition, even bottom-up extraction using traditional passband models, where the RF carrier is still present, will not provide the required speed-up. Only the combination of bottom-up model extraction techniques in combination with so-called complex baseband or low pass equivalent models, where the carrier signal is suppressed, will lead to simulation times that enable package-error-rate analysis at full-chip level.

Generating behavioral models that include the detailed behavior of even simple blocks can be difficult and requires a specialized skill not commonly found in the design team. Therefore, automated tools and methodologies to generate detailed behavioral models with verified accuracy and an open application programming interface (API) to modify the existing templates according to specific application and/or technology needs are required.

CONCLUSION

Comprehensive trade-off analysis of the relevant figures of merit prior to and a continuous verification during the RFIC implementation is key for a successful design. The non-ideal effects that impact on the overall system performance need to be considered both during top-down modeling and within the bottom-up verification. Especially with the virtual prototype, crucial decisions regarding the architecture and block parameter specification could be made early on. ■

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LFCN-95+	DC-95	230	3.99			•		
LFCN-105+	DC-105	250	3.99			•		
LFCN-120+	DC-120	280	3.99			•		
LFCN-225+	DC-225	460	2.99	•		•		
LFCN-320+	DC-320	560	2.99	•		•		
LFCN-400+	DC-400	660	2.99	•		•		
LFCN-490+	DC-490	800	2.99	•		•		
LFCN-530+	DC-530	820	2.99	•		•		
LFCN-575+	DC-575	900	2.99	•		•		
LFCN-630+	DC-630	1000	2.99	•		•		
LFCN-800+	DC-800	1400	1.99		•		•	
LFCN-900+	DC-850	1275	1.99		•		•	
LFCN-1000+	DC-1000	1550	1.99		•		•	
LFCN-1200+	DC-1200	1865	1.99		•		•	
LFCN-1325+	DC-1325	2100	1.99		•		•	
LFCN-1400+	DC-1400	2015	2.99				•	
LFCN-1450+	DC-1450	2025	2.99				•	
LFCN-1500+	DC-1500	2100	2.99				•	
LFCN-1525+	DC-1525	2040	2.99				•	
LFCN-1575+	DC-1575	2175	2.99				•	
LFCN-1700+	DC-1700	2375	1.99		•		•	
LFCN-1800+	DC-1800	2425	2.99				•	
LFCN-2000+	DC-2000	3000	1.99		•		•	•
LFCN-2250+	DC-2200	2900	1.99		•		•	•
LFCN-2400+	DC-2400	3600	1.99		•		•	•
LFCN-2500+	DC-2500	3675	1.99					•
LFCN-2600+	DC-2600	3750	1.99					•
LFCN-2750+	DC-2750	4000	1.99					•
LFCN-2850+	DC-2800	4000	1.99					•
LFCN-3000+	DC-3000	4550	1.99					•
LFCN-3800+	DC-3900	6000	2.99					•
LFCN-4400+	DC-4400	6700	2.99					•
LFCN-5000+	DC-5000	6850	1.99		•		•	•
LFCN-6000+	DC-6000	8500	1.99		•		•	•
LFCN-6700+	DC-6700	9300	1.99		•		•	•
			Total number of units in kit:	35	60	55	90	65

LFCN Models: U.S. Patent 6,943,646 except LFCN-800+, -1325+, -2000+ & -2400+.

HSPA: New Challenges for Power Amplifiers in UMTS User Equipment

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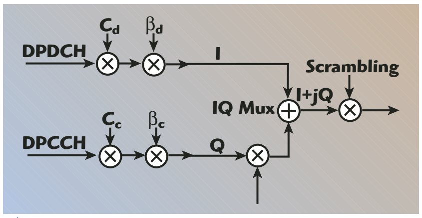
Mobile radio technology, based on the universal mobile telecommunications system (UMTS), is developing at breakneck speed. Network operators worldwide are currently upgrading their networks with new high speed downlink packet access (HSDPA) technology, which optimizes the data transmission from the network to the user equipment (downlink). New transmission methods allow data rates of several Mbit/s, and theoretically data rates of up to 14 Mbit/s are possible. In addition, HSDPA increases the capacity of mobile radio networks. Another advantage for mobile radio subscribers is faster service access times to a data service. HSDPA is part of release 5 of the Third Generation Partnership Project (3GPP) specifications, although this by no means marks the end of the development of UMTS technology. Manufacturers of mobile radio infrastructure and user equipment are already working hard on implementing high speed uplink packet access (HSUPA), a part of the 3GPP Release 6. HSUPA contains a large number of improvements for the data transmission from the terminal to the network (uplink), including data rates of several Mbit/s, higher throughput and faster access times. It is expected to be launched commercially in 2007. The fusion of HSDPA and HSUPA is referred to as high speed packet access (HSPA). All data services, in which large volumes of data are transmitted in both directions and which require a fast interaction between the downlink and the uplink, will benefit from HSPA. Mobile office applications, voice over IP and videoconferencing are some examples.

The Air Interface

Advantages of HSPA will be achieved by using new techniques on the air interface. This includes the introduction of a fast data transmission protocol (hybrid automatic repeat request, HARQ) in the uplink and downlink, for example, which allows the recipient to automatically request that the transmission of errored packets be repeated. In contrast to UMTS, where new data packets can only be transmitted every 10 ms, HSPA allows transmission every 2 ms. The network is then able to respond more quickly to changed channel conditions. The basic structure of the UMTS transmission



▲ *Fig. 1 Transmission of the DPCCH and DPDCH uplink channels.*

frame with a length of 10 ms and 15 time slots is retained. Only subframes of 2 ms and three time slots each will be introduced for HSPA and one data packet per subframe can be transmitted. Another major innovation in HSPA involves the base station, which is responsible for assigning the resources for the data transmission with HSDPA and HSUPA. It continuously performs measurements to determine the uplink transmission conditions, on the basis of which the scheduling algorithm in the base station makes the decision regarding the assignment of the uplink resources available. The base station analyzes regular measurements of the mobile phones based on the channel quality to ensure an optimum assignment of the downlink resources. HSPA not only requires numerous changes in physical transmission parameters and the introduction of new physical transmission channels but also changes in the protocol architecture. The implementation of HSPA for the manufacturers of network elements, terminals, chipsets and modules is not an easy job. This article describes the difficulties that have to be overcome particularly in the design of power amplifiers for HSPA-compatible terminals.

UPLINK CHANNELS FOR HSPA

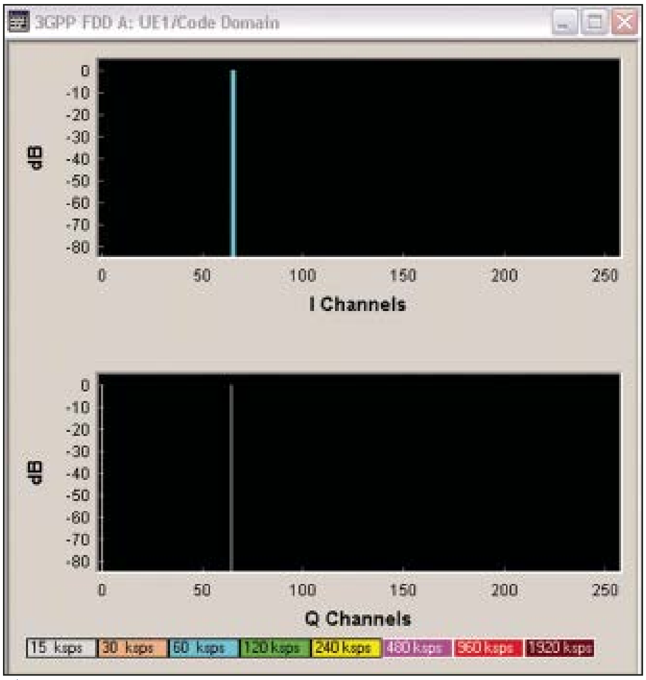
UMTS and HSPA use the wideband code division multiple access (WCDMA) method for multiple access to the air interface. Instead of dividing the resources per frequency or time multiplex into channels, the signal is distributed across the entire frequency spectrum by code spreading. The spreading factor is indicated as a measure of the code spreading. Lower spreading factors allow the transmission of larger data volumes but less spreading gain. Before the introduction of HSPA, two uplink channels were relevant for data transmission in UMTS: the dedicated physical data channel (DPDCH) for transmitting payload and the dedicated physical control channel (DPCCH) for transmitting control information. Both are transmitted using the IQ multiplex method in the uplink (see ***Figure 1***). The DPDCH is located on the I domain and the DPCCH on the Q domain. Both are individually spread: the DPDCH has a variable spreading factor c_d depending on the data rate, while the DPCCH is always located on code 0, having the spreading factor 256. A new uplink channel, the high speed dedicated physical control channel (HS-DPCCH), is needed for control purposes, although HSDPA targets an enhancement of the downlinks. This channel is primarily used to transmit measurements for determining the channel quality from the terminal to the network. This information is also called the channel quality indicator (CQI). In addition, the correct reception of the packets received in the downlink is confirmed on the HS-DPCCH. For this purpose, the terminal sends an ACK (acknowledgement). If an errored data packet is received, it can be requested again by using a NACK (negative acknowledgement) on the HS-DPCCH. The HS-DPCCH is transmitted as a third code channel in the uplink and is located on the Q domain. As a result, a view of the code domain, as shown in ***Figure 2***, is obtained. The HS-DPCCH is located on code 64, having the spreading factor 256, which corresponds to 15 ksymbols per second (ksps). Due to its special structure, the HS-DPCCH causes some difficulties with the development of power amplifiers. It is not transmitted continuously but only when information has to be sent from the terminals. This results in a burst-like structure. Additionally, it can be predefined in the network that the transmit power is changed depending on the information to be transmitted on the HS-DPCCH. For example, an ACK can be sent with a higher power than a NACK. The CQI information can also be individually scaled. The HS-DPCCH is not necessarily based on the other uplink channels with respect to time. For this reason, the fluctuations in performance caused by the HS-DPCCH do not always occur on the timeslot borders of the dedicated channels DPDCH and DPCCH. Instead, the transmission of a HS-DPCCH subframe may suddenly start in the middle of a DPCCH timeslot. In this case, the terminal has to adapt the absolute transmit powers with respect to the single uplink channels to avoid exceeding the maximum permissible transmit power. The introduction of HSUPA is accompanied by two other channel types in the uplink: the enhanced dedicated physical data channel (E-DPDCH) for transmitting user data with high data rates and the enhanced dedicated physical control channel (E-DPCCH) for transmitting control information. It should be noted that there could be up to four E-DPDCH channels per terminal at once.

Depending on the data volume and transmission power available, the terminal selects how many E-DPDCH channels are required for transmitting the data packet and which spreading factor is necessary. The arrangement of the E-DPDCH channels and E-DPCCH channel on the IQ domain is defined for every possible configuration of the standard. ***Figure 3***, for example, shows the resulting code domain for four E-DPDCHs, measured on a spectrum analyzer. This configuration allows the maximum data rate of 5.76 Mbps for HSUPA. The E-DPCCH is always transmitted on the I domain and is located on code 1 with the spreading factor 256. In this case, the HS-DPCCH is located on code 33 with the spreading factor 256. The new uplink channels for HSUPA also have to be taken into consideration with the development of the power amplifiers in the terminal.

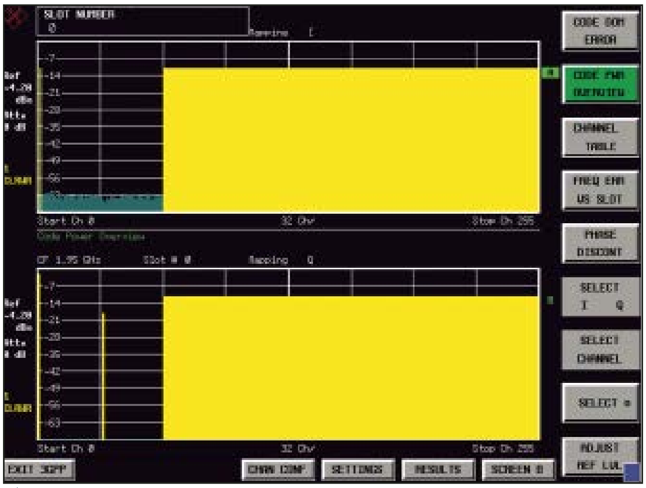
SETTING THE CHANNEL POWER

A special method is used to set the power of the different channels in the uplink. Gain factors (also called beta factors) for the single channels are signaled from the network to the terminal during the connection setup. For the DPCCH they are referred to as β_c, for the DPDCH β_d, for the HS-DPCCH β_{hs}, for the E-DPCCH β_{ec} and for the E-DPDCH β_{ed}. The gain factor is used to describe a particular amplitude ratio that is assumed by the observed channel in relation to the DPCCH. From this amplitude ratio it is possible to determine the power value for the observed channel in relation to the DPCCH. ***Table 1*** shows this using the E-DPCCH as an example.

The values that are signaled from the network to the terminal for the E-DPCCH are listed in the left-hand column. The standard stipulates how these values have to be interpreted by the terminal and which amplitude ratio, $A_{ec} = \beta_{ec}/\beta_c$, is to be set be-



▲ *Fig. 2 Uplink code domain with HS-DPCCH.*



▲ *Fig. 3 HSUPA uplink signal with four E-DPDCHs.*

TABLE I

AMPLITUDE RATIO BETWEEN E-DPCCH AND DPCCH

Signaling Values for $\Delta_{E\text{-}DPCCH}$	Quantized Amplitude Ratios $A_{ec} = \beta_{ec}/\beta_c$	E-DPCCH Power to be Set in Relation to DPCCH
8	30/15	6.02
7	24/15	4.08
6	19/15	2.05
5	15/15	0.0
4	12/15	–1.94
3	9/15	–4.44
2	8/15	–5.46
1	6/15	–7.96
0	5/15	–9.54

tween E-DPCCH and DPCCH. The resulting power ratio, which can be easily determined by calculating 20 log (β_{ec}/β_c), can be read in the right-hand column.

The terminal can now scale all channels in the uplink to one another by using the gain factors. Please note that the gain factors describe the ratio of the channels relative to each other. This ratio remains unchanged irrespective of the total power of the uplink signal, which is preset by mechanisms already known from UMTS. Fast power control in the uplink is crucial. To make this possible, the terminal has to follow the commands of the network, by which the transmit power can be incrementally increased or decreased. It is therefore essential that the maximum permissible output power for the terminal class observed not be exceeded.

PEAK-TO-AVERAGE RATIO

The ratio of peak-to-average power of a signal (PAR) is a particularly important parameter for dimensioning power amplifiers. This topic was extensively discussed when the HSDPA standard was specified in 3GPP Release 5, since the HS-DPCCH (as third code channel) at times significantly increases the PAR of the uplink signal. This results in larger dynamic variations in the signal and stricter requirements on the power amplifier's linearity. It becomes more difficult to remain distortion-free and to adhere to the limits for the permitted adjacent channel interference and for the modulation quality. Moreover, the power amplifiers used are also supposed to operate efficiently in terms of cost. For this reason, the HSDPA standard allows a reduction of the maximum output power of the terminal for the periods during which the HS-DPCCH is sent. The required reduction of the power depends mainly on the amplitude ratio between DPCCH, DPDCH and HS-DPCCH. The permissible reduction of the maximum output power is therefore specified, depending on the gain factor combinations β_c, β_d and β_{hs}. However, the standard only allows a reduction of the output power for very critical combinations, since a large reduction of the transmit power may affect the cell coverage. In the 3GPP, 99.9 percent PAR was used as a benchmark for evaluating the required reduction of the transmit power. Different HSDPA uplink signals were compared with a reference channel that consisted of only DPCCH and DPDCH. As a result, the 3GPP Release 5 stipulated that the maximum transmit power of terminals of power classes 3 and 4, as specified in 3GPP, is allowed to be reduced by up to 2 dB, depending on the gain factor combination, if a HS-DPCCH is transmitted. The result also took into account that even higher PAR values than those described by the 99.9 percent PAR very often occur in a HSDPA signal.

CUBIC METRIC

With the introduction of HSUPA, this procedure has been put to the test again. The experience obtained through HSDPA showed that the increase of the PAR cannot be transferred 1:1 in dB to the required reduction of the transmit power. Therefore, with the introduction of HSUPA, a new benchmark, the cubic metric (CM), was defined in 3GPP Release 6. It is a more precise value for predicting the required reduction of the transmit power to ensure the desired uplink performance.

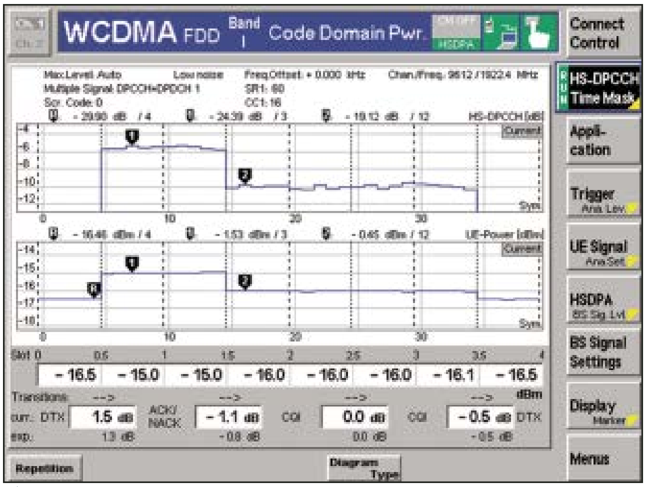
The cubic metric applies equally to HSDPA and HSUPA uplink signals. Depending on the observed channel configuration, the cubic metric is determined in the uplink and describes the ratio of the cubic components in the observed signal to the cubic components of the reference signal. A simple voice signal was selected as the reference signal. The detailed calculation formula can be found in the 3GPP specifications. The cubic metric is based on the fact that third-order nonlinearities in the characteristic of the power amplifier are the main reason for adjacent channel interference in the uplink. Therefore, in the 3GPP Release 6 specifications, the permissible reduction of the transmit power is determined as a function of the cubic metric of the observed signal in the event that HS-DPCCH and/or E-DPDCH/E-DPCCH channels are transmitted. Compliance with the heightened requirements for HSPA depends on the implementation of the power amplifier. Therefore, the 3GPP stipulates various test specifications for transmitter tests.

MEASURING TO THE STANDARD

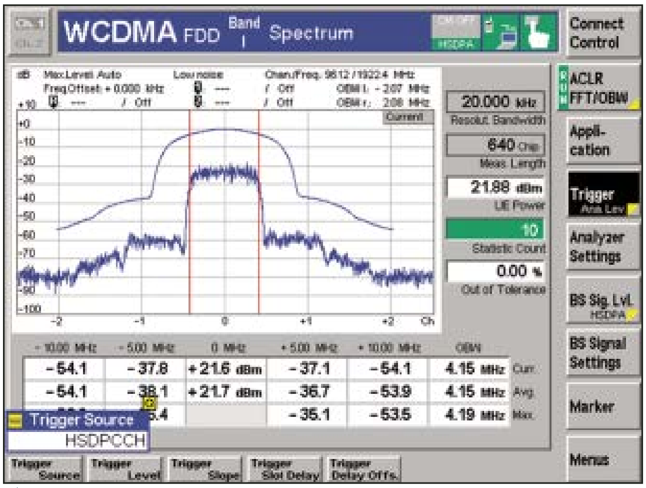
A key test specification applies to checking the maximum output power of HSPA-compliant terminals. This test verifies whether the terminals adhere to the per-

missible transmit power depending on the observed signal configuration. Fixed values are defined for the 3GPP specifications of Release 5, which have to be applied depending on the gain factor combination of the observed signal. As of Release 6, the permissible reduction of the output power in the uplink is based on the cubic metric.

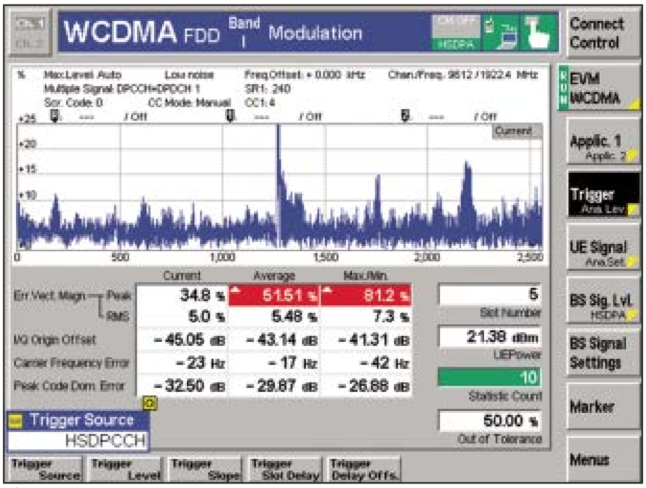
Another important test describes the permissible transmission mask of the HS-DPCCH, which has already been mentioned, and has a burst-like structure. For this reason, it is important that the changes in power remain within specific limits when the HS-DPCCH is switched on or off. ***Figure 4*** shows an appropriate measurement on a mobile radio tester. The transmitter tests for the spectrum mask, adjacent channel interference (adjacent channel leakage ratio, ACLR), modulation quality and phase accuracy, which were already known before the introduction of HSPA, are accordingly expanded for HSPA. For example, an ACLR measurement on an uplink signal containing a HS-DPCCH is shown in ***Figure 5***. The measurement was carried out on a mobile radio tester. ***Figure 6*** shows a noteworthy measurement of the modulation quality, which is evaluated on the basis of the error vector magnitude (EVM). The effect shown is produced by starting the transmission of a HS-DPCCH subframe in the middle of a timeslot of the DPCCH. Special uplink reference signals are defined for all test specifications for transmitter tests as specified in 3GPP. Some channel combinations have been representatively selected as subtests, since the combination of the gain factors considerably influences the signal characteristics. Transmitter tests for HSPA-compatible terminals have to pass all subtests, that is they have to fulfill all requirements for different gain factor combinations. The test specifications described here are not only relevant for conformity tests. They can also be used to determine the quality of an implementation in the early stages of a development.



▲ *Fig. 4 Measurement of the HS-DPCCH transmission mask.*



▲ *Fig. 5 An ACLR measurement on an uplink signal containing a HS-DPCCH.*



▲ *Fig. 6 Measurement of the modulation quality evaluated on the basis of EVM.*

FUTURE PROSPECTS

HSDPA and HSUPA present special challenges for the development of power amplifiers. HSDPA-compatible terminals have been on the market for some time and have proven their success in practice. The first commercial HSUPA-compatible terminals, however, are still being developed and optimized. With the help of powerful test and measurement equipment, these challenges, in the early stages of development, can be tackled. The development of HSPA is not yet complete. To make the new technologies much more efficient, the 3GPP Release 7 will contain additional enhancements for HSPA. ■

Christina Geßner *has been a technology manager for mobile radios at Rohde & Schwarz headquarters in Munich, Germany, since 2004. Her tasks include the development and marketing of the T&M product portfolio for UMTS and HSPA. After completing her studies in electrical engineering with an emphasis on radio frequency engineering at the University of Hanover, she worked in the strategic product management of the mobile radio networks division at Siemens in Berlin and Munich.*

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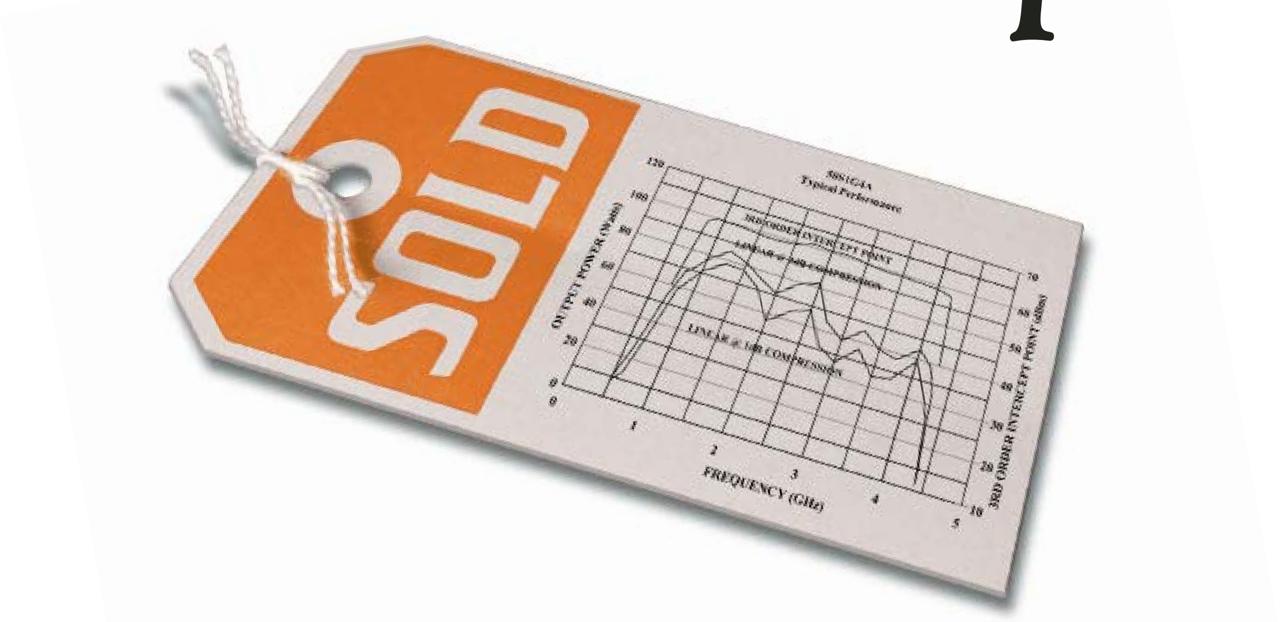

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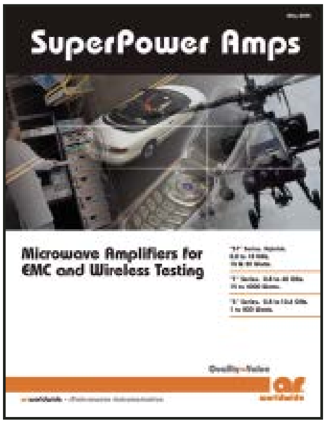

Microwave Amplifier Brochure

The Microwave Amplifier Brochure from AR Worldwide RF/Microwave Instrumentation features a wide range of microwave amplifiers. The brochure highlights the "S" and TWT amplifier series that covers 1 to 4000 W and 0.8 to 40 GHz and includes photographs, descriptions, specifications and performance graphs for each model.

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

RS No. 317

Product Brochure

This product brochure features the company's three product families for RF, microwave and millimeter-wave test solutions in active/passive device modeling, parameter extraction, noise and power characterization test systems, DC and RF pulsed IV test systems, load-pull and noise test systems, on-wafer test, solid-state active and passive mechanical tuners, and synthetic instruments 10 MHz to 50 GHz ATE manufacturing test systems.

Auriga Measurement Systems, Lowell, MA (978) 441-1117, www.auriga-ms.com.

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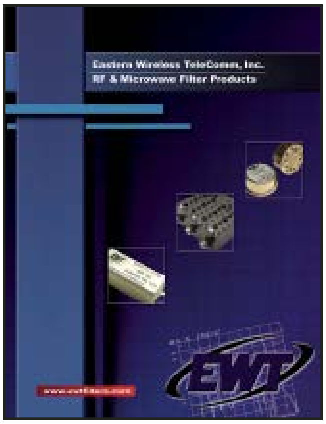

Filter Catalog

This new short form catalog features a sampling of the company's RF and microwave filter products to 40 GHz utilized in military, commercial and wireless applications. The catalog also highlights some of the company's diverse filter design and manufacturing capabilities.

Eastern Wireless TeleComm Inc., Salisbury, MD (410) 749-3800, www.ewtfilters.com.

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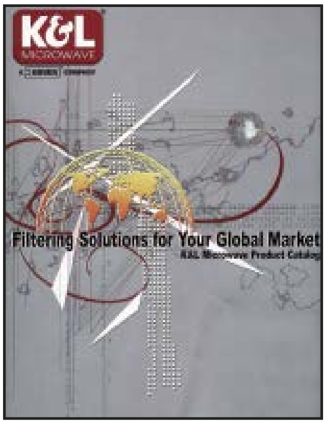

Product Catalog

This edition of the catalog features the latest information on the company's broad range of RF and microwave filter products for defense electronics and telecommunications, including integrated assemblies and a wide assortment of lumped component, cavity, ceramic and suspended substrate filters.

K&L Microwave, Salisbury, MD (410) 749-2424, www.klmicrowave.com.

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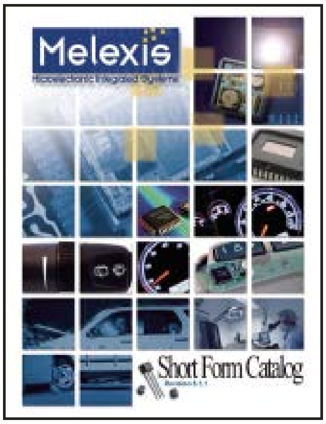

Short Form Catalog

This short form catalog features the company's most popular standard product devices that are currently available. The company produces and delivers semiconductor/IC products that enable customers to achieve product development goals. Products include programmable sensors, sensor interface devices and microcontrollers that provide customers with competitive advantages in system cost, capability and flexibility.

Melexis Inc., Concord, NH (603) 223-2362, www.melexis.com.

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Software Tools Brochure

This brochure features the company's wide range of electromagnetic simulation software tools. The product line includes: XFDTD, the finite difference time domain analysis package, Wireless Insite, a UTD-based urban and terrain propagation tool, and the XGTD software solution for more general UTD antenna and propagation analyses.

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

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WIRELESS TECHNOLOGIES

Designer's Handbook

The Designer's Handbook showcases RFMD's broad product portfolio of RF systems and solutions for applications that drive mobile communications. Includes technical data on RFMD's industry-leading power amplifiers, front-end modules, transceivers, SoCs and other integrated components for mobile handset, cellular base station, Bluetooth®, WLAN and GPS applications—all backed by the company's commitment to service, technical support and quality.

RFMD®
Greensboro, NC (336) 678-5570, www.rfmd.com.

RS No. 323

Product Brochure

The "Handset Solutions" product brochure showcases the company's wide range of specialty materials for handset applications. This literature features high performance foams, electroluminescent lighting and advanced circuit materials. These materials are used in a multitude of handheld device applications. For ease of use, each specialty material is color-coded to correspond to a table listing both its features and benefits.

Rogers Corp.,
Rogers, CT (860) 774-9605, www.rogerscorporation.com.

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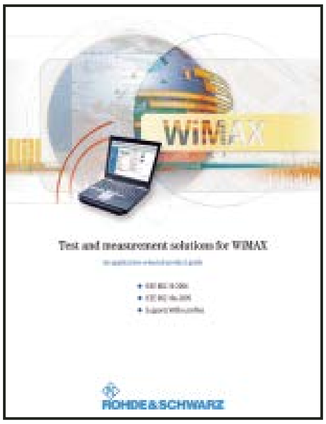

WiMAX Solutions

This new application-oriented product guide titled *Test and Measurement Solutions for WiMAX* provides an overview of the company's complete test and measurement portfolio for this standard. With the appropriate WiMAX options, the company's instruments support measurements in accordance with IEEE 802.16-2004 and IEEE 802.16e-2005, ranging from signal generation and signal analysis to conformance and production tests. In addition, the brochure provides a brief description of the special technical characteristics of WiMAX.

Rohde & Schwarz,
Munich, Germany +49 1805 12 4242, www.rohde-schwarz.com.

RS No. 325

RF Product Selection Guide

This guide features the company's high performance RF components for the commercial communications and A&D equipment markets. The company's integrated circuit (IC) and multi-chip module (MCM) product lines include amplifiers, power amplifiers, transceivers, tuners, discrete devices, RF signal processing components, signal source components, government and military-specified components, and antennae and receivers for satellite radio.

Sirenza Microdevices,
Broomfield, CO (303) 327-3030, www.sirenza.com.

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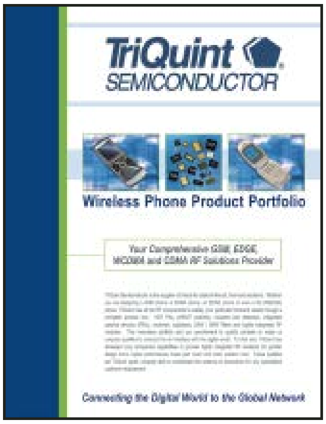

Handset Brochure

This brochure features the company's highly integrated front-end modules and components used by leading handset and mobile device manufacturers. Whether you are designing GSM/EDGE, UMTS/WCDMA or 'WEDGE' devices, a world phone or a CDMA handset, TriQuint offers the modules and components you need.

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

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Lithium Batteries Brochure

This brochure features the company's lithium batteries that deliver unrivaled performance to commercial and military applications. Proven to last over 20 years under the most challenging conditions, the company's lithium batteries and custom battery packs feature high energy density, high capacity, the widest temperature range, UL recognition, and compliance with lead-free RoHS and WEEE EC directives.

Tadiran Batteries,
Port Washington, NY (800) 537-1368, www.tadiranbat.com.

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