Vol. 49 • No. 5

May 2006

# Microwave Journal

Symposium and Exhibition Preview

Building a Strong Commercial Presence in China

Evolution of RFID Reader and Antenna Design

## MTT-S IMS Show Issue

San Francisco, CA

horizon house®
Founded in 1958

www.mwjournal.com

Microwave Journal

MAY 2006 VOL. 49 • NO. 5

# 2006 IEEE MTT-S INTERNATIONAL MICROWAVE SYMPOSIUM & EXHIBITION

## GUEST EDITORIAL

**24** **Welcome to the 2006 International Microwave Symposium**

*John Barr*

A brief introduction by the symposium general chairman to Microwave Week 2006 events scheduled in San Francisco

## SPECIAL REPORTS

**28** **Attending the Conference**

*Harlan Howe, Jr., Editor,* Microwave Journal

Basic information to help you get to and around San Francisco, as well as activities planned for the 2006 IEEE MTT-S International Symposium and Exhibition

**40** **San Francisco: City by the Bay**

*Stephanie Knight, Filtronic Compound Semiconductor Ltd.; Bill Johnson, Johnson Graphic Arts*

A primer on San Francisco and the surrounding area, including where to eat and what to see

**64** **2006 IMS Exhibitors**

An alphabetical listing of companies participating in the Microwave Week exhibition and their respective booth numbers

**74** **Moscone Convention Center Floor Plan**

The layout of halls A, B and C of the Moscone Convention Center for use in conjunction with the exhibitor list to locate participating companies

**78** **2006 IEEE MTT-S Technical Program**

A complete day-by-day schedule of the technical presentations that compose the MTT-S, RFIC and ARFTG conferences

49 Years of Publishing Excellence

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



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



Posted under Canadian international publications mail agreement #0738654

Microwave Journal

# FEATURES

## TECHNICAL FEATURES

**170** **UHF RFID and Tag Antenna Scattering, Part I: Experimental Results**

*Daniel M. Dobkin, Enigmatics; Steven M. Weigand, WJ Communications Inc.*

First in a two-part series on the use of radio frequency communications to identify physical objects in the commercial supply chain

**192** **The Design of a Finite Ground Plane Cross Semi-elliptic Monopole Antenna for UWB Applications**

*Wen-Shan Chen and Mao-Kai Hsu, Southern Taiwan University of Technology*

Implementation and investigation of a cross semi-elliptic monopole antenna and a band-rejected cross semi-elliptic monopole antenna with finite ground plane

**206** **High Harmonic-rejection Matching Filters for Quad-band Power Amplifiers**

*Rajanish, P. Onno and N. Jain, Anokiwave Inc.; C. Weigand, P. McIntosh and B. Rizzi, M/A-COM Inc.; K. Izzac, Paratek Microwave Inc.*

Demonstration of impedance matching filters using monolithic microwave integrated circuit technology with excellent harmonic rejection within a small footprint for quad-band amplifiers

**218** **Understanding the Operation and Test of a Bluetooth Enhanced Data Rate Radio**

*Helen Mills, Agilent Technologies Inc.*

Use of Bluetooth enhanced data rate technology in the development of higher data rates and improved power consumption for portable, multi-media consumer appliances

**228** **Design of a Dual-band Ring Printed Antenna Array**

*M. Abri, N. Boukli-Hacene and F.T. Bendimerad, Université Abou Bekr Belkaïd; E. Cambiaggio, Université de Nice*

Simulation and design of a four-element linear array of ring patches with a planar microstrip feed network operating in the X- and Ku-bands for satellite communications

**236** **Synthesis of a Planar, Coupled-line Marchand Balun with Emphasis on Balance**

*Jong-Hwan Lee and Kyung-Whan Yeom, Chungnam National University*

Presentation of the synthesis of a coupled-line Marchand balun to preserve balance and yield desired passband

## SPECIAL REPORTS

**242** **Radio Frequency Identification: Evolution of Reader and Antenna Circuit Design**

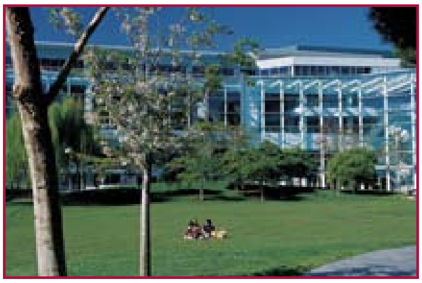
*F. Mohd-Yasin, M.K. Khaw and M.B.I. Reaz, Multimedia University*

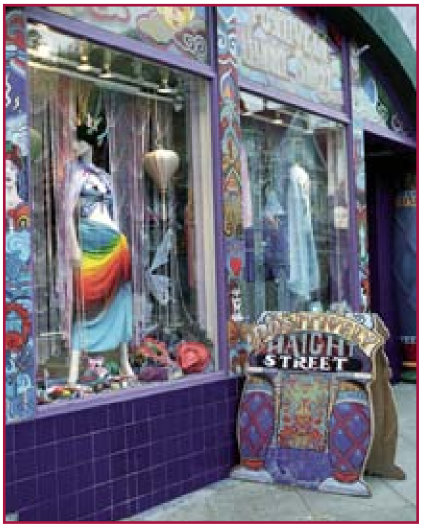
Discussion of several radio frequency identification reader and antenna architectures using advanced radio frequency designs

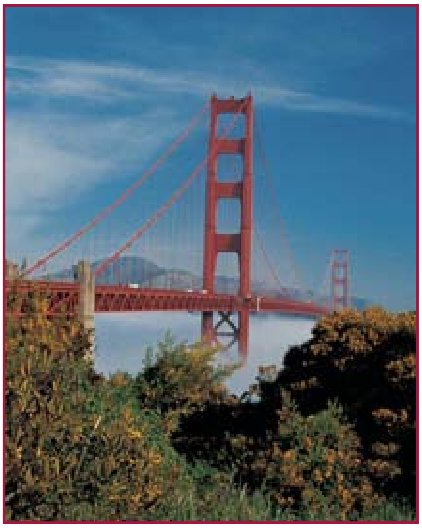
**256** **The Impact of MEMS on Cellular Phone Architectures**

*Mark Chapman, WiSpry Inc.*

Use of radio frequency microelectromechanical systems in the development of cellular phone architectures





Microwave Journal

# FEATURES

## SPECIAL REPORT

**264** **China's RF and Microwave Opportunity: Building a Strong Commercial Presence**

*Jack Daniels, EastBridge Partners LLC*

Important tips for launching a successful sales effort in the radio frequency, microwave and wireless components, materials, subassemblies and test equipment markets in China

## PRODUCT FEATURES

**272** **The Making of a WiMAX Power Amplifier**

*AR Worldwide – Modular RF*

Design of a power amplifier meeting orthogonal frequency division modulation specifications and featuring consistent performance and long-term reliability

**278** **A New Breed of Comb Generators Featuring Low Phase Noise and Low Input Power**

*Picosecond Pulse Labs*

Design of a new line of comb generators based on nonlinear transmission line circuits

**284** **Automated Test and Data Management**

*Summitek Instruments Inc.*

Development of a software application for automating the measurement and evaluation of electrical performance parameters of radio frequency and microwave components

**292** **A Plastic-packaged 13.5 to 15.5 GHz PHEMT Power Amplifier**

*Mimix Broadband Inc.*

Introduction to a Ku-band gallium arsenide power amplifier module in a 4 × 4 mm, plastic QFN surface-mount package

**296** **Revolutionary Phase Noise Performance at 20 GHz Using SiGe Technology**

*Micro Lambda Wireless Inc.*

Introduction to a new line of microwave oscillators with a guaranteed phase noise of –123 dBc/Hz at 100 kHz offset

# DEPARTMENTS

17 . . .Ask Harlan
19 . . .Coming Events
20 . . .Workshops & Courses
145 . . .Defense News
149 . . .International Report
153 . . .Commercial Market
156 . . .Around the Circuit
300 . . .New Products
364 . . .Erratum
364 . . .New Literature
366 . . .The Book End
368 . . .Ad Index
374 . . .Sales Reps

*Photographs courtesy of the San Francisco Convention and Visitors Bureau; Show Guide designed by Janet MacDonald*

## STAFF

**Publisher:** Carl Sheffres
**Associate Publisher:** Edward Johnson
**Editor:** Harlan Howe, Jr.
**Managing Editor:** Keith W. Moore
**Technical Editor:** Frank M. Bashore
**Associate Technical Editor:** Dan Massé
**Staff Editor:** Jennifer DiMarco
**Editorial Assistant:** Barbara Walsh
**Consulting Editor:** Howard I. Ellowitz
**Consulting Editor:** Peter Staecker
**Consulting Editor:** Dan Swanson
**Traffic Manager:** Edward Kiessling
**Traffic Administrator:** Ken Hernandez
**Director of Production & Distribution:** Robert Bass
**Multimedia Designer:** Eli Conner
**Web Editor:** Stephen Weitzman
**DTP Coordinator:** Janet A. MacDonald
**Director of Marketing, Publications and Exhibition Group:** David J. Metta

### EUROPE

**Deputy Publisher:** Michel Zoghob
**European Editor:** Richard Mumford
**Office Manager:** Eugenie Hardy

### CORPORATE STAFF

**Chairman:** William Bazzy
**President & CEO:** Charles A. Ayotte
**Executive Vice President:** William M. Bazzy
**Executive Vice President:** Joan B. Egan
**Senior Vice President & Group Publisher:** David B. Egan



**Executive Editorial Office:**
685 Canton Street, Norwood, MA 02062
Tel: (781) 769-9750
FAX: (781) 769-5037
e-mail: mwj@mwjournal.com

**European Editorial Office:**
46 Gillingham Street, London SW1V 1HH, England
Tel: Editorial: +44 207 596 8730 Sales: +44 207 596 8740
FAX: +44 207 596 8749

www.mwjournal.com

Printed in the USA

# 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 July issue. All responses must be submitted by **June 6, 2006**, to be eligible for the participation of the May 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.

## *March Question and Winning Response*

**The March question was submitted by Richard Chong from Asia Satellite Telecommunications Co. Ltd.:**

Dear Harlan,

I recently came across the term "modulation loss" in the receiver portion shown in the (satellite) link budget. When I check my resources, however, I cannot find a proper definition. Here are my questions:

1. What is the definition of "modulation loss"?
2. Is there a theoretical number associated with each type of modulation scheme (or just a receiver type dependent number)?
3. Where can I locate a table summarizing the "theoretical" modulation loss versus types of modulations, if any?

**The winning response to the March question is from Randolph Kallas of Kallas Consulting:**

1. Yes, there is a precise definition: "The amount of available signal power for a particular channel which is passed by the INPUT SYSTEM RESPONSE, relative to TOTAL RECEIVED POWER, is called the MODULATION LOSS for that particular channel (MLch)."
2. There are theoretical expressions available that enable one to calculate MLch for the channel and are dependent upon the modulation process (for example, FM or PM) that is being used. Since FM and PM are both forms of what is generally referred to as ANGLE MODULATION, the MLch, in this case, is represented by products involving J0 and J1, where: J0, J1 = Bessel functions, first kind; zero and first order, respectively. See Schwartz, Bennett and Stein, *Communication Systems and Techniques*, McGraw-Hill, 1966, Ch. 5, for a discussion of angle modulation (FM, PM) in general and transmission through a linear network (for example, channel) in particular.
3. One may use the Bessel function representations of #2 above, but while working on the Shuttle Program in the '70s, I acquired a copy of the Apollo Comm Link Models which contained the appropriate expression, which I still have occasion to use every now and then.

## *This Month's Question of the Month*

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

**Verne Reynolds has submitted this month's question:**

Dear Harlan,

My wife wants to know if she is endangered by radiation from our stove-top kitchen microwave. When cooking, her face may only be a foot away from the microwave, for minutes at a time. Is she in any danger? Are there any long-term effects we should be concerned with?

If your response is selected as the winner, you'll receive a free book of your choice from Artech House. Visit the Artech House on-line bookstore at www.artechhouse.com for details on hundreds of professional-level books in microwave engineering and related areas (maximum prize retail value $150).

## Lockheed Martin Successfully Concludes Tests of MLRS Rocket

Lockheed Martin successfully conducted four separate flight tests of the Guided Multiple Launch Rocket System (GMLRS) Unitary rocket at White Sands Missile Range, NM, concluding the first phase of the production qualification testing requirement series for the contract. The test objectives included demonstrating the capability of the GMLRS Unitary rockets in point detonate and proximity modes at short and long range against tactically representative targets. These missions were the last in a series of GMLRS Unitary Phase I Production Qualification Tests (PQT) of the GMLRS Unitary Rocket. "We are very pleased that the Guided MLRS Unitary System is performing so well in Iraq," said Lt. Col. Mark Pincoski, US Army Precision Guided Munitions and Rockets product manager. "The GMLRS system represents the state-of-the-art in US Field Artillery precision strike capability and everyone on the GMLRS government and contractor team has worked very hard to put this system into the hands of our soldiers."

Phase II improvements to the GMLRS Unitary will include fuzing and software upgrades to enhance effectiveness and Insensitive Munitions (IM) upgrades to provide the soldier added safety in hostile environments. Guided MLRS Unitary integrates a 200-pound class unitary warhead into the GMLRS rocket, giving battlefield commanders the ability to attack targets up to 70 km away with high precision. This low cost, low risk program will greatly reduce collateral damage by providing enhanced accuracy to ensure delivery of the warhead to the target. Lockheed Martin received a $119 M contract to conduct system development and demonstration (SDD) for a GMLRS variant with a single warhead in October 2003. The SDD contract includes 86 rockets, 71 of which are flight articles, with the balance supporting test and other activities. The contract also provides test hardware to support 26 flight tests for an initial configuration and 39 flight tests of a follow-on configuration.

## Raytheon's Upgraded Early Warning Radar Participates in Successful Missile Test

Raytheon Co. Upgraded Early Warning Radar (UEWR) at Beale Air Force Base, CA, performed successfully in a flight test of the Ground Based Midcourse Defense (GMD) element of the Ballistic Missile Defense System (BMDS). The test was conducted by the Missile Defense Agency (MDA). The UEWR, developed by Raytheon Integrated Defense Systems (IDS), successfully tracked the target system launched from the Kodiak Launch Center, Alaska, for approximately 20 minutes during its flight downrange to the test area, several hundred miles west of California. "This was a critical test of the missile defense capability of the UEWR, and we are pleased that the radar appears to have performed flawlessly," said Pete Franklin, vice president, Raytheon IDS Missile Defense. "This first GMD flight test for the Beale UEWR is particularly significant because it successfully demonstrated the radar's capability to provide information to the GMD system in support of an interceptor engagement." Dave Gulla, director of Early Warning Radar Programs for Raytheon IDS, said, "Based on our initial assessment at Beale, our radar and test team achieved all planned objectives, successfully operated with the other components in the GMD system and provided intercept-quality tracking and object classification data as planned." Continuing the Raytheon heritage with UHF phased array radars, the Beale UEWR program upgrades existing PAVE PAWS and Ballistic Missile Early Warning System radars by adding missile defense capabilities while retaining legacy missile warning and space surveillance missions. A key sensor for the MDA's BMDS, UEWR provides 'no doubt' — midcourse target detection and tracking for the GMD portion of the BMDS to protect the US from ballistic missile attacks. Boeing Integrated Defense Systems is the prime contractor for the GMD program.

## Northrop Grumman Dedicates New Missile Engineering Center

Securing the future of Northrop Grumman Corp. operations in San Bernardino, CA, the company opened its newly constructed Missile Engineering Center. Northrop Grumman's presence in San Bernardino spans more than 43 years of critical support to the nation's defense. With more than 230 scientists, engineers and other professionals in the area, the company occupies 85,000 square feet in this new three-story location, known as Brier Corporate Center. Highlighting the event, which focused on the company's legacy in San Bernardino and its recruiting and nurturing of the next generation of missile engineers, were remarks by US Rep. Joe Baca (D-CA), 43rd Congressional District; Jerry B. Agee, corporate vice president and president of Northrop Grumman Mission Systems; Frank Moore, sector vice president and general manager of the Missile Defense Division for Northrop Grumman Mission Systems; and Ben Overall, division director of the Missile Engineering Center for Northrop Grumman Mission Systems. "We have a rich and historic legacy in San Bernardino with the Intercontinental Ballistic Missile (ICBM) program and we are moving forward to develop the next generation of missile engineers and scientists who will provide the skills needed to support a broader customer base," said Overall. The Missile Engineering Center serves as a vital proving ground for missile technology development and provides support to several key government missile programs. The center's flagship programs include the ICBM Minuteman III modernization program where Northrop Grumman is the prime contractor responsible for maintaining, sustaining and modernizing the nation's fleet of Minuteman III missiles; and the Kinetic Energy Interceptor program — a critical boost/ascent or midcourse-phase missile defense program where Northrop Grumman is the prime contractor developing and testing this capability.

## US Marine Corps Awards Harris Corp. $140 M in Orders for Radios

Harris Corp. announced that the US Marine Corps has awarded the company orders totaling approximately $140 M for Falcon® II AN/PRC-150(C) high frequency (HF) radios and AN/PRC-117F(C) multiband, multimission radios (MBMMR). The orders have been awarded under two previously announced contracts. Harris will supply its AN/PRC-150(C) manpack and AN/VRC-104(V) vehicular systems as well as its AN/PRC-117(C) manpack and AN/VRC-150(V) vehicular systems. The Falcon II software-defined radio systems will allow the US Marine Corps to replace its legacy AN/PRC-104, AN/PRC-113 and AN/PSC-5 radios. "We are privileged to continue serving the US Marine Corps and are honored that they have chosen to replace their current radios with our Falcon II radio systems," said Dana Mehnert, vice president and general manager of US Government Products, Harris RF Communications Division. "Harris has emerged as a primary tactical communications supplier to the US Marine Corps with the MBMMR and HF standardization programs." The AN/PRC-150(C) and AN/PRC-117F(C) radio systems will be used to upgrade and replace the Marine Corps' active duty and reserve components' legacy tactical radio systems and also will be used for other USMC programs such as: Target Location, Designation and Hand-Off System (TLDHS); Expeditionary Fighting Vehicle (EFV); and Light Armored Vehicle-Command and Control (LAV-C²). The Harris AN/PRC-150(C) is an advanced high frequency radio covering the 1.6 to 60 MHz frequency spectrum and its embedded communications security has been certified for transmission of US classified information. The AN/VRC-104(V)3 is a fully integrated, vehicular communications system that includes the Harris AN/PRC-150(C) tactical radio and a 150 W, high frequency power amplifier. The Harris AN/PRC-117F(C) is an advanced multiband radio covering the entire 32 to 512 MHz frequency spectrum. Its embedded COMSEC has NSA certification, ensuring compliance with secure US Government Type-1 encryption algorithms. In addition, the radio is JITC certified for operation over military standard satellites. The AN/VRC-103(V) is a fully integrated, vehicular communications system that includes the Harris AN/PRC-117F(C) tactical radio and the Harris AM-7588 multiband power amplifier. This system also covers the entire 30 to 512 MHz frequency range while offering 50 W transmit power and on-the-move communications capabilities. ■

## Siemens is Promoted to ZigBee Alliance

The ZigBee™ Alliance, the industry association promoting the growth of a global, open standard for wireless control of devices, has admitted Siemens at the highest level of membership — Promoter level. As a result the company joins BM Group, Ember Corp., Freescale Semiconductor Inc., Honeywell, Mitsubishi Electric, Motorola, Philips, Samsung and Texas Instruments on the ZigBee Alliance Board of Directors.

Recently, there has been tremendous momentum in the ZigBee compliant platform supply ramp-up leading to consumer product availability during 2006. And Siemens' support and leadership commitment to the Alliance comes on the heels of significant moves by several industry giants — earlier this year Texas Instruments completed its acquisition of Chipcon and there was the completion of a joint effort by STMicroelectronics and Ember to work together on ZigBee solutions.

"Siemens carefully investigated the various wireless control options available on the market and selected ZigBee because it offers a true, internationally recognized standard that fits well into the product strategies of several of our business units," said Walter Weigel, vice president standardization and regulations of Siemens AG. "Siemens has great experience and vast knowledge in the field of automation that will also benefit ZigBee over the coming years."

## Aerospace Agreement is all Greek to BAE Systems

BAE Systems has signed a partnership agreement with Hellenic Aerospace Industry SA (HAI) of Greece, under which the two companies will examine potential areas of co-operation in both the Greek domestic and export markets. The new agreement commits the two companies to establishing a joint working group to examine potential partnership opportunities in a number of business areas. These include electronic warfare systems, Unmanned Aerial Vehicles (UAV) and associated technologies plus aerostructures and composite structure manufacturing, etc.

In addition to becoming involved in the areas of product development and manufacturing, HAI will also benefit from BAE Systems' knowledge and experience of logistics support, network enabling capabilities plus aircraft modification and upgrade.

Welcoming the agreement, Mike Mendoza, BAE Systems' managing director for international partnerships, commented, "Mutually beneficial partnerships are central to BAE Systems global business philosophy. We are delighted to enter into this strategic alliance with HAI, a leading aerospace and defence company, and look forward to a long-term relationship covering a wide range of defence and aerospace technologies."

## Agility Shown in Finnish R&D Breakthrough

VTT, Technical Research Centre of Finland has announced a new product development technology for the software industry, which it claims can save up to 70 per cent in the development of new software products. The method developed by the research centre is an agile method called Mobile-D,™ which is being introduced in several Finnish and European companies.

Agile methods, which can make the product development of embedded software and the features of the products more efficient, are developed under VTT's leadership in a European project of nine countries and 22 organisations. In addition to VTT, Nokia Oyj, F-Secure Oyj and Hantro Products Oy are involved in Finland. Applications of embedded systems include technology from telecommunications, automotive and avionics industries as well as applications for households, which combine several technologies, such as electronics, software and computer technology.

The most important factor in the new method is the original way of thinking that cuts through the whole organisation, and where agile values, principles and practice meet seamlessly. Enabling and supporting innovation throughout the organisation is one agile principle, in support of which a number of agile methods can be found. Profitability and controllability also occupy a central role. The new methods enable a significantly more flexible and efficient product development process, because methods allow making changes to the software at each stage of the process.

## Wavecom Acquires Sony Ericsson's M2M Business

In a cash transaction that will be valued up to a maximum of €32.5 M, Wavecom SA, a leader in embedded wireless communications platforms for automotive, industrial (machine-to-machine) and mobile professional applications, and Sony Ericsson Mobile Communications AB, have signed an agreement whereby Wavecom acquires certain assets of Sony Ericsson's M2M Communications Business Unit.

This business unit specializes in industrial and automotive wireless solutions and includes the new GX64 GSM/GPRS product family, the GX47/48 GSM/GPRS product family and the CM42/52 CDMA/1xRTT product family, as well as the company's global assets and activities in M2M research and development, marketing and sales. However, the transaction does not include any assets or activities related to Sony Ericsson's mobile phones, accessories, or PC card business, which will remain a part of Sony Ericsson.

The combination of these two businesses offers numerous synergies and benefits, specifically in scale and geographic presence. In particular, Sony Ericsson will bring to Wavecom a solid customer base from the North American automotive and fleet management market that should further reinforce Wavecom's already diverse automotive customer base in Europe.

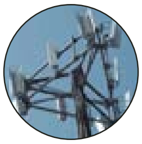
## European Initiative for Integrated Microsystems

The European Commission is funding a €6.5 M, three-year programme aimed at reducing the costs and risks associated with designing, prototyping and manufacturing integrated microsystems. Known as INTEGRAMplus, this new Framework 6 Integrated Project will be coordinated by the UK's QinetiQ and draw on the complementary expertise and facilities of 10 partners from seven different European countries. The consortium comprises: Coventor (France), CSEM (Switzerland), Epigem (UK), IMM (Germany), IMT (Romania), ITE (Poland), Silex Microsystems (Sweden), University of Lancaster (UK) and Yole Développement (France).

The project will adopt a multi-technology, multi-domain approach, with a focus on integrating silicon-based MEMS components, which provide smart functionality, with polymer backplanes and platforms that provide additional functions, packaging and interfacing to the macro-world. Three proof-of-concept demonstrator components will be developed.

INTEGRAMplus builds on the successful Europractice project, INTEGRAM, also led by QinetiQ, which focused on silicon sensors and electronics. Its ultimate goal is to stimulate take-up of micro and nanotechnologies (MNT) by end users by providing flexible design and prototyping services, based on standardised modules, with a route to manufacture for highly integrated microsystems.

Therefore, this project, with its unique combination of pan-European capabilities and supported by an extensive network of supply chain partners, aims to provide the European industry with a world leading facility to stimulate take-up and accelerate time-to-market of smart mixed technology components and products. 'Design for manufacturing' principles, based on state-of-the-art simulation tools, will be used to reduce risk via virtual manufacturing design studies. ■





## Silicon-on-Sapphire Disrupts RF Switch Market

In its latest Insight report, "Silicon-on-Sapphire Switches for Handsets: Stopgap or Disruptive Technology?," Strategy Analytics, the research and consulting company, evaluated CMOS silicon-on-sapphire (SoS) RF switches and found that SoS has begun to disrupt established approaches to transmit-receive (T/R) switching in multi-mode, multi-band cellular handsets. Peregrine Semiconductor has shipped several million CMOS SoS RF switches to customers for GPRS handsets. Recently, the company released SP7T "HaRP" SoS RF switches for dual-mode W-CDMA handsets, claiming that these offer superior performance to GaAs PHEMT switches. "After evaluating this technology, we have concluded that Peregrine's SoS RF switches offer advantages that could displace GaAs in dual-mode WCDMA handsets," says Asif Anwar, director of the Strategy Analytics GaAs service. "However, GaAs vendors have already moved to address PHEMT switch shortcomings with improved performance. They have also developed switches with higher complexity, not yet available in CMOS on SoS. These moves will limit the penetration of CMOS SoS in applications now served by PHEMT switches to a few design-wins at best." "CMOS SoS will continue to have its greatest success in displacing PIN diodes in antenna switch modules," adds Chris Taylor, director of Strategy Analytics RF and Wireless Components (RFWC) service. "The multiple PIN diodes required for complex antenna switch modules (tri- and quad-band) draw significant current. Peregrine has already demonstrated the suitability of its technology for this application."

## Alcatel and Lucent: Managed Services Could Be Ace-in-the-Hole

The proposed merger of Alcatel and Lucent Technologies has been generating a great deal of press. There are logical fits to their respective businesses. Both are large players in the wireless and wired infrastructure markets. On the wireless side, Alcatel plays primarily in the GSM family of technologies while Lucent reportedly has over a 40 percent share of the CDMA2000 air interfaces. Alcatel and Lucent also have long histories on the wireline side. Their businesses also complement each other regionally. All this potential synergy makes sense, but is it the whole story? Is there something different now, other than financials that could be fueling this merger? The wireless and wired infrastructure industries are in a period of transition and both aggressive price reductions and improvements in the efficacy of the equipment have subdued the long-term picture for hardware. Fortunately, a new source of revenue has appeared for the major wireless and wired infrastructure equipment vendors: "managed services" have burst onto the scene with a vengeance. Managed services refer to the management and operation of a wireless or wired network by a third party. Managed services also can include third party hosting of media and end-user applications for transmission over the same networks. Service operators are increasingly turning to these third party vendors to run their networks and manage content for them as they themselves focus on more core business areas such as customer retention, advertising and non-technical business operations. The managed services component of the wireless infrastructure business alone is forecast to have double-digit growth over the next five years and is already a multi-billion dollar a year business. All of the major wireless infrastructure equipment vendors have been quietly positioning themselves to participate heavily in the managed services markets. A recent ABI Research market study on the subject has placed Ericsson at the head of the managed services for mobile wireless pack but Alcatel and Lucent are both in the top five. A combined Alcatel and Lucent managed services business would be as large as Ericsson if not slightly larger, and certainly a powerhouse in this growing and important market segment that could hit the double-digit billion dollar level as early as 2012. This could be the ace-in-the-hole that is prompting the companies to take a new look at a possible merger.

## Bluetooth Market to Exceed 500 Million Radios in 2006

After an explosive year of growth in 2005 that has seen the Bluetooth market more than double, 2006 looks set to provide another healthy year of profits for Bluetooth vendors. In its new study entitled "Bluetooth: The Global Outlook," ABI Research concludes that the market for Bluetooth radios will grow by 71 percent to a level just over 500 million radio shipments in 2006. Stuart Carlaw, principal analyst, Wireless Connectivity, notes, "This growth will be attributed to extremely robust attach rate gains in the cellular handset market as well as a continuation of the explosive growth in the headset market." The report forecasts that the market will grow at a compound annual rate of over 40 percent between 2004 and 2011, and equipment shipments are expected to break the one billion mark by 2009. Several new applications for Bluetooth are likely to come to the fore in the medium term; most notable among these is the gaming market, which is likely to be spurred by the releases of the Nintendo Revolution and Sony's Playstation 3. Carlaw adds, "The importance of the stereo headset cannot be discounted. This product provides one half of a match made in heaven with music-enabled cellular handsets. We expect this type of product to drag Bluetooth into a myriad of other use cases such as rear seat entertainment in the vehicle and the long-awaited Bluetooth MP3 player." The report comes at a critical time for Bluetooth as silicon providers and OEMs begin to consider the inclusion of a UWB physical layer as the high data rate link for Bluetooth. Questions still remain as to whether the battle of the UWB standards will have a serious impact on uptake from a manufacturer's perspective. Going forward, however, Ultra Wide Bluetooth may well be the most prolific application for UWB.

Providing the most comprehensive look at the Bluetooth market available today, "Bluetooth: The Global Outlook — Devices, Semiconductors and Software" includes extensive analysis of the equipment, semiconductor and software markets. It forms part of ABI Research's Short Range Wireless Research Service.

## Camera Phone Soon to Peak

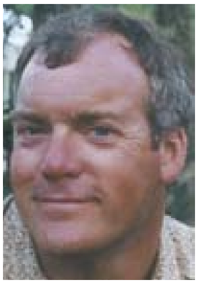
Phones with the ability to take images, both still and video, have captured approximately 40 percent of the wireless phone market, reports In-Stat. Despite the product's popularity, many camera phone users want higher resolution, the ability to use storage media and many of the state-of-the-art features found in modern digital cameras, the high tech market research firm says. "These desires, plus the fact that many users already have a high resolution digital camera, lead In-Stat to forecast that the North American market for camera and camcorder phones will peak in 2007," says Bill Hughes, In-Stat analyst. In a companion report, In-Stat also found that dissatisfaction with picture quality is only one factor that is severely limiting sending or printing camera phone images.

*A recent report by In-Stat found the following:*

- The vast majority of users in the survey also use a high resolution digital camera in addition to their camera phones. Only three percent of the respondents use their phones as their only digital camera.
- Most survey respondents indicated that they take fewer than 10 pictures with their camera phone each month.
- Fewer than two percent of respondents say they will consider a camera phone with less than 1 megapixel, while more than 50 percent say they would consider a handset with more than 2 megapixels of resolution.

The report, "Multi-Megapixel Camera and Camcorder Phones — The End of the Beginning," covers the market for wireless camera and camcorder phones. It contains forecasts for camera and camcorder phone shipments and revenues in North America through 2010. ■

## INDUSTRY NEWS


▲ William Burton Mraz

■ **William Burton Mraz**, 41, of Newfields, NH, died suddenly on March 29, 2006, as the result of an automobile accident. Mraz was vice president and co-owner of UltraSource Inc., Hollis, NH, since 1997. He was in charge of new business development, inside sales, customer service and financial management. He was co-developer of two patents related to new techniques in building ceramic microchips. He was a member of the American Society of Mechanical Engineers. He will be remembered for his generosity, exuberance and love of life. Donations in Mraz's memory can be made to Rockingham Land Trust-Newfields Conservation, 8 Center Street, Exeter, NH 03833.

■ **Wenzel Associates Inc.**, Austin, TX, announced that it has completed the purchase of substantially all the assets of **Vectron International Ltd.**'s crystal manufacturing operation in Whitby from Vectron International. Vectron International, headquartered in Hudson, NH, maintains operating facilities and sales offices in North America, Europe and Asia. Croven Crystals, Wenzel International Inc., begins business in its Whitby, Ontario facility and continues more than 50 years of service providing precision quartz resonators to the communications, aerospace, instrumentation and telemetry markets. The new web site is on-line at www.crovencrystals.com.

■ **Laird Technologies**, a designer and manufacturer of electromagnetic interference (EMI) shielding materials, thermal management products and wireless antenna solutions, announced it acquired all assets of **RecepTec LLC** and all outstanding shares of RecepTec GmbH for $89 M. The purchase broadens Laird Technologies breadth of antenna products for telematics applications. In related news, Laird announced the company's acquisition of **Antenex Inc.** Antenex designs and manufactures antennas and accessory products primarily for the US market.

■ **Mimix Broadband Inc.** announced that it has executed a definitive agreement to sell its GaAs foundry to **Universal Semiconductor Technology Inc.** (USTI), a high technology investment company. As part of this agreement, Mimix and USTI have also entered into a multi-year GaAs wafer supply and non-compete agreement, guaranteeing Mimix customers of continuous supply. In June 2005 Mimix completed the purchase of substantially all of the assets of Celeritek Inc., including the Santa Clara, CA, GaAs foundry that Mimix has sold to USTI. USTI will provide Mimix with foundry services for multiple processes including active GaAs MESFET, PHEMT and HBT, as well as thin film silicon and ceramic circuit components and substrates.

■ **EMS Technologies Inc.** announced the closing of the sale of its Satellite Networks (SatNet) division to **Advantech Advanced Microwave Technologies Inc.**, Montreal, Canada. EMS originally announced the signing of a definitive agreement for the sale on December 22, 2005. During the past couple of months, the two companies have worked to obtain the necessary consents from key suppliers and customers. Final terms of the sale were not disclosed.

■ **Modelithics Inc.** has been contracted by **MicroMetrics Inc.** to create new nonlinear models for its line of high performance limiter diodes, including the MP7100, 7110 and 7120 series. The models will be valid for large signal design allowing designers to better understand the temperature and power dependency of the RF behavior of these diodes for improved design. The models will initially be available in the Agilent Technologies Advanced Design System design simulation software and later ported to other simulators. Users of Modelithics Non-Linear Diode Library will automatically receive the developed models in a future release. Requests for the models along with related RF data will also be made available from the Modelithics and MicroMetrics web sites. In related news, MicroMetrics announced the expansion of the company's epitaxial growth and coating services for the semiconductor fabrication market. The newly expanded Londonderry, NH facility now includes seven Gemini Epi reactors. This business unit supports the growing of three, four and five inch silicon wafers and will soon be offering products to meet the demands of the six inch market.

■ **QUALCOMM Inc.** and China **TechFaith Wireless Communication Technology Ltd.** announced plans to found a new company to focus on the development of application software for wireless devices. The new company, TechFaith Software China Ltd. (TechSoft), which will be based in Beijing and Hangzhou, China, will be funded by QUALCOMM and TechFaith. Subject to the satisfaction of customary closing conditions, as well as the achievement of performance milestones, TechSoft will receive a total investment of cash and in-kind contributions valued at up to US$35 M from QUALCOMM and TechFaith.

■ **RFMD®** announced an $80 M wafer fabrication facility expansion. The planned expansion, located on the company's Greensboro, NC, campus, is expected to increase RFMD's wafer manufacturing capacity by approximately 40 percent from current levels — enabling continued growth in wireless markets utilizing the company's GaAs HBT and GaAs PHEMT process technologies. The expansion is also expected to reduce RFMD's cost per wafer and provide available capacity to increase internal production of GaAs PHEMT.

■ **Rosenberger** announced the formation of the new business unit Wireless Terminal Components (WTC). The new organization will offer a wide range of standard products for various wireless applications, such as cellular and cordless phones, Bluetooth applications, wireless LAN applications and data collecting terminals.

■ **Freescale Semiconductor** is now expanding its India operations with the acquisition of a 300,000 square foot campus in Noida. The company plans to expand its presence to 1500 engineers in India over the next four years to support the company's global research and development efforts.

■ **Peregrine Semiconductor Corp.** announced the opening of its third engineering design site, the New England Design Center, adding technical resources to fuel the company's high growth momentum. Based in Nashua, NH, a concentrated locality of RF, analog and mixed-signal expertise, the initial group is comprised of highly experienced RF/microwave design and product development engineers with an average of 17 years experience.

■ **CoorsTek Inc.**, a technical ceramics supplier and manufacturer of critical components for high technology markets, announced the expansion of its European presence through the acquisition of VZS/Seagoe Advanced Ceramics of Glenrothes, Fife. This acquisition enables a significant expansion of localized manufacturing capabilities and processing services.

■ **Linear Technology Corp.**, a supplier of high performance analog integrated circuits, announced the opening of its first European design center in Munich, Germany. With the opening of the company's 11th design center, Linear's Munich Design Center allows the company to further expand its analog design resources at a location that provides proximity to some of the company's key European customers.

■ **Tecdia Inc.**'s San Jose, CA, sales office has moved to a new location. The new contact information for all departments is Tecdia Inc., 2700 Augustine Drive, Suite 110, Santa Clara, CA 95054 (408) 748-0100 or fax: (408) 748-0111.

■ **RFMW Ltd.** has moved to a new 4000 square foot facility located at 90 Great Oaks Blvd. #203, San Jose, CA 95119 (408) 414-1450, fax: (408) 414-1461. In the first quarter 2006, RFMW has doubled the company's sales organization throughout the US, doubled employees in customer service and doubled space at its new headquarters in San Jose, CA, all to better service and focus on the RF and microwave customer base in North America. RFMW Ltd. is a specialized distributor that provides customers and suppliers with focused distribution of RF and microwave components as well as specialized component engineering support. The company assists in replacement of obsolete and hard to find RF/MW/MMW connectors, passive components and semiconductors.

■ **PropheSi Technologies™ Inc.**, a provider of semiconductor modules for high efficiency wireless infrastructure power amplifiers, announced it has changed its name to **PulseWave RF™** and that it has successfully demonstrated its digital multi-carrier power amplifier module, which enables a digital power amplifier for use in wireless base stations.

■ **TestMart** announced an exclusive agreement with **VXI Technology**, a designer and manufacturer of high density modular test instruments and switching systems for both electrical and mechanical test applications. The deal provides the US government and federal contractor marketplace with savings on select VXI Technology VXIBus, VMIP,™ SMIP,™ VME™ and the new Ethernet-based LXI products.

■ **Aeroflex** and **7 layers** announced a partnership on 3G mobile handset conformance testing. The 7 layers test and service facility in the UK will use Aeroflex's 6401 AIME/CT conformance test system complete with inter-system handover capability for its 3G handset testing requirements. The partnership is the result of the long-standing working relationship between the two companies that goes back to the inception of 7 layers in the UK in 2001.

■ **Agilent Technologies Inc.** announced an OEM agreement with **Protocol Analytics** to distribute the company's SanAlytics software. SanAlytics is a post-processing software that complements the Agilent 1735A Fibre Channel traffic-generation and protocol-analysis solution. This combination of products will help engineers accelerate the development of Fibre Channel SAN equipment and speed troubleshooting and debugging.

■ **Northrop Grumman Space Technology** (NGST) presented **Mini-Systems Inc.** (MSI) with two of its prestigious "Gold" Supplier Awards. MSI's Thick and Thin Film Divisions were both recognized for their high reliable product quality and reputable delivery. This is the second in a row and third in four years. In order to achieve "Gold" Supplier status, vendors to NGST must, at a minimum, maintain 98 percent product quality and 95 percent on-time delivery. Mini-Systems' excellent quality, responsiveness and delivery performance exceeded the expectations of NGST, making MSI 1 of 57, out of 1100 vendors, to receive this award.

■ The South Florida Manufacturers Association selected **SV Microwave Inc.**, West Palm Beach, FL, for the Manufacturer of the Year – Mid-sized Manufacturers award, as embodying the right combination of innovative systems and products, growth over the past two years, as well as commitment to employees, quality, customers and the community.

■ **Comarco Wireless Test Solutions** announced that **7 layers**, an internationally recognized certification company, has completed testing of Comarco's line of domestic and international multi-technology RF scanners. 7 layers certifies that Comarco's scanners meet or exceed all specifications.

■ **Millennium Microwave Corp.**, Fruitland, MD, announced that the company has been awarded AS9100:2004 and ISO 9001:2000 certification from Perry Johnson Registrars.

■ **TT electronics IRC Advanced Film Division** has developed RoHS-compliant versions of its resistor products, including the LR family of thick film current sense resistors and the PFC series thin film precision resistors. The company will also continue to produce the tin-lead terminations of its products based on continuing customer demand, especially in military electronic systems, which are exempt from the RoHS compliance regulations.

## CONTRACTS

■ **Micronetics Inc.** announced that it received a follow-on order of over $1 M for microwave subsystems from a leading antenna manufacturer. The microwave subsystems are part of a fully integrated antenna system that receives airborne Direct Broadcast Satellite (DBS) television signals and distributes them to an onboard in-flight entertainment system. Micronetics expects to start delivering in the first quarter of FY 2007, with a completion date expected early in the second quarter.

■ **ABI**, a global leader in business-to-business marketing public relations, was selected by **Dow-Key Microwave** and **K&L Microwave** to spearhead strategic marketing and public relations campaigns for their respective microwave switch and filter businesses in North America, Europe and China.

■ **Sirenza Microdevices** announced it has been chosen by **Wavesat Inc.**, a Montreal-based designer and manufacturer of baseband chips for WiMAX compliant systems, to supply Sirenza's recently introduced power amplifier IC, SZA-3044, for Wavesat's customer premise equipment (CPE) solution. Wavesat's CPE solution utilizing Sirenza's SZA-3044 power amplifier was the first CPE solution to be certified by the WiMAX Forum.

## FINANCIAL NEWS

■ **ANADIGICS Inc.** reports sales of $33.3 M for the fourth quarter of fiscal year 2005 ended December 31, 2005, compared to $22.4 M for the same period in fiscal 2004. Net loss for the quarter was $3.9 M ($0.11/per share), compared to $10.3 M ($0.31/per share) for the fourth quarter of last year.

■ **SiGe Semiconductor** reports sales of $31.8 M for 2005 revenues, compared to $19.5 M for the same period in 2004. The company also announced the appointment of **William H. Burke** as chief financial officer and treasurer. Burke brings more than 20 years of experience in all aspects of corporate finance, accounting and treasury functions for multi-national private and public companies.

■ **Ansoft Corp.** reports sales of $19.7 M for the third quarter of fiscal 2006 ended January 31, 2006, compared to $17.4 M for the same period in fiscal 2005. Net income for the quarter was $4.3 M ($0.33/per diluted share), compared to a net income of $2.8 M ($0.21/per diluted share) for the third quarter of last year.

■ **WiQuest Communications Inc.**, a fabless semiconductor company focused on the design and production of complete high performance, ultrawideband-based wireless silicon solutions, announced the closing of $18 M in series B funding. This round of funding was led by new investor Sequoia Capital and also included full participation by Series A investors, Menlo Ventures, Palomar Ventures and iD Ventures America. WiQuest will use these new funds to ramp production of its existing products and to further expand its growing portfolio of WiMedia and Wireless USB solutions.

■ **Superconductor Technologies Inc.** reports sales of $7.4 M for the fourth quarter ended December 31, 2005, compared to $3.9 M for the same period last year. Net loss for the quarter was $3 M ($0.02/per diluted share), compared to a net loss of $11.3 M ($0.11/per diluted share) in the fourth quarter of last year.

■ **RF Industries Ltd.** reports sales of $3.4 M for the first quarter ended January 31, 2006, compared to $2.9 M for the same period last year. Net income for the quarter was $265,000 ($0.07/per diluted share), compared to a net income of $206,000 ($0.05/per diluted share) in the first quarter of last year.

■ **Unity Wireless Corp.** announced that it has completed a US $2.2 M three-year debt financing by institutional investors. Unity Wireless plans to use the proceeds from the transaction for general corporate purposes.

## NEW MARKET ENTRIES

■ **evissaP Inc.** ("Passive" backwards), San Jose, CA, purchased the assets of AVNET MTS' cable division in December 2005. Prior to asset purchase, evissaP supported AVNET MTS as a CM/ODM for cable assemblies and custom connectors. evissaP's products include RF and microwave cable assemblies, custom connectors, custom RF transformers and custom adapters. For more information, visit www.evissaP.com.

■ **Peak Devices Inc.**, an RF transistor manufacturer, has announced its current and ongoing efforts to offer the market a viable alternative to recently obsolete RF LDMOS transistors, formerly provided by Cree Microwave®

■ **Signal Support LLC**, McLean, VA, is a new manufacturers sales representative company that will focus on RF and microwave devices, component and distribution sales. Signal Support will cover the Maryland, Virginia and Washington, DC territories. For more information, contact Steve Wilmer at (703) 356-7005.

## PERSONNEL

▲ *Donn Mulder*

■ Anritsu Co. president Frank Tiernan announced the appointment of **Donn Mulder** to the position of vice president/general manager of Anritsu's Microwave Measurement Division (MMD). In his position, Mulder will oversee the research, development, manufacturing, marketing and sales support of MMD's products. Mulder replaces Tiernan, who has been serving the dual role of president of Anritsu Co. and general manager of MMD. In addition to heading the MMD operations based in Anritsu's Morgan Hill, CA facility, Mulder will be responsible for the RF products developed in Anritsu's European facilities. Mulder has been with the company for 13 years.

■ Fairchild Semiconductor announced the appointment of **Mark S. Frey** as executive vice president and chief financial officer. Frey will report directly to president and CEO, Mark Thompson. Frey previously was vice president, finance and corporate controller for Lam Research Corp., a major supplier of wafer fabrication equipment and services to the world's semiconductor industry. He was responsible for a range of financial processes and organizations, implementing rigorous measurement programs to improve gross margins. Prior experience included serving as vice president of finance for Raychem Corp.'s Electronics OEM Division.

■ eRide Inc. announced that **Gary L. Fischer** has joined the company as chief financial officer. Most recently, Fischer served as president and chief operating officer at Integrated Silicon Solutions Inc., a fabless semiconductor company. Fischer's first assignment will be to assist in raising funds to finance eRide's growth.

▲ *Larry Fagan*

■ Trompeter announced that **Larry Fagan** has joined the company as a direct field salesperson for the Los Angeles, CA territory. Fagan brings with him 20 years of sales experience in the Los Angeles area, including 10 years at Newark Electronics. His most recent position with Newark was as commercial accounts manager and prior to that as government account manager.

■ WJ Communications Inc. announced that it has significantly increased its presence in Asia. **Tony Liang** has been appointed as the director of Asia sales. Liang comes to WJ with 18 years of experience in the telecom industry. Previously he was vice president of APAC sales for AMI Semiconductor Inc. and director of sales at PMC-Sierra. In addition, **Taine Wu** and **KM Choi** have been appointed as country managers for China and Korea, respectively. Wu brings 18 years of experience in the semiconductor component industry. Prior to joining WJ, Wu was a re-




gional sales manager of South China for Fairfield Semiconductor. Choi joins the company with more than 15 years of experience in sales and marketing positions in the telecom industry. Prior to joining WJ, Choi served as market business development director for Qualcomm.

▲ *David Wynants*

■ **David Wynants**, senior process engineer of Taconic Advanced Dielectric Division in Petersburgh, NY, was presented with a Distinguished Committee Service Award by the IPC – Association Connecting Electronics Industries at the recent IPC Printed Circuits Expo in Anaheim, CA. This award was given to Wynants, along with other committee members, in appreciation and recognition of their contribution to the development of IPC-4412A, specification for finished fabric woven from "E" glass for printed circuits.

▲ *Tom Larson*

■ TREK Inc. announced that **Tom Larson**, sales engineer at Trek, was recently designated an "ESD Certified Professional – Program Manager" by the Electrostatic Discharge Association (ESDA). Larson was one of the first six individuals to attain such status from this new certification program. According to the ESDA, this certification represents a thorough knowledge of the core competencies for ESD control.

## REP APPOINTMENTS

■ **TRAK Microwave Corp.** announced the appointment of **Pamcor Inc.** as its exclusive sales representative in southern California and southern Nevada. Pamcor will represent all of TRAK's products. Pamcor can be contacted at 4000 Long Beach Boulevard, Suite 207, Long Beach, CA 90807 (562) 637-3124, fax: (562) 637-3125 or e-mail: sales@pamcor.com.

■ **International Manufacturing Services Inc.** (IMS), a manufacturer of high quality thick film resistors and substrates to the electronics industry, announced the appointment of **Marathon Associates**, headquartered in Freeport, TX, to represent IMS products in Texas, Oklahoma, Arkansas and Louisiana. The firm can be contacted at 727 Live Oak, Freeport, TX 77541 (409) 233-7026 or e-mail: mrepf@cebridge.net.

■ **Eastern Wireless TeleComm Inc.** recently announced the appointment of **Advanced Communications Sales** to represent the company's products in northern California and northern Nevada.

■ **COMSOL Inc.** has named **ZhongFang Information Technology Ltd.** (also known as CnTech) as its distributor in the Peoples' Republic of China (including Hong Kong and Macao), effective immediately. The firm, based in Shanghai, is responsible for all marketing, sales, local training and support of the COMSOL product line along with the supplier's other mathematical modeling and analysis software.

■ **MI Technologies** announced it has selected **Test Solutions**, Sofia, Bulgaria, to represent the company's line of RF and microwave test and measurement products to customers in Bulgaria and Macedonia.

■ **StratEdge**, a designer and producer of semiconductor packages for microwave, millimeter-wave and high speed digital devices, announced that **BSW TestSystems & Consulting AG** will represent StratEdge in Germany and the Benelux (Belgium, the Netherlands and Luxemburg) countries. BSW can be contacted at BSW-AG, Oskar-Messter-Strasse 12, 85737 Ismaning, Germany +49 (0) 89 960574-0, fax: +49 (0) 89 960574-11 or e-mail: info@bsw-ag.com.

■ **EMA Design Automation**,™ a full-service provider of Electronic Design Automation solutions, announced that its **Cadence Design Systems Inc.** product sales portfolio has expanded to include products from the Virtuoso® custom design platform, Incisive® functional verification platform and Design for Manufacturing technologies. A Cadence® distributor since 1988, EMA's role has been expanded to allow EMA to offer pre-selected Cadence customers a broader portfolio of Cadence products fully supported by Cadence's customer support group.

■ **CDM Electronics Inc.** announced the signing of a worldwide distribution agreement with **Adam Tech**. Under the terms of the agreement, CDM will distribute Adam Tech's extensive range of standard, fully RoHS-compliant connectors, as well as deliver engineering and design support services through all phases of custom manufacturing.

## WEB SITES

■ **W.L. Gore & Associates Inc.** has added assemblies to its on-line interactive design guide, available at www.gore.com/designacable. The tool now provides a menu of connector options to configure a complete GORE™ high flex flat cable assembly or GORE™ trackless cable assembly, with 10 day lead times.

■ **Rogers Corp.** announced the creation of its new "Green Leader" web site (www.rogersgreenworld.com), which contains information on the company's environmentally friendly specialty materials and related subjects.

# UHF RFID and Tag Antenna Scattering, Part I: Experimental Results

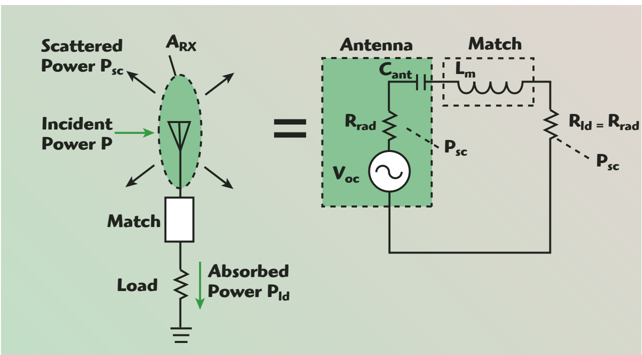
Basic antenna theory shows that the scattering cross-section of an antenna is often much larger than the physical cross-section of the metal wires from which the antenna is constructed. In the case of RFID tags, a large number of tag antennas may be present in close proximity to one another when many articles are to be tagged. In such circumstances, it is shown that strong scattering effects influence the ability to read tags due to the tag antennas. Collective scattering modulation in certain types of tags (EPCglobal class 0) is also demonstrated, which may lead to tag confusion and failures of the anti-collision procedure in the protocol. These phenomena influence the choice of antenna designs for certain applications and may limit the applicability of UHF RFID, even with the use of improved communications protocols.

The use of radio frequency communications to identify physical objects — radio frequency identification (RFID) — is an old technology that has gained increased interest of late, as reduced costs and increased capabilities have made implementations practical in the commercial supply chain.[1] Low cost tracking of tagged cartons or cases can be implemented using passive tags, consisting of an etched, stamped, or printed antenna and a single integrated circuit mounted on an adhesive backing. Power is extracted from the incident RF to avoid the need to incorporate a battery, and backscattered transmission — variation in the load attached to the antenna to vary the backscattered power — is used in lieu of a local transmitter. Operation in the US ISM band at 902 to 928 MHz, or similar bands in other jurisdictions, allows resonant or near-resonant antennas of a convenient size, license-free operation and moderate range.

DANIEL M. DOBKIN
*Enigmatics*
*Sunnyvale, CA*
STEVEN M. WEIGAND
*WJ Communications Inc.*
*San Jose, CA*

The path loss budget for such passive tags is much less generous than is the case for a typical active radio, and represents an important constraint on the range at which the tags can be read. A typical tag IC requires around 50 to 500 microwatts to operate (that is –13 to –3 dBm). Transmitters in the US are limited to 36 dBm effective isotropic radiated power, so only approximately 40 to 50 dB of path loss is allowed before insufficient power is available to operate the tag. For example, a typical low cost WiFi (IEEE 802.11) radio has a sensitivity of around –90 dBm at 1 Mbps data rate; a passive tag is on the order of 80 dB less sensitive than a conventional radio. The range is a few meters in US operation, and tolerance to additional propagation impairment is very limited.

Today, RFID tags are generally employed to uniquely identify cases or cartons of items, each case typically tens of centimeters to over a meter on a side. Thus, even when such cases are stacked on a pallet or in a cage for transport, the density of tags is very low, and interactions between tags can be neglected (though interactions with the contents of the boxes strongly influences the received power and the read range of the tags[2]). In the future, however, it is anticipated that the cost of tags and readers will fall, and the infrastructure for handling information will improve, so that it will become economically advantageous to use RFID tags to identify individual consumer items. In such applications, one might expect to encounter dense regular arrays of tags, with spacing comparable to the size of the antenna. The purpose of this article is to demonstrate that in such cases, the interactions of the tags with the incident field can be large and must be accounted for. Empirical observations of tag interactions have been reported before,[3] but the details of the interactions between antennas were not examined.



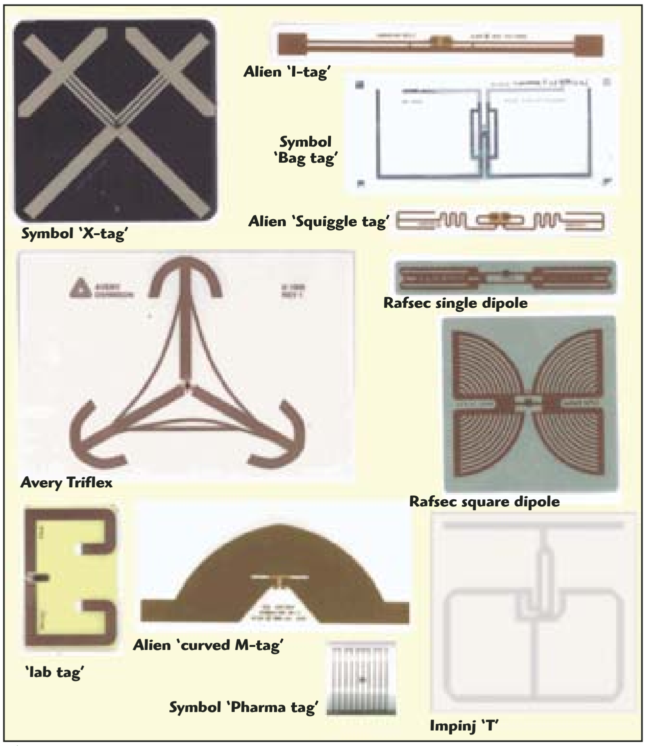

▲ *Fig. 1 Equivalent circuit of a short antenna with a conjugate-matched load.*

**TABLE I**

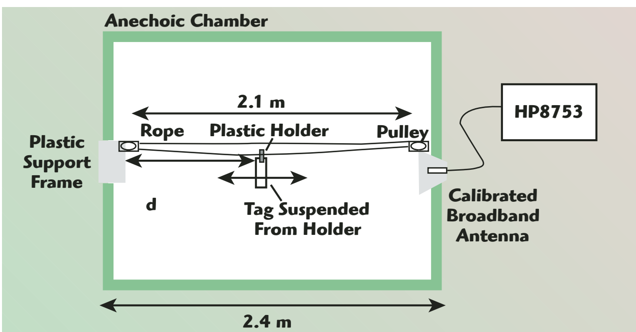
**ABSORPTION AND SCATTERING BY A RESONANT DIPOLE AT 915 MHz**

| Load Resistance (Ω) | Absorption Cross-section (cm²) | Scattering Cross-section (cm²) |
|---|---|---|
| 0 (short circuit) | 0 | 550 (4 × matched) |
| ≈ 65–70 (matched) | 140 | 140 |
| 130 | 70 | 35 |
| ∞ (open circuit) | 0 | ≈ 12 |

As background for the discussion, it is well to recall some results from basic antenna theory. An incident field encountering an antenna induces currents on the antenna, and those currents in turn radiate new fields, the net result being that some of the incident power is scattered. A convenient means of characterizing the scattering is to define a scattering cross-section: an equivalent collecting area which, when multiplied by the energy density of the impinging radiation, gives the total scattered power. For the simple case where the antenna is conjugate-matched, half of the power, $P_{ld} = P \times A_{RX}$, is dissipated in the load resistor and half the power, $P_{sc} = P_{ld}$, is dissipated in the radiation resistance — scattered — so the cross-section for scattering is equal to the effective aperture ARX of the antenna (see ***Figure 1***). This is the condition of maximum power delivered to the load, clearly desirable for maximizing the range of a passive RFID tag, so it is plausible that an RFID tag may scatter a power comparable to that it receives. In the more general case of a dipole or dipole-like antenna, with arbitrary load impedance, the effective aperture due to the total scattered power is given by[4]




▲ *Fig. 2 Tag antenna designs examined in this work.*




▲ *Fig. 3 RSC measurement setup.*

$$A_{sc} = \frac{\lambda^2}{4\pi} G \left| \frac{2R_a}{Z_L + Z_a} \right|^2 \quad (1)$$

where

G = antenna gain
$R_a$ = antenna (radiation) resistance
$Z_L$ = complex load impedances
$Z_a$ = antenna impedance

For a resonant antenna ($Z_a = R_a$), presented with a short-circuited load, the scattering aperture is four times larger than in the conjugate-matched condition, and the absorption cross-section is zero since no power is delivered (undesirable for a tag). On the other hand, increasing the load impedance will reduce the power scattered as roughly the square of the load, whereas the absorbed power will fall only linearly: one can decrease antenna scattering and still absorb power, at the cost of a reduction of absorbed power relative to that obtained from a conjugate match. Thus, the balance between absorption and scattering is dependent on the details of the tag IC load and antenna impedance. A few simple examples are provided in ***Table 1*** to give a feel for the typical magnitudes involved. The 12 $cm^2$ scattering cross-section for an open circuit load resistance is a measured value. The equivalent circuit model suggests that the scattered power ought to go to 0 in this case, but in fact a finite current flows in the shorter wire segments, as a more accurate model would demonstrate.

Antenna designs for passive UHF RFID tags encounter several special constraints, and are not usually simple resonant dipoles. The tag antenna is directly coupled to the integrated circuit, which presents a high resistance, slightly capacitive load. In order to provide good power match and maximize the voltage gain, most tag antennas use a short inductive stub or a folded-dipole-like configuration to resonate out the IC capacitance and match the high resistance IC. Minimizing the physical size of the antenna is a matter of considerable importance for many commercial applications. To reduce size, the antennas are often bent, wiggled, or meandered. Tip loading or bow-tie-like structures are also used to reduce the linear extent of the tag antenna and improve bandwidth. Antennas may also be bowed or curved, or multiple independent antennas employed, to provide polarization diversity. Examples of representative tag-antenna designs are shown in ***Figure 2***. Since the absorption cross-section can never exceed the scattering cross-section, and tags must absorb power in order for the IC to turn on and respond to interrogation, tags designed for long range can be expected to have large scattering cross-sections and thus interact strongly with one another when placed in close proximity. In the remainder of this work, the results of a number of experiments are described, demonstrating the importance of tag-antenna interactions on the ability to read closely spaced passive UHF tags.

## EXPERIMENTAL RESULTS

### Radar Cross-section Measurements

As noted above, the ability of a tag to scatter incident radiation can vary considerably depending on the geometry of the antenna and the load impedance, and tag-antenna geometries are complex and vary widely from one tag to another. Thus, it is helpful to have some measurement of the scattering properties of various tags as a guide for interpretation of experiments involving multiple scattering. Measurements of the radar cross-section (RCS) were therefore performed for a number of tags. The radar cross-section of an object is the equivalent cross-sectional area that will collect enough energy from the incident beam, re-radiated it isotropically, to match the measured backscattered signal from the object. As long as scattering is fairly isotropic, this is a reasonable surrogate for the scattering cross-section of the tag (the numerical values differ by the gain of the tag antenna, approximately 1.5 to 1.6). The setup used is depicted in ***Figure 3***.

The measurements were performed in an anechoic chamber, using a very simple and substantially RF-inactive movable rope and plastic holder to suspend and move the tags. An HP8753 network analyzer was used to extract the reflected signal from a calibrated horizontally polarized antenna. The vector reflection coefficient of the tag was estimated by subtracting the reflection measured when the tag is not present in the chamber. Reflections were measured at various distances from the antenna and fit to the radar equation[5]

$$\mathrm{RCS} = \left(\frac{\Gamma_1^2}{G_a^2}\right)\frac{(4\pi)^3}{\lambda^2}r^4 \qquad (2)$$

by adjusting the value of $\Gamma_1$ to obtain an estimate of the radar cross-section.

Here

$\Gamma_1$ = measured reflection coefficient at the antenna due to the sample
$G_a$ = gain of the test antenna
$r$ = sample-antenna distance
$\lambda$ = wavelength

An example of the measured and modeled data is shown in ***Figure 4***. The results are summarized in ***Table 2***. The scattering cross-sections vary from as little as 3 cm² to as large as 465 cm². (Some variation is observed in measurements of nominally identical tags. There are two likely main sources of variation: the orientation of the tags is not accurately maintained by the rope suspension, and can vary by approximately 20°, and different tags of the same model often show significant variations in range, possibly reflecting varying load impedances.) This variation some-

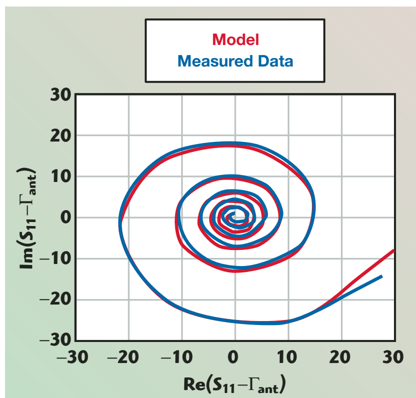



*Fig. 4 Measured and modeled reflection data for a Symbol "X-tag" at 910 MHz for tag-antenna distances from 190 to 40 cm.*

**TABLE II**

**RADAR CROSS-SECTION MEASUREMENTS (IN $cm^2$) OF VARIOUS RFID TAGS**
**DISTANCES SLIGHTLY ADJUSTED TO MATCH THEORETICAL PREDICTIONS FOR RESONANT DIPOLE**

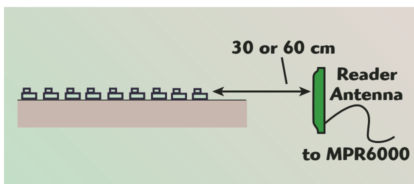
| | | Frequency (MHz) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Tag** | **Condition** | **865** | **900** | **910** | **930** | **955** | **960** | **1000** |
| X-tag | facing antenna, ground legs up to 45° | 185 | | 260 | | 201 | | |
| X-tag | folded in half, long axis vertical | 12 | 16 | | 21 | | 27 | |
| X-tag | folded in half, long axis horizontal | 167 | 158 | | 128 | | 89 | |
| X-tag | same tag unfolded, ground legs 45° down | 232 | 264 | | 251 | | 203 | |
| X-tag | same tag unfolded, ground legs 45° left | 107 | 169 | | 225 | | 282 | |
| I-tag | facing antenna, horizontal pol | 59 | | 464 | | 486 | | |
| I-tag #2 | on cardboard, facing antenna, horizontal | 49 | | 244 | | 342 | | |
| I-tag #2 | same conditions, scalar measurement | 62 | 199 | | 404 | | 406 | 21 |
| I-tag #2 | same conditions, remeasure 9/16 | 65 | 269 | | 488 | | 502 | |
| Bag tag | horizontal, short end to antenna | 4 | | 11 | | 38 | | |
| Bag tag | horizontal, long end to antenna | 16 | | 29 | | 39 | | |
| Bag tag | facing antenna, long end horizontal | 23 | | 40 | | 55 | | |
| Squiggle tag | facing antenna, horizontal pol | 283 | | 52 | | 99 | | |
| Avery Triflex | facing antenna, long end horizontal | 68 | 64 | | 56 | | 45 | 4 |
| Avery Triflex | facing antenna, long end vertical | 49 | 50 | | 52 | | 51 | 4 |
| Impinj T | T turned horizontal | 45 | 76 | | 99 | | 127 | 11 |
| Rafsec square dipole | dipole horizontal | 101 | 276 | | 419 | | 194 | 3 |
| Rafsec | horizontal, facing antenna | 31 | 66 | | 64 | | 20 | |
| Lab tag | bent dipole, horizontal, facing antenna | 8 | 16 | | 32 | | 87 | 13 |
| Curved Mtag | horizontal, facing antenna | 341 | 545 | | 256 | | 51 | 0.5 |
| Pharm a tag | horizontal, facing antenna | 1 | 3 | | 3 | | 2 | |
| Pharm a tag | horizontal, facing antenna | 0.6 | 1.9 | | 1.9 | | 0.9 | |
| Bare wire | 16 cm long, horizontal, perpendicular to boresight | 524.5 | 462.6 | | 361.4 | | 260.1 | |
| | 15.6 cm long, as above | 454.9 | **561** | | 446.5 | | 329.6 | |
| | Theory, dipole: | | **569** | | | | | |
| | Error: | | 2% | | | | | |

what exaggerates the variation expected in a multiple-tag effect. Since multiple-tag scattering depends on the sum of scattered potentials and thus on the induced current rather than scattered power of each tag, it is the square root of the RCS that will determine the importance of tag interactions. This quantity still varies quite substantially, from approximately 1.7 to 22 cm, suggesting that different tags will have differing effects when present in a dense array.

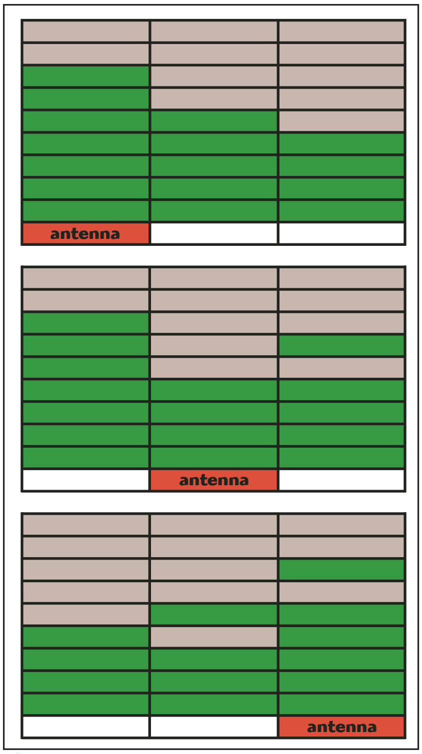
## Tag Read Range

The strongest scattering effects are to be expected from tags with the largest radar cross-sections. Alien I-tags display some of the largest values of RCS in the ISM band (902 to 928 MHz), so the focus is on them first. The read range of a dense planar array of such tags was examined, first with the direction of propagation in the plane of the array (see ***Figure 5***). The planar arrays are constructed using rows of tags, affixed to thin cardboard backing, placed onto a non-conductive foam support at spacings of 20 cm lengthwise and 5 cm perpendicular to the tag axis. The default array was configured as three columns of nine tags each. A WJ Communications MPR6000 reader, with 0.5 W transmit power, was connected to a horizontally polarized 9 dBi antenna. A total of four groups of 10 inventories were performed in each condition, with a tag reported as having been read if its electronic product code (EPC) was observed in any inventory operation. Note that it is indispensable to employ the binary tree collision resolution ('PING') capability available in EPCglobal class 1 tags in this environment; a 'global scroll' inventory will read only 2 to 4 tags, versus the 24 to 30 tags that are obtained in a single anti-collision inventory. The frequency range was limited to 923 to 925 MHz to avoid uncontrolled excursions in results due to frequency hopping.

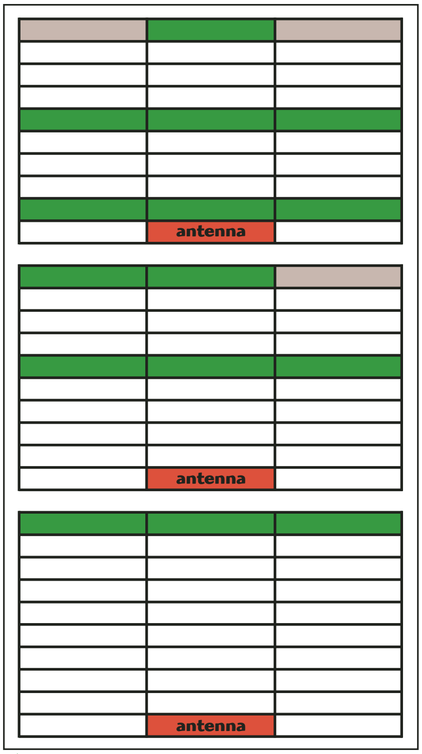
Some of the results are shown. ***Figure 6*** shows the ability to read tags in a fully populated 3 by 9 array. The antenna was displaced laterally to view the left, center and right columns, as shown schematically in the figure. The antenna distance from the nearest tag was set at 30 or 60 cm. Since the array size is approxi-



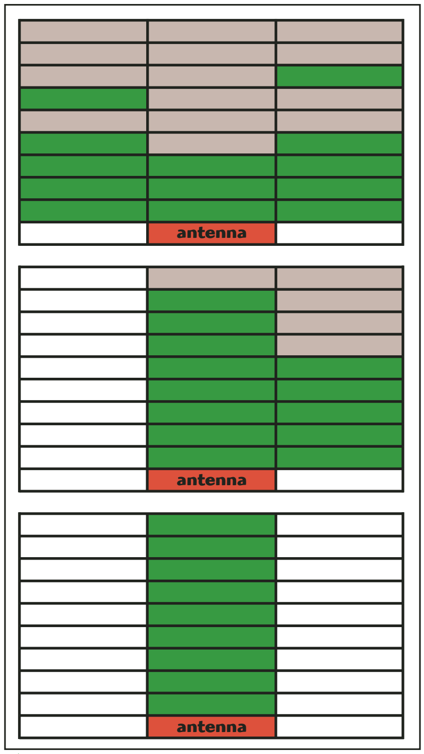

▲ *Fig. 5 Cross-sectional view of a read-range experiment using Alien I-tags and Squiggle tags.*




▲ *Fig. 6 Tags read from fully populated 3 by 9 array of I-tags (tags read are shown in green; tags not read are shown in gray).*



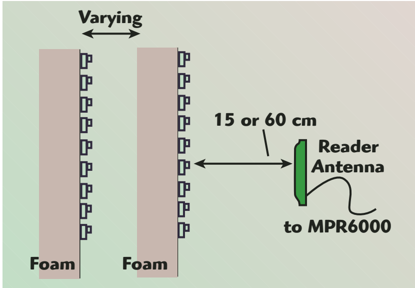

▲ *Fig. 7 Same as Figure 6, with tags removed from the array (locations with no tags are shown in white; other conventions remain the same).*



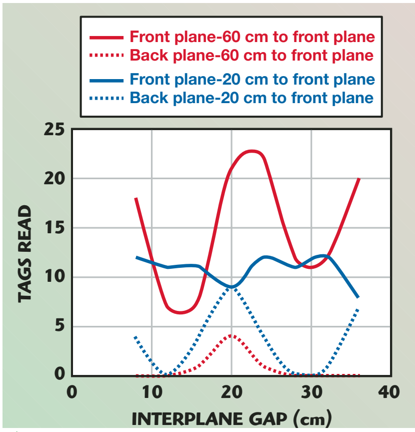

▲ *Fig. 8 Same conventions as in Figure 7 (distance from antenna to nearest tag = 30 cm).*



mately 45 cm, the most distant tag was at most 1 meter from the antenna, easily within the 2.5 to 3.5 meter read range for an isolated I-tag. Thus, if scattering was negligible, all tags should have been readable. However, as shown, only the tags nearest the antenna were accessible. It is also notable that the center column is read very poorly, with at most 5 out of 9 tags, whereas the left and right columns both provide read-outs to the seventh tag. Increasing the tag-antenna distance from 30 to 60 cm results in a slight improvement in the number of tags read. The ability to read the most distant row when the effects of other tags are removed is examined in ***Figure 7***. When only three rows are populated, the most distant tag in the center column is read (top). When only the most distant row is populated, all the distant tags are read (bottom), verifying that even the most distant row can be seen by the reader when the intervening tags are removed. Finally, ***Figure 8*** shows that the effects are not confined to the line of sight: when the left column of tags is removed, the center column (heretofore mostly invisible) becomes largely read, and when both side columns are removed, the center column is read in its entirety. A second geometry of considerable practical interest is a multiplane array (as the first step towards a full three-dimensional array). A two-plane array was examined, consisting of the 3 by 9 array shown above, arranged in front of a 3 by 6 array with the same spacing (see ***Figure 9***). The distance between the planes of tags (interplane gap) was varied and the number of tags read in the front and back planes was recorded. The resulting tags, read as a function of interplane gap, are shown in ***Figure 10***. If only the line of sight was important, it might be expected that the two planes would interact only weakly and most or all tags in both planes would be read. However, the results show that this is not the case. The back plane of tags is nearly invisible except at an optimal spacing of approximately 20 cm, and the ability to read tags in the front plane is strongly influenced by the presence of the back plane. Furthermore, the front-plane readability at 60 cm spacing to the antenna shows pronounced periodicity of roughly 16 cm, corresponding to approximately 1/2 wavelength at the operating frequency. This result is qualitatively similar to that one might expect from a solid metal reflector: constructive interference at odd quarter-wavelength spacings increases the field at the front plane.

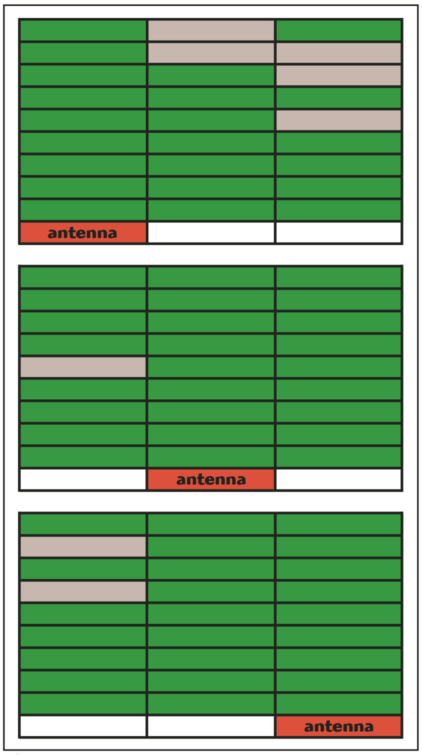



▲ *Fig. 9 Test configuration, multiple planes of tags.*

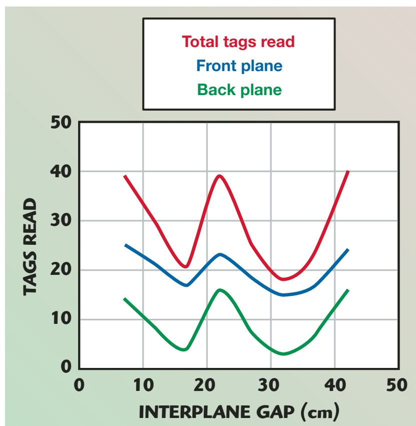



▲ *Fig. 10 Front and back plane tag read as a function of interplane gap for two different distances from the reader to the first plane.*

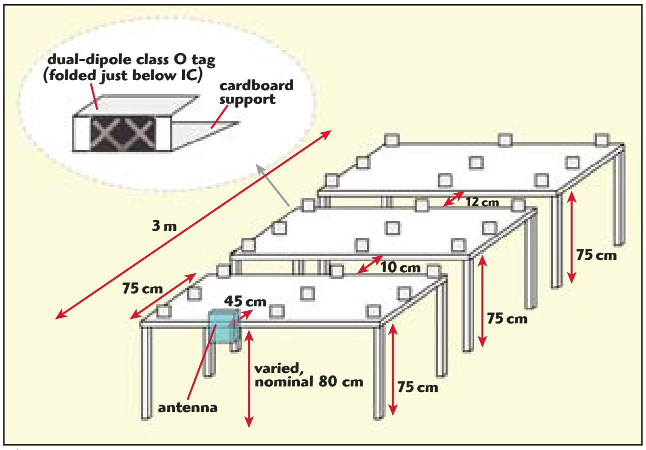
From the results of Table 2, it might be expected that the effects of scattering would be reduced using a Squiggle tag in place of an I-tag, for example, as the RCS of the Squiggle is much smaller. ***Figure 11*** shows the results of an experimental configuration essentially identical to that used before, except




▲ *Fig. 11 Tags read from a fully populated 3 by 9 array of Squiggle tags (tags read are shown in green; tags not read are shown in gray).*




▲ *Fig. 12 Front and back planes of Squiggle tags read in the two-plane array as a function of interplane distance.*

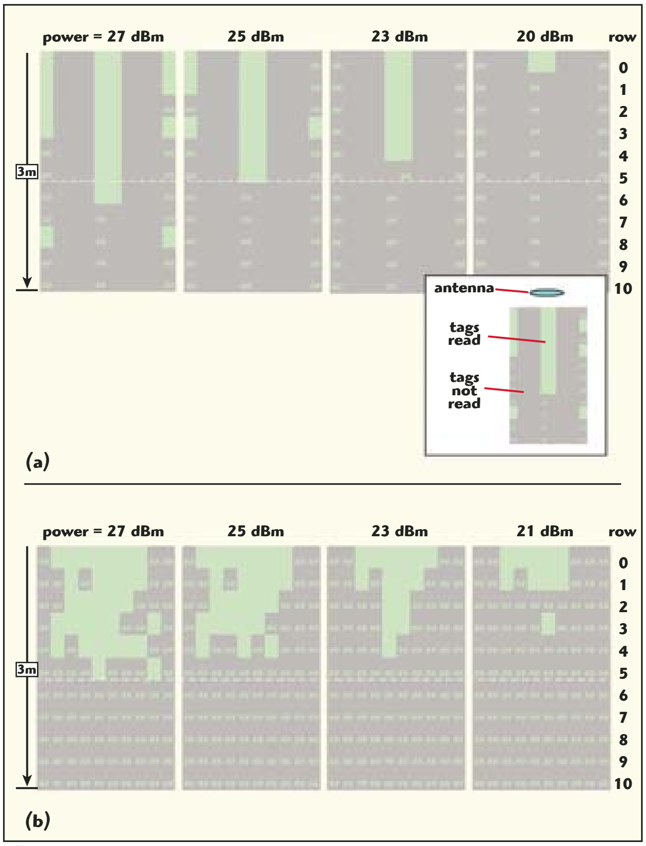



▲ *Fig. 13 Experimental setup for Symbol X-tags.*

that Squiggle tags are substituted for I-tags (in the same positions). The distance between the antenna and the nearest tag is 50 cm. In contradistinction to the previous results, here almost all tags are read when the antenna is centered on the array, and predominantly only the most distant tags from the antenna fail to be read.

***Figure 12*** shows the analogous result for multiple planes of tags. The visibility of both planes is considerably higher than was the case for I-tags, but it is also obvious that scattering effects remain of considerable importance: the visibility of both planes is again strongly and periodically dependent on the spacing between them.

Also, non-negligible scattering effects have been observed at lower tag densities. In one set of experiments, using the configuration depicted in ***Figure 13***, Symbol X-tags (folded just below the IC for mounting convenience) were laid out on a set of wooden tables over an area of roughly 3 by 2 meters. The rows were populated with three tags each (as shown) or 10 tags each. The row-to-row spacing was approximately 30 cm; the column-to-column spacing was approximately 90 cm (three tags per row) or 20 cm (10 tags per row). The tags were illuminated by the same reader and antenna setup using a vertically polarized antenna to minimize floor reflections.




▲ *Fig. 14 Tags read (green) and not read (gray) for the configuration of Figure 13 as a function of reader transmit power; (a) three tags per row and (b) 10 tags per row.*

As shown in ***Figure 14***, when only three tags per row were present, tags as far as 2.5 meters from the antenna were read. (Note that the range along the center column was less than that observed in the left and right columns, suggesting that even at this low tag density scattering of the signal limits the range.) When each column is populated with 10 tags, the range is reduced to approximately 1.5 meters.

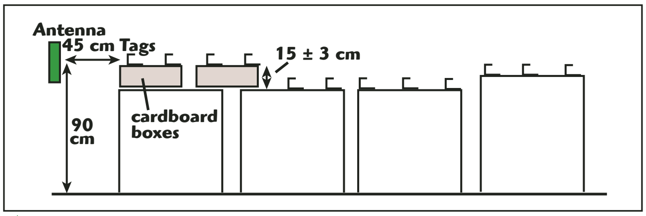
In order to examine the role of scattering in the plane, empty cardboard boxes were used to elevate the front few rows of tags, as shown in ***Figure 15***.

The results, shown in ***Figure 16***, provide a vivid illustration of the importance of in-plane scattering, as well as confirming that it is other tags and not any limit on read range that is making distant rows invisible. When the first four rows are elevated, the fifth row, sporadically visible before, is almost completely read at 27 dBm transmit power, and the sixth and seventh rows become partially visible. If two additional rows are elevated (see ***Figure 17***), rows 7 and 8 become partially visible, even though the nearer (but shadowed) rows 5 and 6 are not read at all. Note that these fairly strong effects are observed despite the fact that, according to Table 2, the folded X-tags present a rather modest RCS of approximately 15 to 20 square centimeters when oriented perpendicular to the incident polarization, as is the case here.

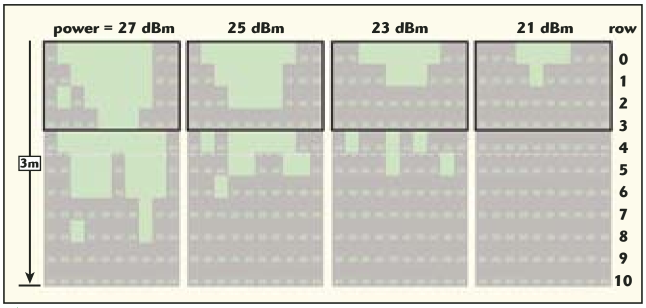
## Direct Measurements of Signal Strength

In order to demonstrate quantitatively the effects of tags on the received signal strength, a tag-like antenna was used to sample the local field strength as RFID tags were added near the receiving antenna. The configuration is shown in ***Figure 18***. An I-tag-like dipole antenna fabricated on 0.35 mm FR4 was employed to collect the transmitted signal from the reader; an Agilent transmitter tester displayed the time-dependent signal and allowed selection of the CW portion or modulated portions as desired. An MPR6000 reader provided the illumination, with the frequency fixed at 915 MHz, driving a 9 dBi right-hand-circular-polarized patch antenna. Tag arrays were constructed between the receiving antenna and the reader antenna, using either I-tags or Squiggle tags, both mounted on cardboard, the whole assembly supported on a block of nonconductive foam. A spacing of 5 cm between rows was used. The data was taken with either one central column of tags, or three columns of tags; in the latter case, the centers of the tags in adjacent columns were spaced by 20 cm.

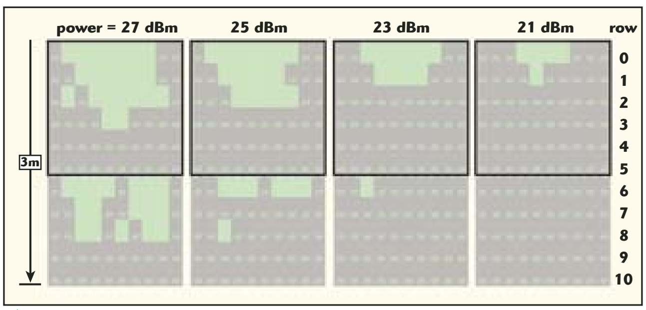
***Figure 19*** shows the signal power during the CW period of an inventory, versus the number of rows and columns, and the type of tag. As might be expected from previous results (Figures 6 and 11), I-tags have a larger effect on the received signal than Squiggle tags. The overall effect on the received signal is quite substantial, given the constrained forward link budgets for passive tags, and readily explains the difficulties previously noted in reading the rear rows of dense I-tag arrays. A single column of Squiggle tags has little effect on received power, though a dense array of three columns with more than four rows of Squiggle tags



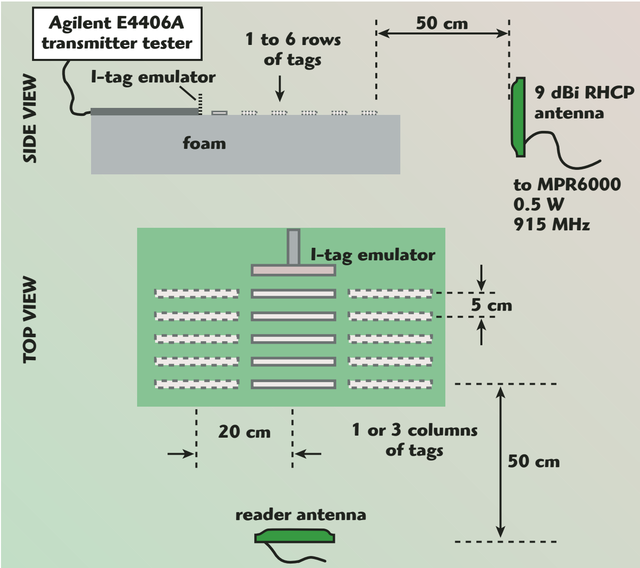

▲ *Fig. 15 Alternative configuration with the first rows of tags out of plane.*




▲ *Fig. 16 Tags read as a function of reader transmit power for the configuration of Figure 15 (first four rows elevated).*




▲ *Fig. 17 Tags read as a function of reader transmit power when the first six rows are elevated.*

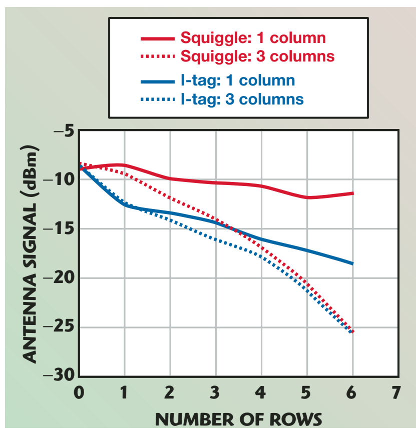



▲ *Fig. 18 Configuration for received power versus tag array measurements.*

results in more than 10 dB of attenuation of the received signal.

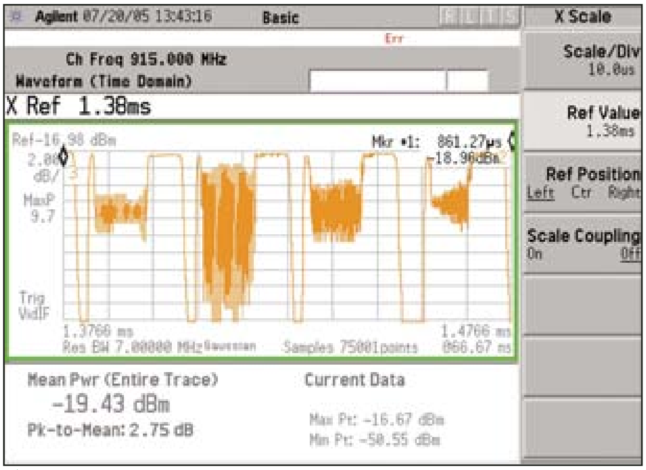
An interesting related phenomenon is the question of collective modulation of the received signal by other tags. The EPCglobal class 0 standard uses a bit-by-bit communications protocol in which tags backscatter using the continuous-wave portion of each bit symbol from the reader. One option for collision resolution uses the tag EPCs as guidance for navigation of the binary tree by the reader: each tag scatters the next bit of its EPC, and if it hears the reader echo that bit, it continues by scattering the next bit. Otherwise, it falls silent until the next attempt to traverse the tree. If all the tags in an array share many initial bits, all tags will scatter in unison during a significant portion of the tree traversal. Substantial time-dependent scattering, and thus changes in the received signal in a specific tag, can result. To demonstrate this effect, a similar experiment was performed using Symbol class 0 'Bag Tags.' A dense array of 'Bag Tags' was mounted on a foam support, with roughly 5 cm and 12 cm spacings (some inlays varied in size by approximately 1 cm resulting in modest displacements). A reader-receiver spacing of 75 cm was used in this experiment. The reader was instructed to identify individual tags using the tag EPC (known as ID2 in the terminology used in the standard). A portion of a resulting inventory operation is shown in ***Figure 20***. In this diagram, the 3 or 6 microsecond wide deep pulses are the reader symbols binary 0 and 1. After each such pulse, the reader signal goes HIGH for the remaining 20 or so microseconds of the symbol. During this time, the tags scatter their reply at either 2.2 or 3.3 MHz, visible as the rapid variations in signal strength. The large variation in the amplitude of the tag signal seen from one symbol to the next is not the result of a change in the number of tags responding as, in this portion of the traversal, all tags share the same EPC bits. Rather, it seems to reflect variations in the timing of the various local MHz tag oscillators, so that the various tags sometimes modulate in unison and sometimes fall out of phase. The magnitude of these collective effects is substantial. Even when the tags appear to be out of phase, the average signal strength is reduced by 6 dB below the reader CW level, which is already attenuated by approximately 17 dB below the unobstructed signal strength. When the tags scatter in unison, an 18 dB dynamic swing in received power is observed. These large changes in received power may be sufficient to interfere with the ability of the tags to correctly decode the reader






▲ *Fig. 19 Received power versus number of tags inserted between reader and receiver antennas.*




▲ *Fig. 20 Received signal power versus time.*

symbols, with detrimental effects on the operation of the protocol. For example, if a tag that has fallen out of a traversal decodes a 'NULL' symbol (an extra-long LOW pulse, here around nine microseconds) followed by a '0,' it assumes a new traversal has started and begins to backscatter its EPC. The reduction in signal strength resulting as other tags scatter might be mistaken for a long LOW pulse, causing a tag to reenter the traversal in the middle and possibly block any tag from being read for that traversal.

## CONCLUSION

These results clearly indicate that RFID tag antennas scatter incident radiation and collectively have significant effects on neighboring tags. The practical result is that dense arrays of tags will limit read range to much shorter distances than expected for an isolated tag of the same design. Scattering effects are observed for both EPCglobal class 0 and class 1 tags, suggesting that they are not artifacts of any particular protocol. The magnitude of these effects is generally correlated with the radar cross-section of an isolated tag. Protocols in which tags modulate collectively may produce significant dynamic modulation of the reader signal. This effect should take place for class 0 and class 1 tags, and may lead to artifacts in class 0 as tags mistake collective modulation of reader CW signals for reader symbols. (Note that in the EPCglobal class 1 gen II protocol, a slotted Aloha collision resolution method is used, in which it is unlikely that more than one or two tags will modulate at once.) The results suggest that optimal tag types for dense tag environments differ considerably from optimal isolated tags. For example, I-tags provide high performance as isolated tags, with relatively long read ranges, but when placed in a dense array are inferior in performance to the Squiggle tags, a distinction explained by the difference in their radar cross-sections. Tags with small RCS are preferred for dense environments, but some results show that, even in this case, scattering effects cannot be neglected. Finally, in the case where the impinging radiation is close to a plane wave, one would expect a regular array of low RCS tag antennas to produce strongly enhanced scattered fields along low index directions in the reciprocal lattice if the spacing is larger than a wavelength. In most cases, such arrays will be composed of cases with cubic or rectangular prism shape, and thus the array is cubic or orthorhombic.[6] For these lattices, the reciprocal lattice vectors are in the same direction as the low index directions of the physical lattice; that is, for a three-dimensional lattice (a stack of tagged boxes) the (100), (110) and (111) directions will show strong reflections. Arrays may thus act as directive reflectors, possibly causing reader-reader interference and tag reads in unexpected locations. ■

## References

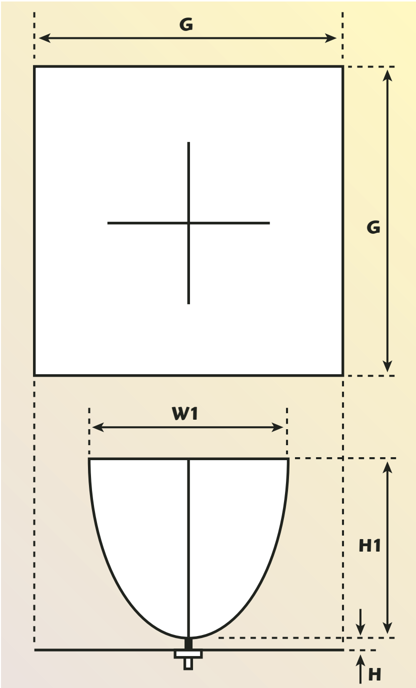
1. D. Dobkin and T. Wandinger, "A Radio-oriented Introduction to Radio Frequency Identification," *High Frequency Electronics*, Part 1, June 2005; Part 2, August 2005.
2. D. Dobkin and S. Weigand, "Environmental Effects on RFID Tag Antennas," *2005 IEEE MTT-S International Microwave Symposium*, paper TU3A-2.
3. V. Pillai, J. Peternel, H. Heinrich, R. Martinez and K.V.S. Rao, "Using Volatile State Storage for Substantial Improvement in RFID Throughput," *Fourth IEEE Workshop on Automatic Identification Advanced Technologies Digest*, October 17–18, 2005, pp. 101–105.
4. C. Balanis, *Antenna Theory*, Third Edition, John Wiley & Sons Inc., Hoboken, NJ, 2005, p. 103.
5. C. Balanis, *Antenna Theory*, Third Edition, John Wiley & Sons Inc., Hoboken, NJ, 2005, p. 98.
6. http://www.chemsoc.org/exemplarchem/entries/2003/bristol_cook/latticetypes.htm and http://www.matter.org.uk/diffraction/geometry/3D_reciprocal_lattices.htm.

# THE DESIGN OF A FINITE GROUND PLANE CROSS SEMI-ELLIPTIC MONOPOLE ANTENNA FOR UWB APPLICATIONS

*A cross semi-elliptic monopole antenna with a finite ground plane is presented. Both impedance and radiation characteristics of this antenna are studied. Experimental results indicate that an impedance bandwidth of 10.15 GHz is achieved at operating frequencies from approximately 1.85 to 12 GHz, which covers the bands of most wireless and ultrawideband (UWB) applications. By cutting four narrow slits on the cross semi-elliptic monopole antenna, a band-rejected (5.24 to 6.04 GHz) UWB antenna can be implemented. Good dipole-like radiation characteristics of the constructed prototype are also shown in this article. The broad bandwidth and good radiation properties of the proposed design are suitable for UWB applications.*

Since the Federal Communications Commission (FCC) released UWB technology,[1] many researchers have made efforts to develop UWB radio systems.[2,3] As the antenna is a key component of a UWB radio system, many antenna designs for UWB applications have been published.[4] A monopole antenna has the advantage of having a very wide impedance bandwidth; hence, it is a good candidate for a UWB antenna. Monopole antennas can be classified into three types: solid monopole, quasi-solid monopole and planar monopole. A conventional solid monopole antenna is made of metal, shaped as a specific body. This antenna has a good impedance bandwidth and a perfect omni-directional radiation characteristic. However, it is expensive to fabricate a solid monopole antenna. The planar monopole antenna is low cost, with wideband characteristics, but suffers from distortion of the radiation pattern at higher operating frequencies, which leads to non-omni-directional radiation. Therefore, improving the monopole antenna characteristics to match the regulations or standards requirements is an important issue. Some designs to overcome the pattern distortion have recently been implemented and presented.[5–7] The cross-shaped monopole[5] has the advantage of an omni-directional radiation in the horizontal plane and of retaining a wide operating impedance bandwidth. A dual-frequency cross-shaped monopole[6] has been fabricated and investigated. Good rejection of an undesired frequency band was obtained. However, the

WEN-SHAN CHEN AND MAO-KAI HSU
***Southern Taiwan University of Technology***
***Tainan Hsien, Taiwan, ROC***



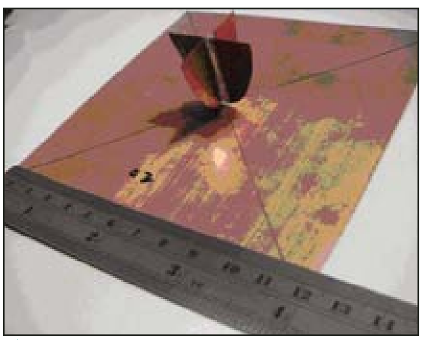

▲ *Fig. 1 Geometry of the cross semi-elliptic disc monopole antenna.*

designed operating frequency band cannot exactly match the requirements of the UWB regulation. A cross semi-circular monopole was proposed,[7] but the effect of the size of the ground plane was not shown.

In this article, a novel design for a finite ground plane cross-shaped semi-elliptic monopole antenna is presented and investigated. The bandwidth of the proposed antenna can cover a number of wireless communications. By cutting four narrow slits into the lobes of the cross-shaped monopole antenna, a band-reject from 5.25 to 6.05 GHz is obtained.

## CHARACTERISTICS OF THE CROSS SEMI-ELLIPTIC MONOPOLE ANTENNA

***Figure 1*** shows the geometry of the cross semi-elliptic monopole antenna.



▲ *Fig. 2 The cross semi-elliptic monopole antenna.*

The monopole is made of 0.1 mm thick copper sheets, which are located vertically above a square ground plane of dimension GG mm$^2$. The cross semi-elliptic monopole is made by using two semi-elliptic conducting plates. The length of the major axis is 2 $H_1$; the length of the minor axis is $W_1$. A photograph of the fabricated prototype antenna is shown in ***Figure 2***. The measured return loss of the proposed antenna is plotted in ***Figure 3***, where the antenna dimensions are $H_1$ = 28 mm, H = 0.5 mm, $W_1$ = 32 mm and G = 120 mm. It shows that a very large impedance bandwidth, from 1.85 to more than 12 GHz, can be obtained with this design. It can cover the UWB and future wireless applications above 10 GHz. Please note that since the SMA connector offers good performance from only DC to 12 GHz, the measurement frequency is up to 12 GHz. When an operating frequency greater than 12 GHz is desired, the use of a high performance SMA or other high frequency connector is suggested. In addition, for most modern portable devices, the size of the overall antenna must be kept small. In a monopole antenna, reducing the size of the monopole and the ground is an important issue. In the conducted experiments, the height of the cross-elliptic monopole antenna, corresponding to 0.255λ, is larger than that of the cross semi-elliptic monopole antenna, corresponding to 0.172λ for the same size ground plane. Therefore, the use of the cross semi-elliptic monopole antenna has the advantage of a compact size compared to the cross-elliptic monopole antenna.

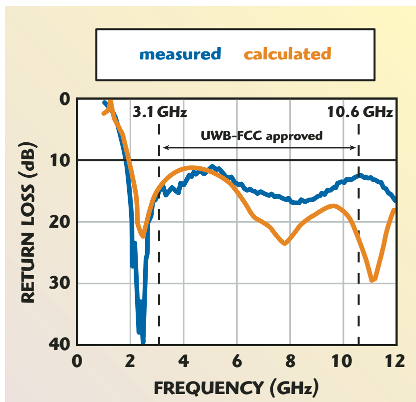
The design parameters of the proposed antenna can easily be determined. When the size of the ground plane of the antenna is much larger than that of the antenna itself, the lowest operating frequency $f_L$ is determined from the following formula

$$f_L = \frac{c}{\lambda} = \frac{300 \times 0.24}{\ell + r}\ (\text{GHz}) \qquad (1)$$

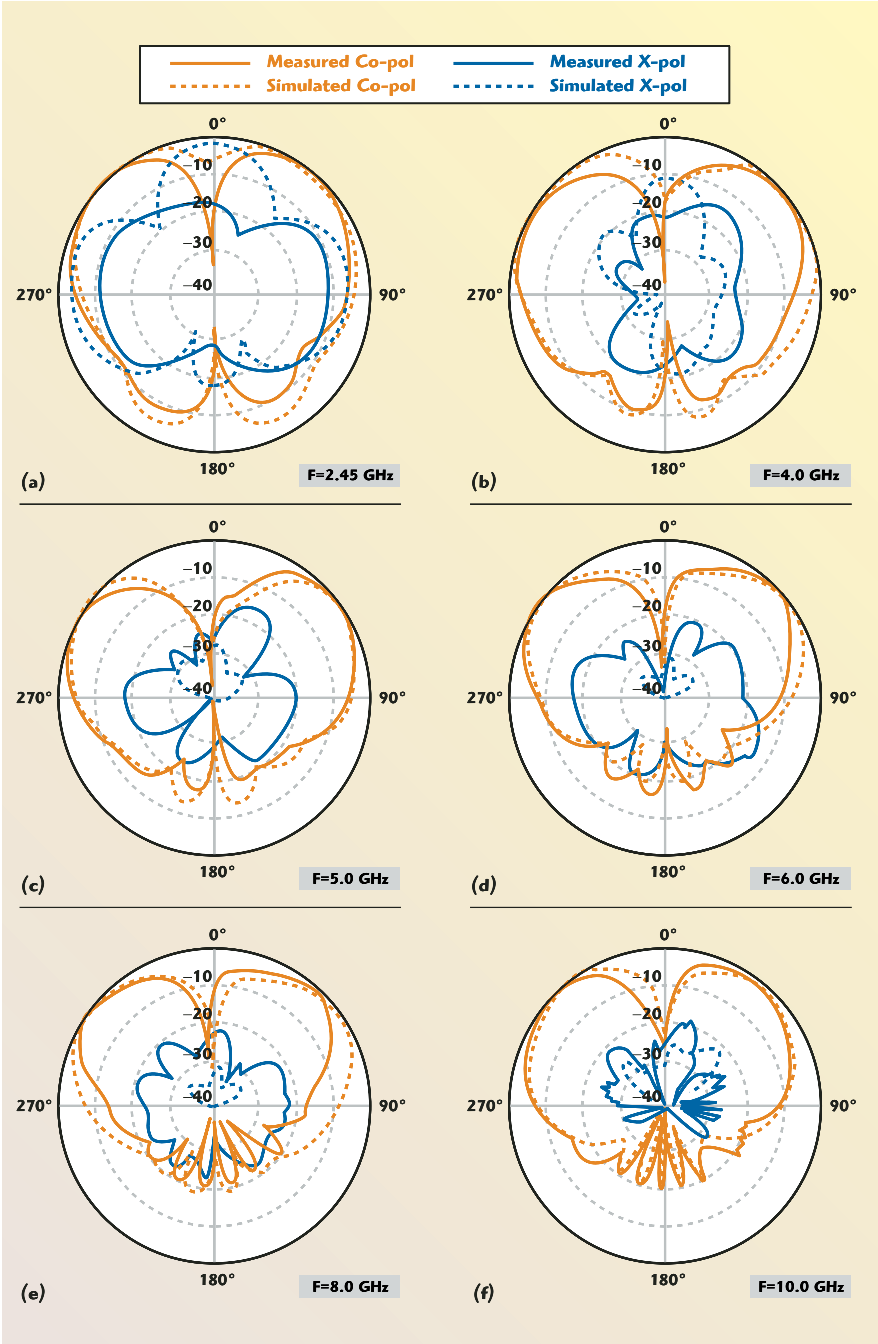
**TABLE I**

**MEASURED AND CALCULATED LOWEST OPERATING FREQUENCY OF THE CROSS SEMI-ELLIPTIC MONOPOLE ANTENNA AS A FUNCTION OF THE GROUND PLANE DIMENSION**

| No. of the Experiments | G (mm) | $f_L$ Measured (GHz) | $f_L$ Calculated (GHz) | Error |
|---|---|---|---|---|
| 1 | 280 | 1.88 | 1.807 | 0.073 |
| 2 | 260 | 1.91 | 1.819 | 0.091 |
| 3 | 240 | 1.91 | 1.831 | 0.079 |
| 4 | 220 | 1.88 | 1.843 | 0.037 |
| 5 | 200 | 1.79 | 1.855 | 0.065 |
| 6 | 180 | 1.87 | 1.867 | 0.003 |
| 7 | 160 | 1.88 | 1.879 | 0.001 |
| 8 | 140 | 1.75 | 1.891 | 0.141 |
| 9 | 120 | 1.84 | 1.903 | 0.063 |
| 1 | 120 | 1.84 | 1.760 | 0.080 |
| 2 | 110 | 1.93 | 2.020 | 0.090 |
| 3 | 100 | 1.99 | 1.986 | 0.004 |
| 4 | 90 | 2.06 | 2.099 | 0.039 |
| 5 | 80 | 2.12 | 2.212 | 0.092 |
| 6 | 70 | 2.23 | 2.325 | 0.095 |
| 7 | 60 | 2.40 | 2.438 | 0.038 |
| 8 | 50 | 2.49 | 2.451 | 0.039 |
| 9 | 40 | 2.63 | 2.664 | 0.034 |
| 10 | 30 | 2.97 | 2.777 | 0.193 |




▲ *Fig. 3 Measured and simulated return loss of the cross semi-elliptic monopole antenna.*




▲ *Fig. 4 Measured and simulated y-z radiation patterns for the proposed antenna.*

where

r = equivalent radius[9] of the monopole antenna, determined by

$$r = \frac{A}{2\pi\ell}(\mathrm{mm})$$

$$A = 2\times\left[0.5\pi\left(\frac{W_1}{2}\right)H_1\right] = \pi\left(\frac{W_1}{2}\right)H_1(\mathrm{mm})$$

$$\ell = h + H_1(\mathrm{mm}) \qquad (2)$$

where

A = area of the proposed antenna

$\ell$ = total height of the proposed antenna

In most antenna designs, the dimensions of the ground plane have a strong effect on the lowest operating frequency. This was observed and studied. The conventional monopole antenna usually has a large ground plane,[8,9] greater than $\lambda/2 \times \lambda/2$, to fit the image theory. When the dimensions of the ground plane are dramatically reduced, the lowest operating frequency is increased. The lowest operating frequency of the cross semi-elliptic monopole antenna as a function of the ground plane dimensions was measured and listed in ***Table 1***. The other antenna dimensions are the same as in ***Figure 3***. It can be seen that the lowest operating frequency is increasing when the side length G of the ground plane is less than that 120 mm, corresponding to a half wavelength. Consequently, the variance of the lowest operating frequency must be considered when the side length is smaller than λ/2.

From Table 1, a formula can be found by fitting the data using the curve-fitting technique of MATLAB (using the polynomial y = a + bx). Here, the height of the probe feed is H = 0.5 mm, and the lengths of the major axis and of the minor axis are fixed. When the side length of the ground plane is smaller than λ/2, the lowest operating frequency can be obtained from

$$F_L = 3.1160 - 0.0113\ G$$

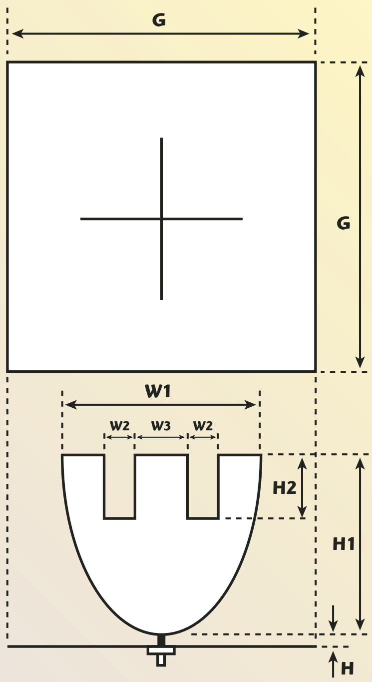
where

$F_L$ = the lowest operating frequency in GHz
G = the side length of the ground plane in mm

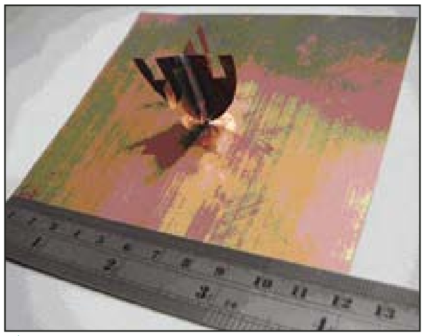
Similarly, when the side length of the ground plane is larger than λ/2, the lowest operating frequency can be obtained from

$$F_L = 1.975 - 0.006\ G$$

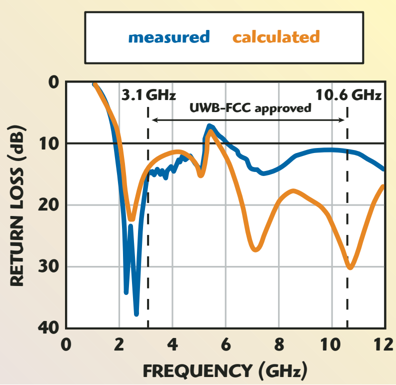
A more accurate formula could be obtained by using a higher order polynomial from MATLAB but, as can be seen, the measured and curve-fitting results of the lowest operating frequency are in good agreement. The antenna bandwidth is slightly reduced when the side length G of the ground plane is reduced, but the impedance of the proposed antenna still has a very large bandwidth of approximately 10 GHz. ***Figure 4*** shows the measured radiation patterns in the y-z plane at f = 2.45, 4, 5, 6, 8 and 10 GHz for the proposed antenna. The x-y plane radiation patterns are almost omni-directional and are not shown for brevity. It is also noted that the patterns of the proposed antenna



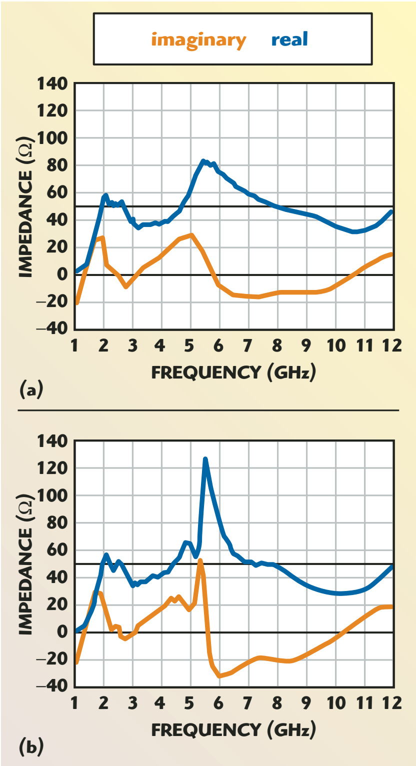

▲ *Fig. 5 Configuration of the band-rejected cross semi-elliptic disc monopole antenna.*



▲ *Fig. 6 The band-rejected cross semi-elliptic monopole antenna.*




▲ *Fig. 7 Measured and simulated return loss of the band-rejected cross semi-elliptic monopole antenna.*




▲ *Fig. 8 Impedance of the proposed antennas (a) without slits and (b) with four narrow slits.*

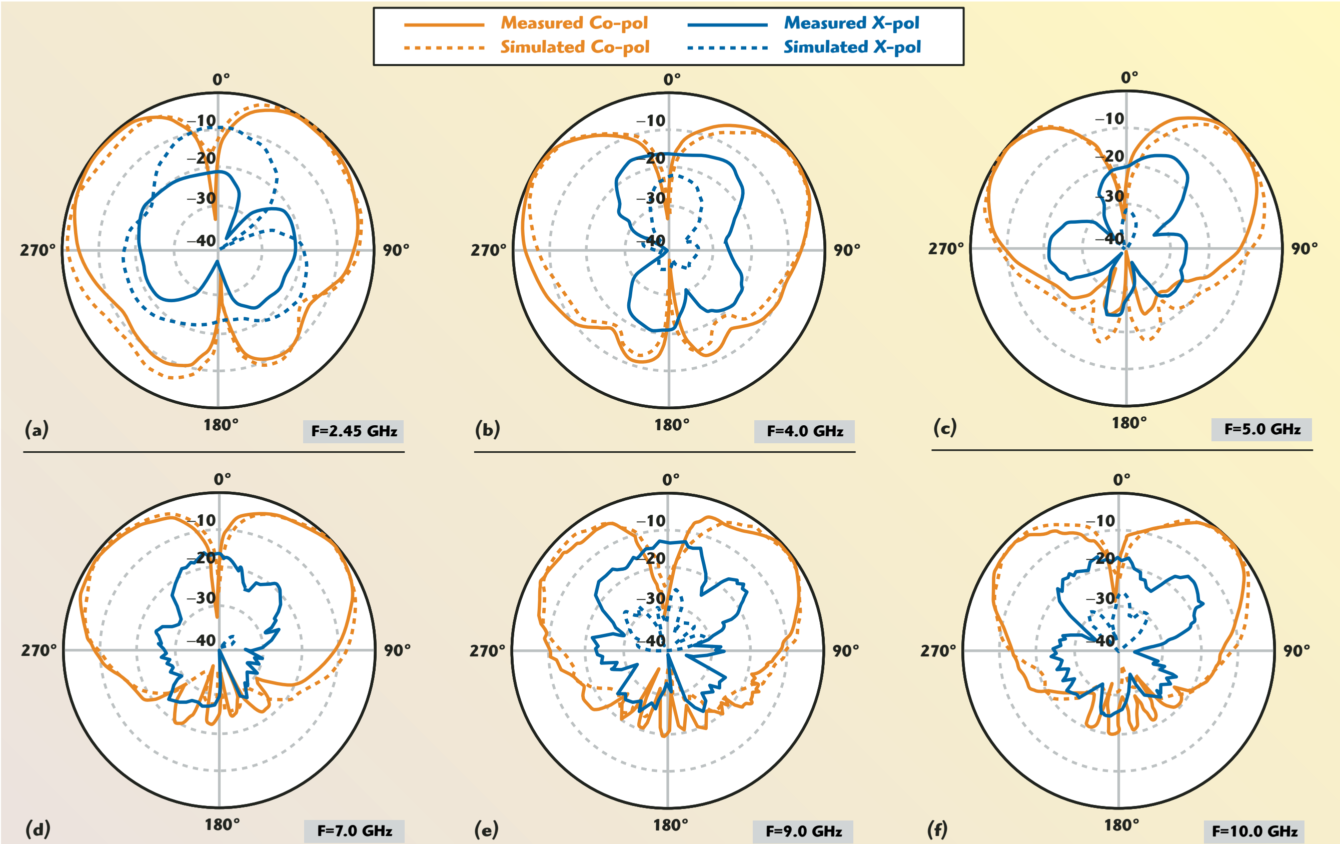
are dipole-like radiation, which makes the proposed antenna suitable for practical UWB applications.

## BAND-REJECTED CROSS SEMI-ELLIPTIC MONOPOLE ANTENNA

The configuration of the band-rejected cross semi-elliptic monopole antenna is shown in ***Figure 5***. The four narrow slits of length $H_2$ and width $W_2$ are symmetrically cut into the cross semi-elliptic monopole antenna. They strongly disturb the current distribution in the specified band-rejected frequency. It leads to the band-reject characteristics of the proposed antenna. The length of the narrow slit is approximately $0.179\lambda_c$, where $\lambda_c$ is the center frequency of the rejected band. A photograph of the band-rejected proposed antenna is shown in ***Figure 6***. ***Figure 7*** shows the measured and simulated return losses of the band-rejected proposed antenna with operating bandwidths of 1.85 to 5.24 GHz and 6.04 to 12 GHz with a return loss greater than 10 dB. The antenna dimensions were $H_1$ = 28 mm, $W_1$ = 32 mm, H = 0.5 mm, $W_2$ = 2 mm, $W_3$ = 16 mm, $H_2$ = 9.5 mm and G = 120 mm. The impedance bandwidth obtained with the present design fits the requirement of the proposed DS-UWB.[11] The lowest operating frequency with finite ground dimensions of the band-rejected proposed antenna can be determined by using the formulas of the cross semi-elliptic monopole antenna given previously. By observing the influence of various parameters on the antenna performance, it was found that the position and width of the narrow slits slightly affect the band-rejected properties. The dominant factors in the proposed antenna design are the length of the narrow slits cut into the cross semi-elliptic monopole antenna.

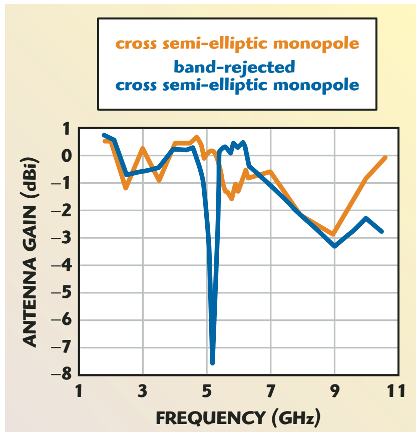
***Figure 8*** compares the real and imaginary impedances of the cross semi-elliptic monopole antenna and the band-rejected cross semi-elliptic monopole antenna. It is observed that the real impedance of the proposed band-rejected antenna is dramatically increased in the band-rejected frequency band and the imaginary impedance of the proposed band-rejected antenna is dramatically changing in the rejected frequency band, which leads to the band-rejected characteristics of the cross semi-elliptic monopole antenna with four narrow slits. The increased real part of the impedance within the rejected frequency band of the proposed antenna is contrary to that of the band-notch monopole antenna.[10]

***Figure 9*** shows the measured radiation patterns in the y-z plane at f = 2.45, 4, 5, 7, 9 and 10 GHz for the proposed band-rejected antenna. The x-y plane radiation patterns are almost omni-directional and are not shown for brevity. It is also noted that the patterns of the proposed antenna are dipole-like radiation, which makes the proposed antenna suitable in practical UWB applications. The measured x-y plane peak antenna gain for the proposed antenna and the band-rejected proposed antenna over the impedance bandwidth is shown in ***Figure 10***. It is obvious that, in the proposed antenna with four narrow slits, the x-y plane peak gain is significantly affected in the band-rejected bandwidth. The measured y-z plane peak antenna gain for

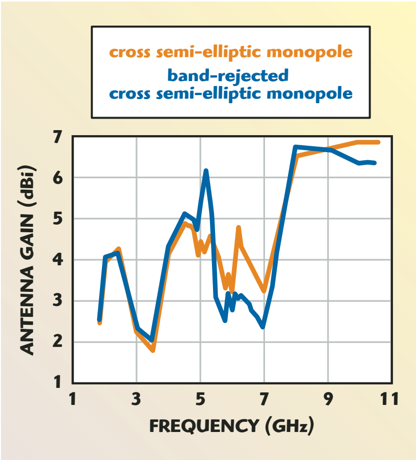



▲ *Fig. 9 Measured and simulated y-z plane radiation pattern of the proposed band-rejected antenna.*

the proposed antenna and the band-rejected proposed antenna over the impedance bandwidth is also presented in ***Figure 11***. The proposed antenna shows a peak antenna gain of about 6.88 dBi, with a gain variation less than 3.6 dB. The band-rejected proposed antenna shows a peak antenna gain of about 6.80 dBi and a gain variation less than 3.6 dB.




▲ *Fig. 10 Measured x-y plane antenna gain of the cross semi-elliptic monopole antenna (orange) and the band-rejected cross semi-elliptic monopole antenna (blue).*




▲ *Fig. 11 Measured y-z plane peak antenna gain of the cross semi-elliptic monopole antenna (orange) and the band-rejected cross semi-elliptic monopole antenna (blue).*

## CONCLUSION

A cross semi-elliptic monopole antenna and a band-rejected cross semi-elliptic monopole antenna, with finite ground plane, have been implemented and investigated. Experimental results show that the impedance bandwidths obtained from the two designs of antenna fit the requirements for UWB applications. The dipole-like radiation patterns over the operating bandwidth are also shown in this article. The proposed antennas have a compact size, compared to the corresponding elliptic monopole antenna. The proposed design of this antenna with finite ground is suitable for practical UWB applications. ■

## ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of this study by the National Science Council, Taiwan, Republic of China, under contract number NSC94-2213-E-218-006.

## References

1. FCC, First Report and Order, FCC 02-48, February 14, 2002.
2. D. Porocino, "Ultrawideband Radio Technology: Potential and Challenges Ahead," *IEEE Communications Magazine*, 2003, pp. 66–74.
3. G.R. Aiello and G.D. Rogerson, "Ultrawideband Wireless Systems," *IEEE Microwave Magazine*, June 2003, pp. 36–47.
4. H. Schantz, *The Art and Science of Ultrawideband Antenna*, Artech House, Norwood, MA, 2005.
5. M.J. Ammann, "Improve Pattern Stability for Monopole Antennas with Ultrawideband Impedance Characteristics," *2003 IEEE Antennas and Propagation International Symposium Digest*, Vol. 2, pp. 818–821.
6. Y. Rikuta and R. Kohno, "Characteristics of Planar and Orthogonal Planar Monopole Antenna with Dual Frequency for UWB System," *2004 IEEE Antennas and Propagation International Symposium Digest*, Vol. 1, pp. 171–175.
7. P.V. Anob, K.P. Ray and G. Kumar, "Wideband Orthogonal Square Monopole Antennas with Semi-circular Base," *2001 IEEE Antennas and Propagation International Symposium Digest*, Vol. 1, pp. 294–297.
8. C.A. Balanis, *Antenna Theory: Analysis and Design*, Second Edition, John Wiley & Sons Inc., Hoboken, NJ, 1997.
9. N.P. Agarwall, G. Kumar and K.P. Ray, "Wide Band Monopole Antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 46, 1998, pp. 294–295.
10. S.W. Su, K.L. Wong and C.L. Tang, "Band-notched Ultrawideband Planar-monopole Antenna," *Microwave and Optical Technology Letters*, Vol. 44, February 2005, pp. 217–219.
11. R. Fisher, R. Kohno, H. Ogawa, H. Zhang, M. McLaughlin and M. Welborn, *DS-UWB Proposal Update*, Doc.: IEEE 802.15-04/140r3, May 2004.

**Wen-Shan Chen** *received his BS degree in electronic engineering technology from the Taiwan Institute of Technology (now the National Taiwan University of Technology) and his PhD degree from Sun Yat-Sen University, Kaohsiung, Taiwan, ROC, in 2001. From 2001 to 2002, he was an assistant professor at the Chien-Kuo Institute of Technology, Changhua, Taiwan, ROC. He is currently an assistant professor of electrical engineering at the Southern Taiwan University of Technology, Tainan, Taiwan, ROC. His research interests include antenna design, RF and microwave circuits.*

**Mao-Kai Hsu** *received his BS degree from the China Institute of Technology, Taipei, Taiwan, ROC, in 2003. He is currently pursuing a master's degree in the department of electronic engineering at the Southern Taiwan University of Technology. His research interests include monopole antennas for wireless communications, especially the cross monopole antenna for UWB applications.*

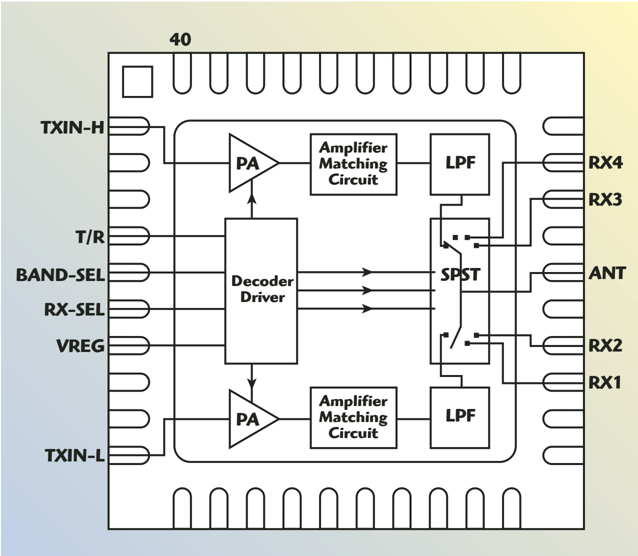
# HIGH HARMONIC-REJECTION MATCHING FILTERS FOR QUAD-BAND POWER AMPLIFIERS

*In this article, matching filters for GSM amplifiers capable of providing large harmonic rejection are demonstrated using M/A-COM's high Q GaAs MMIC technology. The matching filters are designed for the output of the quad-band (GSM 850/900/1800/1900 MHz) wireless handset amplifier module. Two sets of high harmonic-rejection matching filter circuits are designed and fabricated, one each for the GSM 850/900 MHz and GSM 1800/1900 MHz bands, respectively. For the second harmonic, the amplifier with the matching filter in the plastic-packaged module gave a rejection better than –63 dBc for the GSM 850/900 MHz band at the fundamental output power of 33 dBm and better than –63 dBc for the DCS 1800/1900 MHz band at the output power of 31 dBm. The higher harmonics had a better than –62 dBc rejection. The in-band insertion loss is measured as low as 1.2 dB in the 800/900 MHz band. To the best of the author's knowledge, this is the highest harmonic rejection achieved through a low pass matching filter for GSM handset amplifiers based on a MMIC process.*

Recent advances in mobile phone RF modules have been made for the miniaturization and integration of components in such a manner that they can address all of the global standards. The stringent specifications for the different systems have to be met using inexpensive surface-mount plastic modules, which integrate diverse functionality with just a few chips. In addition, the module needs to perform over a wide frequency band in the smallest possible layout space. In the GSM arena, the trend has been towards evolving a GSM mobile phone that supports all the four major GSM frequency bands in a single handset, making it compatible with all the major GSM networks worldwide.[1,2]

Worldwide GSM has four bands: GSM 850 MHz and GSM 1900 MHz (Personal Communication Services, PCS) bands are used in America, while GSM 900 MHz and GSM 1800 MHz (Digital Cellular Services, DCS)

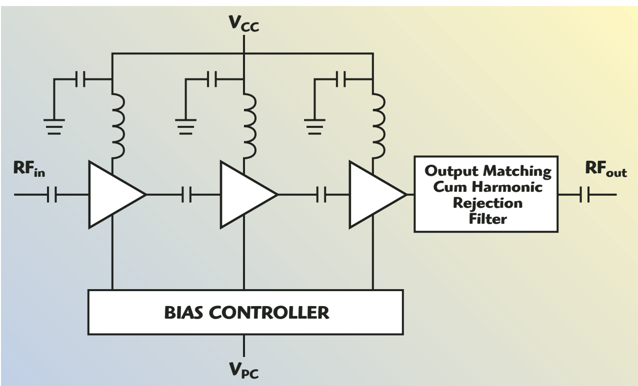
RAJANISH, P. ONNO AND N. JAIN
***Anokiwave Inc.***
***San Diego, CA***
C. WEIGAND, P. MCINTOSH AND B. RIZZI
***M/A-COM Inc.***
***Lowell, MA***
K. IZZAC
***Paratek Microwave Inc.***
***Nashua, NH***




▲ *Fig. 1 Block diagram of the quad-band transit module.*

bands are used in Europe and elsewhere in the world. The quad-band GSM mobile handset requires power amplifiers that meet stringent harmonic rejection at the specified output power with the maximum power-added efficiency (PAE) possible. The FCC's harmonic rejection specifications require that the output power level at harmonics be less than –30 dBm for all $nf_0$, where $n \geq 2$ and $f_0$ is the fundamental frequency of transmission. At the low GSM band (GSM 800/950 MHz), the specified output power is 33 dBm, thus requiring better than –63 dBc rejection, while at the high GSM band (GSM 1800/1900 MHz), the specified power is 31 dBm, requiring better than –61 dBc rejection. Traditionally, the harmonic rejection is achieved by employing an output impedance matching circuit followed by a harmonic-rejection filter. SAW filters are being used since they are small, with low insertion loss, and can provide the required rejection. However, SAW filters are expensive and not easy to incorporate in the module. Using high Q passive substrates, the best figures reported are –40 to –49 dBc for second- and third-harmonic filters.[3,4] The disadvantages of using independent circuits for matching and filtering are two-fold: greater insertion loss due to a larger number of elements and thus the requirement for larger chip area. However, to design an optimal low pass circuit with the highest possible harmonic rejection is a theoretically challenging problem.[5] It becomes more challenging if there are implementation constraints such as layout size, which is driven by today's cost requirements. The design challenges are further aggravated by the impedance matching transformation ratio (of the order of 20 to 50) required to match high power amplifiers to a 50 Ω load.

In this article, the design of a smaller footprint, single passive circuit, providing a high impedance matching transformation ratio and a very high harmonic rejection, is demonstrated. The designed impedance matching and harmonic-rejection filters (also called matching filters) are integrated in a quad-band module comprised of GSM power amplifiers (PA), an antenna-diversity switch and a digital controller. This single module provides a commercially viable method of integration at reduced cost and low form-factor in a more reproducible manner.




▲ *Fig. 2 Block diagram of the three-stage power amplifier followed by the harmonic rejection filter.*

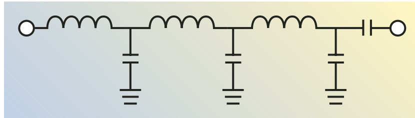
## DESIGN DETAILS

### Power Amplifier

***Figure 1*** shows the schematic representation of the blocks inside the quad-band transmit module. The quad-band transmit module consists of two sets of power amplifiers and matching filter circuits, one antenna-diversity switch and a CMOS controller in an FQFP-N plastic package. One set of power amplifiers and their matching filter circuit operates in the 824 to 915 MHz frequency band (GSM low band), while the other operates in the 1710 to 1910 MHz frequency band (GSM high band). The power amplifiers are made by a 4-mil standard iHBT GaAs process, the antenna switch by a pHEMT process and the matching filter by a high Q GaAs MMIC process. Both amplifiers have three stages, as shown in ***Figure 2***. The amplifiers provide a gain greater than 30 dB. The loss through the pHEMT switch is approximately 0.5 dB in the low band and 0.7 dB in the high band.[6] The amplifiers were measured separately on PC boards, using the traditional methods of matching for efficiency.[8] The optimum output powers of the amplifiers, at low and high GSM bands, were measured to be 35 and 33 dBm, with PAEs of 55 and 45 percent, respectively. The measured harmonics were –5 and –15 dBm, respectively. Clearly, from these measurements, including the switch loss alone, the expected composite PAE for low and high bands would be less than 49 and 38 percent, respectively. A theoretical analysis, with two transmission zeros (TRZ) at $2f_o$ with a Q of 30, predicts a composite PAE of 39 and 31 percent for the low and high band, respectively. The FQFP-N package was modeled in two parts. The lead frames were modeled using libraries in ADS, whereas the ground current paths in the paddle were accurately simulated using Sonnet's *Em*™. An isolation of approximately 50 dB was observed through the package at the low band requiring design layouts based on EM results to achieve greater than 60 dB of harmonic rejections.

### Impedance Matching Filter

For the quad-band module, a matching filter is designed for each GSM low band and GSM high band. The starting point for the design is a low pass matching filter with a three-stage L-C impedance-transforming network configuration, as shown in



▲ *Fig. 3 Basic architecture of the three-stage low pass filter.*

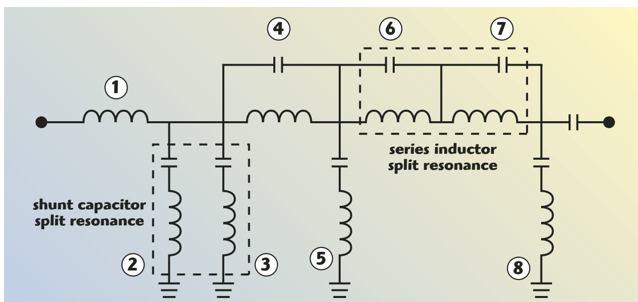
***Figure 3***. The number of stages is based on a careful trade-off between size, rejection and performance. The impedance transformation ratio is selected based on the effect of the impedance ratio on the efficiency of L-C networks.[7] Since inductors are the primary power dissipation element, the intermediate impedance ratios were selected so that the inductors were of optimum size. For a given area, there is an inductor value that provides the best Q and optimum loss.[8] The matching circuit was designed to be able to achieve optimum Q for a given area. The lumped L-C network circuit component parameters were obtained for an impedance transformation of 2 Ω (nominal) to 50 Ω for the GSM 850/900 MHz band and 2.5 Ω (nominal) to 50 Ω for the GSM 1800/1900 MHz band. Multiple transmission zeros (TRZ) were then judiciously added to provide adequate harmonic rejections. In addition, the frequency band for a quad-band module is much larger than that of a single-band module, which in turn increases the harmonic-rejection bandwidth and thus the design complexity. The most challenging part is to provide more than 65 dB rejection at the second harmonic and at the same time provide minimum loss in the fundamental band whose bandwidths are 90 MHz for the GSM low band and 200 MHz for the GSM high band. The increased rejection was achieved through a combination of shunt capacitor split resonance (patent pending) and series inductor split resonance techniques (patent pending) shown in the schematic of ***Figure 4***. Here, the shunt arm capacitor is split into two parallel arms labeled 2 and 3. The series inductor is split into two additive series arms, 6 and 7. The shunt capacitances are designed for series resonance with an inductor, whereas the series inductances are parallel resonated with capacitors. Both of these give extra transmission zeros to achieve high out-of-band rejection. The component values of series L-C resonances are determined by the following equations

$$C_{eff} = \frac{C}{1-\omega_0^2 LC} \tag{1}$$

$$\left(n\omega_0\right)^2 = \left(LC\right)^{-1} \tag{2}$$

where

$C_{eff}$ = effective capacitance at the fundamental frequency obtained through impedance transformation for maximum in-band efficiency

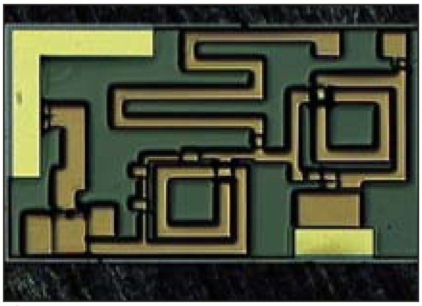



▲ *Fig. 4 Matching filter with split-shunt and split-series arms.*

n = harmonic number
$\omega_0$ = geometric mean of the lower frequency $\omega_L$ and the higher frequency $\omega_H$

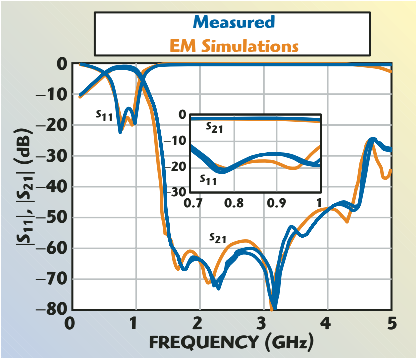
$$\omega_0 = \sqrt{\omega_L \omega_H} \qquad (3)$$

The multiple TRZs are designed at $2f_o$, $3f_o$, $4f_o$ and $5f_o$. Three transmission zeros are provided at $2f_o$ for the GSM low and high band. For the optimum band rejection at $2f_o$, one of the $2f_o$ resonances is provided with the highest possible capacitance for a small resonator physical size and a high unloaded Q. Two other $2f_o$ resonances are provided at shunt arms 5 and 8 and are detuned by small amounts from $2f_o$. This makes the net transmission null broader to suppress the second harmonics for the whole fundamental band.

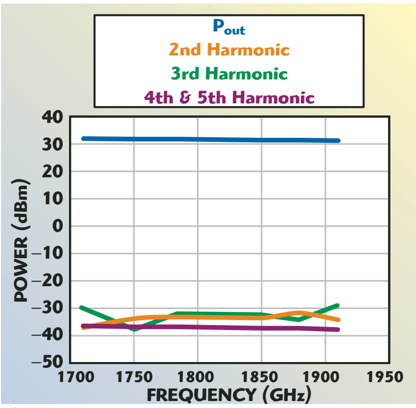


▲ *Fig. 5 The matching filter chip for the 1800/1900 MHz GSM band.*

Another consideration is the choice of TRZ at the first split shunt resonance, legs 2 and 3. Leg 2 was chosen to have a resonance at $2f_o$ and leg 3 to have a resonance at $4f_o$. Another possible choice is for leg 3 to have a resonance at $3f_o$. This would result in peaking of the harmonic level at the higher edge of $2f_o$ due to a reactance pole between $2f_o$ and $3f_o$, thus compromising the $2f_o$ rejection. By selecting $4f_o$ as the companion resonance with $2f_o$, the pole could be placed farther from $2f_o$. The effect of the pole is suppressed by another arm of the filter, arm 4. The design of the series elements would be similar. Also, for high efficiency, the inductance at arm 1 is designed so that the second and higher harmonics see a high inductive load through inductance peaking techniques.[9] The initial circuit was designed in Agilent's ADS software, using idealized elements but with realistic loss factors (Q). The circuit was then laid out in Sonnet's *Em* simulator. The space constraint of 2.2 × 1.38 mm made the modeling of coupling critical and therefore required EM-based optimization and design. The critical sections were simulated in Sonnet *Em* to accurately model the coupling between nearest neighbors. For certain other elements, scalable models using circuit parameter lookup tables were used. Equivalent-circuit models of the inductors of different dimensions and turns were extracted and libraries created to provide Q as a function of the geometry of the inductors.[8] This method of modeling and design provides a quick insight into the performance of the whole matching filter chip in the presence of nearest neighbor electromagnetic interactions. However, it did not include long distance coupling. Therefore, EM-based optimization in Sonnet *Em* was needed to achieve the best performance accounting for long distance coupling. Since a full circuit optimization requires a huge amount of computer memory and time, smaller subsets of a large circuit can be simu-




▲ *Fig. 6 Simulated and measured S-parameters of the 850/900 GSM filter with $Z_{in}$ = 2Ω and $Z_{out}$ = 50Ω.*




▲ *Fig. 7 Fundamental and harmonic output power levels for the GSM 1800/1900 MHz band.*

lated. Dividing the circuit in an EM-coupled environment is not always obvious but, by careful study of the layout and EM coupling, the circuit can be optimized. ***Figure 5*** provides a photograph of the designed GSM matching circuit for the high band.

## PERFORMANCE

To demonstrate the overview and efficacy of the concept, two sets of measured data are presented. First, the S-parameters of the matching filters were measured in a 50 Ω environment with an on-chip measurement setup for the GSM 850/900 MHz band. Second, a power measurement of the entire quad-band module with a novel matching filter was taken for the GSM 1800/1900 MHz band. The S-parameters for the GSM low band are measured in a 50 Ω environment and later renormalized to the input port impedance of 2 Ω and output port impedance of 50 Ω. This is done to estimate the harmonic-rejection level seen by the amplifier. ***Figure 6*** shows the very close agreement between simulated and measured S-parameters of the matching filter for the GSM 850/900 MHz band. A 100 MHz shift at $2f_o$ between simulated and measured data was expected due to a variety of factors including non-inclusion of metal thickness in Sonnet *Em* and process variations. The measured insertion loss is 1.2 to 1.4 dB across the 90 MHz wide GSM low band and is within 0.1 dB of the predictions. The output power and composite PAE of the amplifier, matching filter and switch were measured for the quad-band module. The data were taken at 5 dBm input power with supply voltages of 3.5 V and a control voltage of 2.7 V. An output power of 32 to 33 dBm was measured across the 90 MHz GSM low band with a composite PAE up to 38 percent. Excellent rejections of –63 to –67 dBc are obtained for the second harmonic across the band. The rejection of the higher harmonics is greater than 62 dBc. For the GSM 1800/1900 MHz band, the output power of the quad-band module chain is 31 to 32 dBm across the 200 MHz band with harmonic rejections of the order of –64 to –67 dBc. The measured results are shown in ***Figure 7***. The composite PAE for the GSM high band exceeds 30 percent.

## CONCLUSION

State-of-the-art impedance matching filters using MMIC technology with excellent harmonic rejection have been demonstrated within a small footprint for quad-band amplifiers. The FQFP-N-packaged quad-band amplifier module, based on the MMIC matching filters, shows the feasibility of further miniaturization and part count reduction, thereby allowing a higher level of chip integration and minimizing of on-board components for more efficient commercial handset manufacture. ■

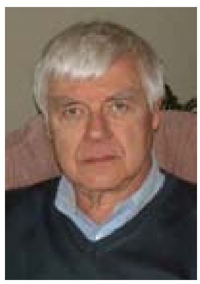
## ACKNOWLEDGMENTS

The authors wish to thank the M/A-COM team for their discussions and measurement support, specifically Phil Beucler, Kenneth R. Mcpherson, Laura A. Griskevich and Jacqueline L. Gaffney for their layout support. The authors also thank Roland Cayer and Suja Ramnath for their directions.

## References

1. S. Zhang, J. Madic, P. Bretchko, J. Mokoro, R. Shumovich and R. McMorrow, "A Novel Power Amplifier Module for Quad-band Wireless Handset Applications," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 51, No. 12, November 2003, pp. 2203–2210.
2. R. Magoon, A. Molnar, J. Zachan, G. Hatcher and W. Rhee, "A Single-chip Quad-band (850/900/1800/1900 MHz) Direct Conversion GSM/GPRS RF Transceiver with Integrated VCOs and Fractional-n Synthesizer," *IEEE Journal of Solid-State Circuits*, Vol. 3, No. 12, December 2002, pp.1710–1720.
3. A. Raghavan, D. Heo, M. Maeng, A. Sutono, K. Lim and J. Laskar, "A 2.4 GHz High Efficiency SiGe HBT Power Amplifier with High Q LTCC Harmonic Suppression Filter," *2002 IEEE International Microwave Symposium Digest*, Vol. II, pp. 1019–1022.
4. H. Kayano, S. Obayashi, T. Maeda and Y. Suzuki, "A Power Amplifier Module with Harmonics Suppression for Digital Mobile Communication," *1997 IEEE International Microwave Symposium Digest*, Vol. II, pp. 743–746.
5. N. Sokal, "Unsolved Theoretical Problem in Design of Optimal Low Pass Filter for Harmonic Suppression in Radio-transmitter Output," *IEEE Transactions on Circuits and Systems*, Vol. 27, March 1980, pp. 235–235.
6. http://www.macom.com/data/datasheet/Final%20MASWSS0091%20Rev%203.pdf.
7. F.E. Terman, *Radio Engineers' Handbook*, McGraw Hill, New York, NY, 1943.
8. Internal Memo, Anokiwave Inc., 2003.
9. F.J.O. González, J.L.J. Martin, A.A. López and G.T. Penalva, "High Efficiency Load-pull Harmonic Controlled Class E Power Amplifier," *IEEE Microwave and Guided Wave Letters*, Vol. 8, No. 10, October 1998, pp. 348–350.

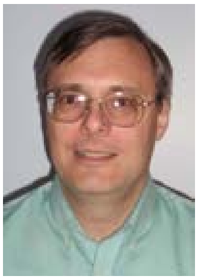
**Rajanish** *received his PhD degree in electrical communication engineering from the Indian Institute of Science, Bangalore, India, in 2001. He is currently working as a senior RF design engineer with Anokiwave Inc., San Diego, CA. His current interests include the design of power amplifiers, mixers, switches, filters, phase shifters and baluns for microwave and millimeter-wave wireless applications, electromagnetic modeling of passive components and RF systems analysis.*



**Peter Onno** *received his BE degree in engineering physics from McGill University, Montreal, Canada, in 1958, and his MS and PhD degrees in nuclear instrumentation in 1962 and 1965, respectively. From 1964 to 1970, he worked at Bell Laboratories on exploratory development for phased-array radars, planar circuit modeling, precision microwave filter design and high power phase shifters. Before joining M/A-COM in 1983, he was involved in early cellular mobile telephone system development, ranging from instrumentation and programming for field studies though cell*

*site diagnostics to cellular engineering software. More recently, he has worked on microprocessor controlled tunable filters, phase shifters and switches, microwave component models and libraries and CAD tools.*

**Nitin Jain** *received his B.Tech degree from IIT, Madras, India, in 1986, and his PhD degree from Rensselaer Polytechnic Institute (RPI), Troy, NY, in 1991. From 1991 to 1998, he worked at the corporate R&D, M/A-COM, Lowell, MA, as a senior principal engineer, followed by a faculty position at the Indian Institute of Science, Bangalore, India, where he taught microwave and RF graduate courses. Since November 2000, he has been CEO of Anokiwave Inc., San Diego, CA, which he helped start.*



**Christopher Weigand** *received his BS and MS degrees in electrical engineering from Tufts University in 1977 and 1979, respectively. He has been involved in the design, development and manufacture of RF components and sub-systems since 1979, including SCPC telephone modems, phase modulators, vector modulators, PHS base station diversity switches, control components including switches, attenuators, drivers and phase shifters. He joined M/A-COM in 1981 and is a senior principal engineer. In his current role, he is developing RFID reader RF boards and components for use in RFID readers.*

**Paul McIntosh** *received his ME and PhD degrees from the University of Leeds, UK, in 1994 and 1998, respectively. From 1998 to 2003, he was a principal design engineer at Raytheon Commercial Electronics. In 2003, he joined M/A-COM, Lowell, MA, where he is a staff principal engineer and leads the power amplifier design group, engaged in the design and development of power amplifiers for the infrastructure, handset and WLAN/WiMAX markets, using GaAs/SiGe HBT, GaAs PHEMT and GaAs MESFET technologies.*

**Brian J. Rizzi** *received his PhD degree in electrical engineering from the University of Virginia in 1994. He has held MMIC design and engineering management positions with Raytheon Co. and M/A-COM, where his MMIC design activities have included VCOs, low noise amplifiers and power amplifiers for a variety of commercial and military applications. He is currently the engineering manager for the IC products group at M/A-COM, where he leads a team of engineers designing MMIC products for cellular handset and base station, WiMAX, WLAN and point-to-point radio applications.*

**Khayo Izzac** *received his BS and MS degrees in electrical engineering from San Jose State University. He has been a practicing principal design engineer working on MMICs, PAMs and FEM designs for Celeritek, Santa Clara, CA, Skyworks Solutions Inc., Woburn, MA, and Tyco Electronics – M/A-COM, Lowell, MA. He is currently working for Paratek Microwave Inc., Nashua, NH, on tunable GSM/EDGE power amplifier and front-end modules utilizing Paratek tunable capacitors.*



# UNDERSTANDING THE OPERATION AND TEST OF A BLUETOOTH ENHANCED DATA RATE RADIO

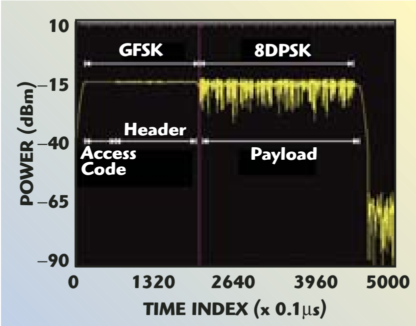
Bluetooth® wireless technology is a short-range communication system intended to provide connectivity of voice and data between information appliances. Bluetooth enables point-to-point and point-to-multipoint networking without the need for a formal wireless infrastructure. Two or more devices sharing the same wireless channel form an ad-hoc network or piconet. With one device acting as a master, up to seven other devices or slaves can be actively operating in the piconet.[1] As Bluetooth wireless technology found its way into a variety of consumer products, applications requiring higher data rates have emerged such as streaming CD-quality audio, digital image transfer and printing. In addition, consumer demand for short-range wireless connectivity is moving beyond running a single application into a desire to run multiple applications simultaneously within the same piconet.

To meet consumer demand, Bluetooth wireless technology continues to evolve with recent improvements for higher data rates and longer battery life with the introduction of the enhanced data rate (EDR) mode. The Bluetooth EDR mode is a physical layer addition to the core specification[2] that provides a two to three times increase in effective data rate over earlier versions while maintaining backwards compatibility. As a result of the higher data rates provided by EDR, the radio operates at a reduced duty cycle resulting in lower power consumption and longer battery life for the wireless appliance. The EDR mode also allows multiple applications to more effectively utilize the available bandwidth and achieve higher overall performance.

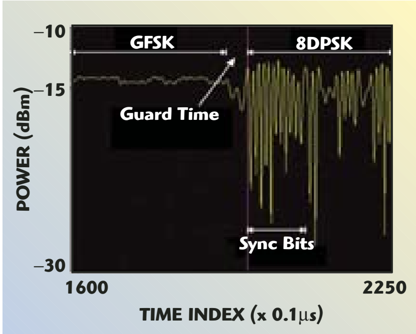
## BLUETOOTH EVOLUTION

Bluetooth systems, as originally defined in version 1.0 (v1.0) of the core specification, operate in the unlicensed industrial-scientific-medical (ISM) band at 2.4 GHz. Low power RF transmission provides communication between devices over a range of 10 to 100 m. The system uses a frequency hopped spread spectrum (FHSS) method for multiple access and interference mitigation. The hopping rate is nominally 1600 hops per second occurring over 79 channel frequencies in the ISM band.

HELEN MILLS
*Agilent Technologies Inc.*




▲ *Fig. 1 Power versus time measurement for an EDR packet.*




▲ *Fig. 2 Power versus time waveform showing the transition between GFSK and 8DPSK modulation schemes.*

The core specification was modified in version 1.2 (v1.2) with the introduction of adaptive frequency hopping (AFH). One reason for the change was the result of co-existence problems occurring between Bluetooth and 802.11b/g WLAN. Using AFH, the Bluetooth system is capable of measuring interference and avoiding those frequency channels that could result in lower system performance. The system can adjust its number of usable channels from 79 down to 20 as needed.[3] Another major improvement implemented in v1.2 resulted in faster connection times. Improvements to the inquiry and paging operations provided connection times below 0.5 seconds compared to 4 to 5 seconds in devices compliant with v1.0. Additional improvements were obtained in the quality of the link by using data retransmission when errors occur and an improved flow control, with the introduction of new packet types, enhanced the functionality of v1.2 devices while maintaining backwards compatibility with v1.0 specifications.

The core system specification was recently updated to include higher data rate modes with the introduction of EDR in version 2.0 (v2.0+EDR).[2] This latest specification has all the functional characteristics of v1.2 with the addition of two new modulation schemes implemented in the payload section of the packet. These EDR packet types provide peak data rates of 2 and 3 Mbps. The increase in the peak data rate beyond the basic rate of 1 Mbps is achieved by modulating the RF carrier using differential phase shift keying (DPSK) resulting in a two to three times increase in the number of bits per symbol transmitted. To maintain backward compatibility to v1.2 and provide simultaneous operation of v1.2 and v2.0+EDR radios in the same piconet, all devices use the same access code, header and frequency-hopping scheme.

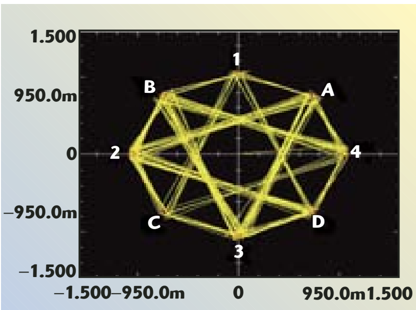
## PACKET STRUCTURE AND MODULATION FORMAT

The Bluetooth system uses a time division duplexing (TDD) scheme where the physical channel is sub-divided into time slots. The time slot length is a function of the frequency hop rate resulting in a nominal length of 625 μsec. The data is transmitted between the master and slaves in packets that are contained within the time slots. All packets contain an access code, header and payload. The access code is used for synchronization, DC-offset compensation and identification of the packets in the physical channel. Access codes are also used in paging, inquiry and park operations in a Bluetooth system. The header contains link control information that includes the packet type. The payload contains voice and data, and may also contain error correction and control information depending on the type of packet transmitted. To maintain backwards compatibility to the earlier versions of the core specification, the access code and header information is modulated onto the RF carrier using Gaussian frequency shift keying (GFSK). The GFSK modulation scheme provides a 1 Mbps peak data rate by modulating one bit per symbol resulting in a symbol rate of 1 Ms/s. The data is modulated onto the RF carrier using a shift or deviation in the carrier frequency of a minimum of 115 kHz. The binary one is represented by a positive frequency deviation and the binary zero is represented by a negative frequency deviation. The modulation format in the payload portion of the general rate packet is also GFSK. The general rate packet is now referenced as the basic rate packet in v2.0+EDR to distinguish the 1 Mbps GFSK scheme from the two higher data rate EDR packet formats. The GFSK modulated signal uses Gaussian pulse shaping to provide spectral efficiency by maintaining a –20 dB bandwidth of 1 MHz.

For the higher data rate EDR modes, as specified in v2.0+EDR, the payload data is modulated onto the RF carrier using one of two DPSK modulation schemes. The EDR packet for 2 Mbps transmission, mandatory for an EDR device, uses a payload modulated with π/4 rotated differential encoded quaternary phase shift keying (π/4-DQPSK). The optional 3 Mbps EDR packets use 8-ary differential encoded phase shift keying (8DPSK) modulation. As an example demonstrating the two different modulation formats in an EDR packet, ***Figure 1*** shows a measurement of the amplitude versus time for an EDR waveform using GFSK modulation during the access code and header and an 8DPSK modulation during the payload. For this waveform, the packet length is approximately 450 μsec, which is contained within the specified 625 μsec time slot. Spectral efficiency in an EDR packet is achieved by using a root-raised cosine pulse shaping over the DPSK modulated portion of the waveform. This pulse shaping technique results in a –20 dB bandwidth of 1.5 MHz, which is larger than the bandwidth for the GFSK modulation format. The FCC has accepted the use of Bluetooth EDR radios in the 2.4 GHz ISM band by relaxing the –20 dB occupied bandwidth requirement from 1.0 to 1.5 MHz.

As a result of the modulation change in the EDR packet, additional timing and control information is required for synchronizing to the new modulation format. Following the header in an EDR packet is a short time period that allows the Bluetooth device time to prepare for the change in modulation to DPSK. This short time or guard time is specified to be between 4.75 and 5.25 μsec. The guard time is followed by a synchronization sequence that contains one reference symbol and ten DPSK symbols. This sequence is required for synchronizing the symbol timing and phase for one of the two modulation types used in an EDR packet. ***Figure 2*** shows a measurement of amplitude versus time for an EDR packet during the time when the modulation changes from GFSK to 8DPSK. It shows the 5 µsec guard time and the eleven synchronization bits at the beginning of the EDR payload.

A differentially encoded phase modulated signal used in the EDR mode has the advantage that the signal can be demodulated without estimating the carrier phase. In this case, the received signal in any given symbol time is compared to the phase of the preceding symbol.[4] As stated, the differentially encoded modulation format defined for 2 Mbps transmission is π/4-DQPSK. The π/4-DQPSK constellation can be viewed as the superposition of two QPSK constellations offset by 45° relative to each other. Symbol phases are alternately selected from one QPSK constellation to the other for each symbol time. As a result, successive symbols have a relative phase difference that is one of four angles ±π/4 and ±3π/4. The symbol transitions from one constellation to the other always guarantees that there is a phase change between symbols, making clock recovery easier.[4] ***Figure 3*** shows the π/4-DQPSK constellation for the EDR portion of a packet. It shows a measurement over many symbols resulting in the eight desired constellation points. Note that, during any one-symbol time, only four constellation points or transitions are available resulting in the transmission of two bits per symbol. The figure shows the combination of two separate QPSK constellations separated by 45°, labeled A, B, C and D for one constellation, and 1, 2, 3 and 4 for the other.




▲ *Fig. 3 Measurement constellation of an EDR payload using a $\pi/4$-DQPSK modulation.*

The second EDR modulation format defined for 3 Mbps transmission is 8DPSK. The further increase in data rate is achieved through the addition of four more constellation points for each symbol. The total of eight constellation points allows a transmission of three bits per symbol resulting in a three times improvement in data rate over the GFSK modulation scheme. This type of modulation has many of the same benefits as π/4-DQPSK, including the use of non-coherent demodulation schemes. Demodulation of an 8DPSK occurs by examining the relative phase difference between successive symbols resulting in phase angles of 0, ±π/4, ±π/2, ± 3π/4 and π. As all eight constellation points or transitions are available between symbols, three data bits per symbol can be transmitted. The increase in data rate does not come without a penalty, as an 8DPSK modulated signal is more sensitive to noise due to smaller separation between constellation points when compared to π/4-DQPSK signals.

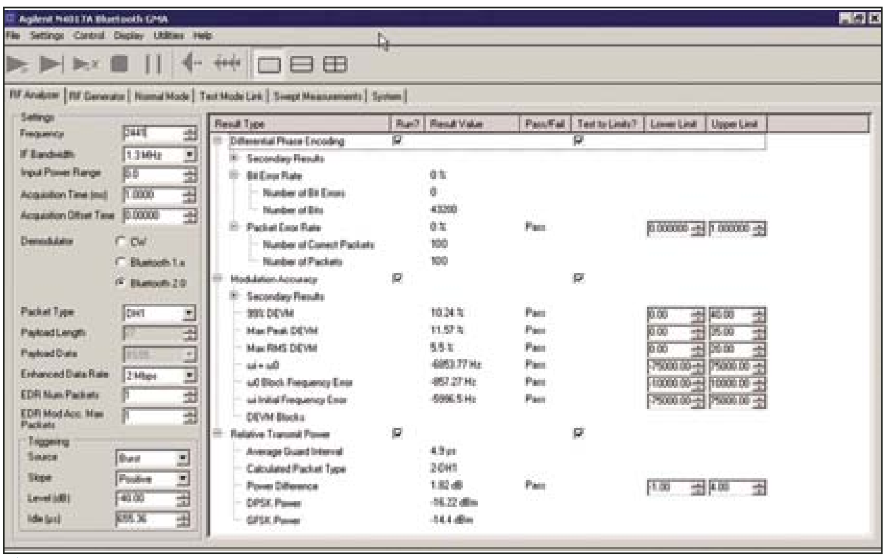
## EDR TEST PROCEDURES AND TEST CASES

With the introduction of EDR to the Bluetooth core specification, additional EDR-specific measurements have been added to the RF layer test procedure and specification (TSS/TP).[5] The new measurements allow provisional testing of Bluetooth devices under non-loop back operation, which may be very useful during the early stages of radio development. The EDR tests specific to transmitters include relative transmit power, carrier frequency stability, modulation accuracy and differential phase encoding. The EDR tests specific to the Bluetooth receiver include sensitivity, bit error rate (BER) floor performance and maximum input level.

### EDR Transmitter Test Cases

The EDR relative transmit power test verifies that the difference between the average transmit power during the GFSK modulation and the average transmit power during the DPSK modulation is within the specified range of +4 to –1 dB. The relative power is calculated from the difference of the average power measurement taken over at least 80 percent of the GFSK portion of the packet to the average power measurement taken over at least 80 percent of the DPSK portion. ***Figure 4*** shows the relative transmit power measurement of an EDR signal using π/4-DQPSK modulation with the RF carrier at the mid-band frequency of 2441 MHz. As shown, the average power measurements for the GFSK and π/4-DQPSK waveforms are –14.4 and –16.22 dBm, respectively. The relative transmit power is calculated as +1.82 dB and is within the specified difference of –1 and +4 dB.

The EDR carrier frequency stability test begins with a determination of the initial center frequency error in the GFSK header. The frequency deviations in logic 1 bits and logic 0 bits are



▲ *Fig. 4 Measurement of an EDR packet using $\pi/4$-DQPSK modulation.*

measured and reported as $\Delta\omega_1$ and $\Delta\omega_2$, respectively. The initial frequency error is calculated as the average frequency error between logic 1 and logic 0 bits and reported as the initial frequency error, $\omega_I$ ($\omega_I = [\Delta\omega_1+\Delta\omega_2]/2$). The initial frequency error is specified between ± 75 kHz. The frequency error in the EDR portion of the packet is corrected using this initial frequency error, $\omega_I$. The corrected waveform is then partitioned into 200 blocks of 50 symbols in length. The remaining frequency error in each block is reported as $\omega_0$. The worst-case block frequency error, $\omega_0$, is specified to be within ±10 kHz. Lastly, the Bluetooth specification limits the maximum value of the combined frequency errors, $\pi_I + \omega_0$, to ±75 kHz. This value represents the maximum excursion of the frequency error, which includes the initial error in the access code and the frequency drift that may occur over the measured blocks. The given measurement example shows the frequency stability of an EDR waveform. In this case, the initial frequency stability is measured as –5.997 kHz, the block frequency error as –0.857 kHz and the combined frequency error as –6.854 kHz. All these measured values are shown to be within the required specifications.

The EDR modulation accuracy test verifies the quality of the differential modulation and is intended to highlight errors that would cause problems to a real differential receiver. The modulation accuracy is tested using a differential error vector magnitude (DEVM) measurement that is similar to the traditional error vector magnitude (EVM) measurement specified in other digital communication systems.[6] The DEVM is defined as the magnitude of the error between two received signals spaced one symbol apart in time. The DEVM measurement is made over the synchronization sequence and payload of 200 blocks of 50 symbols in each block. The modulation accuracy is reported as three separate values, the 99 percent DEVM, RMS DEVM and Peak DEVM.[1] The modulation accuracies, measured and reported in percentages for the measured EDR waveform using π/4-DQPSK modulation, are 10.24, 11.57 and 5.5 percent, respectively. As shown, all measured DEVM values for this waveform are within the required specifications.

The differential phase encoding test verifies the operation of the differential PSK modulator used in the transmitter. For the EDR payload, the modulator is required to map correctly the binary data stream into a set of specified phase angles in the complex plane. The EDR payload is modulated with a PRBS9 sequence and a packet error rate measurement is performed over 100 packets. It is specified that 99 percent of the packets be received with no bit errors or, in other words, that the packet error rate is less than one percent. The packet error rate for the EDR waveform measured is zero percent or, in other words, no errors found.

### EDR Receiver Test Cases

Bluetooth EDR receiver testing requires measuring the BER performance using test signals containing a variety of frequency and timing impairments. The BER performance measurements of all receivers are calculated over 16,000,000 bits by comparing the received data to the original PRBS9 sequence transmitted by the test source or test equipment.

The EDR sensitivity is measured using three groups of 20 packets corrupted with different timing errors and frequency offsets.[5] The first group of packets contains no impairments. The second group of packets contains a carrier frequency offset of +65 kHz and a symbol timing error of +20 ppm. The third group of packets contains a carrier frequency offset of –65 kHz and a symbol timing error of –20 ppm. The receiver BER performance is required to be $10^{-4}$ under these conditions.

The EDR BER floor performance is a BER measurement at a received power level of –60 dBm. The BER is calculated by comparing the received data to a transmitted PRBS9 sequence. Under these conditions the BER performance is specified as $10^{-5}$.

The EDR maximum input level test shows the receiver BER performance when the input signal level is –20 dBm. This test shows the receiver performance under possible front-end compression when driven with a high input power level. The BER performance is specified as $10^{-3}$ using this input power level.

## CONCLUSION

The need for higher data rates and improved power consumption required in portable, multi-media consumer appliances is expected to drive the transition to Bluetooth EDR technology. The EDR evolution will provide multi-use scenarios where numerous devices operate concurrently in the same piconet. In addition, new portable devices are anticipated which combine several wireless interfaces, such as GPRS and WiFi with Bluetooth EDR, in order to provide simultaneous and seamless connectivity across multiple network types.

Bluetooth and the Bluetooth logos are registered trademarks owned by Bluetooth SIG Inc., US, and licensed to Agilent Technologies Inc. ■

## References


1. *Bluetooth Enhanced Data Rate (EDR): The Wireless Evolution*, Agilent Technologies Application Note 5989-4204EN, November 2005.
2. Specification of the Bluetooth System, Version 2.0+EDR, Specification Volume 1: Architecture & Terminology Overview and Volume 2: Core System Package, November 4, 2004.
3. "How 802.11b/g WLAN and Bluetooth Can Play Together," *Philips Semiconductors White Paper*, Document 9397-750-13426, June 2004.
4. J.G. Proakis, *Digital Communications*, 3rd Edition, McGraw-Hill, New York, NY, 1995.
5. "Radio Frequency Test Suite Structure (TSS) and Test Purposes (TP) System Specification 1.2/2.0/2.0+EDR, Rev. 2.0.E.3, Document Number RFTS/2.0.E.3," March 21, 2005.
6. *Digital Modulation in Communications Systems — An Introduction*, Agilent Technologies Application Note 1298, 5965-7160E, March 14, 2001.


**Helen Mills** *received her MS degree in electronic and electrical engineering from the University of Glasgow, Scotland. She joined Hewlett Packard/Agilent Technologies Inc. in 1996. During her nine years at HP and Agilent, she has worked in a variety of product marketing and planning roles for signal generators, signal analyzers, power meters and wireless connectivity test equipment. She is currently a product manager with Agilent Technologies, Wireless Division for the N4010A wireless connectivity test set.*

# DESIGN OF A DUAL-BAND RING PRINTED ANTENNA ARRAY

*In this article, a novel design is proposed for a linear printed antenna array with ring radiating elements, able to operate over a wide operating band at X- and Ku-band. The simulation was conducted using Agilent ADS and Momentum software. The printed array has been fabricated and tested. A good agreement between the simulated and experimental results has been obtained.*

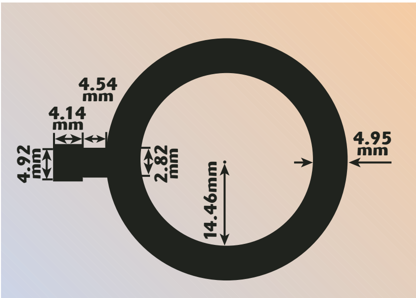
With recent advances in telecommunications, the use of microstrip antennas is increasing for a wide range of modern microwave systems. This is mainly due to the features of microstrip antennas: low profile, lightweight, conformable to nonplanar surfaces, and easy and inexpensive mass production. They are well suited for integration with their feeding networks and microwave devices, using modern microwave integrated circuit technology. Microstrip antenna arrays have a wide range of applications in civil, military or scientific domains. Today, an increasing number of radio services, such as communications, navigation and broadcasting, must be available and a single antenna must be operating for several applications. Therefore, much research has been conducted both on antenna miniaturization and multi-band operation.

The ring printed antennas are well known for their multi-band abilities and advantageous characteristics. They are used in communication systems, and several structures have been recently proposed in the literature.[1–4] Usually, the designer needs to alternate between circuit and electromagnetic simulation tools to design the feed circuit and the radiating elements. The design and development of a linear array in microstrip technology may be made easier by combining commercially available CAD software tools, such as the Agilent ADS and Agilent Momentum planar electromagnetic solver.[5] They are suitable for modeling microstrip patch antenna elements, feeding transmission lines in radiating layers, optimization and layout production. The proposed design is described in detail in this article and experimental results for the prototype built are presented and discussed.

M. ABRI, N. BOUKLI-HACENE AND F.T. BENDIMERAD
***Université Abou Bekr Belkaïd Tlemcen, Algeria***
E. CAMBIAGGIO
***Université de Nice – Sophia Antipolis Valbonne, France***

## ANTENNA DESIGN

Two procedures are used to design the compact dual-band antenna. The first step is the design of the radiating element and the second concerns the power divider.



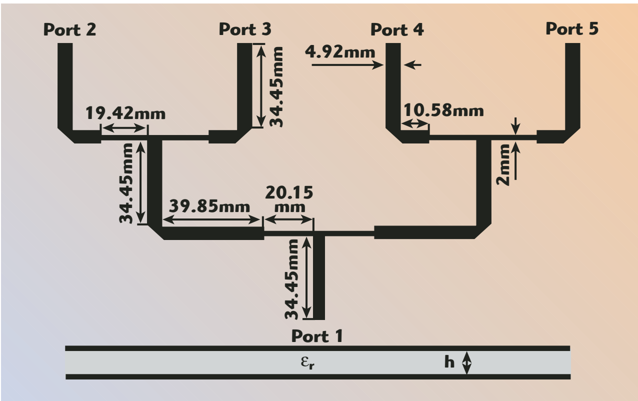

▲ *Fig. 1 The ring antenna with its quarter-wave transformer.*

### Radiating Element

The radiating element is a ring patch fed by a power divider and is printed on the same substrate. The dimensions of the antenna have been simulated to operate at the desired frequencies. Quarter-wave transformers have been used in order to match the antenna input ports to the power divider output ports. The antenna mask layout with its quarter-wave transformer is shown in ***Figure 1***.

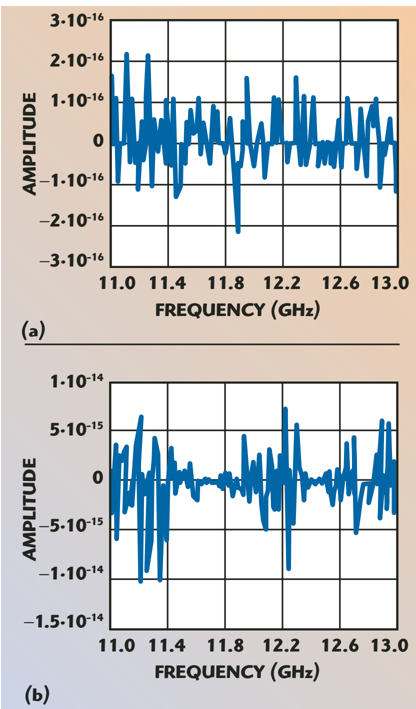
### Power Divider

A corporate power divider with four output ports, able to operate from 10 to 14 GHz, has been designed for equal phase and power level at all outputs with a high isolation between ports. In order to reduce the mutual coupling effects between adjacent patches, the inter-element distance was chosen to be approximately $2\lambda_1$, where $\lambda_1$ is the wavelength corresponding to the lowest frequency. A symmetrical structure, well suited to obtain equal phase outputs, has been chosen. The power divider and antennas have been designed for the same epoxy substrate with a relative permittivity $\varepsilon_\rho = 4.55$, loss tangent tan $\delta = 0.01$ and thickness h = 1.55 mm. A 50 Ω coaxial connector is used to feed the network. ***Figure 2*** shows the proposed layout of the power divider.




▲ *Fig. 2 Corporate feed network layout.*

The simulated results, for frequencies between 11 to 13 GHz, are presented in ***Figure 3*** for amplitude difference and ***Figure 4*** for phase difference between output ports. Notice that both power and phase at the outputs are equal since the difference in amplitudes and phases are very close to zero.

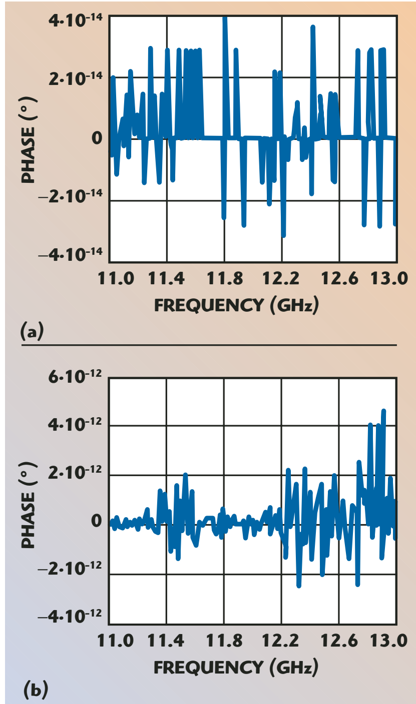



▲ *Fig. 3 Amplitude difference between $S_{21}$ and $S_{31}$ (a) and between $S_{41}$ and $S_{51}$ (b).*

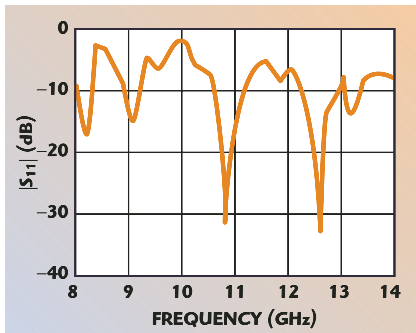
## SIMULATION RESULTS

### Return Losses and Input Impedance

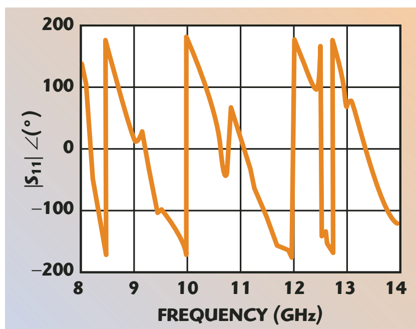
The simulated input reflection coefficient of the corporate fed antenna array is displayed in ***Figure 5***. The dual-band operation is emphasized by the two minimum return loss frequencies (10.8 and 12.6 GHz) with –32.7 and –34.5 dB, respectively. The bandwidth is 8.3 percent for the first frequency and 11.1 percent for the second one. ***Figure 6*** shows that the input phase at the two operating frequencies are equal. The impedance locus at the input of the antenna array from 8 to 14 GHz is illustrated on the Smith chart in




▲ *Fig. 4 Phase difference between $S_{21}$ and $S_{31}$ (a) and between $S_{41}$ and $S_{51}$ (b).*




▲ *Fig. 5 Simulated return loss of the corporate feed input.*

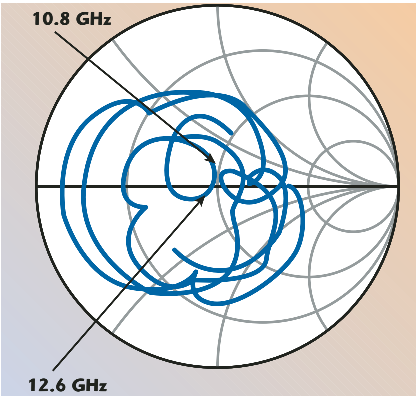



▲ *Fig. 6 Simulated phase of the return loss of the corporate feed input.*

*Figure 7*. A very good match is obtained at the frequencies for which the impedance points are close to the Smith chart center, which corresponds to an ideal match.

### Radiation Patterns

*Figure 8* shows the radiation patterns at 10.8 GHz for $E_\theta$ (cross-polarization) and $E_\phi$ (co-polarization). Notice that the $E_\phi$ amplitude is higher than the $E_\theta$ amplitude, the first side lobes are less than –10 dB and the pattern exhibits an excellent symmetry. The $E_\theta$ amplitude does not show a main lobe and the side lobes are less than –7 dB. *Figure 9* shows the antenna array gain, exhibiting a high directivity. The maximum gain of the antenna array is 9.5 for the first working frequency.




▲ *Fig. 7 Input return loss ($S_{11}$) of the antenna array.*

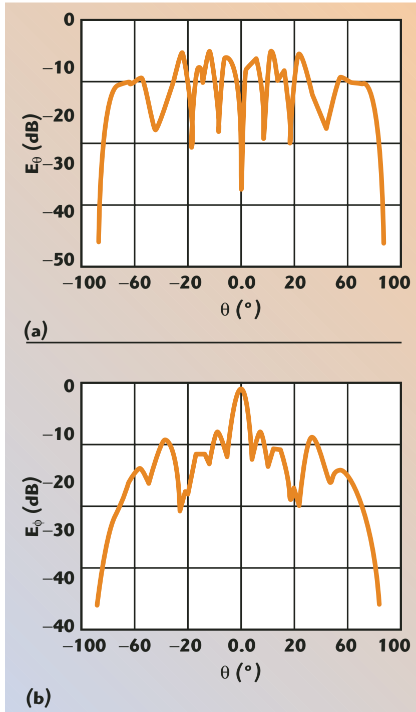
## EXPERIMENTAL RESULTS AND DISCUSSION

*Figure 10* shows a photograph of the array, with its feeding network, which has been built and tested. The input reflection coefficient $S_{11}$ has been measured using a HP5510 network analyzer and is shown in *Figure 11*. This experimental antenna array can operate at three distinct frequencies: 10.9, 13.0 and 15.1 GHz. The simulated and experimental results of the input return loss at the two resonant frequencies are shown in *Table 1*.

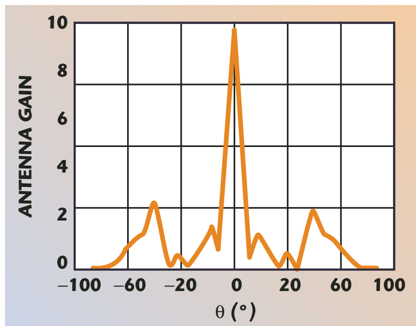
The bandwidths ($\Delta f/f_0$ at –6 dB), corresponding to the first and second frequency, are 7.3 and 8.4 percent, respectively. The simulated frequencies, $f_1$ = 10.8 GHz and $f_2$ = 12.6 GHz, are close to those measured. The shift observed for the second frequency can be due to various reasons, such as tolerances in the electrical and mechanical parameters of the dielectric material, and/or manufacturing problems.

## CONCLUSION

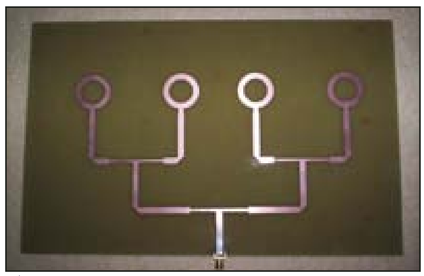
A four-element linear array of ring patches, with a planar microstrip feed



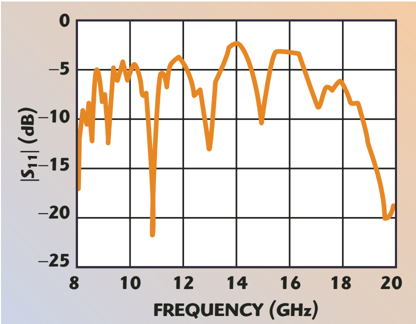

▲ *Fig. 8 Radiation patterns at f=10.8 GHz; (a) $E_\theta$ and (b) $E_\phi$.*




▲ *Fig. 9 Antenna array directivity at 10.8 GHz.*



▲ *Fig. 10 Photograph of the antenna array prototype.*




▲ *Fig. 11 Measured input return loss of the antenna array.*

**TABLE I**
**SIMULATED AND MEASURED RESULTS**

| | Simulation | Measured |
|---|---|---|
| $f_1$ (GHz) | 10.8 | 10.9 |
| $S_{11}$ (dB) | –32.7 | –34.5 |
| $f_2$ (GHz) | 12.6 | 13.0 |
| $S_{11}$ (dB) | –24.0 | –14.5 |

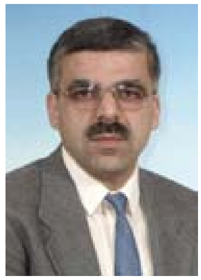
network operating in the X- and Ku-bands for satellite communications with a linear polarization, was successfully simulated and designed. The dual-band is obtained by using a ring antenna as a radiating element. The simulation was conducted using Agilent ADS and Momentum software. A prototype was built and tested, which satisfies in general the requirements for the application. ■

## References


1. B.L. Ooi, S. Qin and M.S. Leong, "Novel Design of Broadband Stacked Patch Antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 50, No. 10, October 2002.
2. E. Gschwendtner and W. Wiesbeck, "Ultra-broad Car Antennas for Communications and Navigation Application," *IEEE Transactions on Antennas and Propagation*, Vol. 51, No. 8, August 2003.
3. K.L. Wong, G.Y. Lee and T.W. Chiou, "A Low Profile Planar Antenna for Multiband Operation of Mobile Handsets," *IEEE Transactions on Antennas and Propagation*, Vol. 51, No. 1, January 2003.
4. J.M. Laheurte, "Dual-frequency Polarized Antennas Based on Stacked Monofilar Square Spirals," *IEEE Transactions on Antennas and Propagation*, Vol. 51, No. 3, March 2003.
5. Momentum, Agilent Technologies Inc., Santa Rosa, CA, 2000.
6. J.M. Ribero, R. Staraj and J.P. Damiano, *Antennas and Associated Systems for Mobile Satellite Communications*, M.E. Bialkowsky, Ed., "Analytical Models for Fast Analysis and Synthesis of Various Printed Antennas," University of Queensland, Australia, pp. 23–39.



**Mehadji Abri** *received his state engineer and master diplomas from Abou Bekr Belkaïd University in 2001 and 2004, respectively. He is currently a junior researcher within the telecommunications laboratory. His main research interests include the analysis and synthesis of multi-band antennas and arrays.*



**Noureddine Boukli-Hacene** *received his diplome d'etudes approfondies in microwave engineering (DEA communications optiques et microondes) and his doctorate degree (prepared at the Centre National d'Etudes Spatiales, Toulouse, France) in electrical engineering from Limoges University, France, in 1982 and 1985, respectively. He is now a lecturer at the University Abou Bekr Belkaïd, Tlemcen, Algeria. His research interests include microstrip antennas and microwave circuits.*

**Fethi Tarik Bendimerad** *received his state engineer diploma in 1983 from Oran Sciences and Technologies University, Algeria, and his doctorate degree from Nice Sophia Antipolis University, France, in 1989. He is currently a professor and director of the Telecommunications Laboratory at the University Abou Bekr Belkaïd, Tlemcen, Algeria, where he is responsible for the antenna section. His main research interest is microwave techniques and radiation.*

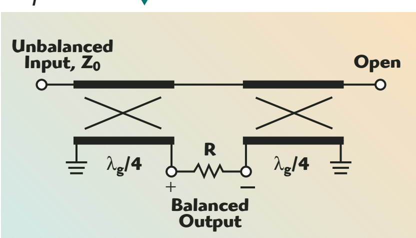
**Edmond Cambiaggio** *received his PhD degree in physics from the University of Marseille, France, and his French 'doctorat d' etat' degree in physics from the University of Nice, France, in 1970 and 1978, respectively. He is currently the head of the department of electronics at the University of Nice – Sophia Antipolis. His research interests include microstrip antennas, microstrip antenna arrays, conformal antennas, conformal arrays, and the simulation and modeling of antennas.*

# SYNTHESIS OF A PLANAR, COUPLED-LINE MARCHAND BALUN WITH EMPHASIS ON BALANCE

The Marchand balun may be one of the most popular forms of microwave balun used to generate a balanced signal. In particular, the planar coupled-line Marchand balun shows good compatibility with microwave integrated circuits (MIC) and monolithic MICs (MMIC).[1] Numerous studies about its design and analysis have been done since it was first introduced in 1944.[2] Most designs, however, emphasize maximum power transfer to the balanced load within a specified passband using a quarter-wave transmission line equivalent circuit.

In this article, it will be shown that maximum power transfer does not preserve the balance property of the two balanced outputs. The balance property of the Marchand balun may be more crucial in some applications such as for a mixer. The conditions for preserving the balance property will be explained. Under this limitation, the systematic synthesizing procedure for a coupled-line Marchand balun is then presented to yield the desired passband characteristics.

*Fig. 1 The Marchand balun using quarter-wave length coupled lines.*

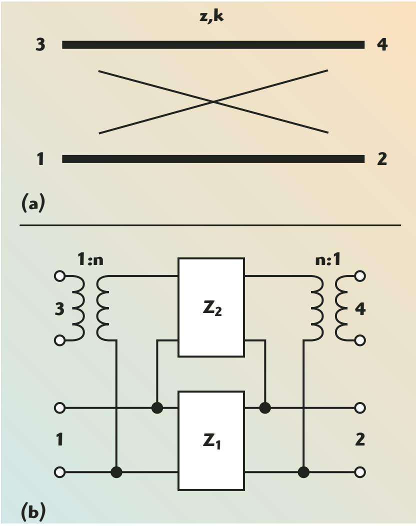



## DESIGN CONSIDERATION

The planar coupled-line Marchand balun is shown in ***Figure 1***. Two quarter-wave length coupled lines transform the unbalanced input signal into the balanced output signal across the load.

The coupled line, shown in ***Figure 2***, can be represented by a four-port equivalent circuit through a capacitance matrix transformation.[3] $Z_1$ and $Z_2$ are the characteristic impedances of quarter-wave transmission lines, and n is the turn ratio for the transformers. The relations of $Z_1$, $Z_2$ and n to the coupled line with the characteristic impedance, Z, and the coupling constant, k, can be written as[4]

JONG-HWAN LEE
AND KYUNG-WHAN YEOM
*Chungnam National University*
*Daejeon, Korea*




▲ *Fig. 2 The four-port circuit for the coupled line; (a) coupled line and (b) its equivalent circuit.*

$$z = \sqrt{Z_{oe} Z_{oo}} \quad (1)$$

$$k = \frac{Z_{oe} - Z_{oo}}{Z_{oe} + Z_{oo}} = \frac{1}{n} \quad (2)$$

$$Z_1 = \frac{z}{\sqrt{1-k^2}} \quad (3)$$

$$Z_2 = z\frac{\sqrt{1-k^2}}{k^2} \quad (4)$$

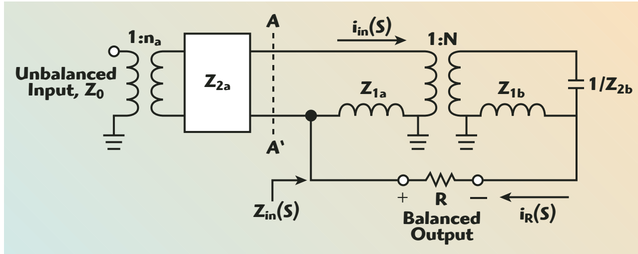
In the above equations, $Z_{oe}$ and $Z_{oo}$ are the even- and odd-mode impedances of the coupled line. The overall equivalent circuit for the Marchand balun can be readily obtained by replacing the coupled line with the four-port equivalent circuit. Some simplifications and the Richard's transform for the open- and short-ended quarter-wave transmission lines result in the circuit shown in ***Figure 3***. Here, the subscripts a and b are added to denote the left and right sides of the coupled lines, and N is $n_b/n_a$. Let the node voltages on each side of the load R be $v^+(S)$ and $v^-(S)$. Their ratio is

$$\frac{v^+(S)}{v^-(S)} = \frac{SZ_{1a}\{i_R(S) - i_{in}(S)\}}{-SZ_{1b}\left\{i_R(S) - \frac{i_{in}(S)}{N}\right\}} = \frac{Z_{1a}\{(1-N)SZ_{1b} - NR\}}{Z_{1b}\{(1-N)SZ_{1a} + R\}} \quad (5)$$

where

$$S = j\tan\left(\frac{\pi}{2}\frac{\omega}{\omega_o}\right)$$

According to Equation 5, only when $Z_{1a} = Z_{1b}$ and $N = 1 (n_a = n_b = n)$ does the magnitude and the phase of the ratio become 1 and 180°, respectively, regardless of frequency. This means that the Marchand balun should have a symmetrical structure to provide a frequency independent balanced signal.




▲ *Fig. 3 Simplified equivalent circuit for the coupled-line Marchand balun.*

As an example of this limitation, a theoretical result is shown in ***Figure 4*** for a coupled-line Marchand balun with a balanced load of 100 Ω and a 50 Ω source impedance for a bandwidth ratio of 1.7:1. The element values in this case are $Z_{1a} = 139.74$ Ω, $Z_{1b} = 91.01$ Ω and $n_a = n_b = 1.285$. Although the in-band return loss shows a good performance (which means a maximum power transfer to the load without loss), there is a substantial amount of inherent phase error (±5°) within the band of interest, which is crucial in many applications.

## BALUN SYNTHESIS

Under the previous design limitation, the circuit can be redrawn with the quarter-wave transmission line equivalent circuit shown in ***Figure 5***.

In this circuit, the impedances looking into the source, $z_{i1}$ and the load, $z_{in}$ are to be calculated as[5]

$$z_{i1} = \frac{z_2^2\left(1+\tan^2\theta\right) + jz_2\tan\theta\left(z_2^2 - 1\right)}{z_2^2 + \tan^2\theta} \quad (6)$$

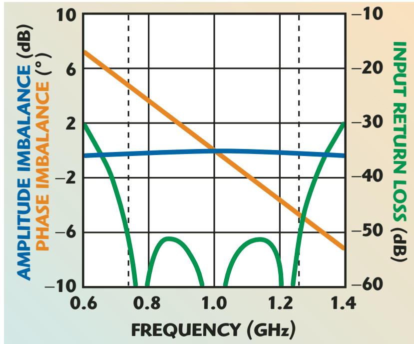
$$z_{in} = \frac{r(2z_1)^2\tan^2\theta + jr^2 2z_1\tan\theta}{r^2 + (2z_1)^2\tan^2\theta} - jz_2\cot\theta \quad (7)$$

The normalized load resistance r can be expressed as a function of $z_1$ and $z_2$ by

$$r = \frac{z_1}{z_2 + z_1}\frac{R}{Z_0} \quad (8)$$

The reflection coefficient of the circuit is then

$$\rho = \left|\frac{z_{in} - z_{i1}^{*}}{z_{in} + z_{i1}}\right| \quad (9)$$




▲ *Fig. 4 Simulated performance of an asymmetrical Marchand balun.*

Thus, the synthesis of the Marchand balun is now reduced to the problem of finding the characteristic impedances $z_1$ and $z_2$ to yield the specified passband characteristics, as shown in ***Figure 6***. At θ = π/2, the reflection coefficient is obtained from Equations 6, 7 and 9.

$$\rho\Big|_{\theta=\frac{\pi}{2}} = \left|\frac{r - z_2^2}{r + z_2^2}\right| = \rho_0 \quad (10)$$

Substituting r from Equation 8 into Equation 10 yields

$$z_1 = \frac{-(1+\rho_0)z_2^3}{-\frac{R}{Z_0}(1-\rho_0) + (1+\rho_0)z_2^2} \quad (11)$$

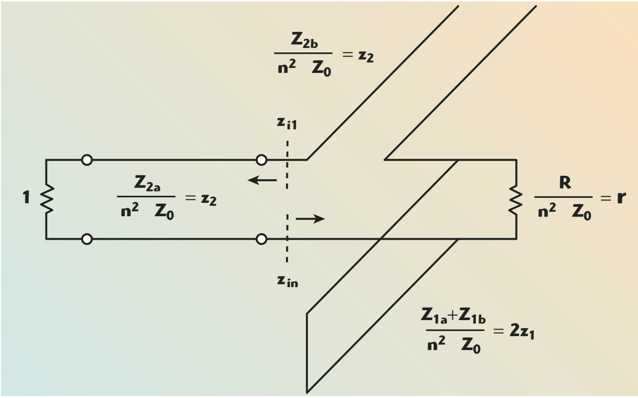
Substituting Equation 11 again into Equations 6 and 7, the reflection coefficient in Equation 9 is then dependent only on $z_2$. The reflection coefficient at $\theta = \theta_c$ given by

$$\theta_c = \frac{\pi}{\frac{f_U}{f_L} + 1} \quad (12)$$

should satisfy

$$\rho\Big|_{\theta=\theta_c} = \rho_0 \quad (13)$$

to yield the desired passband characteristics.




▲ *Fig. 5 Transmission line equivalent circuit of the coupled-line Marchand balun.*

Using the determined $z_1$ and $z_2$, these values can be translated into the even- and odd-mode impedances using the relations of Equations 1 to 4 as

$$Z_{oe} = \frac{z_2}{1-k} Z_0 \quad (14)$$

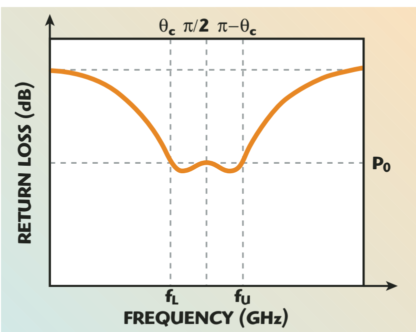
$$Z_{oo} = \frac{z_2}{1+k} Z_0 \quad (15)$$

## SYNTHESIS EXAMPLE

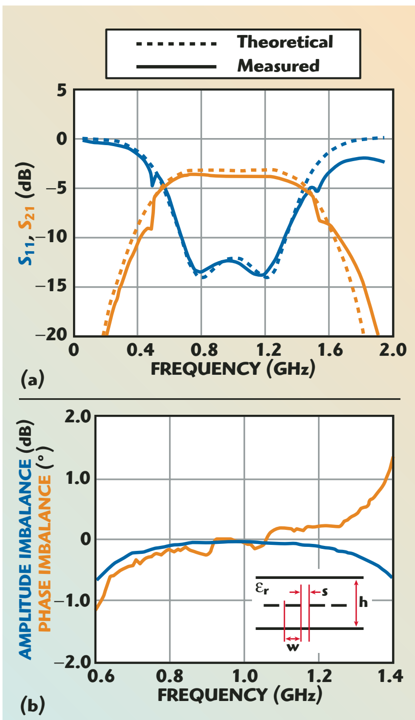
As an example, a coupled-line Marchand balun is synthesized to meet the design requirements for a bandwidth ratio 1.7 ($=f_U/f_L$), an in-band return loss of 13 dB for a 100 Ω balanced load and a source impedance $Z_0 = 50$ Ω. From the given specifications, $\theta_c$ is calculated to be 66.7° from Equation 12, and $\rho_0$ is 0.224. Using Mathsoft's MathCAD,™ $z_2$ in Equation 13 is determined as 0.59, $z_1$, given by Equation 11, is 0.223. These $z_1$ and $z_2$ impedances correspond to $Z_{oe}$ = 62 Ω and $Z_{oo}$ = 19 Ω as calculated from Equations 14 and 15, respectively.

A four-coupled stripline is employed to implement $Z_{oe}$ = 62 Ω and $Z_{oo}$ = 19 Ω on an FR4 ($\varepsilon_r$ = 4.5~4.8) substrate. The cross section geometry is determined using Agilent's ADS™ and the results are w = 0.35 mm, s = 0.1 mm and h = 1.6 mm.

The frequency responses of the fabricated balun are measured between the unbalanced input and one of the balanced outputs with the other output terminated by 50 Ω, with a full two-port calibrated vector network analyzer. The amplitude and phase imbalances are then calculated from the measured data. The results are shown in ***Figure 7***. The measured insertion and return losses show a good agreement with the presented synthesis method and the in-band insertion loss is approximately 3.7 dB. The magnitude ratio between the two balanced outputs is almost 1 and the phase difference from 180° is ±0.5° over the passband, which is due to the imperfections in the fabrication of the two identical coupled-lines. Theoretically, the proposed design has no phase error, as opposed to the conventional design shown previously.




▲ *Fig. 6 The passband characteristics of the Marchand balun.*




▲ *Fig. 7 Measured characteristics of the Marchand balun; (a) insertion and return losses, and (b) amplitude and phase imbalance.*

## CONCLUSION

The conventional design based on the maximum power transfer does not provide a good phase balance between the two balanced outputs. The synthesis of a coupled-line Marchand balun preserving the balance is presented to yield the desired passband. The presented synthesis may be useful in applications where the balance between the two outputs is more crucial. ■

## ACKNOWLEDGMENT

This research was supported by the Agency for Defense Development, Korea, through the Radiowave Detection Research Center at the Korea Advanced Institute of Science & Technology.

## References

1. S.A. Maas and K.W. Chang, "A Broadband, Planar, Doubly Balanced Monolithic Ka-band Diode Mixer," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 41, No. 12, December 1993, pp. 2330–2335.
2. N. Marchand, "Transmission Line Conversion Transformers," *Electronics*, Vol. 17, December 1944, pp. 142–145.
3. J.A.G. Malherbe, *Microwave Transmission Line Filters*, Artech House Inc., Norwood, MA, 1979.
4. C.L. Goldsmith, A. Kikel and H.L. Wilkens, "Synthesis of Marchand Baluns Using Multilayer Microstrip Structure," *International Journal of Microwave and Millimeter-Wave Computer-Aided Engineering*, Vol. 2, No. 3, 1992, pp. 179–188.
5. V. Trifunovic and B. Jakanovic, "Review of Printed Marchand and Double-Y Baluns: Characteristics and Applications," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 42, No. 8, August 1994, pp. 1454–1462.

**Jong-Hwan Lee** *received his BS and MS degrees in radio science and engineering from Chungnam National University, Daejeon, Korea, in 1998 and 2000, respectively. He is currently working toward his PhD degree. His research interests include RF/microwave circuit and system designs.*

**Kyung-Whan Yeom** *received his BS degree in electronics from Seoul National University, Seoul, Korea, in 1980, and his MS and PhD degrees in electrical engineering from the Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Korea, in 1982 and 1988, respectively. From 1985 to 1991, he was with LG Precision, as a principal engineer. From 1991 to 1995, he was with LTI, where he was involved with power amplifier modules for analog cellular phones. He is currently a professor in the department of radio science and engineering at Chungnam National University, Daejeon, Korea. His research interests include the design of hybrid and monolithic microwave circuits and microwave systems.*

# RADIO FREQUENCY IDENTIFICATION: EVOLUTION OF READER AND ANTENNA CIRCUIT DESIGN

*Radio Frequency Identification (RFID) has become and will continue to be very important in the area of automatic identification. The purpose of this article is to discuss the various circuit designs of two RFID components — the antenna and the reader — performed by various individuals and organizations. The reader circuit design is more complex than for the antenna. It is found that limited information, for both antenna and reader circuit designs, has been published since most of it is proprietary. Therefore, this article provides various crucial design concepts of antenna and reader.*

Radio Frequency Identification (RFID) has become and will continue to be very important in the area of automatic identification. Regarded as a potential successor to the bar-coding technologies and other automatic identification methods that are used today, RFID's significant advantage is the contact-less, non-line-of-sight nature of the technology. RFID has the ability to allow energy to penetrate goods and read a tag that is not visible. Tags can withstand harsh, rugged environments and can be read through a variety of visually challenging substances at remarkable speeds. The ability to receive, modify and pass on information, as well as being able to store data in large memories regarding any object embedded with a tag, brings a whole new dimension to its various applications.

A basic RFID system consists of three components: antennas, a reader and a tag. The antennas are attached to the reader and the tag and are the liaison between the two, which control the system's data acquisition and communication. A reader typically contains a radio frequency module (transmitter and receiver), a control unit and an additional interface (RS232, RS485, etc.) to enable it to forward the data received to another system.

## CATEGORIES OF RFID SYSTEMS

Today, various types of RFID systems are used, depending on their applications needs. RFID systems can generally be divided into two major types, in terms of wireless communications between the reader and the tag, and in terms of its carrier frequency.

### Wireless Communications Between the Reader and the Tag

Two wireless communication methods distinguish and categorize RFID systems: inductive coupling and propagating electromagnetic waves. The former applies to RFID systems

F. MOHD-YASIN, M.K. KHAW AND M.B.I. REAZ
*Multimedia University*
*Cyberjaya, Malaysia*

**TABLE I**

**RFID FREQUENCIES FOR PASSIVE DEVICES**

| Frequency Range | LF 125 kHz | HF 13.56 MHz | UHF 868–915 MHz | Microwave 2.45 GHz and 5.8 GHz |
|---|---|---|---|---|
| Typical max read range (passive tags) | < 0.5 m | ~1 m | 4–5 m (for unlicensed readers) 10 m (for site license in the US) 33 cm (in Europe due to current power restrictions. However, this is expected to improve to near 2 m as power emissions increase from 0.5 to 2 W. | ~1 m |
| Standards specifications | ISO/IEC 18000-2 | ISO/IEC 18000-3 Auto ID HF class 1 ISO 15693, ISO 14443 (A/B) | ISO/IEC 18000-6 Auto ID class 0, class 1 | ISO/IEC 18000-4 |
| General characteristics | Larger antennas resulting in higher cost tags. Least susceptible to performance degradations from metals and liquids. | Less expensive than LF tags. Best suited for application that does not require long reading range of multiple tags. Has the widest application scope. | In large volumes, UHF tags have the potential for being cheaper than LF and HF tags due to recent advances in IC design. Offers good balance between range and performance – especially for reading multiple tags. More affected than LF and HF by performance degradations from metals and liquids. | Similar characteristics to the UHF tag but with faster read rates. Drawback is microwaves are much more susceptible to performance degradations from metal and liquids. Offers the most directional signal, ideal for certain applications. |
| Tag power source | Mainly passive using inductive coupling (near field). | Mainly passive using inductive coupling (near field). | Active and passive tags using E-Field backscatter in the far field. | Active and passive tags using E-Field backscatter in the far field. |
| Typical applications today | Access control, animal tagging, vehicle immobilizers. | Smart cards, access control, payment, ID, item level tagging, baggage control, biometrics, libraries, laundries, transport, apparel. | Supply chain pallet and box tagging, baggage handling, electronic toll collection. | Electronic toll collection, real time location of goods. |

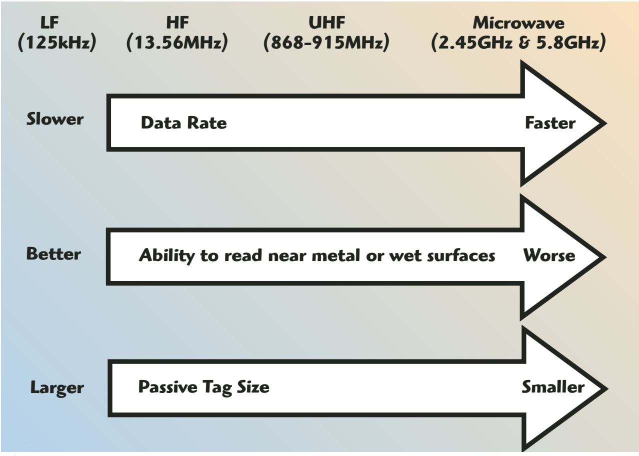
using low frequency (LF) and high frequency (HF) bands, whereby two resonant circuits are tuned at frequencies as close as possible. The latter applies to RFID systems operating in the ultra high frequency (UHF) and microwave band. To transfer data efficiently via the air interface requires the data to be superimposed (modulated) upon a carrier wave. Modulations are essentially based upon changing one parameter of the transmitting field; its amplitude, frequency or phase in accordance with the data carrying bit stream.

Passive tags mostly use the principle of load modulation by changing the load of the tag's antenna (amplitude and/or phase) to transmit data back to the reader. The data can also be modulated onto a sub-carrier. Higher frequency sub-carriers are generally used for higher data rates.[1] Other RFID systems, in the low frequency range, use the energy to charge a small capacitor and use the tuned tag circuit with an oscillator function to send a frequency shift keying (FSK) modulated tag signal back to the reader, for example. UHF and microwave systems use a backscatter modulation to communicate the data from the tag to the reader.

## Carrier Frequencies

There are four frequency ranges generally distinguished for RFID systems: low frequency, high frequency, ultra high frequency and microwave. ***Table 1*** shows the four frequency ranges used in the passive RFID devices with their performance overview, along with typical system characteristics and examples of major areas of application.[2] Based on the table, the different characteristics, standards specifications, applications and performance of the LF, HF, UHF and microwave passive tags can be compared.

LF tags are notably the largest installed base due to their long existence and technology maturity. Their almost interference-free from metals and liquids characteristics gives this type of tag an added edge to track goods. However, due to their large antennas and consequently larger tags, many manufacturers are turning to higher frequency ranges to save cost. The low reading range and LF data rate are two other drawbacks. On the other hand, HF tags are gaining popularity worldwide due to the adoption of smart cards in many current applications, such as personal identification, personnel access control and in transportation. Cheaper tags, longer reading ranges and faster read rates of UHF and microwave tags are the major factors that make these frequency range tags attractive to the RFID scene. Unfortunately, the usage is deterred by restrictions of the allowed power. The power allocation is different in the US and Europe. For example, in the US, 4 W of effective isotropic radiated power (EIRP) is allowed for the 915 MHz tags, whereas in Europe, about 0.5 W of equivalent radiated power (ERP) is allowed for the 868 MHz tags. Mi-

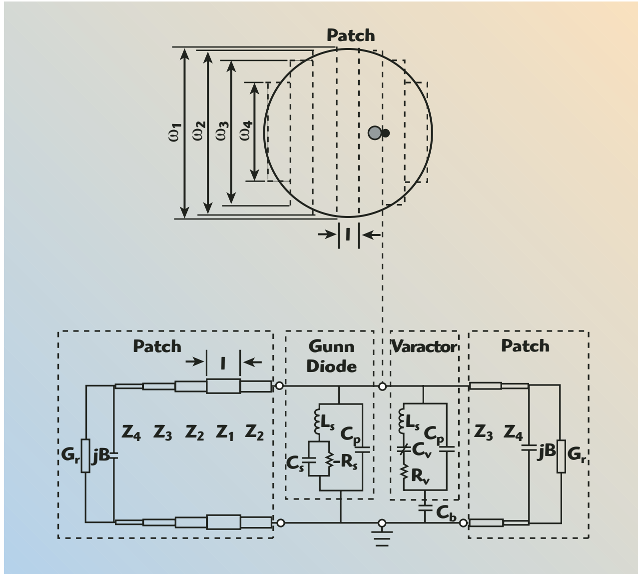



▲ *Fig. 1 Performance overview.*

crowave tags at 5.8 GHz are not explored for use in RFID applications. It may be because of their sensitivity and inability to be read in wet places and near metals. ***Figure 1*** shows a summary of the performance that can be expected from the LF, HF, UHF and microwave systems.

## ANTENNA CIRCUIT DESIGN

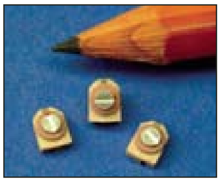
The antennas are components attached to the reader and the tag and are responsible for the wireless communication between the two. Some of the antenna architectures developed to date by several researchers and implemented into RFID systems are described. Some have already been used in current RFID systems, while others have the potential to be part of future RFID systems.




▲ *Fig. 2 Antenna circuit model. (Ref. 3, © 1996 IEEE)*

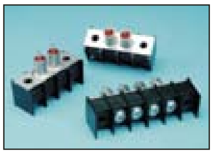
A cavity-backed, Gunn-diode-driven, self-mixing active, inverted stripline circular patch antenna has been reported.[3] In this design, a Gunn diode, self-mixing oscillator with a simple biasing scheme was integrated with an inverted stripline antenna to form an active antenna configuration, allowing the addition of a varactor diode in the resonator cavity to provide electronic frequency tuning. To eliminate unexpected surface modes and reduce coupling, a trapped inverted microstrip is used. The active antenna consists of an inverted stripline circular patch antenna press-fitted onto a cylindrical cavity. ***Figure 2*** shows a simple equivalent circuit used to model the active antenna. The antenna has second harmonic self-mixing capabilities, which allows the active antenna to be used in identification systems that return a modulated second harmonic signal, simplifying the tag design since a microwave source is not needed. The antenna provides good radiation performance with cross-polarization levels 18 dB below co-polarization at boresight and operates well in a self-mixing mode with a conversion gain of 2 dB when the incoming RF signal is mixed with the fundamental frequency and a 3.7 dB conversion loss when the incoming RF signal is mixed with the second harmonic of the active antenna. A 13 percent electronic tuning bandwidth was achieved with a power variation of ±1.0 dB. Therefore, this tunable ac-

## McQ512 Trimmer Capacitor



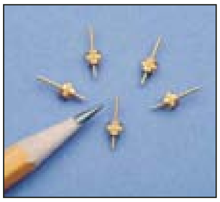
Tusonix's smallest Miniature All-Ceramic Surface Mount Trimmer Capacitor - the McQ 512 Series - is offered in an incredibly compact size for those applications that demand high Q and space-saving solutions. The state-of-the-art McQ 512 Trimmer is perfect for an endless variety of applications that require miniaturized capacitance trimming, including avionics apparatus, communications equipment, oscilloscopes, crystal oscillators and crystal filters.

## 30 AMP Terminal Blocks



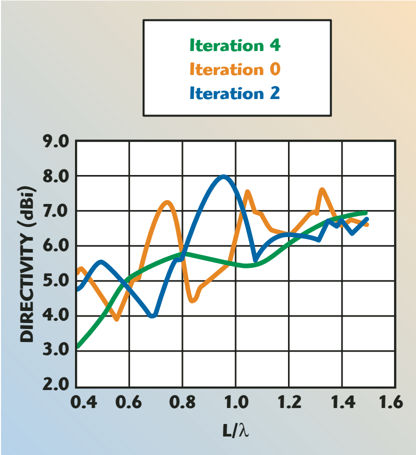
Designers can eliminate unwanted EMI with TUSONIX's UL Recognized Filtered Terminal Blocks, which have an increased current up to 30 Amps with a working voltage of 150Vdc and capacitance values up to 15,000pF. Applying an existing design concept, these filtered terminal blocks eliminate EMI at a critical point in the circuit without increasing component count or adding solder connections. These quality engineered terminal blocks are ideal for those applications that require filtration at high frequency.

## Ultra Mini Press-In Filters



The ultra-miniaturized 4306 Press-In Ceramic EMI filter suppresses unwanted EMI and allows a fast, mechanical bonding that is free from soldering. And, by offering an excellent alternative to the traditional soldering installation, these finely designed, knurled filters significantly reduce assembly costs. TUSONIX's Press-In EMI filters are perfect for a variety of microwave and RF applications that include attenuators, oscillators, synthesizers and combiners.






▲ *Fig. 3 Directivity versus projected arm length of a Koch V-dipole for different fractal iterations.*

tive antenna is well suited for commercial and military applications as a transceiver for microwave ID applications or for short communication links.

At the same time, a novel microstrip antenna using an alumina ceramic/polyimide, multi-layer dielectric substrate was proposed.[4] The multi-layer configuration, in which two different materials with very different permittivities and thicknesses are stacked together, can be used for designing an antenna with selective substrate thickness. Thus, this configuration gives the antenna the advantage of being able to select the optimum substrate thickness for the desired frequency. Both 10 and 18 GHz band antennas, which are designed and fabricated on the same substrate, achieve perfect matching and acceptable radiation characteristics.

Multi-layer substrates are extremely suitable for building active array systems, integrated with active devices and monolithic microwave/millimeter-wave integrated circuits (MMIC), as well as for constructing multi-frequency antennas. Multi-frequency operations can overcome the bandwidth limitation of microstrip antennas.

As researchers are trying to design low cost tags, small size antennas play a part in helping to decrease the overall cost. Small fractal antenna structures have been proposed for RFID applications.[5] Fractal antennas are possible designs for effective miniature and frequency-independent or multiband antennas. Compared to a conventional half-wave dipole, this antenna, referred to as the Koch fractal dipole, has approximately a 33 percent smaller projected arm length. The antenna also radiates more energy than the ordinary dipole, with the same projected arm length. Besides that, the input impedance matching and directivity can be improved. ***Figure 3*** shows how the directivity of a V-dipole antenna can be improved by replacing the arms with the Koch fractal curves. New, miniaturized, self-resonant meander line antennas with improved gain have been designed[6] for application in passive radio frequency identification. The antenna shape and size were optimized by using a genetic algorithm (GA), taking into account the conductor losses.

Meander line antennas were chosen to reduce the size of the tag in the UHF band. By folding the elements in the meander, a wire configuration with both capacitive and inductive reactance, which mutually cancels, was produced. As a result, resonances occur at much lower frequencies than in the case of a straight wire antenna of the same height, at the expense of narrow bandwidth and low gain, especially when the antenna surface needs to be contained within a square with a few centimeters per side (or less, to label small objects). The antenna generally found on most UHF tags is 160 mm long. The move to cut the antenna size in half to make it fit within an ordinary barcode label results in the antenna being able to capture only three percent of the energy of the conventional size antenna. This will reduce the read range dramatically, which offsets the key advantage of a UHF tag. However, Trolley Scan successfully developed an antenna for the new EcoTag,[7] which is half the size of the typical antennas used on other UHF tags. It measures 80 by 33 mm and is far more efficient than most UHF antennas of that size. With this antenna, the EcoTag can operate at ranges as far as 28 feet (nine meters). The EcoTag antenna can be produced using simple manufacturing processes, such as printing directly onto the packaging with a printing machine using conductive ink. This design is ideal for producing tags with antennas that use conductive inks applied with a printing press. This is possible because printed antennas are in a flat plane, rather than three-dimensional.

Printed antennas are cheaper and easier to produce than the etched, solid metal antennas, and they do not interfere with the recycling of packaging. For a 915 MHz tag, the dipole antenna has an aperture of 134 $cm^2$. When 250 µW of RF power passes through that aperture, the tag will receive enough power to operate fully and communicate all its data. Parmod ink[8] was developed, which can print at high speeds highly conductive RFID antennas on paper and also on polyester. Parmod VLT uses an organic base that decomposes and leaves an antenna that is more than 99 percent metal. These inks make the printed antennas three to 10 times more conductive than polymer-based inks. Greater conductivity means longer reading distance capability. It further reduces the cost of the antenna because less ink is needed to create an antenna with the same performance level.

A novel design of low cost broadband dual-polarized microstrip array antennas has been reported.[9] It uses a slot-coupled feed for one polarization, while a microstrip line feed with slotted ground plane is used for the other polarization. The array antenna can make good use of the space on both sides of the ground plane, as the feed circuits for the two orthogonal polarizations are placed on each side of the ground plane. The prototype four-element array antenna, designed at C-band, yields a bandwidth greater than 14 percent at both ports and an isolation below –30 dB is obtained. The cross-polarization levels are below –20 dB in both E- and H-planes. The array is simple in structure, easy to fabricate and low in cost.

Antenna coils can be configured in many different ways. It mostly depends on the purpose of the application and the constraints given by the mechanical setup. For example, a car immobilizer or a handheld reader requires different configurations. At 125 kHz, a thin wire is usually used for antennas with about 40 turns or more. At 13.56 MHz, printed circuit boards or thin-film technology is often used to place one to approximately seven turns. At frequencies in the microwave range, such as 2.45 GHz, the antennas are commonly designed as dipoles, according to the corresponding wavelength. Patch or microstrip antennas are used in RFID systems, due to their design simplicity. These antennas can therefore be manufactured cheaply and with high levels of reproducibility using PCB etching technology.[10] The other approaches in designing the antennas include reducing the size of the tag and enabling multi-frequency operations.

## READER CIRCUIT DESIGN

A reader is needed to communicate with the tag and to store or update information in the computer host, after the data is acquired from the tag. In the following, some advanced designs of RFID readers performed in the last two years are highlighted.

Nokia unveiled the world's first RFID-enabled global system for mobile communication (GSM) cell phone-reader.[11] The Nokia mobile RFID kit includes RFID reader shells, in the form of plastic housings, which fit over a cell phone and the software to enable mobile workers to scan 13.56 MHz tags and access information remotely. The software for the reader is written in the Java programming language. This RFID reader works with the Nokia 5140, a GSM phone that is water resistant and more rugged than a typical cell phone. Users simply slide off their existing Xpress-on cover and slide on the RFID reader. The software needed to run the reader is automatically loaded into the phone and the reader becomes operational. The readers use the ISO14443A communication protocol. The read range is typically 2 to 3 cm. An engineer checking a meter on a gas pipeline or other industrial equipment can simply slide on the RFID reader shell to his phone and conveniently scan the tag attached to a meter to identify which meter is being read. The phone-reader records the time of the read, and the engineer keys-in the meter reading using the buttons on the phone. The data is then stored in the phone and can be downloaded to a PC via an infrared connection. Data can also be transferred via the GSM system.



Trolley Scan launched a compact long-distance RFID reader[12] that offers read ranges as far as 11 meters, even when tags are attached to metal objects. This reader is housed in a molded ABS plastic case, weighing just 3.5 kg and operates on main power. It functions at the UHF frequencies of 860 to 930 MHz and uses a bi-static antenna system that can read up to 500 tags in a field at a time. As the system operates on a 10 kHz bandwidth with a "tag-talks-first" protocol, the system can operate in very close proximity, something that is not possible with the currently proposed EPC and ISO18000-6 systems. The ability of the RFID readers to work in close proximity will become an important consideration in the future, with the continuing proliferation of RFID technology. This new reader complements the existing range of fixed and portable readers and offers a very impressive range performance for passive UHF technology. The reader is also compatible with the EcoTag, Ecochiptag, Ecowoodtag and the laundry tag produced by Trolley Scan and its licensees. YRP Ubiquitous Networking Laboratory unveiled the UC-Watch.[13] The UC-Watch is an RFID reader embedded in a wristwatch. It features a function to read data based on "ucode," an RFID code system that the Ubiquitous ID Center had developed. Users can pick up objects that contain an RFID chip to read the information, which is then displayed on the 120x160-pixel screen on the RFID wristwatch.

The world's smallest RFID reader, known as "io,"[14] was developed by Innovision Research & Technology. It measures 12 × 2 mm in size. For comparison, the device is smaller than a US dime. It is a near-field RFID reader and is inexpensive. The reader is expected to cost around one-tenth the price of existing technology. The "io" reader features an on-board RISC processor with low power consumption, suited to 2.7 V battery operation. The "io" RFID module reads and writes to industry-standard RFID tags and smart labels operating at 13.56 MHz. This low cost and low power reader is compliant with ISO14443A and also with the forthcoming near field communications (NFC) standard. SmartCode did further work in its existing UHF reader by integrating the reader with cellular data capabilities.[15] Therefore, the new reader can be deployed wirelessly to a corporate network even when there is no local area network (LAN) connectivity. This reader can operate worldwide at 900 MHz, 1.8 and 1.9 GHz, on general packet radio service (GPRS), code-division multiple access-1X (CDMA-1X) voice and data cellular networks. GPRS operates on GSM cellular systems, which have been deployed worldwide; the data transmission rate over a GPRS network ranges from 9.6 to 155 kbps.

CDMA-1X systems, which offer a peak data rate of 153 kbps,[16] are the basis for 3G wireless systems and are prominent primarily in the US and South Korea. By providing readers' capabilities of connecting to enterprise applications over a cellular connection, the compliance policy guide (CPG) manufacturer can track its tagged shipments without having to use the retailers' network facilities or build out network facilities where they are not present. The cellular-enabled readers can be used to either transmit tag data as it is collected or send data at specific intervals.

The SkyeRead H2 handheld reader[17] is a higher performance RFID scanner for use in commercial and industrial applications, compared to the Nokia's reader. Operating at the same 13.56 MHz frequency, the SkyeRead H2 not only supports the ISO14443 but also the ISO15693 protocols. Its reading range is much better, with up to a 14 cm reading distance. Besides that, it can identify multiple RFID tags in a field. This RFID reader comes with a built-in RS232 cable to connect easily to the host. A full suite of developer tools, device drivers and software libraries are also available for quick, easy integration and deployment. There are also readers that read multi-frequency tags. The TwoSENSE (TSR222) reader,[18] produced by Northern Apex, provides portable data collection capabilities in a variety of industrial and commercial applications. It can be configured as a 13.56 MHz reader capable of reading tags from TagSys, Texas Instruments, Phillips and all other ISO15693 and ISO14443 tags. The TwoSENSE reader can also be configured to read HF 900 MHz and communicates with EPC-compliant 64 and 96 bit UHF 900 MHz labels from Matrics and multiple vendors of UHF EPC compliant technologies. Another unique feature of the reader is the extreme flexibility of the device to allow it to function with numerous personal digital assistant (PDA) and personal computer (PC) devices. PDA devices include iPAQ, Symbol, Palm or other similar PDAs that have a serial connection COM port and available interface. Texas Instrument's (TI) S4100 multi-function reader (MFR) module[19] is adaptable to all ISO/IEC14443 and ISO/IEC15693 standards-compliant 13.56 MHz RFID tags, while providing an easy migration path to support current tags not fully compliant to these standards. The MFR's unique software architecture enables users to download firmware upgrades down to the ISO standard protocol level, when specifications are adjusted or new standards are added, without changing the hardware residing in the finished reader. This capability allows end-users to make RFID reader infrastructure investments today without worrying about reader hardware obsolescence when new applications are introduced or ISO standards are modified or developed. TI's MFR module supports multi-applications such as payment, loyalty and many smart label applications. Furthermore, with the open software platform feature, a range of application and security architectures can be designed, depending on the specific needs of the application.

Omron's new V720 RFID gate reader[20] also operates at 13.56 MHz. Its advantage, compared to the other readers, is that it is capable of reading up to 128 Omron V720 RFID tags at the same time in any orientation. The width of the RF curtain can be up to 1 m, allowing enough room for a person to pass through, thus enabling human applications. The 1 m widths also allow adaptation to a variety of applications, whereas previous short read ranges made these RFID applications impractical. The V720 gate reader is read- and write-able, allowing the data to be fully dynamic, always current and changeable as needed. The 13.56 MHz frequency also allows the security of the data to be accurate and transferred quickly, thus increasing the efficiency and speed of the items or people traveling through the V720 gate reader. With good noise immunity and little interference, this reader is ideal to be used as an alternative to the conventional barcode scanning check counter at a supermarket.

## CONCLUSIONS AND RECOMMENDATIONS

It has been observed that antennas printed on ordinary labels or cardboard with conductive inks could, within a few years, replace conventional solid copper RFID antennas. Printed antennas are less expensive and more flexible than the solid metal ones. The use of conductive inks will cut antenna costs by 50 percent. An RFID tag with a printed antenna costs about 15 to 30 cents today and will cost less as higher speed printing machines come on line in the years to come. Soon, it could be possible to print both the IC and the antenna of a tag with inexpensive inks. Besides that, printed antennas have other advantages over solid metal antennas. They can be attached to a microchip and turned into a tag up to 10 times faster than conventional antennas. The solid metal antennas pose environmental concerns because of the chemicals used to create them and they are not recyclable. Ultimately, ink producers seek to formulate the most conductive ink possible and a chemistry that is suitable for the widest range of substrates. Excellent flexibility and adhesion at the lowest possible cost are also key considerations. RFID antennas and printed electronics will continue to evolve over the next decade and grab a significant share of the marketplace.

Several RFID reader architectures using advanced RF designs have been discussed. It is established that the reader is the more complex part of the RFID system. Different readers can vary quite a lot in complexity, depending on what kind of tag they can read and what functions they want to perform on the data read. Moreover, the readers are usually compatible with their own manufacturers' tags. Some are able to scan tags in a specific frequency range while there are some who can read tags at multiple frequencies. While some readers do simple readings, some can perform more sophisticated functions like signal conditioning, parity error checking and correction. Readers also come in various packaging, depending on their application, practicality, size constraints and convenience in their use. In general, a practical reader should be robust, user friendly, able to read at any orientation and to read multi-frequency tags. The need for longer reading ranges of a reader differs for various systems. Shorter reading ranges are useful in areas where privacy of tracking goods is of most concern, to avoid unauthorized scanning at a far and wider range. RFID systems supporting the recently ratified EPCglobal Inc. Generation 2 (Gen 2) specification should be produced. The EPCglobal Gen 2 is a standards-based UHF technology platform that allows for global interoperability, read/write capabilities and migration to future EPC classes. Gen 2 resolves all of the shortcomings of the older specifications, innovating and improving on global compliance, tag throughput, re-writable ability, security, privacy and robustness in high density reader environments. This new UHF RFID standard is broadly supported by users and manufacturers within the RFID industry and will facilitate the widespread deployment of EPC RFID technology in the retail supply chain. ■

## References


1. "Compatibility Between Inductive LF and HF RFID Transponder and Other Radio Communication Systems in the Frequency Ranges," *Electronic Communications Committee (ECC)*, 2002.
2. "A Basic Introduction to RFID and Its Use in the Supply Chain," *White Paper, LARAN RFID 2004*, April 2005, http://www.laranrfid.com/modules/movies/scenes/home/index.php?fuseAction=pages&rubric=pages&article=downloads.
3. C.M. Montiel, L. Fan and K. Chang, "A Novel Active Antenna with Self-mixing and Wideband Varactor-tuning Capabilities for Communication and Vehicle Identification Applications," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 44, No. 12, December 1996, pp. 2421–2430.
4. K. Kamogawa, T. Tokumitsu and M. Aikawa, "Multi-frequency Microstrip Antennas Using Aluminaceramic/Polyimide Multi-layer Dielectric Substrate," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 44, No. 12, December 1996, pp. 2431–2437.
5. P. Jonsson, "Fractal Antenna Design for RFID Applications," Electronics Design Division, Department of Information Technology and Media, Mid-Sweden University, http://www.ite.mh.se/~elektro/forskningsweb/Posters2002/posters/PosterFractalAntennas.pdf.
6. G. Marrocco, "Gain-optimized Self-resonant Meander Line Antennas for RFID Applications," *IEEE Antennas and Propagation Letters*, Vol. 2, 2003, pp. 302–305.
7. "New Energy-efficient RFID Tag," *RFID News, RFID Journal (on-line)*, December 13, 2003, http://www.rfidjournal.com/article/articleview/718/1/1.
8. "New Ink for Printed RFID Antennas," *RFID News, RFID Journal (on-line)*, February 5, 2003, http://www.rfidjournal.com/article/articleview/296/1/1/.
9. S. Gao and A. Sambell, "Low Cost Dual-polarized Printed Array with Broad Bandwidth," *IEEE Transactions on Antennas and Propagation*, Vol. 52, No. 12, December 2004, pp. 3394–3397.
10. K. Finkenzeller and R. Waddington, *RFID Handbook*, John Wiley & Sons Ltd., England, 2003.
11. "Nokia Unveils RFID Phone-reader," *RFID News, RFID Journal (on-line)*, March 17, 2004, http://www.rfidjournal.com/article/articleview/834/1/1.
12. "Long-distance RFID Reader," *Food Production Daily News (on-line)*, May 26th, 2004, http://www.foodproductiondaily.com/news/news-NG.asp?id=52356.
13. "RFID Reader Wrist Watch," July 14, 2004, http://www.i4u.com/article1780.html.
14. "io Reader," Technical datasheet, Version 1.1, *Innovision Research & Technology*, June 2004, http://www.innovisiongroup.com/images/io_Technical_Datasheet_1v1.pdf.
15. J. Collins, "RFID Readers Get Cellular," *RFID News, RFID Journal (on-line)*, December 22, 2004, http://www.rfidjournal.com/article/view/1298.
16. "CDMA 1x," *Technology Info, ZappMobile*, http://www.masoara-ti-viteza.ro/technology/cdma/.
17. "SkyeRead H2," *SkyeTek RFID Engineering*, http://www.skyetek.com/readers_H2.html.
18. "The TwoSense RFID Reader," *Northern Apex Solutions Integrator*, http://www.rfidread.com/pdf/tsr222.pdf.
19. "S4100 Multi-function Reader Module," Document: 11-06-22-715, Texas Instruments Inc., October 2003, http://www.ti.com/tiris/docs/manuals/refmanuals/rf-mgr-mmmn_ds.pdf .
20. "RFID Gate Reader: Omron V720 Gate Reader Reads up to 128 RFID Tags at Once in Any Orientation," *Yenra*, November 13, 2001, http://www.yenra.com/rfid-gate-reader/.

# The Impact of MEMS on Cellular Phone Architectures

Carriers are launching third generation (3G) wireless networks globally and numerous analyst groups are predicting 2006 to be the year of 3G networks. The first nationwide 3G networks will be fully operational in 2006, and at least three service providers are expected to have full consumer and business 3G data services available. These newer 3G standards provide a variety of services, including data and on-demand video. As wireless networks advance, however, so do the challenges for mobile phone designers.

Advanced 3G standards pose significant technical challenges to system designers and product architects from several aspects. The radio itself is much more advanced, requiring higher performance components. Applications, such as video, demand increasingly sophisticated circuitry, and the expected usage profile is very different from voice, placing additional demands on battery consumption. Making this even more difficult, new 3G phones need to be backward compatible with the older GSM and CDMA networks in order to ensure coverage and seamless handover. Additionally, they cannot be significantly larger than last generation phones and need to have similar talk and standby battery lifetime. Recent developments in wireless communications have also resulted in handheld cellular phones that can utilize up to seven different wireless standards or bands including DCS, PCS, GSM, EGSM, CDMA, WCDMA, GPS and Wi-Fi. Each standard has its own unique characteristics and constraints, and brings with it its own specific challenges. Radio frequency microelectromechanical systems (RF-MEMS) may help engineers design phones that meet the challenges of integrating multiple bands while maintaining long battery life and progressively reducing the overall size of the handset as well as adding new capabilities, while keeping these devices small and affordable.

Approximately 75 percent of the 100 or so components in a mobile phone are “passive” elements such as inductors, variable capacitors and filter devices. MEMS versions of these components promise to make phones more reliable and power efficient. If they succeed, say the industry analysts at Cahners In-Stat Group, the market for RF-MEMS is expected to grow to nearly $350 million in 2006. Analysts at MegaTech Resources predict the quantitative model forecasts to reach $100 billion in worldwide MEMS shipments in 2010. The long-term potential is estimated at $2 trillion by 2025.

Mark Chapman
*WiSpry Inc.*
*Irvine, CA*

## TRENDS

From a design standpoint, the evolving definition of 3G handsets requires an increasing focus on power consumption, space and architectural efficiency. Perhaps the biggest change, at least from an RF standpoint, is the requirement for multiband and multimode operation (see ***Figure 1***). Meeting the stringent RF standards for several bands and technologies has greatly increased the complexity of the RF front-end. For example, European phones are expected to support at least three bands (900, 1800 and 2100 MHz) and two dissimilar technologies (GSM and WCDMA), not withstanding the addition of WLAN, Bluetooth or GPS, etc., in higher end handsets. Each technology requires its own specific filters designed for specific bands, making the front-end complex, large and costly. Making matters worse, adding switches or other components at the front-end of the phone to efficiently route signals creates loss and distortion that may impair performance or increase power consumption. Anything inserted between the antenna and the first low noise amplifier (LNA) results in a higher noise figure, which impacts overall radio sensitivity. Moreover, the active battery life is heavily influenced by the power consumption of the power amplifier (PA). Simply put, any loss in front of the PA will dissipate power that should go out the antenna, further reducing battery life. Perhaps less obvious is the fact that successive generations of wireless standards have sought to eke out more efficiency from the limited spectrum by using more complex signal waveforms. While this certainly places demands on baseband processing, the advancing sophistication of digital circuits has kept pace, if not driven, the evolution of wireless modulation and coding technologies. However, these increasingly complex signals require very linear RF components in order to limit distortion and ensure high signal throughput. A practical example of this is the extensive use of GaAs power amplifiers in most CDMA handsets. Despite efforts to integrate PAs into the transceiver, these components have remained external, largely due to the constraints of maintaining linearity at high power levels across wide frequency bands. What is needed is a technology that can deliver low loss with excellent linearity, while drawing no additional power and occupying the smallest possible area. Ideally it should be capable of further integration with a transceiver or other active components. ***Figure 2*** shows the complexity of an RF front-end as additional frequency bands and RF technologies are included. This growing complexity enables tunable RF solutions with RF-MEMS switch and filter technologies that simplify this architecture.

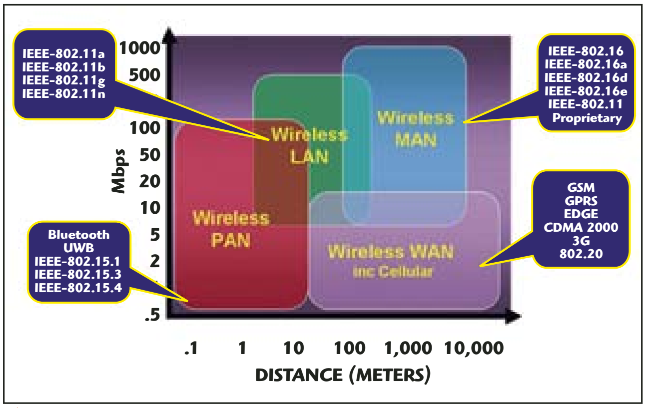



Fig. 1 *As new wireless technologies have evolved, a proliferation of wireless bands and standards have also emerged.*

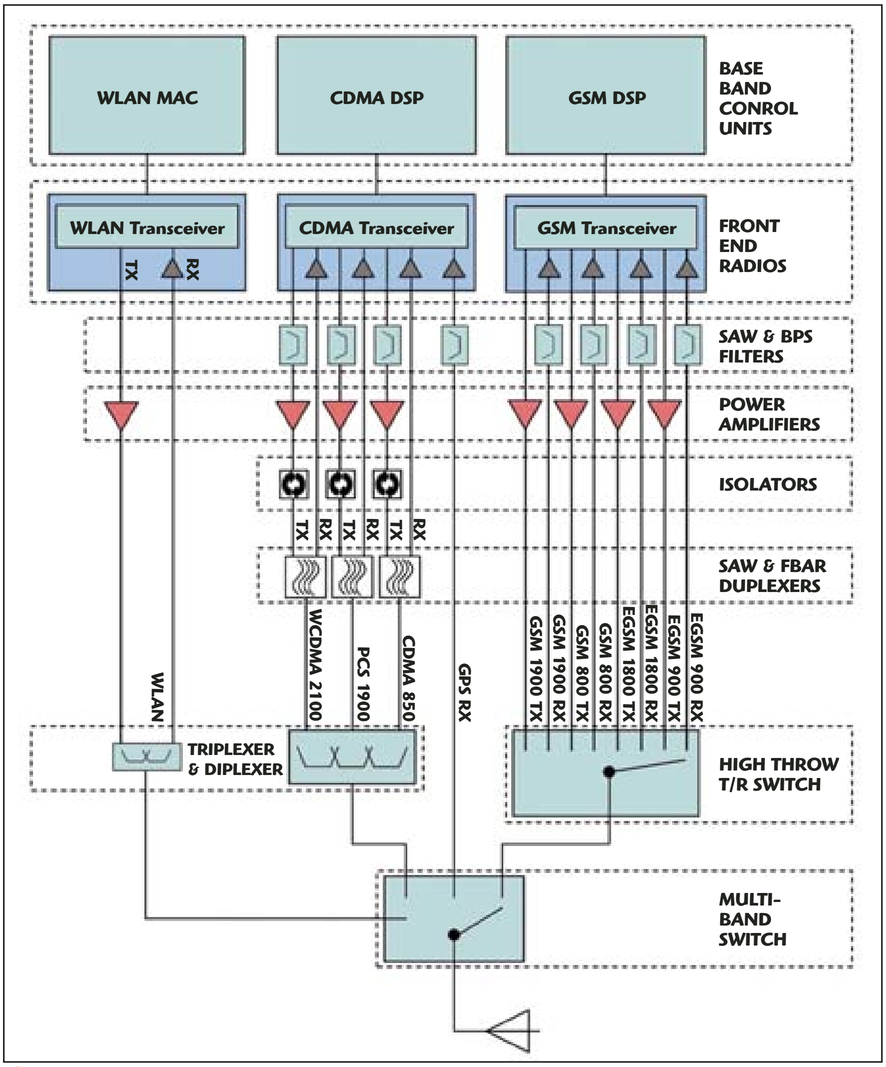
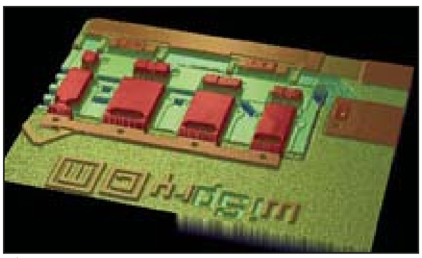



Fig. 2 *A mobile phone's complexity continues to grow as multiple standards are implemented.*

MEMS technology is a leading candidate to address this emergent problem. RF-MEMS uses microscopic moving structures that are built using silicon chip manufacturing technologies. MEMS devices are not new and have found widespread application in airbag sensors, accelerometers, micro-optics, video projection systems and printer heads, to name but a few.

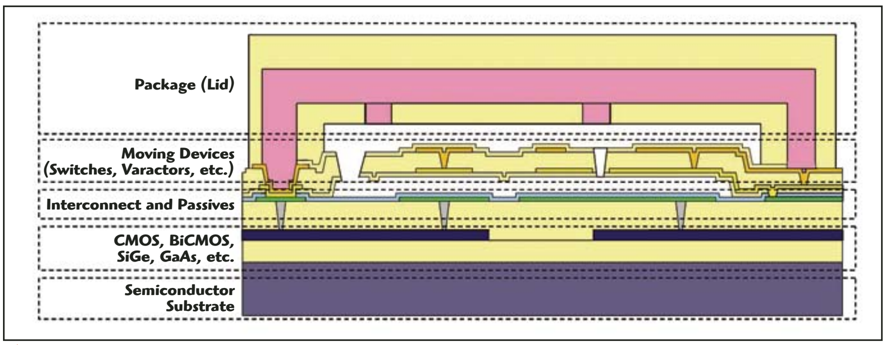
Using the integration of mechanical elements, actuators and circuits on a common silicon substrate, MEMS devices are built through micro-fabrication technology. While electronics are fabricated using integrated circuit (IC) process sequences (such as CMOS, bipolar or BICMOS processes), MEMS components are fabricated using "micro-machining" processes that selectively etch away parts of the silicon wafer or add new structural layers to form tiny mechanical and electromechanical devices. RF-MEMS-based devices are tiny, almost perfect physical switches, with none of the inherent limitations of semiconductor-based switch technology. Therefore, they reduce space and cost while simultaneously achieving a combination of high isolation and low insertion loss that is unachievable with conventional silicon technology. MEMS-based RF components can thus improve performance, while reducing power consumption and lowering cost, all critical factors in the front-end components of cellular phones as well as other high performance RF applications. It is worth noting that there are already MEMS-based components in cellular phones. Both surface acoustic wave (SAW) filters and film bulk acoustic resonance (FBAR) filter devices are forms of MEMS devices. FBAR, in particular, is a worthy example of a technology that is simple to create, but took years of perfecting before it became practical in terms of performance, cost and yield for cellular phone applications. FBAR devices, now featured in most CDMA phones, exhibit good performance at a very low height profile. This reduced height made them an essential choice, driving the volumes of FBAR devices produced up and costs down. Several manufacturers now have FBAR and bulk acoustic wave (BAW) filters in production and they are finding significant favor in today's smaller and thinner phones. ***Figure 3*** shows a high resolution image of an actual RF-MEMS structure that can be used as a building block for filters similar to FBAR.



▲ *Fig. 3 Detail showing a digital RF-MEMS capacitor array that offers a unique solution for precision tuning in RF devices.*

## PROBLEMS TO OVERCOME

RF-MEMS switches have been in development for several years, but like all new and potentially disruptive technologies, there are several key problems to overcome. Initial developments of RF-MEMS switches were focused on the very fast T/R switch that is used in all GSM phones. However, while significant advances have been made, the very mechanical nature of MEMS devices limits its switching speed. It may still be possible for MEMS devices to meet GSM specifications, but not easily or without compromising cost or performance in other areas. As with FBAR devices, however, the application has serendipitously evolved into the sweet spot for RF-MEMS, rather than the other way around. The need for multiband, multimode switching, with low insertion loss while maintaining excellent linearity for WCDMA or CDMA signals, is driving the need for RF-MEMS-based devices. The problem and the value of the solution are only expected to increase as new and more complex waveforms such as WiMAX are added to the mix. Being essentially broadband devices, RF-MEMS switches are far less affected by frequency than semiconductor solutions and are more suitable at even higher frequency bands. This makes a front-end based on this technology a very adaptable platform, saving design time, cost and speeding time to market.




▲ *Fig. 4 Implementation of die level sealing as a practical replacement to hermetic packaging.*

## RF-MEMS FOR SOFTWARE-DEFINED RADIO APPLICATIONS

There is also significant interest in RF-MEMS for software-defined radio applications or those such as in the US Joint Tactical Radio System (JTRS) intended for first responders and other government and military users, where a reconfigurable front-end is part of the value proposition. Key problems still remain, however, largely in driving down costs and size. First, most MEMS devices are electrostatically activated, using relatively high voltages (20 to 80 V) to operate, but at infinitesimal currents. In the long run, this is really a system architecture problem since there is no reason why such a voltage could not be made available in a phone if the benefits are apparent at the system level. In the meantime, vendors are building charge pumps into their offerings in order to adapt them to current generation designs. Longer-term solutions involve monolithic integration of the control and charge circuitry into the MEMS devices themselves by building MEMS on top of active circuitry, or relocating the circuitry to other front-end components where the functionality can be absorbed on an incremental basis. This is particularly attractive in the context of highly integrated front-end modules. Also, as with SAW filters and FBAR devices, MEMS switches require a fair degree of hermeticity for reliable performance. MEMS devices are very sensitive to moisture, atmospheric particulates and other contaminants, which may interact with the contact surfaces. This means packaging the switches in a low cost, low profile, sealed package. This is the key problem for the MEMS industry to solve if it is to successfully intersect the high volume cellular phone world. The good news is that the SAW industry is already pioneering solutions that can be adapted to the needs of MEMS devices. SAWs originally started in ceramic packages and have progressed through flip-chip to chip-scale packaging, with wafer-scale packaging on the horizon. While the technology and needs of MEMS devices are slightly different, there is every reason to expect RF-MEMS devices to leverage the significant body of experience and low cost technology that has been perfected. ***Figure 4*** shows how advanced semiconductor processing technology can permit MEMS devices to be sealed at the wafer level during manufacture, to provide hermetic encapsulation of the critical MEMS devices. This process simplifies device singulation and allows the use of standard packaging techniques. Subsequent overmolding provides additional strength and resilience, also ensuring long-term hermeticity.

The other main impediment to-date has been unproven reliability or the need to demonstrate in excess of $10^{11}$ (100 billion) cycles. This requirement was dictated by the fast switching T/R specification and while still valid, can be significantly relaxed if only band switching is contemplated, again making MEMS a more immediate prospect. In addition, MEMS devices have made significant strides in this area with numbers in excess of four billion cycles and, in some cases, being well beyond published results. The last requirement is adapting MEMS to low cost fabrication techniques that will lead to an intrinsically low cost base and will permit further integration. Initially MEMS devices were built in specialty shops, using custom MEMS processes in order to cater to very special needs and deliver products that were targeted at very high end applications. Now, companies such as WiSpry and others are building MEMS devices in standard high volume fabrications, using processes and material sets that are compatible with high volume CMOS manufacturing techniques. This not only leverages the significant infrastructure that exists in the semiconductor world, but ensures a path to further integration with active devices.

## THE FUTURE OF MEMS

It is this potential for integration that really excites the semiconductor world. FBAR devices, SAW filters, PIN diodes and GaAs components used in today's cellular phones are all very much discrete technologies that, to-date, have resolutely resisted integration. Most of the innovation in size and cost reduction has taken place at the packaging level with the evolution of front-end modules (FEM) emerging as the key solution for many applications. MEMS devices offer a path to the integration of filter and switching technologies, creating a road map for intrinsic size and cost reduction for FEM providers and system architects.

As with previous technologies, volume dictates its own solutions and as the opportunity becomes apparent and measurable, companies are applying the resources to solve these last remaining hurdles to widespread adoption. A virtual circle of innovation and reward exists to be tapped.

These initial applications for RF-MEMS devices will undoubtedly lead to more advanced applications as this disruptive technology becomes more widely adopted and its benefits proven. Simple applications such as band select switches will lead to more complex and integrated solutions as MEMS technology is integrated into the silicon fabric itself.

System architectures will undoubtedly evolve where designers can take full advantages of the low loss, high linearity and essentially broadband operation capabilities that MEMS devices offer, designing around the capability to maximize performance or lower cost elsewhere in the design. The loss saved by using a MEMS switch may be just enough to enable a more efficient solution to be used elsewhere in the design, allowing the use of a CMOS LNA or PA instead of a SiGe or GaAs one. Doing so may allow even further integration of transceiver technology in association with a highly integrated MEMS-based front-end.

Looking forward, MEMS-based switches, switched filters and tunable filters will form key components in more integrated solutions. Tunable filter solutions based on MEMS devices simplify the design of front-end modules that need to support an increasing number of frequency bands and communication standards. They may also be used to create tunable structures integrated with other active components to create wideband power amplifiers, broadband tunable matching networks or adaptive antenna matching, giving rise to a new class of adaptive RF components. Similarly, MEMS devices may be used to vary the load impedance match of a power amplifier, ensuring it is operating at the highest possible efficiency at all power levels, thus improving power-added efficiency (PAE) and increasing battery life. The latter is an area of great interest to system designers, given that WCDMA phones are far less power efficient than the GSM ones they hope to replace. MEMS-based resonators are also being investigated heavily as a means to drive further integration of tunable or at least integratable filters into silicon devices. As the benefits of MEMS-based RF technology become evident and as the technology itself matures to the point where it can be integrated with other devices, new architectures are becoming possible that will take full advantage of the many capabilities that MEMS has to offer; as MEMS transform architectures through wide adoption, the industry is seeing great potential for RF designs in cellular and personal communications systems (PCS), wireless networking, the wireless Internet and other platforms that operate up to the mid-2 GHz range. ■

**Mark Chapman** *is vice president of business development for WiSpry Inc. His past experience includes serving as the president and CEO of Ditrans Corp., and executive level positions for Comarco Wireless Technologies and Rockwell Semiconductor (now Conexant).*

# CHINA'S RF AND MICROWAVE OPPORTUNITY: BUILDING A STRONG COMMERCIAL PRESENCE

The market for RF, microwave and wireless components, materials, subassemblies and test equipment in Greater China (defined as Hong Kong, the People's Republic of China, Singapore and Taiwan) has grown dramatically during the past five years. The market, once dominated by small domestic military programs and low technology/low margin commercial programs such as police radar detectors and C-band LNBs transferred to contract assembly houses, has evolved into the most dynamic market in the world. There is a substantial and growing demand for power amplifiers, large format antennas, last mile broadband components, cellular base station infrastructure and digital radios.

The fastest growing geographic segment is now found in mainland China. The central government provides strong incentives for wireless infrastructure development and China's technical universities are doing their part by minting electrical engineers specializing in RF technology at a fast clip. China's large telecom players define a portion of the opportunity; however, the prospects represented by the small and medium size wireless companies are just as attractive.

Developing new sales in the Chinese market is certainly an attractive goal for foreign microwave companies, although the terrain and the rules of good business are somewhat different than in the West. Before jumping into the market, it is necessary to craft a China focused plan.

As you would at home, when considering a new territory or market segment, it is worthwhile to study the terrain to learn if there is a fit between your products and the market needs. Generally speaking, market entry plans follow the continuum: is it feasible; is it desirable; is it practical; and how do we do it?

## IS IT FEASIBLE?

With dedicated resources and sustained effort, any Western microwave company can develop new sales in China. The question will always be: is it worth the effort in dollars, effort and opportunity cost to craft a new commercial presence? Before committing to this type of program it is necessary to profile the

JACK DANIELS
*EastBridge Partners LLC*
*Brookline, MA*

market. There are a number of ways to carry out a market profile study including engaging a consultant that specializes in market research, utilizing profiles produced by Chinese professional societies and academic groups or utilizing statistical indices produced by government entities.

These methods are a poor substitute for getting on a plane, flying to China and knocking on doors. In a society that values personal relationships, especially with foreign technology companies, arranging for discussions and interviews with microwave companies is quite possible. While this sounds daunting if you have little or no experience in China, if you are willing to share some information about your products, technology and company, it is quite possible. What you will need is an introduction by someone that knows you, your company and the individuals you would like to visit. Introductions can be arranged through the assistance of your state or provincial government and national government's trade development offices. Another and often more productive source of introductions are foreign companies operating in China. Companies in allied or related technical sectors to that of your company are a good source of introductions and may be interested in forming a commercial alliance with you in the future.

## IS IT DESIRABLE?

Once you have determined that there is a market for your products in China, it is necessary to decide if the opportunities you have discovered are attractive enough to launch a commercial effort. When rolling out a new product introduction plan in China, it is a sound strategy to challenge conventions, which are internal to your company in existing markets. Local requirements related to pricing, field support, technical standards, packaging and overall fit and finish may be quite different than what you are accustomed to at home.

One example of this difference can be illustrated by lead-time requirements. The overall pace of business in Greater China and more specifically south China is much faster than that found in the West. Compounding this cultural bias, contract manufacturers and OEMs in China are dealing with compressed lead times from their customers. Extending their supply chain thousands of miles to your shipping dock is an additional challenge for them and you. Accommodations such as signing up a local stocking distributor or training company, agreeing to a consignment program or future extended payment terms soften the blow (and cost) of longer shipping times.

An additional factor to consider is how to settle payments in China. During the period when you are developing a commercial relationship with new customers, it is advisable to start out with cash in advance (CIA) or letter-of-credit (LOC) terms. CIA terms are great for your business, but most customers are resistant to them. LOCs are a virtual guarantee of payment; however, they do have a cost in terms of banking and paperwork fees and administrative burden. One other approach in the case of transplanted customers from the West may be to secure a payment guarantee from their corporate parent.

Before exporting to the RF and microwave market in China, it is critical to implement an export control and compliance plan. Many assemblies and components produced by microwave companies are considered to be "dual use" by the US Department of Commerce (and in some cases the Department of State). That translates to understanding if your goods can be used either for commercial or military end uses. Because you do not want to run afoul of the US government, you are duty bound to determine which end uses in China's military segment are restricted.

Understanding the prohibitions and requirements of the Export Administration Regulations (EAR) is complicated and will require some homework in order to create an internal knowledge base about the obligations of you the exporter, embargoed destinations, end user/end use profiles, the Denied Parties List, the Entities List, specially designated nationals list and the re-export policy.[1]

An important adage to help in grasping all of this new jargon is "know your customer." Implementing an export compliance plan becomes much easier if you have visited your customers in China, toured their facilities and have developed a personal relationship with a senior executive. The key point to remember is that you cannot trade with Chinese customers at arms length. Even if there is an intermediary company such as a distributor or trader, it is your ultimate responsibility to know who you are selling to and that the goods actually end up in the place they are destined.

## IS IT PRACTICAL?

Once you have developed a profile of the market in China and identified enough opportunities to warrant taking the next step, it is crucial to model how the plan will fit with your overall business goals. The process of setting up a China focused organization is significant and can be distracting. If you are not prepared to support a two- to three-year effort with funding, internal resources, time and emotional energy, you probably should not start at all.

Key predictors of success in China fall into several categories, including: senior management's commitment to the project; the assignment of the right person in the role of "China Champion"; providing training to your customer service group; and the persistence of your organization taken as a whole. One of your executives needs to be a regular presence (perhaps four times per year in years one and two) in front of customers and trading partners in China. This is a society that places an emphasis on face time. If you want to do business at the highest levels, your company cannot send a junior engineer to fill the shoes of a C-level executive.

Within the organization, it is necessary to stay on point and keep the China effort visible. This is best done by assigning one person to direct all aspects of the development program. It is stiff necked and impractical to expect distributors, representatives and customers new to your company to be able navigate the complexities of your organization. Funneling all correspondence through one person will streamline your response, focus the organization on what is important and significantly shorten the sales cycle.

Even with an active champion in place, your customer service group will likely be challenged with a flurry of demands presented in a form of

English that they do not often encounter. Training is key to prepare them for reading and interpreting non-standard English and responding in a simplified style. Customer service specialists will also encounter a sense of urgency on the part of Chinese customers that can be frustrating and at times painful. Remember that China's mercantile culture is at least five thousand years old — we in the West are newcomers to international trade and cannot impart our norms overnight. Resilience on the part of the customer service group and the broader organization will allow you to overcome this cultural bias.

Taken together, all of these elements are a measure of a company's readiness to do business in China. While much of this may be new, it is all learnable. Also, if you stumble, you can get up and keep going.

### HOW DO WE DO IT?

When your company has decided to dedicate resources to the China market, you must decide how to take the first step. Most companies will default to assigning one or more manufacturers' representatives, shipping off a box of literature, providing an initial sales training and then hoping for the best. While this approach often works in the West, in a market as complex as China's it may not be the best approach. Broadly stated, new product and line introductions in China are difficult. Representative organizations sell best when the going is easy. You will always be competing for mind share within the rep's organization and space in his catalog case.

If you choose the rep route, it is best to put your best foot forward with them and their customers. This means re-crafting your web site to include a Chinese language toggle switch and printing bilingual brochures and collateral materials in an aesthetic that is attractive to Chinese technical people. It also means assigning a dedicated resource within your company — one person to field all questions related to doing business with you.

If your product is sufficiently complex, using rep organizations alone may not be the most efficient route. Many Western companies find that they can accelerate sales growth by placing their own staff on the ground in China. A tried and true approach is to recruit and hire an experienced "rain maker" in the role of country manager or business development manager. (The knotty problem of employing a Chinese national before you have an official presence in China can be dealt with by using the employment agencies found in most major cities in China). She can provide day-to-day management of a corps of representatives, guide your exhibition and trade show strategy and, most importantly, develop a personal relationship with your customers and their customers. As greater Shanghai is the business capital of China, Shanghai or one of its industrial suburbs is a logical home for your first employee.

After the business development manager has gained ground, many companies begin to hire field application engineers (FAE) to provide technical credibility and enhance service. With employee number one in Shanghai, each new FAE can broaden your footprint. The microwave and RF industry is concentrated in four areas: the Pearl River Delta (southeast corner of China); the Shanghai-Kunshan-Suzhou corridor including Nanjing; greater Beijing; and, recently, Chengdu. It is important to have a coherent strategy to place staff in all of these locales.

A special note regarding employment profiles in China: the culture in your company is likely to be oriented to the West. Even with the best international business culture training as preparation, you and your colleagues may be somewhat rigid when presented with the cultural tableau presented by China. Because of this challenge, it is useful to recruit and hire Chinese nationals that have already had some form of Western cultural exposure. This may include having lived abroad, having attended a college or university in the West, past business travel outside of China or time spent as the employee of a large multinational company or organization.

Another factor to consider is the ability of key employees to travel internationally. It is difficult for some Chinese to obtain visas to travel to the US and some other Western countries. This can be mitigated by hiring employees that have a current US visa, are married or both. It may also be necessary for your staff to support customers in Taiwan. Travel to Taiwan for Chinese nationals, although not impossible, is very difficult and requires many months of advance planning.

## A MORE TANGIBLE PRESENCE

After you have built a market presence and the orders are accumulating, the next step is to consider establishing real and tangible business in China. Everyone likes to trade locally and launching an official entity in China will be a credible step in becoming a local supplier.

There is a hierarchy of commercial tangibility for foreign companies operating in China. The most informal is airlifting in staff from the home office occasionally to support export sales. The next step is having your own employees in China (via an employment service). After this, a more substantive presence can be in the form of a Representative Office. "Rep Offices" as they are known in local parlance can perform commercial management including marketing, product promotion, sales training and technical service. Rep offices cannot enter into contracts, issue invoices or accept remittances from customers. There is no long-term commitment attached to operating a rep office.

A more substantive business can be had in the form of a trading company. Foreign trading companies can import finished goods, markup the price, convert the currency to yuan, issue official tax invoices and collect payment. In some cases, these entities are tax advantaged. Almost all foreign trading companies are located in the Wai Gao Qiao free trade zone section of Shanghai and carry a capitalization requirement of US $200,000. Trading companies are often a good choice for companies that want to serve the Chinese market but plan on keeping manufacturing at home.

The most concrete form of entity available to foreign companies is the Wholly Foreign Owned Entity (WFOE). WFOEs can be resident in any of China's special economic zones and a variety of attractive tax incentives are available. This type of entity allows foreign companies to manufacture in China and be considered local producers (no import duties are levied). They can sell domestically as well as export to markets outside of China. Officially, there is a very small registered capital requirement, but from a practical perspective, US $200,000 is the minimum entry requirement.

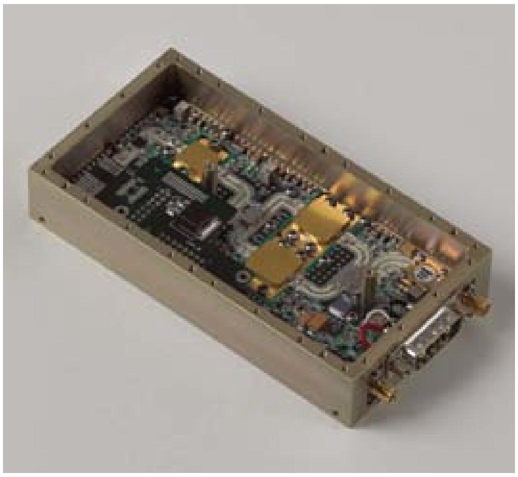
## CONCLUSION

The most important factor in launching a successful sales effort in China is organizational persistence. This process can be enlightening and fun for your company, but it is work. Changing the way that you do business is never easy and will stretch your colleagues and the corporation. International travel, long hours spent on the phone calling across multiple time zones, rapid paced demands and unique technical requirements are ever-present challenges. To keep your company on target, remember that you got to this point because you have a product that is in demand in China and many Western companies have succeeded by following the same route. With dedicated effort, new customer relationships will emerge, orders will become substantial and profits will increase. ■

EastBridge Partners LLC, headquartered in Boston, MA, with offices in Hong Kong, Shanghai and Suzhou, PRC, is a specialized consulting company formed in 2003 to meet the emerging needs of European- and North American-based companies seeking professional guidance in establishing their businesses in Asia. Clients include both large and small manufacturers of advanced materials, consumer items, industrial goods, electronic components, high technology products and software. Please visit http://www.EastBridgePartners.com for more information.

## Reference

1. Editor's Note: More information on EAR may be obtained in "Export Compliance: Understanding ITAR and EAR," by Shawn Cheadle, *Microwave Journal*, Vol. 48, No. 10, October 2005, pp. 80–91.



# THE MAKING OF A WIMAX POWER AMPLIFIER

The power amplifier in telecommunication is one of the oldest pieces of the transmission system and has continuously evolved over the years. Over the past decade, RF power amplifier design has witnessed tremendous improvement with the advent of window-based computer-aided design, allowing engineers to do real-time modeling and load-pull measurements before even lifting a soldering iron. In addition, manual and cumbersome test equipment that could only do basic modulation has given way to sophisticated test equipment that allows us to create complex digital signals and make measurements in seconds.

The days of fickle transistors with limited power handling and low frequency response are no more. Better power devices and gain blocks are available and continue to improve each year with regard to linearity and efficiency. Today's new power devices include:

- GaAsFET devices that have better power linearity and the comfort of operating at elevated temperature.
- LDMOS devices that provide lots of power and efficiency without running into complex circuitry to achieve high output power.
- MMICs that not only provide higher power and gain but also serve as RF power pull down and gain controls.
- GaN (gallium nitride) and SiC (silicon carbide) devices, all promising happy days for power amplifier designers.

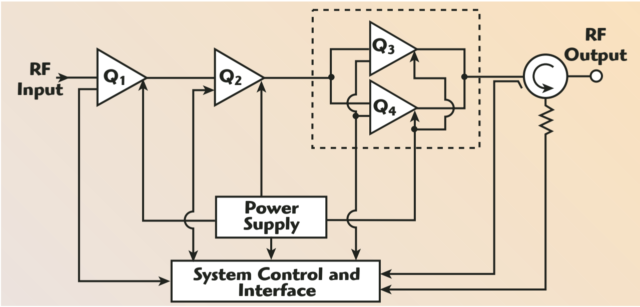
Every component that is involved in the making of power amplifiers has seen a dramatic improvement in quality and functionality.

With all these advancements in power device technology one can imagine that designing a "good" power amplifier should be easy. In some ways that is true, but in many others it is not.

The growth in communication technology brings with it a more stringent demand on power amplifier design engineers to come up with amplifiers that can handle analog and digital modulated signals with little or no distortion, higher efficiency and offer many different interface/communication protocols. Yes, there are engineering tools available to help meet these challenges but the complexity of the new modulation modes, demands for ultra high linearity and differing interface control systems have taken the task to a new level. An engineer with specific experience in wireless power amplifier design is an absolute must, as these designs are no longer "kitchen table projects."

As an example, this article will examine a WiMAX orthogonal frequency division modulation (OFDM) amplifier. This is a standard (IEEE 802.16)-based wireless technology that promises broadband connectivity and can be deployed for various applications. This power amplifier (PA), like in any base station, is usu-

AR WORLDWIDE – MODULAR RF
*Bothell, WA*




▲ *Fig. 1 Layout block diagram.*

ally the most expensive module in the system and the one most likely to diminish the mean time between failure (MTBF) of the base station, so the issue of quality and reliability has to be addressed from the design conception of the PA.

The power amplifier design engineer must understand the system requirements of the amplifier and the IEEE 802.16 requirements effect on the amplifier:

- What is the downlink power need?
- What is the peak-to-average power ratio of IEEE 802.16 OFDM signal?
- What parameters effect the error vector magnitude (EVM)/(RCE) relative constellation error characteristics of the power amplifier?
- The environment that the PA will be operating within is very important as it will influence the choice of power devices, taking into consideration the junction resistance, channel temperature, drain efficiency, along with the mechanical structure and heat sinking.

## A NEW PA DESIGN

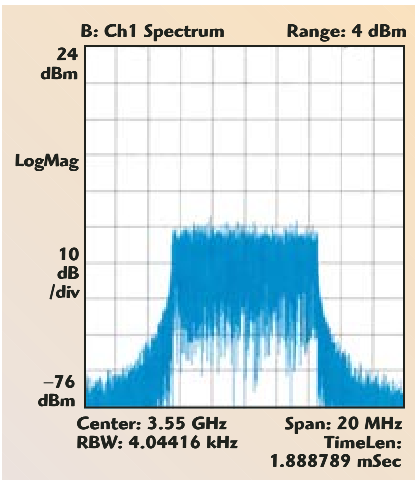
In designing the AR Modular RF 20 W model KMS1070 WiMAX amplifier, Eudyna (formally Fijitsu) GaAsFETs and Hittite devices were chosen considering the power supply requirements and the hostile environment the PA must operate in. The block diagram in ***Figure 1*** illustrates the basic building block of the KMS1070 PA module.

In addition, quality factors were taken into consideration since this module is likely to be produced in thousands, so no technician tweaking will be needed after the board has gone through an automated assembly line. The circuit topology using a balanced configuration was chosen to enhance repeatability and also to take into account the wide band requirement of the PA. Signal reflections due to mismatches caused by component discrepancies that normally degrade digital signal performance will be canceled out using this arrangement. A small-signal simulation was done to optimize gain and stability of the amplifier. The driver stages are perfectly matched I/O power devices that will further reduce the need for tuning the cascade sections in production.

Sparing the mathematical and simulation details of this WiMAX power amplifier design, which, of course, is not any different from any other digitally modulated signal power amplifier, there are some pertinent issues that are vital to achieve a better EVM number in a WiMAX power amplifier.

One of the key issues is the physical location of the DC insertion points to the gate and drain of the power devices. This has a big effect on the RCE number and the quality of the output signal. Phase and amplitude mismatches are also an issue to watch for.

Separating the RF and DC bias voltage ground at the drain of the FET is a good practice which will diminish the chances of the power amplifier going into oscillation because of the large signal envelope swing and the high peak-to-average power ratio of the WiMAX-OFDM signal with approximately 200 sub-carriers.




▲ *Fig. 2 The output spectrum of the KMS1070 PA module with a 3 W WiMAX signal output.*

The Agilent E4440A PSA spectrum analyzer and the 89600 vector signal analysis software were used to verify the design. The results in ***Figure 2*** show the spectral quality of the KMS1070 at 3 W output power of a WiMAX (IEEE 802.16) signal.

The OFDM subframe information in ***Figure 3*** shows the details of the modulation format used, while ***Figure 4*** shows graphic results, indicating how tightly guarded the I/Q and the tabular function is (shown in ***Figure 5***). These data verify that the module has an impressive 1.9 percent EVM across the frequency band of 3.4 to 3.7 GHz. The complementary cumulative distribution function (CCDF) curve (see ***Figure 6***) shows the peak-to-average power deviation is below the Gaussian noise reference line with little power waste. It should be noted that there is no change in the quality of the signal when the bandwidth is increased from 10 to 20 MHz.

The gain-frequency response has to be extremely stable across the entire operating frequency band and a temperature range of 0° to 60°C. ***Figure 7***

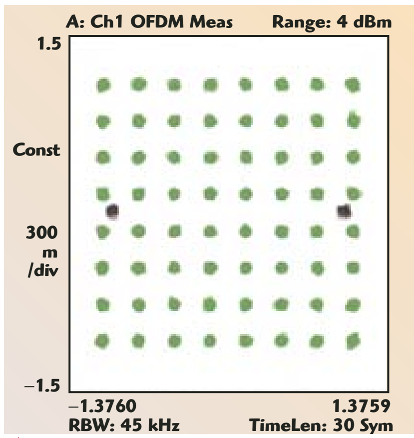
F: Ch1 OFDM Subframe Info 501.1872 mV

| | ModFmt | Len(sym) | Pwr(dBm) |
|---|---|---|---|
| Long Pmbl | QPSK | 2 | 3.1105 |
| FCH | BPSK | 1 | 0.24153 |
| Burst | 64QAM | 29 | 0.25882 |
| Total | *** | 32 | 0.50323 |

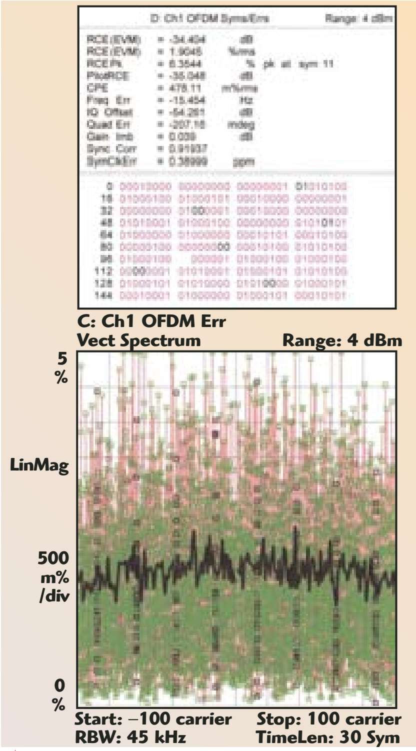
FCH HCSPassed

| | | | | | |
|---|---|---|---|---|---|
| BSID: 0 | FrmNum: | 0 | CnfChg: | 0 | re |
| RateID: 0 | Pmbl1: | N | Len1: | 0 | |
| DIUC2: 0 | Pmbl2: | N | Len2: | 0 | |
| DIUC3: 0 | Pmbl3: | N | Len3: | 0 | |
| DIUC4: 0 | Pmbl4: | N | Len4: | 0 | |
| HCS: 0x0 | zpad: | 0x0 | | | |

▲ *Fig. 3 Downlink subframe information.*

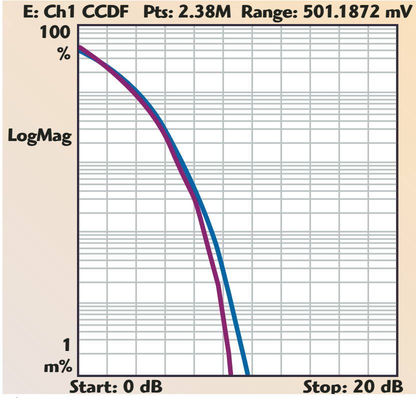



▲ *Fig. 4 I/Q constellation results.*




▲ *Fig. 5 RCE/EVM results.*

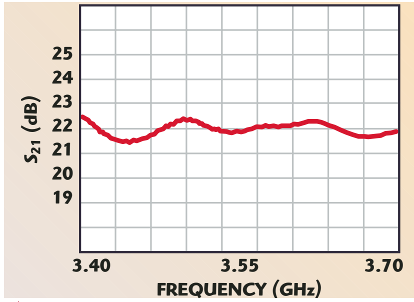
shows a ±0.25 dB result. This number was maintained at all temperatures.




▲ *Fig. 6 CCDF plots.*

## PACKAGING AND LAYOUT

The housing of an amplifier such as this unit is an important part of the design. It is important to try and contain the RF fields and RF ground currents within the RF amplifier portions of the housing. Ideally, if room exists, the RF and control systems should be separated by some physical distance, or contained within a walled structure or box. Secondary components on the ground side of the board should be avoided if possible as that will require the box to be relieved so there is room for the components or wiring. Wherever possible continuity should be maintained across the ground side of the board and narrow ground connections avoided, while utilizing multiple securing screws to keep RF ground currents to a minimum. As much wall thickness as possible should be maintained around the devices or heat sources to help reduce the temperature gradients within the unit.




▲ *Fig. 7 Gain vs. frequency response.*

The KMS 1070 is housed in 6" × 3" × 1" chassis, which is particularly small, and a complex box structure is required to keep the outside dimensions to a minimum. The operational environment (high temperature and low air flow) for this unit's initial application meant that the module has been built to withstand high operating temperatures.

The unit has been equipped with all necessary interfaces to operate an OFDM transmitting terminal. The unit can be shut down via the power circuitry (usually a relatively slow means of controlling the amplifier), or via the gating provided on the early amplification stage. This gating stage will give 50 dB of isolation at the output of the amplifier and is very fast in its operation, typically allowing a turn on and turn off time of 74 nanoseconds.

## CONCLUSION

A power amplifier meeting the OFDM specification has been designed that features consistent performance and long-term reliability. The new KMS1070 power amplifier module utilizes state-of-the-art device technology and the latest innovative design techniques to meet today's demanding communications requirements.

**AR Worldwide – Modular RF, part of AR Worldwide, Bothell, WA (425) 485-9000, www.ar-worldwide.com.**

***RS No. 300***


# A NEW BREED OF COMB GENERATORS FEATURING LOW PHASE NOISE AND LOW INPUT POWER

Picosecond Pulse Labs (PSPL) has introduced a new line of comb generators based on monolithic GaAs nonlinear transmission line (NLTL) circuits. The products are known as PSPL's Low Phase Noise (LPN) Comb Generator product line.

The most commonly used semiconductor device for comb generation has historically been the step recovery diode (SRD). While SRDs have proven very useful in this application, they do have limitations, most prominently the introduction of undesired phase noise and a very limited range of input frequency and power. This new family of comb generators utilizes a different circuit to generate harmonics, a device called a nonlinear transmission line (NLTL). NLTLs employ a completely different physical mechanism for frequency multiplication. The significant technical advantages of NLTL-based comb generators relative to SRD-based comb generators include:

- Low Phase Noise – better phase noise performance improves overall multiplier module performance. The poor phase noise performance of SRD comb generators often limits multiplier phase noise performance.
- Wide Range of Input Frequency – flexibility of input frequency allows changes in input frequency or a single device to be used in multiple applications.
- Low Input Power – relaxes power requirements on amplifiers. This simplifies multiplier design by reducing supply voltages and improving amplifier performance.
- High Power in High Frequency Harmonics – NLTLs generate faster transitions that have more frequency content, producing more power in higher frequency harmonics. NLTLs also enable higher frequency inputs, increasing the power in each harmonic and increasing harmonic spacing, which simplifies filter design. This allows the use of multiplier-based frequency sources at higher frequencies than was previously possible with SRD-based comb generators.

The LPN Comb Generators cover inputs ranging from 80 MHz to 2 GHz and outputs to 50 GHz. ***Table 1*** lists the various LPN Comb Generator models and their input/output characteristics.

The LPN Comb Generator product line currently has three major sub-groupings:

- Low Input Power (models 7100, 7102, 7103) – designed to operate with less input power.

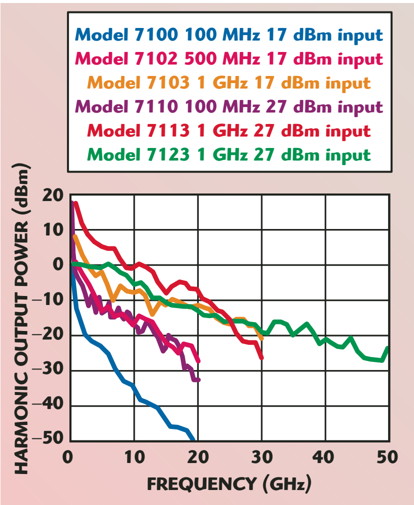
PICOSECOND PULSE LABS
*Boulder, CO*

**TABLE I**

**LPN COMB GENERATOR MODELS**

| Model | Typical Input Power (dBm) | Typical Input Frequency Range (MHz) | High Output Harmonic (GHz) |
|---|---|---|---|
| LPN 7100 | 15 to 20 | 80 to 250 | 20 |
| LPN 7102 | 15 to 20 | 300 to 700 | 20 |
| LPN 7103 | 15 to 20 | 500 to 1200 | 30 |
| LPN 7110 | 20 to 30 | 80 to 250 | 20 |
| LPN 7112* | 20 to 30 | 300 to 700 | 20 |
| LPN 7113 | 20 to 30 | 500 to 1200 | 30 |
| LPN 7123* | 20 to 30 | 800 to 1200 | 50 |
| LPN 7124* | 20 to 30 | 1000 to 2000 | 50 |

*models are not currently released




▲ *Fig. 1 Harmonic output power vs. frequency for six LPN Comb Generator models.*

- High Output Power (models 7110, 7112, 7113) – designed to operate with higher input power (comparable to SRD-based comb generators) to offer maximum output harmonic levels and a "drop-in" solution to replace SRD comb generators and improve phase noise performance.
- Extended Harmonic Frequency Range (models 7123, 7124) – designed to produce more high frequency harmonic content.

Each of these models is offered in small coaxial, surface-mount, or drop-in style packages. Coaxial packages provide easy prototyping, testing and characterization, while surface-mount and drop-in style packages are well suited to volume production assembly.

The output harmonic power versus frequency for six of the LPN Comb Generator models is shown in ***Figure 1***. Each of the models is being driven at its nominal input frequency and power. The same data plotted as conversion loss versus harmonic number shows that each of the models has a comparable conversion loss for a given harmonic, with some modest differences.

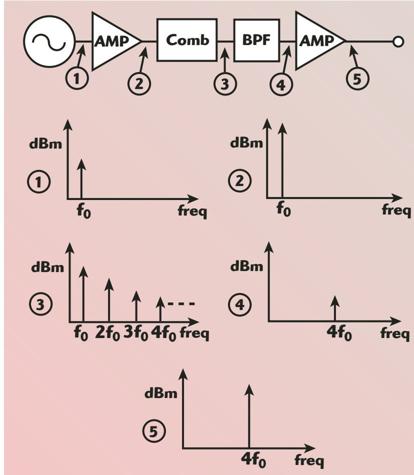
## APPLICATIONS

The primary application for comb generators is as frequency multipliers to produce a high frequency phase-locked to the input. A typical example of this would be to use a 100 MHz crystal reference oscillator and multiply it up to a higher frequency for driving the LO of a mixer in a receiver downconverter. In some cases this multiplication may consist of multiple stages, such as multiplying from 100 to 500 MHz, then from 500 MHz to 10 to 12 GHz for applications such as X-band radar.

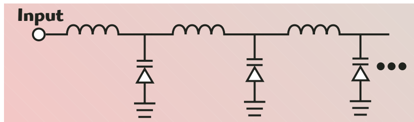
In a multiplier application, the output of the oscillator is typically fed to an amplifier (to obtain the proper drive level for the comb generator). This signal is then fed to the comb generator that generates harmonics of the input signal. These harmonics are spaced at intervals of the input signal frequency. The harmonic of interest is then filtered off with a bandpass filter (passes only the harmonic of interest). Finally, the isolated harmonic is amplified to the desired level. An example diagram of a multiplier chain is shown in ***Figure 2***.

## SRD VS. NLTL OPERATION

SRD comb generators create a fast edge and generate harmonics by sweeping stored minority carriers from the depletion region during the transition from forward to reverse bias with large reverse recovery currents. As a result, SRDs are subject to recombination noise as well as shot noise. These processes add timing jitter to the output pulse, which manifests itself in the frequency domain as additional phase noise above the baseline 20logN increase of the ideal frequency multiplier. This can add as much as 15 dBc/Hz to the output phase noise, depending on the quality of the source used. The NLTL is a synthetic transmission line, where Schottky varactor diodes are distributed along a high impedance transmission line, and their lumped capacitance is "absorbed" into the line (see ***Figure 3***).

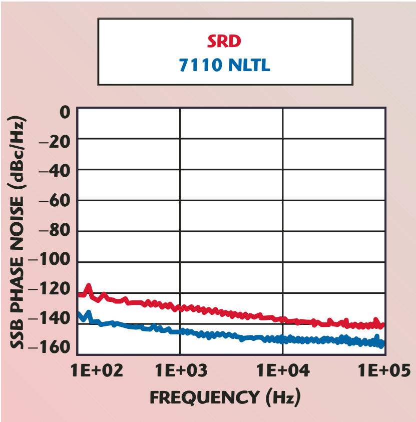



▲ *Fig. 2 A typical comb generator-based multiplier chain.*




▲ *Fig. 3 Nonlinear transmission line (NLTL) basic circuit diagram.*

The capacitance of a reverse biased Schottky diode is nonlinear (voltage dependent) such that the capacitance at low reverse bias is much greater than the capacitance at high reverse bias. As such, a signal propagating on a synthetic transmission line made with varactors experiences a propagation velocity that is voltage dependent. A large step signal that transitions from low to high voltage will be compressed in time as the initial low voltage portion of the step travels down the line slower than the later, higher voltage portion of the step. Consequently, the higher voltage portion of the waveform "catches up" with the lower voltage portion of the step, resulting in "edge compression", increasing the edge speed of the low-to-high transition. This behavior is similar to an ocean wave getting steeper and steeper as it approaches the shore, when the trough of the wave is slowed by interaction with the ocean floor, while the crest continues at a higher velocity, until the wave "breaks."

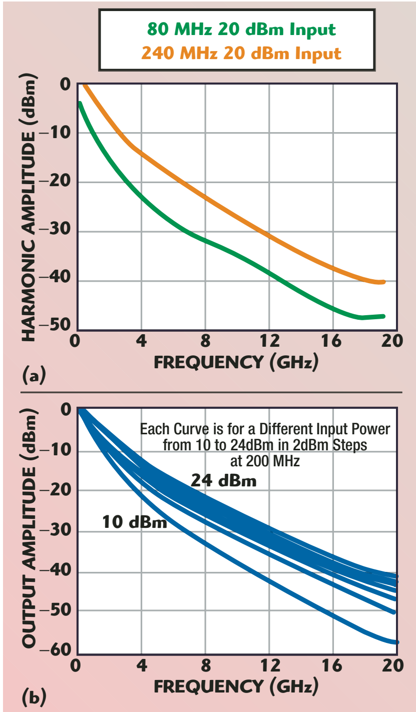



▲ *Fig. 4 Model 7110 NLTL- and SRD-based comb generator residual phase noise comparison, measured at 2 GHz (10th harmonic) with a 200 MHz input.*

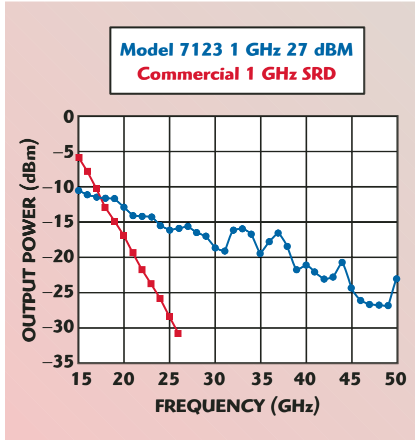
## LPN COMB GENERATOR PERFORMANCE

Since NLTLs are basically passive (albeit nonlinear) majority carrier devices, they do not suffer from recombination and shot noise, and consequently have much better phase noise performance, as illustrated in the comparison residual phase noise plot of NLTL [PSPL Model 7110] and SRD based comb generators shown in ***Figure 4***.

In addition to low phase noise, NLTL-based comb generators also offer several other advantages over narrowband tuned SRD-based comb generators. Typically, SRD-based comb generators have less than a five percent input frequency range and are available only for specific frequencies. SRDs also require a specific amount of input power to effectively drive the harmonic generation process. Since NLTL lines are inherently broadband, they can accommodate well over an octave of input frequency range in a single device and they easily accommodate a broad range of input power (on the order of 10 dB). As an example, see the harmonic power output plots shown in ***Figure 5*** for the LPN model 7100 comb generator operating over a range of input frequencies and input powers.




▲ *Fig. 5 LPN model 7100 output harmonic power at different input frequencies (a) and different input power levels (b).*




▲ *Fig. 6 NLTL and SRD comb generator comparison with 1 GHz, 27 dBm input.*

In addition, since NLTLs have faster transitions, and can be driven at much higher input frequencies than SRD-based comb generators, they have more power in the higher harmonics (see the plot of a LPN model 7123 comb generator vs. a commercial SRD comb generator shown in ***Figure 6***). All of these performance and functional advantages translate into better performance, greater system design flexibility and simpler system architectures.

**Picosecond Pulse Labs, Boulder, CO (303) 443-1249, www.picosecond.com.**

***RS No. 304***

# AUTOMATED TEST AND DATA MANAGEMENT

Spartan Automated Test and Data Management is a value-added software application for automating the measurement and evaluation of electrical performance parameters of RF and microwave components, subsystems and systems. Spartan adds value to the organization through efficient test automation and a built-in data management system.

Although the initial test implementation for Spartan has been S-parameter measurements, its architecture has been designed to serve as a test bed framework that can be expanded to accommodate a wide variety of tests that might be performed on RF and microwave devices. For example, in addition to S-parameter tests, Spartan has implemented a DC attenuation test capability, and passive intermodulation will be added within the next few months. The significance of this capability is that test results for items that are evaluated for a variety of performance parameters can be correlated. Furthermore, if tests are performed at various stages of product development or manufacturing, the results can be compared and variations evaluated. An example of this would be the testing of high reliability devices that are measured before, during and after high temperature burn-in.

## VALUE ADDED IN TEST AUTOMATION

Companies large and small are looking to gain competitive advantage through cost reduction, faster delivery, specification improvement, product quality and customer support. To achieve these goals, companies employ programs such as value stream mapping, lean manufacturing and Six-Sigma Quality. Spartan can be an important contributor toward these goals.

In lean manufacturing and value stream mapping, the objective is to reduce waste and streamline the manufacturing process. A guiding principle in the design and development of Spartan is that it must add efficiency to the test process and users must be able to put it into use with a minimal impact on their current process.

Six-Sigma programs aim at identifying the causes of deviations and eliminating them with the ultimate benefit a decrease in manufacturing defects and improved reliability. Spartan supports Six-Sigma goals through the use of consistent test procedures and performance criteria. Additionally, the data mining

SUMMITEK INSTRUMENTS INC.
*Englewood, CO*

features facilitate design and manufacturing enhancements and process improvement.

## A PRODUCTION EXAMPLE

Spartan is being used by Polyphaser to perform production testing of their lightning protectors. Because Spartan is implemented as a Client-Server application, where various databases reside on the server and are accessible over a secure network, the test procedures are created by Polyphaser engineering in Nevada, and available for use at their production test stations in both Nevada and China.

In their production area, Spartan has been implemented with a bar code reader for data input, which minimizes the chances for error, and a touch screen monitor to keep the test area clear of computer accessories (keyboard and mouse). Testing proceeds as follows:

- The person performing the test scans the part number bar code on the work order; this recalls the test procedure and acceptance specifications from the test sequences database
- Spartan automatically sets up the vector network analyzer (VNA) and verifies calibration status
- Prior to testing the first item, a second bar code is scanned to enter the Work Order Number. Because Polyphaser uses the Auto-Increment Serial Number feature, it is not necessary to enter the serial number. Spartan checks the database of prior tests and enters the next available serial number.
- The first item to be tested is connected to the VNA and the operator presses Run on the touch screen
- The measurement is performed and the operator is given a pass/fail status
- The test operator disconnects that part, attaches the next part, and presses Run

It is useful to note that no knowledge of the test is required by the operator, so labor of all skill levels can be used. Also, the test process is reduced to the barest minimum to cut time and cost. The operator never touches the test equipment, so the test is run exactly as defined in the test procedure (see ***Figure 1***) and the acceptance criteria are consistently applied. This improves data accuracy and reduces errors. In addition, all data is stored for future processing. If the network analyzer goes out of service for any reason, a different network analyzer can be substituted, and even if it is not the same model or from the same manufacturer, the tests can proceed exactly as before. The operator interface and test process are completely independent of the instrument.

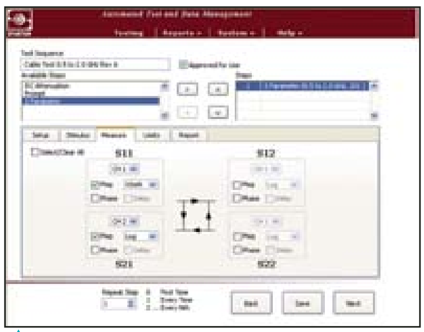
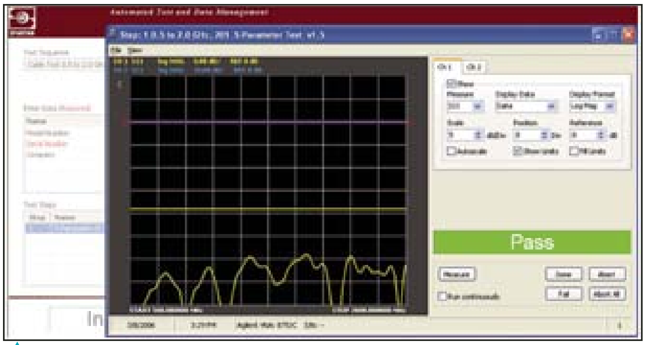


*Fig. 1 The Spartan Test Sequence Editor used to define the test procedure.*



▲ *Fig. 2 Display of test results.*

## AN ENGINEERING EXAMPLE

The previously described process works great for production test, but would leave product development engineers unsatisfied. For product development or troubleshooting, an interactive version of the automated test exists. This allows the engineers to track the performance data on various iterations of the test and annotate the results as desired. In this mode, the analyzer can be running in a continuous sweep mode to monitor performance and then captured on command. Note that this same mode is useful in production testing where parts may be tuned to optimize performance prior to final test.

## TEST DATA MANAGEMENT

Modern automated test systems generate a significant amount of data and within this data resides valuable information beyond a simple pass or fail decision, although that is certainly a first tier need. This information can be used to identify manufacturing trends, track first pass yields, match current production items to prior ship sets, improve product design, evaluate system performance models and more. The ability to readily access that data for analysis is a key feature of Spartan (see **Figure 2**).

Each time that a test is performed, Spartan saves the raw test data along with numerous variables. Some of these variables are system controlled such as time, date, model number and serial number, while others are defined by the organization using Spartan. For example, maybe it is important to be able to keep track of connector types on the product; this can then be added as a database variable.

Because Spartan includes a built-in data management system, authorized users can mine the data and filter it against any of the variables in the database using the Spartan query tool. If new test variables are added at some point in the future, the existing data is not impacted and the sort routines will work with both the old and the new data. This is an important advantage over systems without a data management system.

## DATA MINING EXAMPLES

Sorting, categorizing and analyzing data is extremely important. Some examples of the data management functions facilitated by Spartan include:

- Trend Analysis – Compare performance between production lots to identify changes — good or bad.

- Sort Parts by Performance – Categorize parts based on performance results and save the best parts for the most demanding requirements.
- Compare Design Iterations – What are the variables affecting performance? Can cost be reduced through design changes? Material changes? Process changes?
- Determine First Pass Yields – How often do parts need to be reworked? Are some manufacturing lines more consistent or producing better parts?
- Phase and Amplitude Match to Prior Shipments – Compare and match electrical performance to ship sets previously supplied.

## THE MAKE vs. BUY DECISION

Modern test instruments and software development tools make it easier than ever to realize an automated measurement capability. So why consider an investment in Spartan?

- Usability – Summitek's products have long been praised for the quality of the operator interface and ease of use.
- Test Efficiency – The Spartan design is focused on streamlining the testing process.
- Flexibility – Spartan provides flexibility in the types of tests that can be performed and the way in which to perform them.
- QA Process Control – The Spartan Test Sequence Editor is used to define how measurements are to be performed and the acceptance criteria to assure everybody follows the same process each and every time.
- Test Data Management – The ability to readily access test results for additional analysis and statistical processing is a key product differentiator.
- Professional Software Development, Code Control and Long-term Support – Extensive testing before product release means the user is operational with minimal impact on his or her business. In addition, by participating in the Software Maintenance Program the user can stay current with Spartan test capabilities and features.
- Cost – The investment in Spartan is readily justified relative to any alternative, including continuing to operate in a non-automated mode.

## CONCLUSION

Spartan Automated Test and Data Management raises the bar in the test and evaluation of RF and microwave components and systems. Implementing Spartan in production facilitates lean manufacturing goals and will provide access to the data that can provide a competitive edge. The flexibility and power of Spartan allows the user to confidently outsource his or her test automation, so that the focus is on deriving benefit from the information contained within the data rather than the data collection.

Persons interested in Spartan can evaluate the product prior to purchase by contacting Summitek or visiting www.SpartanTest.com.

**Summitek Instruments Inc., Englewood, CO (303) 768-8080, www.summitekinstruments.com.**

***RS No. 302***

# A PLASTIC-PACKAGED 13.5 TO 15.5 GHZ PHEMT POWER AMPLIFIER

Cost is a major factor driving the component choices for today's communication systems. Low cost without sacrificing performance is key. One of the major device cost drivers has traditionally been component packaging. To help alleviate this expense, Mimix Broadband is introducing a Ku-band gallium arsenide (GaAs) power amplifier module (PAM) in a low cost 4 × 4 mm, plastic QFN surface-mount package.

Using GaAs pseudomorphic high electron mobility transistor (PHEMT) device model technology, the CMQ1432-QH PAM provides 33 dB of gain and delivers 32 dBm of saturated output power over a 13.5 to 15.5 GHz frequency range. The new low cost, ultra-compact PAM is lead-free, with 50 Ω input and output terminals, and is designed to offer VSAT and multi-point radio system manufacturers significant cost savings with no degradation in performance or quality.

**TABLE I**

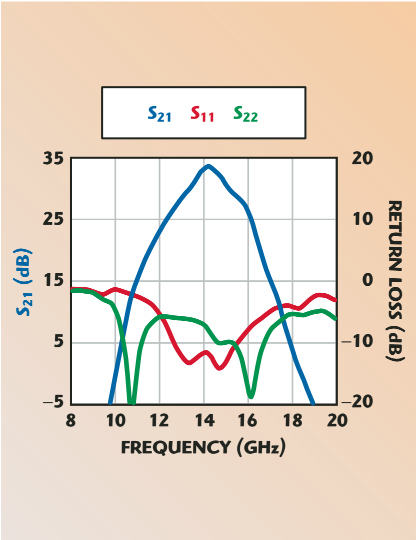
**ELECTRICAL SPECIFICATIONS**

| Parameter | Min. | Typical | Max. |
|---|---|---|---|
| Operating frequency (GHz) | 13.5 | | 15.5 |
| Drain current (DC bias under RF drive) (mA) | – | 770 | 950 |
| Drain voltage (V) | 5.9 | 7 | 7.5 |
| Gate voltage (RF ON) (V) | –2 | – | –0.2 |
| Gate current (mA) | – | 0.5 | 5 |
| Linear gain (dB) | 27 | 33 | 36 |
| Input/output VSWR | – | 2.0:1 | 3.0:1 |
| Noise figure (dB) | | 9 | 11 |
| Saturated output power (dBm) | 30.5 | 32 | 34 |
| Power @ 1 dB compression gain (dBm) | | 29 | |
| Power added efficiency (at saturation) (%) | | 27 | |
| Output power variation over temperature (dB) | – | 0.5 | 1 |

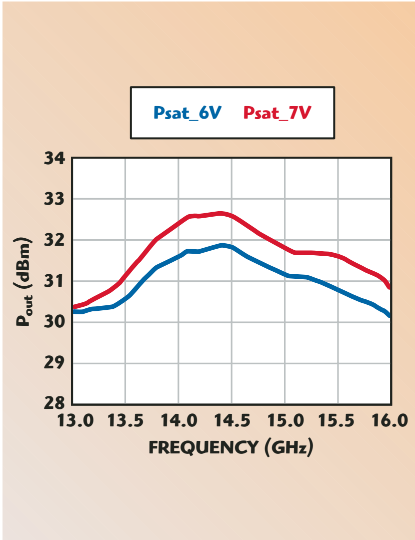
## PRODUCT DESCRIPTION

The CMQ1432-QH plastic-packaged PHEMT PAM features a high efficiency peak power operation and an enhanced thermal design based on a comprehensive thermal analysis. It can supply 32 dBm of saturated power output and also features an analog bias current adjustment for low power efficiency enhancement. Its mean time between failures (MTBF) has been established for a 10-year lifetime. ***Table 1*** lists its electrical specifica-

MIMIX BROADBAND INC.
*Houston, TX*




▲ *Fig. 1 Small-signal performance at $V_d$ = 7 V and $I_d$ = 770 mA.*




▲ *Fig. 2 Saturated output power at $P_{in}$ = 8 dBm and $I_{dq}$ = 770 mA.*

tions. **Figures 1** and **2** show the CMQ1432-QH power amplifier module's typical performance curves.

The new CMQ1432-QH PAM is unconditionally stable and its internal matching allows for a reduction in external components, thus offering a simple and low cost amplifier solution. Its RoHS compliance and on-chip ESD protection make it ideal in all manufacturing environments. The CMQ1432-QH PAM is intended for use as the final amplifier in extended Ku-band satellite applications.

Although the ultra-compact surface-mount QFN plastic package is considered nonhermetic, the package is regarded as a moisture sensitive level 1.

Engineering samples are currently available from stock and technical support is available from the company's applications engineers with only a phone call. An evaluation board is also available. The CMQ1432-QH datasheet and additional product information may be obtained from the company's web site.

**Mimix Broadband Inc.,**
**Houston, TX (281) 988-4600,**
**www.mimixbroadband.com.**

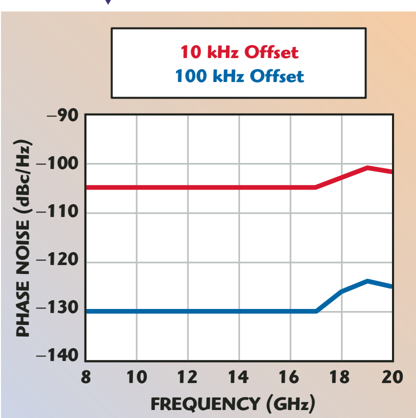
***RS No. 303***

# REVOLUTIONARY PHASE NOISE PERFORMANCE AT 20 GHZ USING SIGE TECHNOLOGY

Micro Lambda Wireless Inc. has just released a new line of microwave oscillators that has set a new standard for phase noise performance. Utilizing new SiGe transistor technology, oscillators are now available with unparalleled phase noise performance at 20 GHz.

New production transistors have been integrated into wide band thin-film oscillator circuit designs to yield 6 to 18, 8 to 18 and 8 to 20 GHz frequency ranges. Previous wide band oscillator designs were limited in their phase noise performance by the availability of good microwave transistors. Silicon bipolar transistors only operated up to 15 GHz with good performance. Above 15 GHz, designs had to utilize FET transistors, which limited their phase noise performance.

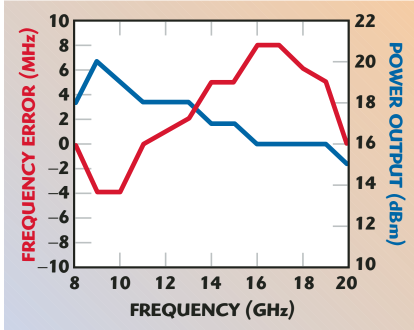
*Fig. 1 Phase noise performance of the Extreme series 8 to 20 GHz oscillator.*




Early in the 1990s Micro Lambda Wireless set the standard for 8 to 20 GHz YIG-tuned oscillators with phase noise performance of –108 dBc/Hz at 100 kHz offset. Now the company has set a new standard for phase noise performance at 20 GHz with guaranteed phase noise of –123 dBc/Hz at 100 kHz offset. This is a 15 dB noise improvement over previous designs. ***Figure 1*** shows the new 8 to 20 GHz oscillator's phase noise performance versus frequency for both 10 and 100 kHz offset frequencies.

The MLXB-Extreme series of oscillators is comprised of the MXLB-0818 (8 to 18 GHz), MLXB-0618 (6 to 18 GHz) and MLXB-0820 (8 to 20 GHz) YIG-tuned oscillators. They operate from +12 and –5 VDC bias voltages and utilize a low power heater operating at +12 VDC as well. High output power levels of +14 to +15 dBm minimum, depending on frequency band, are available in the standard products. Wide bandwidth FM coils of 2 MHz minimum are provided for phase locking and/or modulation throughout the product offering. ***Figure 2*** shows the Extreme series oscillator's typical frequency error and power output versus frequency.

MICRO LAMBDA WIRELESS INC.
*Fremont, CA*




▲ *Fig. 2 Frequency error and power output performance of the 8 to 20 GHz oscillator.*

Standard units are available operating over the 0° to +65°C temperature range. Models are available operating over the extended temperature range of –40° to +85°C on special order.

The oscillators utilize thin-film construction for superior reliability and low cost, and are available in standard 1.25" cube or 1.75" cylinder packages that operate over both commercial and military environments. Units up to 18 GHz are also available in 1" cube packages for commercial applications, making all the units in this new series mechanically interchangeable with existing designs. All units in this new series can be ordered with optional integrated or remote analog, 12-bit TTL or 16-bit serial drivers.

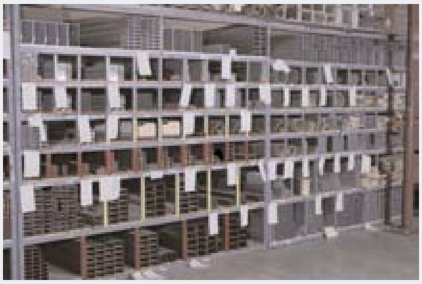
These new oscillators are ideal for test and measurement designs where previous design architectures utilized lower frequency oscillators with the higher frequency ranges obtained by multiplication. Utilizing these new low noise sources could make it possible to change the architecture of new designs to utilize higher frequency sources in the fundamental mode and minimize the multiplication factors to obtain higher frequencies. An added benefit could be the potential of further improving lower frequency phase noise performance by dividing the frequencies of these higher frequency oscillators down, thereby gaining phase noise performance. Additional applications include communications, SatCom and TeleCom, wide band receivers for SIGINT and ELINT, ECM, EW, and a multitude of general-purpose applications.

**Micro Lambda Wireless Inc., Fremont, CA (510) 770-9221, www.microlambdawireless.com.**

***RS No. 301***

*The following booth numbers are complete as of April 11, 2006.*

## Silver Waveguide Tube



Coin silver waveguide tube has been added to the company's growing list of "in stock" items. The company stocks all ridged aluminum, copper, bronze, invar and stainless steel waveguide tube along with the newly added WR3 to WR75 coin silver. It stocks aluminum flange in sizes WR22 to WR137 and aluminum double-ridged waveguide tube in all popular sizes. The company also supplies WR28 to WR284 bronze and aluminum cast bends. It offers "same day" shipping for all items in stock.

***A-Alpha Waveguide Co., El Segundo, CA (310) 322-3487, www.a-alphawaveguide.com.***
**Booth 423** **RS 216**

## Filter and Duplexers

These passband filter and duplexers are available in three different frequency ranges that

include 2150, 2600 and 3500 MHz for WiMAX technology applications. Main features for the 2150 MHz frequency range include a center frequency tunability of 2067.5 to 2242.5 MHz, frequency shift of 175 MHz and 20 dB return loss bandwidth of 84 MHz. Insertion loss in the bandwidth Fo±42 MHz is 1.5 dB maximum.

***ABF Elettronica s.r.l., Arcore (Mi), Italy +39 039 613561, www.abfelettronica.it.***
**Booth 852** **RS 217**

## Dielectric Chip Capacitors

These single layer air or vacuum chip capacitors offer high working voltage and ultra-

low intrinsic ESR. Capacitors with air or vacuum as a dielectric have no practical limitation to their use in the upper GHz spectrum (10 to 200 GHz) with respect to RF losses. Furthermore, the dielectric constant $\varepsilon_o$ is not subject to change as frequency increases into the upper GHz area. These high performance chip capacitors provide an optimum and reliable workhorse for most demanding mm-wave applications (US Patent No.: 76,755,124B2).

***ADC Tech International Ltd., Wanchai, Hong Kong 852-2527-4565, www.adccomponent.com.***
**Booth 323** **RS 218**

## Miniature Pulse Modulator

The SPST0XXXH series is a miniature pulse modulator that features a unique design and


offers input/output in a 50 Ω system under any condition (switch off or on) resulting in a sharp and clear rise/fall time. Features include: no need for isolator at input/output, fast response time of 4.0 nsec, low insertion loss of 3 dB is typical, high isolation of 80 dB and three frequency ranges are available including 2 to 6, 6 to 18 and 2 to 18 GHz. Applications include on and off switch, and it is ideal for radar transmitter (emitter) with a high data rate transmission of up to 60 MBS.

***Advanced Microwave Inc., Sunnyvale, CA (408) 739-4214, www.adv-mic.com.***
**Booth 411** **RS 219**

## Bipolar Transistor

The model MDS500L is a Vcc = 50 V, class C bipolar transistor specifically designed to han-


dle the heavy pulsing of the Mode-S ELM format (32 µS on/18 µS off × 48 pulses burst). The transistor provides greater than 500 W of output power with an input power of 70 W. The hermetically sealed package and gold metal die with integral emitter ballasting provide optimal reliability. This device is robust enough to operate at full power into a 3:1 VSWR with no damage.

***Advanced Power Technology RF, Santa Clara, CA (408) 986-8031, www.advancedpower.com.***
**Booth 1905** **RS 220**

## Broadband Power Amplifier

The model SSPA 0.5-2.5-10 is a high power, broadband, silicon carbide (SiC) RF amplifier

that operates from 0.5 to 2.5 GHz. This power amplifier is ideal for broadband military platforms as well as commercial applications because it is robust and offers high power over a multi-octave bandwidth. This amplifier operates with a base plate temperature of 85°C with no degradation in the MTBF for the SiC devices inside. This amplifier offers a typical P1dB of 15 W at room temperature. Size: 6" × 8" × 2".

***Aethercomm Inc., San Marcos, CA (760) 598-4340, www.aethercomm.com.***
**Booth 1810** **RS 221**

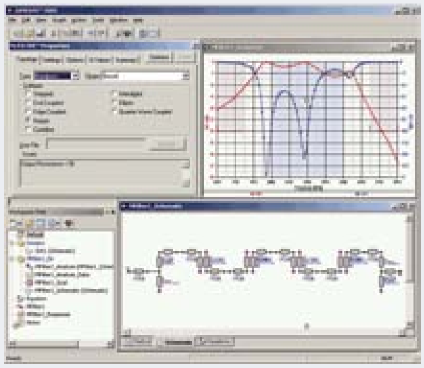
## Four-port Network Analyzer

The N5230A four-port PNA-L network analyzer combined with the new 20 GHz four-port

test set (product Z5623A, opt k44) provides an 8×8 matrix of measurements and eight-port error correction to fully characterize eight-port devices, including isolation characteristics between ports. The PNA-L N5230A's scalar mixer calibration function provides accurate, match-corrected conversion loss measurements of mixers and converters. The Equation Editor allows PNA series network analyzers to automatically calculate and show application-specific parameters such as the K-factor of amplifiers from S-parameter measurement data.

***Agilent Technologies Inc., Component Test Division, Santa Rosa, CA (800) 829-4444, www.agilent.com.***
**Booth 1429** **RS 222**

## Design and Verification Software



EMDS is a 3D electromagnetic (EM) design and verification product. Based on the Finite Element Method (FEM), EMDS delivers the full-wave electromagnetic modeling capability needed for characterizing 3D design geometries. The company also announces access to Eagleware's powerful RF architecture and industry-standard circuit synthesis tools from within the Advanced Design System in Release 2006A. These announcements provide more design insight and intelligence allowing RF and microwave designers to start closer to the finish line.

***Agilent Technologies Inc., EEsof Division, Santa Rosa, CA (800) 829-4444, www.agilent.com.***
**Booth 1429** **RS 223**

# NEW WAVES

## Built-in Measuring Receiver

The PSA built-in measuring receiver (Option 233) converts the general-purpose, PSA series high performance spectrum analyzer into the flexible and compact N5531S measuring receiver system. The N5531S consists of a PSA including an optional audio input, a P-Series power meter and a sensor module with single-input connection up to 50 GHz. It sets a new standard for signal generator and attenuator calibration to meet the most stringent metrology/calibration requirements.

***Agilent Technologies Inc.,***
***Signal Analysis Division,***
***Santa Rosa, CA (800) 829-4444,***
***www.agilent.com.***
***Booth 1429*** ***RS 224***

## Wireless Connectivity Test Set

Bluetooth® wireless technology was initially designed to support a peak data rate of 1 Mbps; however, the specification evolved to provide 2 to 3 Mbps peak data rates with the introduction of enhanced data rate (EDR). The N4010A wireless connectivity test set (with option 107) supports Bluetooth EDR test mode, ensuring devices adhere to the Bluetooth 2.0 standard by enabling loopback testing of EDR transmitters and receivers. With six of eight EDR test cases built-in, the N4010A provides fast, accurate EDR testing.

***Agilent Technologies Inc.,***
***Wireless Division,***
***Spokane, WA (800) 829-4444,***
***www.agilent.com.***
***Booth 1429*** ***RS 225***

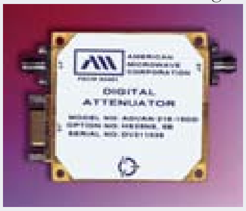
## Microwave Components

These microwave components include waveguides and tubes that confine and guide propagating electromagnetic waves, normally consisting of hollow metallic conductors, usually rectangular, elliptical or circular in cross section and sometimes containing solid or gaseous dielectric materials. Other microwave components include electroforming services on WG transitions, transducers, filters, polarizers, horns, antenna feeds and flight qualified hardware for satellite applications.

***A.J. Tuck Co.,***
***Brookfield, CT (203) 775-1234,***
***www.ajtuckco.com.***
***Booth 2105*** ***RS 226***

## Digital Attenuator

The model ADVAN-218-15DD with options HS25NS and 5B is a digitally variable attenuator. This attenuator operates over the frequency range of 2 to 18 GHz with a switching speed of 25 ns, an insertion loss of 6 dB and a dynamic range of 15 dB minimum. This attenuator utilizes a 5-bit binary control. Size: 1.90" × 2" × 0.45".



***American Microwave Corp.,***
***Frederick, MD (301) 662-4700,***
***www.americanmicrowavecorp.com.***
***Booth 723*** ***RS 227***

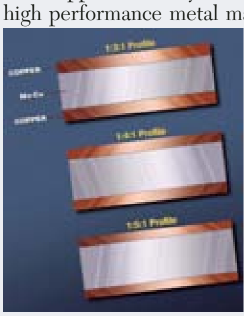
## Microelectronic Packages

These high precision glass-to-metal seal (GTMS) and ceramic-to-metal seal (CTMS) products are designed for mission-critical electronics used in the aerospace, defense, industrial, telecommunications and petrochemical markets. The microelectronic packages range from standard outlines (transistor outlines, dual in-line, plug-ins and flatpacks) to sophisticated and complex metal composite packages. HCC offers an expertise in critical machined features for substrate placement and offers a variety of high frequency RF and low frequency DC feedthrus.

***AMETEK HCC Industries,***
***New Bedford, MA (508) 998-3141,***
***www.hccindustries.com.***
***Booth 616*** ***RS 228***

## Metal Matrix Composites

This copper clad molybdenum-copper strip is a high performance metal matrix composite that offers high thermal conductivity. It offers an adjustable coefficient of thermal expansion from 6 to 10 ppm/°K or beyond and is available in a variety of ratios (1:3, 1:4, 1:5) and custom profiles as well as a range of Mo-Cu compositions (70/30, 80/20, 85/15).

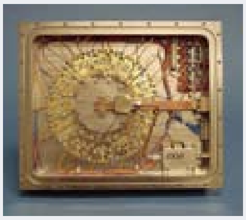


***AMETEK Specialty Metal Products,***
***Wallingford, CT***
***(203) 949-8809,***
***www.ametekmetals.com.***
***Booth 618*** ***RS 229***

# NEW WAVES

## Millimeter-wave Power Amplifiers

These millimeter-wave power amplifiers are based on radial combiner technology and can be configured as power modules or mounted in racks with integral power supply and heat management components. The product line operates in a frequency range of 12 to 40 GHz. Model C2630-45 operates in the 26 to 30 GHz spectrum with 30 W saturated output power. Gain is 45 dB and DC power is +12 V at 30 amps. Standard features include over temperature shut down and TTL output enable. A fast pulse (< 20 nsec RF rise/fall time) function is optionally available.



***Microwave Power Inc.,***
***Santa Clara, CA (408) 727-6666,***
***www.microwavepower.com.***
**Booth 1919** **RS 230**

## Cryogenic Amplifiers

These cryogenic amplifiers operate at temperatures well below those of liquid nitrogen (77K,-196°C), resulting in the absolute lowest noise figures achievable (as low as 0.1 dB). Frequency of operation is 0.1 to 18 GHz, but can be optimized for an exact frequency of operation. These amplifiers are unconditionally stable and efficient providing both high reliability and the lowest possible energy consumption (3.0 VDC). This amplifier is ideal for R&D projects, space applications, medical applications, telephonics, telemetry and other receivers.

***AmpliTech Inc.,***
***Hauppauge, NY (631) 435-0603,***
***www.amplitechinc.com.***
**Booth 904** **RS 231**

## Modulation Measurements Option

This WCDMA/HSDPA modulation quality measurements option is designed for its MS2781A Signature™ high performance signal analyzer. When the option is combined with Signature's signal analysis capability, the result is a comprehensive suite of measurements for developers of WCDMA/HSDPA base stations and related subsystems (for example, power amplifiers) at both the development and production stages. Signature is part of the company's portfolio of test solutions for digital mobile communications.

***Anritsu Co.,***
***Morgan Hill, CA (800) 267-4878,***
***www.us.anritsu.com.***
**Booth 1829** **RS 232**

## Simulation Software

This electromagnetic and circuit simulation software is designed for high performance RF and microwave design. By leveraging electromagnetics across component, circuit and system design, the company is able to achieve best-in-class design, from complex antenna systems, RF circuits (for example, LNAs, PAs, mixers and VCOs) and integrated systems (for example, transceivers, LTCC, SiP and MCM front-ends). Achieve 10× improvements in design complexity and design time using HFSS™ and Nexxim® dynamically linked with Ansoft Designer®.

***Ansoft Corp.,***
***Pittsburgh, PA (412) 261-3200,***
***www.ansoft.com.***
**Booth 1105** **RS 233**

## Processing Board

This wideband (2.2 GSPS) data acquisition and real-time processing board features the ATMEL 2.2 GSPS 10-bit A/D chipset, an Altera Stratix II FPGA, 512 MB of SO-DIMM memory, two 600 MSPS D/A chips, a USB 2.0 interface, a PCI interface and two SCSI connectors for real-time LVDS data output. The board is suitable for a number of diverse applications including wideband digital transceiver for radar or sonar, digital RF memory (DRFM), information gathering and instrumentation.

***Applied Radar Inc.,***
***North Kingstown, RI (401) 295-0062,***
***www.appliedradar.com.***
**Booth 1915** **RS 234**

## High Frequency EDA Software

Microwave Office® 2006 design suite has been radically enhanced to provide a powerful and flexible RF/microwave design environment. The software offers ease-of-use, powerful technologies, and openness and interoperability that enables integration with best-in-class tools for each part of the design process. Microwave Office 2006 design suite now includes the APLAC world class, foundry-approved circuit simulation engine, along with the company's own robust simulators, in the AWR open design environment, delivering key productivity improvements for RF/microwave design.

***Applied Wave Research Inc.,***
***El Segundo, CA (310) 726-3000,***
***www.appwave.com.***
**Booth 1629** **RS 235**

## Solid-state Power Amplifier

The model KMS1070 is a 3.4 to 3.7 GHz solid-state power amplifier module designed for wireless broadband networks. This 20 W, 43 dBm output linear power amplifier offers a scaleable gain of 20 to 50 dB and is designed to meet the WiMAX 802.16d specifications. It can be modified to meet various types of OFDM or NPR requirements. This model was custom designed and built for the emerging wireless access market. The KMS1070 was created in 45 days to meet a client's selected frequency band and a demanding linearity specification.

***AR Worldwide Modular RF,***
***Bothell, WA (425) 485-9000,***
***www.ar-worldwide.com.***
**Booth 1104** **RS 236**

## Broadband Amplifiers

The model 15S5G7 and model 30S5G7 are 15 and 30 W amplifiers respectively designed for the 5 to 7 GHz frequency range. These broadband amplifiers are well suited for testing WiMAX components because the amplified signal they produce is virtually indistinguishable from the signal generator's output. In fact, their performance enables them to be used as substitute transmitters. Since the linearity of the amplified signal is as strong as the signal generator there is no interference with adjacent channels. In addition, the units' high peak-to-average power ratio means they deliver more useable power.

***AR Worldwide RF/Microwave Instrumentation,***
***Souderton, PA (215) 723-8181,***
***www.ar-worldwide.com.***
**Booth 1104** **RS 237**

# NEW WAVES

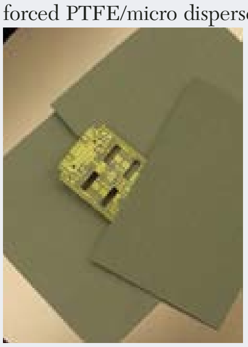
## EMI Absorbers

These Wave~X® absorbers suppress noise at the source, often eliminating the need for complex shielding solutions. Thin, flexible WAVE~X is offered in an array of materials, sizes, features and formulations. WAVE~X enhances RFID performance and absorbs radiated emissions. These absorbers operate in a frequency range from 10 MHz to 40 GHz and offer good near-field attenuation and mode suppression. The WAVE~X has an easy attachment that allows a user to just peel and stick and can be cut to any size and shape. Size: 0.06 to 1 mm.

***ARC Technologies Inc.,***
***Amesbury, MA (978) 388-2993,***
***www.arc-tech.com.***
**Booth 1813** **RS 238**

## Ceramic Laminate

The AD1000 laminate is a woven glass reinforced PTFE/micro dispersed ceramic with $\varepsilon$= 10.2. AD1000 offers a good insertion loss and loss tangent of 0.0023 at 10 GHz and low moisture absorption of 0.02 percent, which is critical in maintaining low loss after processing. PTFE-base with woven glass reinforcement offers good dimensional stability and overcomes brittleness issues with ceramics. Low CTE values and high thermal conductivity are available (0.81 W/m-K) for high power microwave applications.



***Arlon,***
***Rancho Cucamonga, CA (909) 987-9533,***
***www.arlon-med.com.***
**Booth 1835** **RS 239**

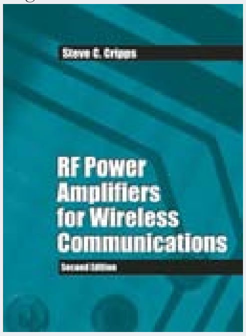
## Single-chip GPS Receiver

The model ATR0635 is a single-chip designed for weak signal tracking GPS technology. This model integrates a complete ANTARIS™ 4 GPS receiver including ROM-based Super-Sense™ software. The small size plus the low power consumption of 62 mW in continuous power mode make the ATR0635 a good fit for handheld and mobile applications (mobile phones, PDAs, smartphones, after-market navigational and recreational consumer products). The ATR0635 supports WAAS, EGNOS and A-GPS, and provides different low power modes to reduce the power consumption down to 5 microAmpere. Size: 7 × 10 mm.

***Atmel,***
***Heilbronn, Germany +49 7131 67-2081,***
***www.atmel.com.***
**Booth 637** **RS 241**

## New Edition of PA Design Book

Several "just published" books for microwave engineers are now available. The second edition of Steve Cripps' *RF Power Amplifiers for Wireless Communications* is sure to attract the attention of all microwave engineers, from freshly minted to seasoned veteran. Addressing topics ranging from basic PA design to advanced linearization techniques, the book includes a CD-ROM packed with timesaving tools for PA performance analysis.




***Artech House,***
***Norwood, MA (800) 225-9977,***
***www.artechhouse.com.***
**Booth 519** **RS 240**

## High Power GaN HEMT

The model EGN010MK is a GaN HEMT device that is in a format compatible with ADS and MWO. Eudyna's GaN HEMT offers high efficiency, high gain, ease of matching, greater consistency and broad bandwidth for high power L-band amplifiers with 50 V operation. These devices target applications that are low current and wideband applications for high voltage. This model features a high voltage operation of $V_{DS}$=50 V, high power of 41 dBm is typical at P3dB and high efficiency of 60 percent is typical at P3dB.


***Auriga Measurement Systems,***
***Lowell, MA (978) 441-1117,***
***www.auriga-ms.com.***
**Booth 2531** **RS 242**

## Custom Test Systems

These application specific test systems are developed from user description without a nonrecurring engineering charge and are available in bands from DC to 18 GHz. Available packaging are 19" rack or bench mount and includes detailing of connector placement, port labeling and private labeling. Control options include GPIB, RS-232, RS-422, RS-485, Ethernet or local control options such as 10 digit keypad with text display, toggle switches, rotary switches or touch screen pad with display. Systems may include virtually any electronic component.

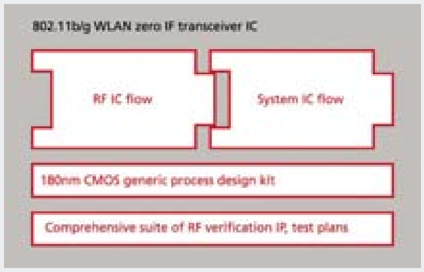
***BroadWave Technologies Inc.,***
***Franklin, IN (317) 346-6101,***
***www.broadwavetech.com.***
**Booth 1121** **RS 244**

## Oven-controlled Crystal Oscillator

The OXLN series is an oven-controlled crystal oscillator (OCXO) designed for applications where ultra-low phase noise and high stability are required. This series offers frequency from 10 to 120 MHz and features SSB phase noise as low as –130 dBc/Hz at 100 Hz offset and –170 dBc/Hz at 100 kHz offset, stability versus temperature ±0.05 ppm typical. Size: 38 × 38 mm.

***Bowei Integrated Circuits Co. Ltd.,***
***Shijiazhuang, Hebei, China***
***+86-311-87091891, www.cn-bowei.com.***
**Booth 2210** **RS 243**

## RF Design Kit

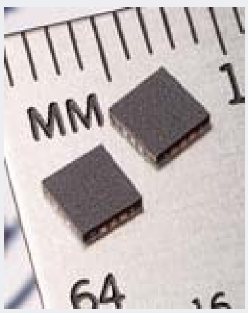



The Cadence® RF Design Methodology Kit helps shorten product development cycle time by increasing silicon predictability and enabling greater RF design productivity. It demonstrates advanced methodologies for intelligently managing RLCK parasitics, inductance synthesis and modeling, and linking system-level design with IC design. The kit also comprises methodologies that enable designers to accurately, yet rapidly verify complete designs that include system-level digital, analog baseband and RF circuitry.

***Cadence Design Systems Inc.,***
***San Jose, CA (408) 943-1234,***
***www.cadence.com.***
**Booth 2440** **RS 245**

## High Power SPDT Switch

NEC's model UPG2157T5F is a SPDT GaAs RFIC switch that features high power handling, low insertion loss, plus internal termination of unused ports across all popular WiMAX bands. This switch is ideal for T/R and diversity switching. This model operates in a frequency range from 0.5 to 6 GHz. The UPG2157T5F features input-to-output isolation of 25 dB at 3.5 GHz and 22 dB



at 5.8 GHz and unused port return loss of 12 dB at 2.3 to 5.8 GHz.
***California Eastern Laboratories,***
***Santa Clara, CA (408) 919-2500,***
***www.cel.com.***
**Booth 835** **RS 246**

## Rack-mount Power Amplifier

The model XS4498R is a rack-mount power amplifier that provides 50 dB of gain and 150 W of RF power over the entire X-band frequency range of 8 to 12.4 GHz. Suitable for use as a high power signal booster for EMI/EMC testing, or as a high power amplifier for EW or lab applications, the unit incorporates a universal power supply that operates from 80 to 240 VAC, 47 to 63 Hz, or is alternately available with a DC supply option. The unit is self-contained, includes integral forced air-cooling capability and features over-temperature self-protection. This product is in development for use by the US Government and associated subcontractors only.
***CAP Wireless,***
***Newbury Park, CA (805) 499-1818,***
***www.capwireless.com.***
**Booth 2535** **RS 247**

## Measurement Platform

The M150 measurement platform delivers precision microwave measurement capability in a highly affordable and flexible platform. It supports 2 and 4 port RF measurements, load-pull and noise parameter test as well as DC and failure analysis applications. Highly affordable value packages include everything needed to start RF probing — prober, microscope, cables, RF probes, impedance standards, and WinCal 2006 VNA calibration software with its new advanced VNA automatic cal algorithms and monitoring-validation tools for enhanced accuracy.
***Cascade Microtech Inc.,***
***Beaverton, OR (503) 601-1000,***
***www.cascademicrotech.com.***
**Booth 1442** **RS 248**

## 7G and 13G Clock Synthesizers

Models TG1C1-A and TG1C7-A clock synthesizers are cost-effective wideband signal generators with high-UI jitter injection capability. These synthesizers are ideally suited for manufacturing testing, device characterization, and research and development lab applications. Each synthesizer features two pairs of differential outputs, one jittered, one unjittered, and four other pairs of jittered and unjittered single-ended outputs. The synthesizers can be controlled from the front-panel or through GPIB. The TG1C7-A operates from 150 MHz to 7 GHz and the TG1C1-A operates from 150 MHz to 13.5 GHz.
***Centellax Inc.,***
***Santa Rosa, CA (707) 568-5900,***
***www.centellax.com.***
**Booth 1647** **RS 249**

## RF Switching Unit

This RF switching unit expands a test set for multi-port operation while continually monitoring and maintaining calibration integrity. Correct for errors caused by cable movement, temperature change or switching without disconnecting the DUT. The broadband unit (400 MHz, 31 GHz) can operate in thermal or TVAC chambers — as close to the DUT as needed. Standard switch matrix configurations are available in 1 ×6, 1 ×18 and 2 ×36 and can be combined according to a connectivity requirement. Custom configurations can also be developed.
***CodeOne™ Test Solutions Group,***
***COM DEV Ltd.,***
***Cambridge, Ontario, Canada***
***(519) 622-2300, www.comdev.ca/codeone.***
**Booth 1414** **RS 250**

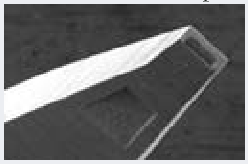
## High Frequency Connectors

These four series of high frequency microwave and mm-wave connectors extend the frequency range of the product line up to 50 GHz. These series include extended-frequency SMA to 26.5 GHz; ultra-precision SMA to 27 GHz; 2.92 mm (SMK) connectors to 40 GHz; and 2.4 mm connectors to 50 GHz. The company's range of MIL-PRF-39012 QPL connectors has also been extended to over 200 configurations, in series BNC, N, SMA and TNC, along with a variety of MIL-PRF-55339 adapters.

***Delta Electronics Manufacturing Corp.,***
***Beverly, MA (978) 927-1060,***
***www.deltarf.com.***
**Booth 923** **RS 251**

## Ceramic Wirebond Wedge

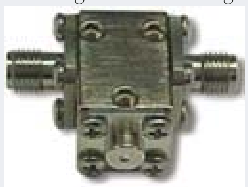
This ceramic wirebond wedge (ribbon and round wire) lasts 20+ percent longer while offering an efficiently tunable wirebond wedge. In addition to wedges, die pick-up tools in Tungsten Carbide, Delrin, Torlon and Vespel materials are also available.



***DeWeyl Tool Co. Inc.,***
***Petaluma, CA (707) 765-5779,***
***www.deweyl.com.***
**Booth 711** **RS 252**

## High Frequency Isolator

The model D3I2640 is a high frequency isolator designed to meet high frequency military needs and high frequency test setup needs. This unit comes standard with K-female connectors and operates from 26.5 to 40 GHz. The unit offers a typical isolation of 15 dB, minimum isolation of 14 dB, typical insertion loss of 0.80 dB, maximum insertion loss of 1.00 dB, typical VSWR of 1.45 and maximum VSWR of 1.50. Delivery: in stock.



***DiTom Microwave Inc.,***
***Fresno, CA (559) 255-7042,***
***www.ditom.com.***
**Booth 1128** **RS 253**

## SP6T Switches

The P/N 565Y-5311 is an SP6T switch with 2.9 mm connectors that operates from DC to 40 GHz. These switches come with a normally open actuator and can be equipped with coils designed for 12, 15, 24 and 28 V. Switching time is 20 ms (maximum). The design of this particular group of 40 GHz switches targets ATE applications and places an emphasis on reliability as well as phase and insertion loss repeatability.

***Dow-Key Microwave,***
***Ventura, CA (805) 650-0260,***
***www.dowkey.com.***
**Booth 1512** **RS 254**

## Microwave and Optical Switch System

# NEW WAVES

The Racal Instruments 1257 is a microwave and optical switch system that is tailor-made to each customer's exact specifications. This allows managers to use their resources more effectively on their own products while leveraging the expertise of an experienced switch system manufacturer to produce a high quality switch solution. The resulting solution is fully documented, easily repeatable and highly serviceable, reducing the headaches encountered in producing a reliable microwave or optical system.

***EADS North America Defense Test and Services Inc., Irvine, CA (800) 722-2528, www.eads-nadefense.com.***
**Booth 332** **RS 255**

## Broadband Synthesizer

This ultra-fast, ultra-low phase noise, high performance, phase coherent broadband synthesizer operates in a frequency range from 0.3 to 18 GHz. The UFS-18 series is based on direct-analog design techniques combined with DDS capability for fine frequency resolution. The unit also provides wideband FM chirp and IF input. The synthesizer achieves simultaneous phase coherent and random access switching at 1 Hz resolution and ≤ 250 nanosecond across the full band utilizing its proprietary digital synthesizer core design.

***Elcom Technologies Inc., Rockleigh, NJ (201) 767-8030, www.elcom-tech.com.***
**Booth 2044** **RS 256**

## Multi-channel Emulator

The PROPSim C8 hardware real-time multichannel emulator provides a powerful platform for testing multiple input multiple output (MIMO) systems. With up to 16 fading channels, PROPSim C8 allows accurate, repeatable emulation of complex real-world radio propagation scenarios up to 4×4 MIMO systems. PROPSim C8 hardware is system independent and supports WLAN, WiMAX and cellular systems. In addition to multi-path fading, PROPSim C8 can also generate other channel impairment effects, including noise (AWGN), CW and modulated interferences.

***Elektrobit Inc., San Diego, CA (858) 231-9697, www.propsim.com.***
**Booth 1744** **RS 257**

# NEW WAVES

## Power Meter

The model DPM-xx is a single-channel average power meter for RF to millimeter-wave frequencies that measures absolute power at 10 MHz to 220 GHz. Easy operation is ensured with automatic zeroing, automatic sensor recognition and a calculation factor table stored in the memory of each power sensor. Its compact size, precise accuracy, reliability and inexpensive pricing make the DPM-xx power meter an attractive asset for design engineering, equipment manufacturing, field engineering and research. Starting price is US$3,834.

***ELVA-1 Ltd., St. Petersburg, Russia (408) 358-5844, www.elva-1.com.***
**Booth 620** **RS 258**

## Phase-locked Oscillators

The XLT series is a high vibration-tolerant phase-locked oscillator and frequency synthesizer that features low phase noise characteristics. This series operates in a frequency range from 5 to 200 MHz in fixed-frequency or serially-programmable bandwidths. The product is ideally suited for use in lieu of conventional clock oscillators in high reliability environments where instantaneous turn-on, high stability and low phase noise over temperature and vibration are stringent requirements. Low power consumption is an additional feature of this product.

***EM Research Inc., Verdi, NV (775) 345-2411, www.emresearch.com.***
**Booth 1446** **RS 259**

## RFID Isolators

These ECCOPAD® RFID isolators offer standard and custom solutions for read-on-metal and liquid problems at HF (13.56 MHz) and UHF (915/868 MHz). The isolators are thin, flexible and rugged elastomers. When placed between the metal surface and the RFID tag, ECCOPAD isolators enable tag operation. ECCOPAD isolators are available with an integral pressure sensitive adhesive on one side, both sides or neither side. Solutions are now available for three new Generation 2 RFID tags.

***Emerson & Cuming Microwave Products Inc., Randolph, MA (781) 961-9600, www.eccosorb.com.***
**Booth 1614** **RS 260**

## Hand-formable Cable Assemblies

These SMA hand-formable, fixed length cable assemblies are part of the Johnson® product line and are designed for RF/microwave applications. With Johnson brand connectors on each end, these assemblies offer good VSWR and low insertion loss up to 18 GHz. The assemblies are manufactured with hand-formable 50 Ω microwave cable and are available in 0.086 and 0.141 cable diameters. These assemblies are available off-the-shelf and are a low cost alternative to making your own cables.

***Emerson Network Power Connectivity Solutions, Waseca, MN (800) 327-8663, www.emersonnetworkpower.com.***
**Booth 1305** **RS 261**

## Solid-state Power Amplifier

The model BBM4A5KDM (SKU #1107) is a solid-state power amplifier (SSPA) that operates from 1000 to 2500 MHz and produces 20 W at P1dB from a 28 VDC source. This ultra-broadband module was designed for mobile jamming applications in the L- and S-bands and other linear applications that require high efficiency and ultimate ruggedness. This amplifier utilizes linear power devices that provide high gain, good linearity, low distortion and wide dynamic range. The module is fully protected against simultaneous overdrive, any load VSWR and temperature variations.

***Empower RF Systems Inc., Inglewood, CA (310) 412-8100, www.empowerrf.com.***
**Booth 305** **RS 262**

## JCA Amplifiers

These JCA amplifiers feature an average gain tracking of ±0.75 dB and ±1.5 dB gain matching across a 2 to 18 GHz bandwidth. The amplifiers are manufactured utilizing an automated assembly process that uses precise pick-and-place machinery and automatic wire-bonding. The result is reliable and repeatable gain matching and phase tracking performance, and reduced RF tuning times by 30 percent.

***Endwave Defense Systems Inc., Sunnyvale, CA (408) 522-3180, www.endwave.com.***
**Booth 1841** **RS 263**

# NEW WAVES

## Open Boundary Quadridge Horn

The model 3164-05 is a quadridge horn that offers a unique open boundary design, which allows for improved patterns and gain. While the optimum frequency range is 2 to 18 GHz, the model 3164-05 is useable from 1.5 GHz. Linear or circular polarized measurements can be made when the antenna is used with a 90° hybrid.

***ETS-Lindgren,***
***Cedar Park, TX (512) 531-6400,***
***www.ets-lindgren.com.***
**Booth 1909** **RS 264**

## 100 W GaN HEMT


These GaN HEMT products are designed for WiMAX and 3G (UMTS, W-CDMA) systems. Primary features of the GaN HEMT products include: 100 W in 0.2 cc (500 W/cc), 180 W in 1.2 cc (150 W/cc), high channel temperature (Tch) of up to 250C, high impedance of close to 50 Ω (ease of matching), high operating voltage of 50 V, high breakdown voltage of 350 V, high output power of up to 180 W (500 W preliminary), high efficiency (saturated operation: 60 percent, W-CDMA operation: 35 percent), high gain of 15 dB at 2.1 GHz and good suitability with digital pre-distortion system.

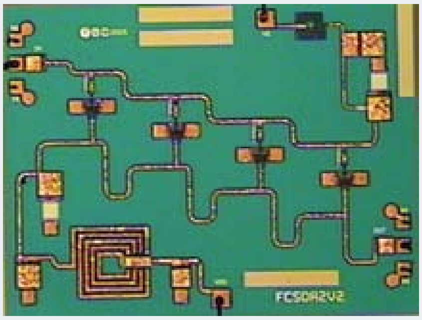
***Eudyna Devices Inc.,***
***San Jose, CA (408) 232-9500,***
***www.eudyna.com.***
**Booth 1547** **RS 265**

## D-subminiature Connectors

These non-magnetic RF and mixed layout D-subminiature connectors are designed for use in magnetic resonance imaging (MRI) medical equipment. These products are manufactured using materials specially selected for their non-magnetic properties. All mechanical and electrical characteristics within the products are maintained to common specifications. Product range includes 50 and 75 Ω RF contacts, 10A to 40A power contacts and high voltage contacts capable up to 3000 V. Standard RF ranges available in non-magnetic forms include SMA, SMB and MCX.

***FCT Electronics LP,***
***Torrington, CT (860) 482-2800,***
***www.fctgroup.com.***
**Booth 2104** **RS 266**

## Broadband MMICs



The models FMA3006, FMA3007 and FMA3008 are broadband MMIC devices designed for a wide range of applications from 2 to 20 GHz. These amplifiers are manufactured using either a single or double heterojunction PHEMT process. These devices operate over the 2 to 20 GHz frequency range and are suitable for applications including electronic warfare, broadband communication infrastructure, cellular backhaul, point-to-point radio and test instrumentation applications.

***Filtronic Compound Semiconductors,***
***Newton Aycliffe, County Durham, UK***
***+44 (0) 1325 306 880, www.filtronic.com.***
**Booth 2122** **RS 267**

## Switched Filter Banks

These switched filter banks are tailored to specific customer requirements. The most appropriate filter and switch technologies are utilized to achieve the best overall performance in the selection of frequency bands of interest. This includes design options such as MMIC FET switches for fast switching requirements, or discrete PIN diode switches for high isolation. Other design options may involve multiple filter topologies or the use of multiplexed filter banks for multi-channel switched filters.

***Filtronic Sage Laboratories Inc.,***
***Hudson, NH (603) 459-1600,***
***www.filss.com.***
**Booth 2118** **RS 268**

## Waveguide Switches

The series 336 waveguide switches are competitively priced and provide high reliability, high repeatability, high isolation of > 60 dB and low insertion loss of < 0.05 dB. Models in the range cover C-band, military X-, extended Ku-, DBS/DTH and Ka- Satcom bands. Options include: 12 and 28 V drive, lockable models, manual override, tell back contacts, MIL Spec connectors to MS3112E10 and weatherproofing in an operational temperature range of –40° to +85°C.

***Flann Microwave Ltd.,***
***Bodmin, Cornwall, UK +44 (0)1208 77777,***
***www.flann.com.***
**Booth 1913** **RS 269**

## Universal Coherent Modulator Subassembly

The model SA-69-BD is a universal coherent modulator subassembly that operates from 2 to 18 GHz and is used in PDOA, ADOA or TDOA applications. It combines amplification and gain equalization stages, a digitally controlled vector modulator and attenuator, pulse modulator and a switched-filter bank to provide modulated signals with high resolution amplitude and phase accuracy. It achieves 360° of phase shift, 120 dB of attenuation and 80 dB of pulse modulation. It is available in optimized bandwidths from 400 MHz to 24 GHz.

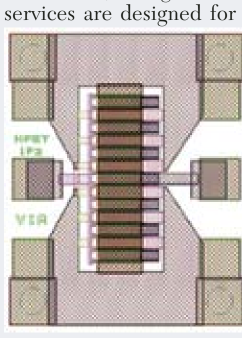
***G.T. Microwave Inc.,***
***Randolph, NJ (973) 361-5700,***
***www.gtmicrowave.com.***
**Booth 906** **RS 270**

## 3.5 mm Coaxial Calibration Standards

These 3.5 mm coaxial calibration standards provide highly accurate and repeatable calibration as a result of the company's precision machining and RF characterization technologies. The precision OPEN, SHORT, LOAD components can be used to calibrate several types of commercial VNA systems up to 9 GHz (model GCS35M-9G) and 26.5 GHz (model GCS35M-26G), respectively.

***GigaLane Co. Ltd.,***
***Suwon, Kyonggi-do, Korea***
***+82-31-233-7325, www.gigalane.com.***
**Booth 2532** **RS 271**

## High Linearity HFET Foundry Process



These 0.5 µm high linearity HFET foundry services are designed for wireless infrastructure amplifier applications. At 2 GHz, when biased at 8 V and 40 percent $I_{dss}$, the 1.2 mm HFET device can achieve an output power of 28 dBm with a TOI of 45.5 dBm and a drain efficiency of ~50 percent. The linearity makes it well suited for use in both analog and digital wireless communication in-

frastructure and subscriber equipment, including 3G, cellular, PCS and fixed wireless systems.
***Global Communication Semiconductors Inc., Torrance, CA (310) 530-7274, www.gcsincorp.com.***
**Booth 507** **RS 272**

## Wedge Wire Bonder

This wedge wire bonder offers 1 µm repeatability over a working area of 305 × 410 mm. The third machine generation — series BONDJET BJ820 is a fully automatic wedge bonder that offers high standards for accuracy, placement, fine pitch, bond speed and high bond quality even on the smallest bond pads. The BJ820 is especially suited to microwave applications that require extreme looping control and consistency. Programming modes allow constant loop height or constant wire length in addition to stitch bonding capability, all while bonding with either gold or aluminum wire. Size: 720 × 1250 mm.
***Hesse & Knipps Inc., San Jose, CA (408) 436-9300, www.hesse-knipps.com.***
**Booth 1236** **RS 273**

## Mixed-signal Integrated Circuits

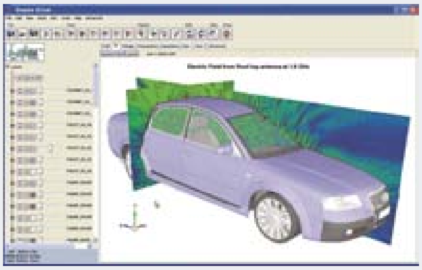

These two new mixed-signal integrated circuits (IC) product lines are based upon BiCMOS semiconductor technology. The new power detector product line features a 50 to 3500 MHz logarithmic detector/controller with dynamic range of up to 75 dB at 900 MHz. The new data acquisition product line features a wideband track and hold SMT IC with an input sampling bandwidth of 4.5 GHz and a spurious free dynamic range of 56 dB at 1 GHz.
***Hittite Microwave Corp., Chelmsford, MA (978) 250-3343, www.hittite.com.***
**Booth 2145** **RS 274**

## RF Power Switch

This plug and play RF power switch is small, reliable, powerful, easy to handle and requires

little maintenance, which makes it cost-effective to use. The RF power provides outstanding benefits for customers — everywhere where switching between channels is required. It guarantees indirect benefits for mobile phone users and network operators.
***HUBER+SUHNER AG, Herisau, Switzerland +41 (0)71 353 41 11, http://powerswitch.hubersuhner.com.***
**Booth 947** **RS 275**

## EM Field Solver

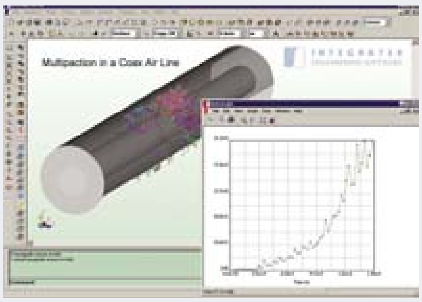


The Empire XCcel™ is a 3D EM field solver that offers a completely revised intuitive graphical user interface. 3D editor, job control and post processing are integrated into one frame and simulations can be adapted from a large template library. A further speed-up of 200 percent can be obtained by a smart cache management. New features include a broadband loss model, meta materials, spice parameter extraction and clipboard links of diagrams.
***IMST GmbH, Kamp-Lintfort, Germany +49 2842 981 100, www.imst.de.***
**Booth 1645** **RS 276**

## RF LDMOS Integrated Circuits

These high power RF LDMOS integrated circuits are based on the company's eighth-generation LDMOS technology. These devices integrate a high power RF broadband FET with passive components and diodes. These products offer good gain and bandwidth characteristics with low AM-AM and AM-PM distortion performance. The first five products operate from 800 to 2300 MHz, with power levels ranging from 30 to 50 W. Samples are available, with production scheduled for 3Q06.
***Infineon Technologies, San Jose, CA (408) 501-6000, www.infineon.com.***
**Booth 1023** **RS 277**

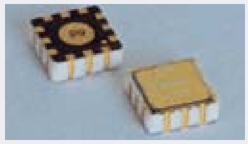
## Electromagnetic Analysis and Simulation Software



The release of LORENTZ-HF is a simulation program aimed at the SATCOM and high energy physics communities. This program has been developed to meet the need for reliable and verifiable computer simulation data for the phenomenon of multipactor discharge (MD) or multipaction. LORENTZ-HF can accurately predict the location of MD and the power conditions required for multipaction to occur within a vacuum environment. LORENTZ-HF combines IES' 3D MoM full-wave program SINGULA with the ray tracing and space charge capabilities of its LORENTZ program.
***Integrated Engineering Software, Winnipeg, MB, Canada (204) 632-5636, www.integratedsoft.com.***
**Booth 2604** **RS 278**

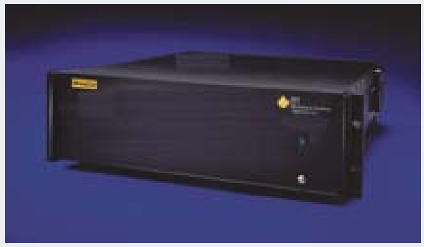
## Components

These SAW filters, delay lines, duplexers and resonators are manufactured in Korea. The



SAW duplexer is available in an LTCC 5050 package that is utilized for CDMA 450 applications.
***ITF Co. Ltd., Gyounggi-Do, Korea +82-32-328-0543, www.itf.co.kr.***
**Booth 721** **RS 279**

## Advanced Digital Synthesizer Technology



WaveCor is a high performance synthesizer that combines advanced direct digital synthesis (DDS) technology with a unique product architecture. WaveCor's distinctive architecture takes full advantage of the company's patented DDS technology to produce good clean signals. The WaveCor synthesizer features good phase noise performance and fast switching anywhere in the operating band. WaveCor's broadband output covers 300 MHz to 18 GHz with a spurious free dynamic range of up to –60 dBc.
***ITT Industries – Microwave Systems, Lowell, MA (978) 441-0200, www.ittmicrowave.com.***
**Booth 1823** **RS 280**

## Laboratory Microprobe Station

The model LMS-E-2709 is a laboratory microprobe station designed for 2+ port S-parameter

RF/microwave through 40 GHz along with low current semiconductor characterization experiments and independent research. Standard isolated vacuum chuck accommodates semiconductor and substrate test devices up to 2" with 1" by 1" movement and a z-lift for removing probe contact. Optional larger, shielded and temperature-controlled chucks are available. The lab microprobe station is affordably priced for today's demanding economy, rugged enough for use in university teaching laboratories and intuitive enough for occasional users.
***J microTechnology Inc., Portland, OR (503) 614-9509, www.jmicrotechnology.com.***
**Booth 541** **RS 281**

# NEW WAVES

## Ka-band Block Converters

These block up and down converters translate L-band signals (1 to 2 GHz) to Ka-band (30 to 31 GHz) and from 20.2 to 21.2 GHz back to L-band. Some key features include phase locked to an external 5/10 MHz or 50 MHz reference, low output phase noise (MIL-STD-188-164A compliant), low output spurious and LO leakage, +15 dBm output power, low noise figure, and operation from a single +12 V at 1.0A maximum for KABUC, and 700 mA for KABDC. Weight: < 1 lb.

***Jersey Microwave,***
***Hackettstown, NJ (908) 684-2390,***
***www.jerseymicrowave.com.***
**Booth 1345** **RS 282**

## Power Dividers

The models 50PD-559, 50PD-560, 50PD-570 and 50PD-585 are power dividers that operate from 800 to 2400 MHz. The models' 5 W power handling capabilities and 20 dB minimum isolation make them perfect for a multitude of wireless applications. Two-, four- and eight-way configurations are available with SMA or N connectors. Price: starting at $55.00.

***JFW Industries Inc.,***
***Indianapolis, IN (317) 887-1340,***
***www.jfwindustries.com.***
**Booth 1604** **RS 283**

## Surface-mount Circulator/Isolators


These 2nd generation surface-mount circulator/isolators are designed for RFID and wireless base station applications. The SMT II series is a low IMD solution for applications that require high performance and solder reflow. Available from 0.8 to 3.8 GHz, this series offers extra small packages of 0.72" or 0.93" in diameter. Circuit-bases are designed for easy PCB assembly and typical IMD is lower than –75 dBc. These products are RoHS compliant. Price: $12.00 each (10,000).

***JQL Electronics Inc.,***
***Buffalo Grove, IL (630) 930-9917,***
***www.jqlelectronics.com.***
**Booth 2121** **RS 284**

## Push/Pull Connectors

These SMA connectors offer a push/pull connection that makes mating quick and easy. These connectors feature electrical performance up to 6 GHz and offer designs that are available for flexible and semi-rigid cables. These connectors allow 360° of the connectors to be mated. The design of the connectors can be easily mated with any kind of standard SMA jack.

***Junper Interconnection Co. Ltd.,***
***Ningbo, ZJ, China 86-574-87901538,***
***www.junper.com.***
**Booth 2016** **RS 285**

## Band Reject Filter

The model 3IN10-2240.8/X15-XO/XO is a band reject filter designed for telemetry applications with a spurious-free upper passband out to 20 GHz. This module facilitates removal of a particular communication channel, such as data or video, while permitting other types of communication to continue unimpeded. The small footprint, 0.6" × 0.9" × 0.235", makes it an ideal candidate for a variety of applications. The design is a hybrid combination of lumped and distributed elements. SSMA connectors are standard.


***K&L Microwave,***
***Salisbury, MD (410) 749-2424,***
***www.klmicrowave.com.***
**Booth 1504** **RS 286**

## RF Test Instruments

The model 2910 is an RF vector signal generator that utilizes software-defined radio architecture, patent-pending synthesizer technology and unique power leveling techniques. This model provides a flexible platform that utilizes software to adapt as test requirements change and reduces test time with fast frequency tuning, amplitude settling and waveform switching available. This model offers a three-year standard warranty. Price: $14,500. The model 2810, an RF vector signal analyzer, and the model 3500, a portable RF power meter, will also be available this summer.

***Keithley Instruments Inc.,***
***Cleveland, OH (800) 688-9951,***
***www.keithley.com.***
**Booth 1743** **RS 287**

## Hybrid Coupler

The model 3100400/K is a 90° hybrid coupler that operates from 10 to 40 GHz. This model offers a coupling of 3 dB, amplitude imbalance of ±0.7 dB, phase imbalance of ±10°, isolation of 12 dB minimum and maximum VSWR of 1.80. This hybrid coupler provides an insertion loss of 2.0 dB maximum, power rating of 20 W average, 3 kW peak and standard connectors include 2.4 mm female and 2.92 mm female. Operating temperature is –54° to +85°C. Unit may be manufactured to meet military specifications. Delivery: stock to 30 days.


***Krytar,***
***Sunnyvale, CA (408) 734-5999,***
***www.krytar.com.***
**Booth 337** **RS 288**

## Extended Range DLVA

The LMV001 is a CW immune extended range detector log video amplifier with an 80 dB (–70 to +10 dBm) dynamic range operating over the 2 to 18 GHz frequency range. It includes an output RF port that delivers 40 dB gain over the full frequency range and chip hybrid circuits are used throughout to minimize size and maximize performance. The frequency flatness of ±2 dB at both the video and RF outputs is maintained over the full dynamic range and temperature range of –40° to +85°C, as is the 25 ns video pulse rise time. Size: 50 × 45 × 12 mm.

***Labtech Ltd.,***
***Milton Keynes, UK +44 1908 261755,***
***www.labtechmicrowave.com.***
**Booth 2221** **RS 289**

## Antenna Solution

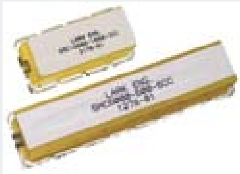
The NanoAnt™ miniature antenna technology offers system designers a small-sized antenna with good performance, implementation flexibility and cost effectiveness for a wide variety of wireless applications. This technology can operate from 1.575 GHz up to 6 GHz enabling GPS, Bluetooth, WLAN 802.11a/b/g, 802.11n MIMO, public safety band and other device functionalities. The NanoAnt is designed for high volume surface-mount attachment through the use of pick-and-place processing, and does not require a ground connection. Among the NanoAnt's unique features is that some applications do not require a keep-out space or clearance area.

***Laird Technologies,***
***St. Louis, MO (314) 344-9300,***
***www.lairdtech.com.***
**Booth 610** **RS 290**

## Surface-mount Combline Filters

These miniaturized surface-mount combline filters are small, lightweight, low cost and tough

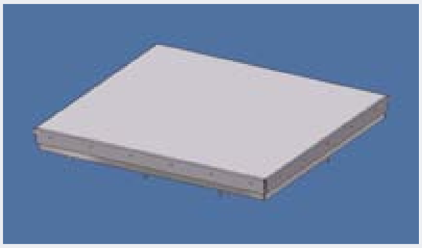
# NEW WAVES



enough for harsh conditions. The filters are easier and faster to mount or install in volume production situations. These filters operate between 5 and 15 GHz with a bandwidth from 3 to 20 percent and offer low insertion loss. The filters are designed to meet military environmental specifications in frontline fighter aircraft.

***Lark Engineering Co.,***
***San Juan Capistrano, CA (949) 240-1233,***
***www.larkengineering.com.***
**Booth 2636** **RS 291**

## Shield Design Process



The Flex-Tech Shield Design process provides a simple pick list of standard product design features that makes it easy to create a custom shield with choices in cover retention, frame design, mating surfaces, multi-cavities and access holes/notches. An example is the new Click-Shield™ that offers unlimited size and placement flexibility, and a unique cover-retention method. This process allows a custom solution using standard features.

***Leader Tech Inc.,***
***Tampa, FL (813) 855-6921,***
***www.leadertechinc.com.***
**Booth 513** **RS 292**

## Solid-state Power Amplifiers

The S71000 Ku-band series of solid-state power amplifier modules operates in a frequency range from 13.75 to 14.5 GHz. This amplifier ranges in output power from 10 to 100 W and provides a high quality, slim-line solution for various low, medium and high power requirements. The S71000 series utilizes state-of-the-art techniques, including a thermal design enabling long-term reliability and a rugged mechanical design offering a suitable product for any type of system architecture.

***Locus Microwave,***
***State College, PA (814) 861-3200,***
***www.locusmicrowave.com.***
**Booth 535** **RS 293**

## GPS Dual-band Reject Filter


The model 5DBR-1227/1575-X10-S is a GPS dual-band reject filter with bi-directional inputs. This filter features 1 dB maximum loss over the passband while achieving a typical notch depth attenuation of 50 dB at 1227 and 1575 MHz. Typically the 3 dB bandwidths are less than 50 MHz. The VSWR is 2.0 from DC to 1700 MHz, excluding the notch area. Size: 4.5 × 1.25 × 0.50, excluding SMA female connectors. If preferred, the filters can be sold as individual filters in separate 3.0" long boxes.

***Lorch Microwave,***
***Salisbury, MD (410) 860-5100,***
***www.lorch.com.***
**Booth 735** **RS 294**

## Electromagnetic Software

PeakView, the company's product suite, is deeply integrated with the Cadence custom IC design environment that offers RF designers an easy way to identify and repair EM integrity design faults. PeakView has been architected upon an EM coupling simulation/modeling technology platform that provides HF circuit and physical design teams' accuracy, speed and capacity. This suite provides comprehensive passive component model and layout synthesis capability. PeakView offers an alternative to existing test chip development, characterization and modeling design practices.

***Lorentz Solution Inc.,***
***Milpitas, CA (408) 922-0765,***
***www.lorentzsolution.com.***
**Booth 644** **RS 295**

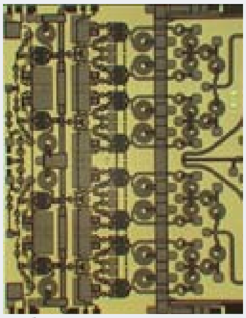
## Circuit Board Plotter

The ProtoLaser 100 combines the capabilities of an advanced milling and drilling circuit board plotter with a sophisticated laser system. The ProtoLaser 100 is an ideal system for the laser structuring, milling and drilling of circuit carriers. A special laser system removes the copper layer between the conductive strips without affecting the substrate. Printed circuit board prototypes with 50 µm (2

mil) structures can be manufactured quickly and flexibly.
***LPKF Laser & Electronics,***
***Wilsonville, OR (503) 454-4200,***
***www.lpkfusa.com.***
**Booth 2222** **RS 296**

## High Power Broadband Amplifiers

The models MAAPGM0074-DIE, MAAPGM-0076-DIE, MAAPGM0077-DIE and MAA-PGM0078-DIE are high power broadband amplifiers that can be used in various applications including communications and military electronic systems. The power levels, up to 16 W, are especially high for multi-octave GaAs MMICs covering frequency bands from 0.7 to 8 GHz.



***M/A-COM,***
***Lowell, MA (800) 366-2266,***
***www.macom.com.***
**Booth 1729** **RS 297**

## DC Blocks

These DC blocks are RoHS compliant and cover wireless band applications from 0.400 to 3.000 GHz. These blocks are available in 7/16 DIN, N, BNC and TNC configurations with RF power ratings to 500 W (2.5 kW peak) and breakdown voltages to 2.5 kV. This makes the blocks ideal for eliminating unwanted DC voltages or surges to tower top amplifiers. Delivery: stock to two weeks. Blocks are made in the US.


***MECA Electronics,***
***Denville, NJ (973) 625-0661,***
***www.e-meca.com.***
**Booth 1347** **RS 298**

## Coaxial Connectors and Adapters

The ZMA series of precision coaxial connectors and adapters is ideal for applications where there are constraints on space. The bayonet-style coupling nut is easily mated and de-mated with a quarter turn, without the need for a torque wrench. For applications such as antenna systems, this connector provides good mechanical stability and eliminates the need for lock wiring in high vibration environments where space is limited. In test systems, this connector provides a fast and accurate method for continuous connects and disconnects.

***MegaPhase LLC,***
***Stroudsburg, PA (570) 424-8400,***
***www.megaphase.com.***
**Booth 505** **RS 299**

## 2.92 mm Connector

This modified 2.92 mm "K" connector provides enhanced performance at high frequencies. The connector operates up to 45 GHz and mates to a standard 2.92 mm interface. The modified 2.92 mm design combines expanded electrical performance in a larger connector, facilitating field maintenance without the hazard of breaking a smaller center contact. The new connector was developed at the request of a customer who needed 40+ GHz performance in the 2.92 mm format.
***Meggitt Safety Systems Inc.,***
***Simi Valley, CA (805) 584-4100,***
***www.meggittsafety.com.***
**Booth 1522** **RS 305**

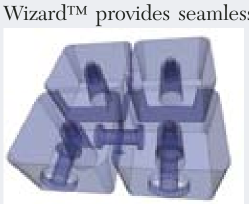
## Portable Spectrum Analyzer

The U3700 series is a portable spectrum analyzer that includes models U3771 and U3772. The model U3771 operates in a frequency range up to 31.8 GHz and model U3772 operates in a frequency range up to 43 GHz. The 3700 series spectrum analyzers are manufactured by Advantest, Japan, and sold and serviced by MetricTest. At 308 cm × 175 × 209 and less than 6 kg, the U3771/U3772 portable spectrum analyzer is small and supports measurements from 9 kHz to 31.8/43 GHz. Designed for convenient field use, the U3771/U3772 can operate either on an AC/DC power source or on a battery with a life of approximately two hours.

***MetricTest,***
***Hayward, CA (510) 264-0887,***
***www.metrictest.com.***
**Booth 2220** **RS 306**

## EM Software Tool

Version 6.0 of the EM-software tool µWave Wizard™ provides seamless integration of 3D FEM simulation technology into the existing mode-matching and 2D FEM framework. This includes optimization, full 3D visualization of the electromagnetic fields, calculation of losses arising from finite wall conductivity as well as an integrated eigenmode solver. The consideration of draft angles for die-casting technology and the modeling of arbitrarily shaped probes in cavities will be possible with new, flexible library elements. The COM capabilities have been extended and provide new VBA commands to automate the µWave Wizard.



***Mician GmbH,***
***Bremen, Germany +49 (421) 16899351,***
***www.mician.com.***
**Booth 1616** **RS 307**

## YIG-tuned Oscillators

The MLX "O" series of YIG-tuned oscillators operates in a frequency range from 6 to 20 GHz. These three models provide phase noise performance that covers 8 to 18 GHz, 6 to 18 GHz and 8 to 20 GHz. Utilizing new SiGe transistors, these units are available in three standard package configurations that include 1.25" cube, 1.75" cylinder and 1" cube. These oscillators provide +14 to +15 dBm power output levels and operate over the 0 to +65°C commercial temperature ranges. Extended temperature models are available for the 1.25" cube and the 1.75" cylinder packages. Delivery: four weeks.

***Micro Lambda Wireless Inc.,***
***Fremont, CA (510) 770-9221,***
***www.microlambdawireless.com.***
**Booth 2123** **RS 308**

## Diode Modeling Tools

MicroMetrics Inc. has contracted Modelithics to create new nonlinear models for its line of high performance limiter diodes, including the MP7100, 7110 and 7120 series. The models will be valid for large-signal design allowing designers to better understand the temperature and power dependency of the RF behavior of these diodes for improved design. The models will initially be available in the Agilent Technologies Advanced Design System (ADS) design simulation software and later ported to other simulators.

***MicroMetrics Inc.,***
***Londonderry, NH (603) 641-3800,***
***www.micrometrics.com.***
**Booth 1004** **RS 309**

## X-band Latching Rotary-field Phase Shifter

This reciprocal latching rotary-field phase shifter with integral driver combines the best of phase shifter technologies. Its rotary-field design operates at high average and peak power levels with minimal phase error while its latching characteristic eliminates the need for holding current thereby reducing the system power needs.

***Microwave Applications Group,***
***Santa Maria, CA (805) 928-5711,***
***www.magsmx.com.***
**Booth 1452** **RS 310**

## Terminations and Connectors

These terminations and connectors operate from DC to 18 GHz and are available in a variety of power levels. The terminations and connectors can be used in a variety of applications and will accommodate many different housing designs. Offered in 50 Ω, these items are designed for fast and easy installation. Delivery: from stock.

# NEW WAVES

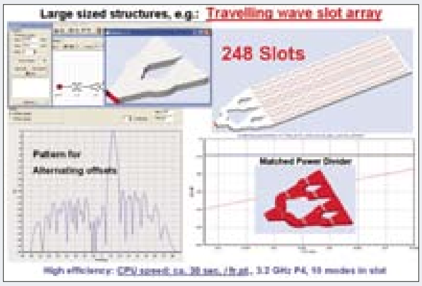
***Microwave Communications Laboratories Inc.,***
***Saint Petersburg, FL (727) 344-6254,***
***www.mcli.com.***
**Booth 2334** **RS 311**

## WiMAX Diplexer

This diplexer was designed for use in WiMAX base stations receiving and transmitting broadband information in the 3.4 to 3.43 GHz and 3.5 to 3.53 GHz bands. These bands are mutually isolated by a minimum of 55 dB with a maximum 1 dB of insertion loss in each band. The use of modern design and production methods yields a compact-sized diplexer with a 4" × 3" × 1.25" footprint.

***Microwave Filter Co.,***
***East Syracuse, NY (315) 438-4700,***
***www.microwavefilter.com.***
**Booth 2306** **RS 312**

## Fast CAD and Optimization Tool




WASP-NET meets the quest of microwave engineers for a new quality of EM CAD and optimization efficiency utilizing its unique hybrid MM/FE/MoM/FD full-wave engine that combines the high speed and flexibility advantages of four solvers in one single tool. The WASP-NET v6.4, featuring multiprocessor and advanced 64-bit options, offers efficient CAD capabilities also for large sized structures with typical optimization times of a few minutes on a PC. WASP-NET application examples include: fast CAD and optimization of all types of waveguide components and aperture antennas/arrays; full-wave synthesis of waveguide, combline, cross-coupled and LTCC filters; dielectric resonator filters; dielectric loaded horns with shaped subreflectors; squarax and stripline elements.

***Microwave Innovation Group (MiG) GmbH and Co. KG,***
***Bremen, Germany +49 421 22 37 96 60,***
***www.mig-germany.com.***
**Booth 1319** **RS 313**

## Power Amplifiers and Drivers

This family of eight high linearity power amplifiers (PA) are designed for WiFi (802.11) and WiMAX (802.16d/e) standards for all three frequency bands, 2.4 to 2.7 GHz, 3.3 to 3.7 GHz and 4.9 to 5.9 GHz. The WPS series offers P1dB up to 36 dBm with IP3 as high as 50 dBm and error vector magnitude (EVM) less than two percent at 29 dBm output power level under 64QAM modulation schedule with 256 WiMAX carriers. The typical gain across the bands is 14 dB.

***MicroWave Technology Inc.,***
***Fremont, CA (510) 651-6700,***
***www.mwtinc.com.***
**Booth 821** **RS 314**

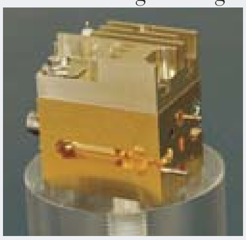
## RF Power Amplifier

This highly efficient, small, 10 W (saturated) RF power amplifier is designed for JTRS related applications. This unit operates from 12 or 24 VDC and can handle a variety of modulating waveforms. It is self-contained in a 3" × 1.6" × 0.78" enclosure (smaller than a business card) weighing 4 oz. Performance from 25 MHz to 2.5 GHz and many options are possible.

***Mid-Atlantic RF Systems Inc.,***
***Forest Hill, MD (410) 893-2430,***
***www.midatlanticrf.com.***
**Booth 1822** **RS 315**

## Active Multipliers

The AMC series of active multipliers are capable of extending the range of sources from 8 to 20 GHz coaxial input to the complete millimeter-wave spectrum from 18 to 110 GHz. Outputs are available in six waveguide bands from WR-42 to WR-10. Recent upgrades have improved the performance of the series with higher output power, lower power dissipation, built-in bias protection and rugged packaging. The AMC-10-RFH00 operates from 75 to 110 GHz and features high power.



***Millitech Inc.,***
***Northampton, MA (413) 582-9620,***
***www.millitech.com.***
**Booth 2029** **RS 316**

## Active Doubler

The model XX1000-QT is a 7.5 to 22.5/15 to 45 GHz active doubler offered in a 3×3 mm QFN surface-mount plastic package that is RoHS compliant. This packaged device combines an active doubler with an output buffer amplifier that delivers constant power over a range of input powers. Using 0.15 µm gallium arsenide PHEMT model technology, the device delivers +15 dBm output power from 15 to 45 GHz and offers good rejection of the fundamental and harmonic products.


***Mimix Broadband Inc.,***
***Houston, TX (281) 988-4600,***
***www.mimixbroadband.com.***
**Booth 1337** **RS 317**

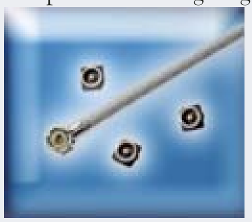
## SPDT Absorptive Switches

Models HSWA2-30DR+ are SPDT absorptive switches with an internal CMOS control driver that delivers performance by providing high isolation, low insertion loss and high input IP3 over the entire DC to 3000 MHz band. Operating from a single positive 3 V supply voltage, these RoHS compliant switches are totally immune to latch-up so they always work, incorporate a unique design-simultaneous switch-off of RF1 and RF2, and provide low DC power consumption, essential for today's portable battery operated wireless devices. These switches are great solutions for base station infrastructure, CATV, DBS, MMDS, wireless WLAN and band switching. Price: from $1.29 each (1000). Delivery: in stock.


***Mini-Circuits,***
***Brooklyn, NY (718) 934-4500,***
***www.minicircuits.com.***
**Booth 829** **RS 318**

## Microwave Coaxial Connectors

The HSC series of microwave coaxial connectors provide a mating height of only 1.2 mm maximum making the connectors an ideal fit for mobile and cordless telephones, GPS units and other microwave equipment. Fully RoHS compliant, the HSC series operates from DC to 6 GHz with good VSWR characteristics. The receptacle size is 2×2 mm making it ideal for high density mounting. Various cable lengths and configurations are available allowing for design flexibility.



***Murata Electronics North America Inc.,***
***Smyrna, GA (770) 436-1300,***
***www.murata.com.***
**Booth 1123** **RS 319**

## Epoxy Resin System Materials

The model N4350-13 RF and the model N4380-13 RF are enhanced epoxy resin system materials with tightly controlled dielectric constants, low signal loss properties and good thermal properties designed to be used in many cost and performance-sensitive applications that would otherwise require a PTFE material. These products are suitable for many applications including amplifiers, components, multilayer boards and short range antennas.

***Neltec,***
***Tempe, AZ (480) 967-5600,***
***www.parkelectro.com.***
**Booth 1219** **RS 320**

## Crystal Filters

The UM series of custom crystal filters offer bandpass and band reject filters packaged in surface-mount and leaded hermetic enclosures. The UM series crystal filters are available in all filter design approximations from 40 to 200 MHz with fractional passband bandwidths from 0.015 to 0.6 percent, in 2- to 10-pole configurations. The filters, available with delay equalization and in phase-

## NEW WAVES

matched sets, feature reduced passband loss and ripple with standard 50 Ω source and load impedances.
***Network Sciences,***
***Phoenix, AZ (602) 258-8095,***
***www.networksciences.com.***
**Booth 1440** **RS 321**

### Low Profile Filter/Amplifier Assembly


The model CS-182-1 is a surface-mount integrated filter/amplifier assembly. The product features a low height profile of 0.170" and performance characteristics include greater than 90 dB of noise floor rejection. Operating frequency can be customized for applications ranging from 150 to 2000 MHz with a variety of sections and sizes ranging from 0.75" to 2" in length are available.
***Networks International Corp.,***
***Overland Park, KS (913) 685-3400,***
***www.nickc.com.***
**Booth 2335** **RS 322**

### Dielectric Multiplexer

This dielectric AMPS+US-PCS multiplexer has been designed for the overseas market. The

multiplexer provides customers benefits in production cost, installation cost and other expenses incurred by unifying the systems.
***Partron Co. Ltd.,***
***Hwaseong-si, Gyunggi-Do, Korea***
***82 (0)31-206-2953, www.partron.co.kr.***
**Booth 2348** **RS 323**

### Spectrum Monitor/Analyzer

Analyze-R,™ model 2261A is a spectrum monitor/analyzer that addresses the 900 MHz and 2.4

GHz unlicensed ISM bands, the 3.4 to 3.6 GHz licensed/unlicensed bands, the 4.9 GHz Public Safety band, the unlicensed 5 GHz U-NII/ISM bands and the 5.8 GHz DSCR band. Unique features of the 2261A include 38 selectable 100 MHz widebands, unattended data recording, auto calculation of C/I, GPS data logging and sensitivity is > –103 dBm. The 2261A is rugged, lightweight (< 7 lbs.) and battery powered.
***Pendulum Instruments Inc.,***
***Oakland, CA (510) 428-9488,***
***www.pendulum-instruments.com.***
**Booth 2414** **RS 387**

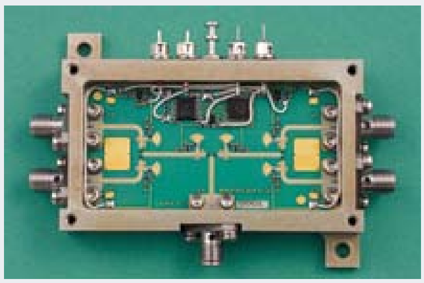
### Amplifier

The model PE2-44-12-1R5NF-15-SFF is an amplifier that offers 46 dB typical gain from 1 to 2 GHz. The gain flatness is better than ±1.5 dB. Noise figure is < 2 dB and the OP1dB is > 10 dBm. VSWR in/out is 2.0 maximum and the current is 250 mA at +15 VDC maximum. This amplifier can be supplied in many choices of housings. Other gain levels are available.
***Planar Electronics Technology,***
***Frederick, MD (301) 662-5019,***
***www.planarelectronicstechnology.com.***
**Booth 2107** **RS 388**

### 200 to 800 MHz SDLVA

The model SDLVA-0120-70 with options DB and 0208 is a successive detection log video amplifier (SDLVA) that operates from 200 to 800 MHz with a limited IF output of –16 dBm and a logging range of –75 to –5 dBm. The input VSWR at –23 dBm is 2.5 and the TSS is –80 dBm typical. The rise and fall times are < 30 ns and the power supply is +15 VDC at 100 mA maximum and –15 VDC at 190 mA maximum. Size: 3.75" × 1.50" × 0.50".
***Planar Monolithics Industries Inc.,***
***Frederick, MD (301) 662-4700,***
***www.planarmonolithics.com.***
**Booth 723** **RS 324**

### SPDT and SP4T Switches



These low loss, microwave SPDT and SP4T switches operate in a frequency range from 12 to 19 GHz. The switches are realized on a low cost Rogers RO4003 substrate utilizing packaged beam-lead PIN diodes, SMT resistors and capacitors, and printed components. Measured insertion loss is 0.85 dB for the SPDT and 1.8 dB for the SP4T. The photograph shown displays the SP4T switch, which incorporates driver and decoder circuitry to allow two-line control using standard CMOS logic levels.
***Plextek Ltd.,***
***Cambridge, England, UK***
***+44 1799 533 261, www.plextek.com.***
**Booth 719** **RS 325**

# NEW WAVES

## Extended Range Filter

This extended range filter is a multi-band frequency-tunable bandpass filter designed for in-

tegration in broadband transceiver applications, where small size, moderate selectivity and low power consumption are paramount. Based on its Mini-Pole technology, the extended range filter provides digitally tunable bandpass filtering from 30 to 450 MHz, with a 10 percent 3 dB bandwidth and ~5 dB insertion loss. This protection against cosite interference is achieved in a miniature package of 2" × 2" × 0.38".

***Pole/Zero Corp.,***
***West Chester, OH (513) 870-9060,***
***www.polezero.com.***
**Booth 855** **RS 326**

## Thick Microwave Laminates

The NorCLAD line of microwave laminates are thick laminates that offer low loss and an

ε of 2.55. These laminates are ideal for broadband antenna applications such as microstrip patches, dipoles and volutes. Typical antenna applications include high precision GPS, broadband ComLink, low profile UAV and various SatCom Subscribers (SDARs, DBS and Voice/Data). Standard thickness includes 0.125", 0.187", 0.250", 0.375" and 0.500".

***Polyflon Co., a Crane Co. company,***
***Norwalk, CT (203) 840-7555,***
***www.polyflon.com.***
**Booth 1619** **RS 327**

## Discrete Clock Oscillators

The J Leaded discrete clock oscillator is utilized for high end military and avionics applica-

tions. The current technology includes a hybrid IC with open blank crystal construction. PDI has been approved with this new discrete technology for space level applications. The enclosed crystal allows for better aging characteristics. The J Leaded package provides long-term reliability through harsh environments. Size: 8.9 × 7.4 mm.

***Precision Devices Inc.,***
***Middleton, WI (800) 274-9825,***
***www.pdixtal.com.***
**Booth 949** **RS 328**

## Hi-Rel Oscillators

The model QT92 is a high reliability oscillator with a built-in bypass capacitor. This drop-in replacement for 5×7 mm oscillators is designed to overcome the inherent quality issues of strip crystals in demanding military/aerospace requirements. The QT92 is a solution for cold starts, stability, activity dips and reliability. Quality is designed in, not screened in. This model is available in 3.3 VDC with LVCMOS logic (550 kHz to 160 MHz) and in 5 VDC with ACMOS, HCMOS or TTL logic (500 kHz to 125 MHz). Tri-state option.

***Q-Tech Corp.,***
***Culver City, CA (310) 836-7900,***
***www.q-tech.com.***
**Booth 1908** **RS 329**

## Organic Semiconductor Packaging

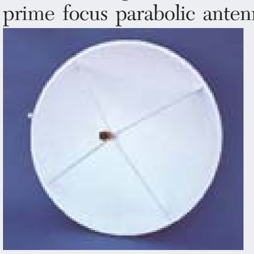
This organic semiconductor and electronic packaging utilizes the company's proprietary

Quantech™ polymer compounds that produce unique advantages in RF microwave packaging. These designs increase performance and improve thermal dissipation by tailoring material properties such as dielectric constant, CTE and adhesion to copper flanges. The packaging provides high temperature stability enabling eutectic die attach processes and complies with the latest RoHS environmental standards.

***Quantum Leap Packaging Inc.,***
***Wilmington, MA (978) 658-7711,***
***www.qlpkg.com.***
**Booth 2218** **RS 330**

## Parabolic Antenna

The model QRP-T0024Z011 is a broadband prime focus parabolic antenna that operates in



a frequency range from 18 to 40 GHz. Typical gain of 30 to 50 dB is available with a typical side lobe of –16 dB for the antenna. Power handling of this antenna is 800 W for CW and 5 kW for pulse. A coax feed connector is also available for the antenna. It is a good choice for applications such as radar cross-section measurement, EW receivers, instrumentation radar and other broadband systems.

***QuinStar Technology Inc.,***
***Torrance, CA (310) 320-1111,***
***www.quinstar.com.***
**Booth 2505** **RS 331**

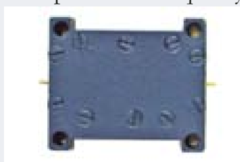
## Coaxial Switches

The R595 Platinum series of DP3T – SPDT coaxial switches complement the R594 Platinum series of high performance, multi-port switches. The R595 Platinum series products offer several configurations, including DP3T and SPDT in both terminated and non-terminated versions. These products are optimized to perform at a high level over an extended life span. The switches feature an insertion loss repeatability of 0.03 dB over a life span of 10 million cycles (up to 26.5 GHz).

***Radiall,***
***Rosny-sous-Bois, France***
***+33 1 49 35 35 35, www.radiall.com.***
**Booth 1047** **RS 332**

## Flat Pack Filters

This flat pack series of miniature combline filters operate in a frequency range from 5 to 20



GHz. These tiny 1/8" profile units pack all of the performance of a larger combline filter into a smaller package. These filters are available in bandwidths of 10 to 30 percent and in 4 to 12 sections. The units are perfect for lightweight or airborne applications and can be supplied with surface-mount pins.

***Reactel Inc.,***
***Gaithersburg, MD (301) 519-3660,***
***www.reactel.com.***
**Booth 324** **RS 333**

## Hardware Acceleration

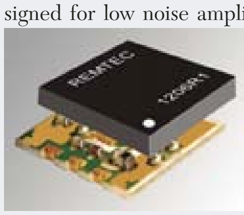
The release of XSTREAM hardware acceleration is designed for XFDTD. XFDTD is an

electromagnetic analysis software based on the finite difference time domain method. XSTREAM uses the latest graphics card technology to provide dramatic speed increases in calculation time, even compared to the MPI multiprocessor cluster version and workstations.

***Remcom Inc.,***
***State College, PA (814) 861-1299,***
***www.remcom.com.***
**Booth 405** **RS 334**

## Leadless SMT Ceramic Packages

These ceramic leadless SMT packages are designed for low noise amplifiers, power ampli-




fiers, switches, transceivers, mixers, splitters, filters, attenuators and other components that vary in sizes from 0.15" to 1" and operate from DC to 32 GHz. Packages feature unique low inductance wrap-around connections, plugged via holes with low resistance (below 1 milliohm) ensuring RF losses below 0.1 dB at 4 GHz and integrated passives. Vias hermeticity to $10^{-8}$ enables a hermetic version of leadless SMT packages. Thermal vias with K ≥ 200 W/Mx°C allow thermal resistance below 1 to 2°C/W providing good thermal management.

***Remtec,***
***Norwood, MA (781) 762-9191,***
***www.remtec.com.***
**Booth 2504** **RS 335**

## Quadrature Hybrid Couplers

These application specific, high power 90° quadrature hybrid couplers are designed for use in WiMAX applications. The units operate at 2.5 and 3.5 GHz and coupling is 3 dB nominal. Electrical performance offers typical insertion loss of 0.5 dB, isolation of 18 dB minimum, VSWR of 1.25 typical and directivity of 15 dB maximum. Power handling is 500 W CW. The devices are available with SMA female connectors standard, and alternate interfaces upon request. Size: 1.3" × 0.4" × 0.4", plus connectors.

***Response Microwave Inc.,***
***Framingham, MA (978) 456-9184,***
***www.responsemicrowave.com.***
**Booth 2110** **RS 336**

## Adapter Kit

The RFA-4031-01 kit features three 3.5 mm precision adapters for use in microwave and RF applications. All adapters in this series offer 50 Ω impedance and are made of non-magnetic, 303 stainless steel with beryllium copper contacts supported with a bead configuration. These adapters are designed to operate up to 34 GHz with a VSWR rating of 1.05+.006 f (f-GHz) maximum, and offer the same electrical length. 3.5 mm series coaxial connectors and adapters intermate with SMA and 2.9 mm connectors and are used primarily on test equipment. Special female design prevents misalignment during engagement.

***RF Industries Inc.,***
***San Diego, CA (858) 549-6340,***
***www.rfindustries.com.***
**Booth 2007** **RS 337**

## GaN Power Amplifier

The model RFP-3500-48-28 is a GaN power amplifier designed for WiMAX applications that operate in a frequency range from 3.4 to 3.6 GHz. Average OFDM output power is 39 dBm at 3.5 GHz, and these amplifiers work well in all 64~16 QAM modulations with a 2 percent EVM specification. This module utilizes GaN HEMT technology that offers high breakdown voltage, high linearity, wide bandwidth and high efficiency.

***RFHIC,***
***Suwon, Korea +82-31-250-5011,***
***www.rfhic.com.***
**Booth 1316** **RS 338**

## Front-end WLAN Module

The model RF5924 is a full front-end module designed for embedded wireless LAN (WLAN) applications. The device requires no external components, which provides the smallest footprint area of any 802.11g front-end module. Featuring the WLAN power amplifier, switch and receive balun, the RF5924 provides all the required functions between the RF transceiver and the system BPF/antenna. With all RF ports 50 Ω matched, the RF5924 is designed to ease system implementation and reduce design cycle time.


***RFMD®,***
***Greensboro, NC (336) 664-1233,***
***www.rfmd.com.***
**Booth 1207** **RS 339**

## Hand Formable Cables

These YouForm™ high quality, jacketed hand formable cables feature stainless steel SMA plugs on each end. These cables are 100 percent VSWR tested for 1.35 at 18 GHz and are available in 2 diameters that include 0.085 (0.102(OD)) and 0.141 (0.161(OD)). Lengths that range from 3" to 18" are in stock. Price: $9.95 each. Longer lengths are available at a higher price. These cable assemblies and connectors are engineered at P1dB by an alumni of companies such as Omni Spectra and M/A-COM.

***RFMW Ltd.,***
***San Jose, CA (408) 414-1450,***
***www.rfmw.com.***
**Booth 747** **RS 340**

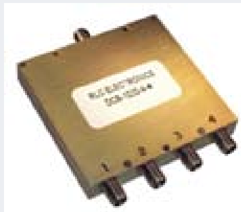
## Amplifier Pallet

The model LDU601C UHF (470 to 862 MHz) is an amplifier pallet designed for analog and digital TV transposers and transmitters. This amplifier pallet provides a power output of 600 W pep (–27 dBc minimum), and features the company's patented "Smart Bias" control and innovative output matching circuits. The LDU601C incorporates microstrip technology and push-pull LDMOS technology (Infineon PTFA043002E RF device) to enhance ruggedness and reliability.

***Richardson Electronics,***
***LaFox, IL (630) 208-2200, www.rell.com.***
**Booth 1922** **RS 341**

## Power Dividers and Combiners

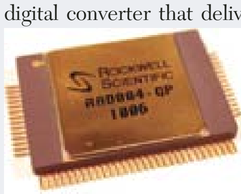
The DCB-1020 series is an in phase power divider/combiner that offers high isolation, small size and good performance in a single package. These two-, three- and four-way dividers/combiners operate in a frequency range from 1 to 2 GHz, with a minimum isolation of 19 or 20 dB minimum. All microstrip and stripline power dividers typically pass DC on all ports. These units utilize microstrip construction with blocking capacitors on all ports except those that are intended to pass DC.



***RLC Electronics Inc.,***
***Mount Kisco, NY (914) 241-1334,***
***www.rlcelectronics.com.***
**Booth 1814** **RS 342**

## Analog to Digital Converter

The model RAD004 is a 6 bit 4 GS/s analog to digital converter that delivers a high sampling rate. This performance provides significant benefits to developers of a variety of applications such as automated test equipment, high performance oscilloscopes, spectrum analyzers and other applications. The RAD004 is usable in the 1st and 2nd Nyquist band, and can capture signals from DC to 4 GHz. Better than 4 ENOB is obtained over the entire bandwidth when clocked at 4 GHz.



***Rockwell Scientific Co.,***
***Thousand Oaks, CA (805) 373-4545,***
***www.rockwellscientific.com.***
**Booth 1719** **RS 343**

# NEW WAVES

## High Frequency Circuit Material

The RO4450B™ series high frequency circuit material is a glass-reinforced hydrocarbon/ceramic thermoset bondply designed for performance-sensitive, multi-layer printed circuit boards. These bondplys are designed to offer good high frequency performance and low cost circuit fabrication. The result is a low loss material, which can be fabricated using standard epoxy/glass (FR4) processes. The RO4450B-dx is a high fill/flow version of the industry-standard RO4450B bondply. It is designed to fill those high density designs while still offering thin dielectric spacing.

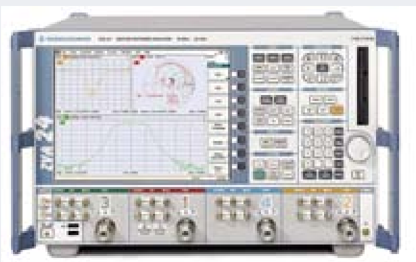
***Rogers Corp.,***
***Rogers, CT (480) 961-1382,***
***www.rogerscorporation.com.***
**Booth 1441** **RS 344**

## Signal Source Analyzer


The FSUP is a signal source analyzer that combines the functionality of the high end spectrum analyzer FSU with the advantages of a pure phase noise tester with low noise DC sources, enabling a user to perform a wide range of measurements. In this single unit, a user can measure phase noise, tuning steepness, transient response, power harmonics and spurious emissions.

***Rohde & Schwarz,***
***Columbia, MD (888) 837-8772,***
***www.rohde-schwarz.com/usa.***
**Booth 841** **RS 345**

## Vector Network Analyzers




The ZVA family of vector network analyzers offers a balance between measurement speed, dynamic range, flexibility and precision, making them ideal for present and future measurement tasks. The fundamental mixing concept employed by the analyzer's receivers ensures high sensitivity and a wide dynamic range. Fast synthesizers make for short measurement times. Its characteristics include new functionality, sophisticated GUI and high flexibility that make the ZVA an indispensable tool for demanding measurement tasks in labs and production.

***Rohde & Schwarz Inc.,***
***Columbia, MD (888) 837-8772,***
***www.rohde-schwarz.com.***
**Booth 841** **RS 346**

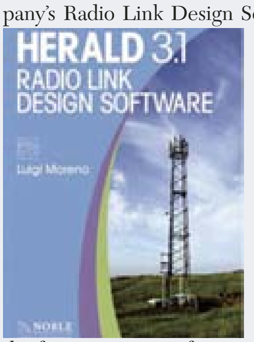
## Cable Assemblies

The RG402/RG405 are quick turn, hand formable cable assemblies that feature VSWR better than 1.20. These hand formable cable assemblies offer anti-torque SMA straight plugs, but other connectors are available. Also released are new low loss, flexible test cables, which feature stainless steel SMA plugs. These test cables feature VSWR of 1.20 through 18 GHz. Prices beginning at $9.95 each at 500 pieces, with delivery in as little as five business days.

***San-tron Inc.,***
***Ipswich, MA (978) 356-1585,***
***www.santron.com.***
**Booth 1847** **RS 347**

## Radio Link Design Software

HERALD 3.1 is the latest release of the company's Radio Link Design Software and a welcome addition to the Noble CD Library of Training and Software. This versatile and well-supported simulation tool runs on Windows. It features point-to-point (multi-hop) microwave links and networks, working in the frequency range from 0.4 to 58 GHz.




***SciTech Publishing Inc.,***
***Raleigh, NC (919) 847-2434,***
***www.scitechpub.com.***
**Booth 2249** **RS 348**

## Coaxial Cables

The HP180 coaxial cable has been paired with a proprietary 3.5 mm stainless steel connector design to deliver low loss at a rated frequency of 32 GHz. The HP cable series is durable cable for communication, test and military/aerospace microwave frequency applications where compliance to tight electrical specifications and/or exposure to extreme environmental conditions are required. HP cable is also available with polyurethane jacketing, which adds substantially improved flexibility and abrasion resistance for applications from –65° to +85°C.

***Semflex Inc.,***
***Mesa, AZ (480) 985-9000,***
***www.semflex.com.***
**Booth 1409** **RS 349**

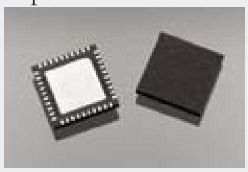
## Temperature/Humidity Chambers

These temperature/humidity chambers are referred to as the Sigma Humidity Solution. The Sigma Humidity Solution concept incorporates a proven, patent pending design that humidifies air from the chamber with treated water and returns it at chamber temperature. By avoiding the steam injection and water spray methods typically used, condensation is greatly minimized, temperature fluctuations are reduced, and temp/humidity transitions are smoother and more accurate, all resulting in reduced test times.

***Sigma Systems Corp.,***
***El Cajon, CA (619) 258-3700,***
***www.sigmasystems.com.***
**Booth 1605** **RS 350**

## 2 W Linear Power Amplifier

The model SZM-3066Z is a 2 W linear power amplifier that utilizes InGaP HBT technology and operates over the full 3.3 to 3.8 GHz frequency range. Features include: adjustable on-chip, active-bias circuit, a single +5 VDC supply, gain = 34 dB, +26 dBm of linear power at 2.5 percent EVM, power up/power down control, and an on-chip power detector. It is an ideal RF amplifier solution for WiMAX applications, and is housed in a low cost, surface-mount 6×6 QFN package.



***Sirenza Microdevices,***
***Broomfield, CO (303) 327-3030,***
***www.sirenza.com.***
**Booth 1035** **RS 351**

## 5 GHz Direct Demodulator

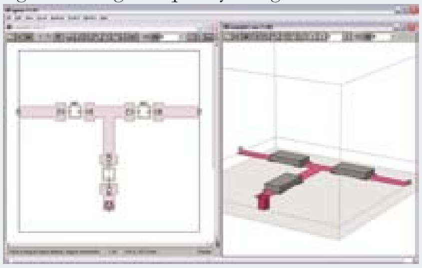
The model SKY73013 is a direct quadrature demodulator with integrated LNA for the 5 GHz band. This model offers good quadrature accuracy performance, noise figure and linearity specifications making the device ideal for even the most difficult modulation formats, including 64-quadrature amplitude modulation orthogonal frequency division multiplexing. The internal "no-pull" architecture offsets the voltage-controlled oscillator from the carrier frequency by a factor of 3/2. This demodulator operates from 4.9 to 5.925 GHz, has a 6 dB noise figure, and input 1 dB compression point of –15 dBm. Size: 4 × 4 × 0.9 mm.

***Skyworks Solutions Inc.,***
***Woburn, MA (781) 376-3000,***
***www.skyworksinc.com.***
**Booth 1705** **RS 352**

# NEW WAVES

## High Frequency EM Simulation

These best-in-class 3D planar electromagnetic simulation tools are designed for high frequency designers around the world. New features will

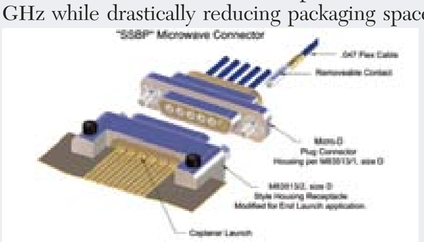


be introduced in the highly anticipated Sonnet Suites Professional Release 11 slated for release this fall. These tools achieve an unparalleled accuracy when attaching surface-mount devices to an EM project and are setting the standard in EM interfacing capabilities with the new Ebridge interface to the Agilent ADS.

***Sonnet Software Inc.,***
***North Syracuse, NY (315) 453-3096, www.sonnetsoftware.com.***
***Booth 1639*** ***RS 353***

## Microwave Contacts

These SSBP microwave contacts provide broad bandwidth through 65+ GHz while drastically reducing packaging space. Using standard plastic




insertion/extraction tools, versions of SSBP contacts fit in Size 20 contact cavities for D-Sub (M24308), Micro-D (special contact arrangements in M83513 housings) and D38999 connectors. These SSBP microwave contacts provide high density packaging, increased signal integrity, improved system reliability and assembly cost reduction.

***Southwest Microwave Inc.,***
***Tempe, AZ (480) 783-0201, www.southwestmicrowave.com.***
***Booth 338*** ***RS 354***

## High Power Isolator/Circulator

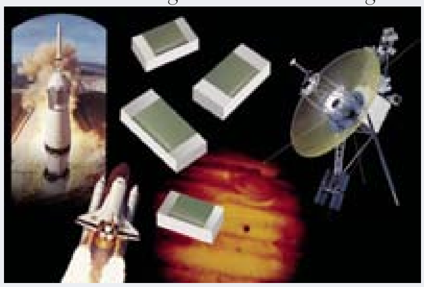
This ETI isolator series is designed to handle high power and high performance applications. This device covers a frequency range from 2 to

2.20 GHz with a power rating of 250 W/fwd and 125 W/rev. This series offers an insertion loss of 0.15 dB (typical 0.12 dB), VSWR of 1:15 maximum and IMD < –82 dBc at 2× 40 W tones. This device is available in both an isolator and a circulator version. The isolator size is 0.75" × 1" × 0.30" and circulator size is 0.75" × 0.75" × 0.30".

***Star Microwave Inc.,***
***San Jose, CA (408) 286-6994, www.starmwi.com.***
***Booth 2421*** ***RS 355***

## Chip Resistors

These miniature, high reliability chip resistors are available in both thick and thin film designs. The resistors range in size from 0202 (0.020" ×



0.020") to 0603 (0.060 × 0.030"), with tolerances from 0.1 percent, power ratings from 20 to 200 mW, temperature coefficients of resistance as low as 25 ppm and voltage ratings from 15 to 50 V. The operating range for these resistors is from –55° to +125°C. A full range of termination styles and termination finishes are available. Price: < $1.00. Delivery: two days ARO.

***State of the Art Inc.,***
***State College, PA (814) 458-3401, www.resistor.com.***
***Booth 805*** ***RS 356***

## Airborne K-band Data Link

This K- to L-band half duplex transceiver is enclosed in a fully hermetic aluminum housing, measuring approximately 5" × 4" × 0.7", weighing less

than 13 ounces, with integrated low phase noise and stable synthesized LO sources. Downconverter offers 10 dB of gain with 10 dB of selectable attenuation, in 0.25 dB steps, controlled via serial interface. Upconverter uses automatic level control (ALC) circuitry to maintain a fixed output power while the input can vary to 15 dB. Output is also –70 dBc spurious-free from DC to 40 GHz.

***STC Microwave Systems Inc.,***
***a Crane Aerospace and Electronics company,***
***Chandler, AZ (480) 961-6269, www.craneae.com.***
***Booth 1621*** ***RS 357***

## Miniature Flexible Cable

A 0.160" diameter cable is being added to the Storm Flex™ line of miniature flexible cables, which currently includes both 0.055" and

0.096" diameter cables. For applications that call for electrical performance typical of 0.047", 0.086" or 0.141" semi-rigid assemblies and reduced development costs, the Storm Flex line offers a classic option. These durable, performance tested cables are designed to fit standard 0.047", 0.086" and 0.141" semi-rigid connectors, eliminating costs associated with time-consuming semi-rigid cable layout.

***Storm Products–Microwave,***
***Woodridge, IL (630) 754-3300, www.stormproducts.com.***
***Booth 822*** ***RS 358***

# NEW WAVES

## Automated Calibration Software

SussCal® Professional is an advanced, automated calibration software for accurate 1-, 2-, 3- and 4-port RF and microwave measurements. SussCal

Professional software includes the LRM+™ calibration method, which provides the most accurate on-wafer calibration up to 110 GHz and beyond. In addition, SussCal Professional includes powerful tools such as SussView™ for visualizing results, *Accura-CV*™ for optimized RF/CV measurements and the SubstrateNavigator™ for easily navigating the calibration substrates. For a powerful manual calibration solution, SUSS has introduced SussCal Lite.

***SUSS MicroTec Inc.,***
***Waterbury Center, VT (802) 244-5181, www.suss.com.***
**Booth 1523** **RS 359**

## Off-line Analysis Software

RSAVu off-line analysis software allows customers to acquire signals using a real-time spectrum analyzer (RSA) and then analyze the captured information off-line on a PC. The real-time spectrum analyzers have been designed to aid customers working with digital RF applications including software defined radios that use complex modulation techniques, radar with its time-varying and pulsed RF signals, and RFID that makes use of momentary communication links. The PC-based RSAVu software can provide the same analysis capabilities as exist on the customer's real-time spectrum analyzer. Customers are able to capture files on one RSA instrument and share these with multiple PC users for off-line analysis.

***Tektronix Inc.,***
***Beaverton, OR (800) 835-9433, www.tektronix.com.***
**Booth 1408** **RS 363**

## Voltage-controlled Oscillators

The DCYR (distributed coupled YIG replacement oscillator) series of multi-coupled slow-wave (MCSW) planar-coupled resonator technology

is designed for voltage-controlled oscillators (VCO). This series covers the frequency range of 250 to 6000 MHz in several models tuning an octave bandwidth and higher-than-octave. The housing is industry-standard surface-mount packaging (0.75 × 0.75" and 0.5 × 0.5"), RoHS compliant. These VCOs can serve as a direct substitute for low noise signal source for microwave communications, test and measurement equipment, radar, local multipoint-distribution systems (LMDS), and multi-channel multipoint-distribution systems (MMDS).

***Synergy Microwave Corp.,***
***Paterson, NJ (973) 881-8800, www.synergymwave.com.***
**Booth 1404** **RS 360**

## Flexible Laminates and Bonding Materials

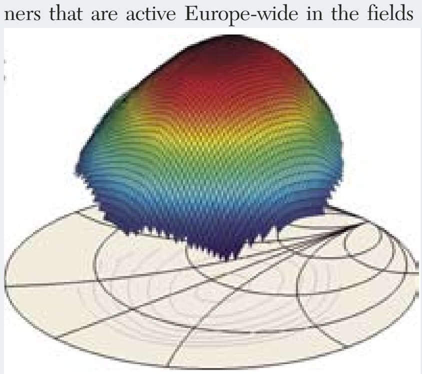
HyRelex is a family of low loss, high reliability, flexible laminates and bonding materials. It is constructed with the benefits of reinforced high

temperature polymer chemistry to provide good thermal, mechanical, electrical and moisture resistant properties. HyRelex is a good value for the high performance demands of flexible applications. The low dissipation factor, thermal stability and smooth surface profile minimize phase shift with frequency and temperature, and yield good low loss circuit performance. HyRelex is ideally suited for high frequency, high temperature and harsh environment applications.

***Taconic Advanced Dielectric Division,***
***Petersburgh, NY (518) 658-3202, www.taconic-add.com.***
**Booth 2041** **RS 361**

## Measurement and Characterization Services

TARGET is a network of excellence of 49 academic and industrial partners that are active Europe-wide in the fields of microwave power am-



plifier research and production. To let industry and academia outside TARGET benefit of its characterization capabilities it offers measurement and fabrication services in organized virtual labs: a virtual lab is dedicated to a certain measurement or fabrication topic and comprises different labs participating in TARGET.

***TARGET,***
***Vienna, Austria +43 (0) 1 505 28 30-0, www.target-net.org.***
**Booth 2423** **RS 362**

## Components and Capabilities

These components and full first-level integration capabilities provide customer-specified integrations of analog and mixed analog-digital de-

signs, including hybrid, MMIC and mixed hybrid-MMIC configurations for military, space and performance-targeted applications. Products include I/Q demodulators, coupled detector assemblies, switched amplifier detector assemblies and multi-band VCOs. The integrated assemblies control schedule and cost risks, and reduce component interface difficulties.

***Teledyne Cougar,***
***Sunnyvale, CA (408) 522-3838, www.cougarcorp.com.***
**Booth 621** **RS 364**

# NEW WAVES

## RF Connector

This RF connector features a built-in bandpass filter with six different bandwidths at a center frequency ($F_0$) between 45 to 2600 MHz. This connector is ideal for use in cellular phones for GSM 1800, AMPS 2000, PDC, WLAN, WiMAX and GPS. Lead-time: 14 days. This connector is suitable for mobile, outdoor, tower systems, laboratories, work plants, RF engineers and students.


***Temwell Corp./Temstron Co. Ltd., Taipei, Taiwan 886-2-25652500, www.temwell.com.tw.***
**Booth 709** **RS 368**

## Coaxial Surge Suppressors

These high performance surge suppressors with gas discharge tubes are offered in two series. One series includes a 2.5 GHz device with an IP 67 rating that is suitable for outdoor use. It can carry loads of up to 300 W and can handle discharge currents of 40 kA. Various designs with DC spark-over voltages from 75 to 1000 V are available. Designs featuring N or 7/16 Din interfaces are available. The other type is a 6 GHz compact device suitable for WLAN applications. It is designed to withstand discharge currents of 10 kV maximum. Designs featuring SMA and R-SMA interfaces are also available.

***Telegartner Inc., Franklin Park, IL (630) 616-7600, www.telegartner.com.***
**Booth 2405** **RS 366**

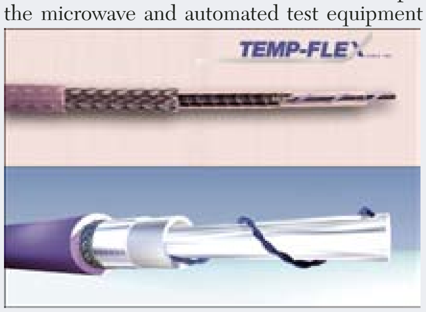
## Solid-state Power Controllers

These DC solid-state power controllers (SSPC) are designed to replace conventional electromechanical circuit breakers in certain applications, thus reducing component count, system weight and cost, while increasing system reliability. The PC150 solid-state power controllers switch, monitor, report status and provide circuit protection for circuits from 2 to 25 amps within the voltage limits and conditions specified in MIL-STD-1275. These SSPCs feature current flow status, load voltage status, trip status signals and built-in transient suppression. Size: 2.74" × 1.34" × 0.370", plus an additional 0.24" for pin depth. Price: $500.00 each (500). Delivery: 12 to 14 weeks.

***Teledyne Relays, Hawthorne, CA (800) 284-7007, www.teledynerelays.com.***
**Booth 621** **RS 365**

## Flexible Microwave Coax

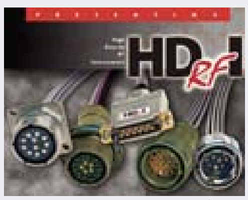
This ultra low loss, flexible microwave coax product line is designed for the microwave and automated test equipment industries. The product line incorporates a patented dual monofilament technology, which can yield an effective dielectric constant of 1.3, and a propagation velocity of 88 percent. The initial release covers two products designed to match the 0.047" and 0.086" diameter of semi-rigid cables, which facilitates the use of a variety of standard connectors. Other attributes of the coax include its flexibility and routability. The cable's design and tight manufacturing tolerances yield a ±1 Ω impedance.



***Temp-Flex Cable Inc., South Grafton, MA (508) 839-5987, www.tempflex.com.***
**Booth 412** **RS 367**

## High Density RF Interconnect

The high density RF interconnect (HDRFI) is a genderless RF interconnect that utilizes an elastomeric interface to achieve a high frequency response of 40 GHz and a tighter packaging footprint. HDRFI is scalable to meet the needs of most design requirements. HDRFI is available in a D-Sub, Mil-Circular, or custom product offering from cable to cable and PCB mount designs along with custom innovative designs.

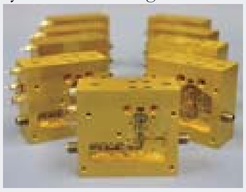



***Tensolite Co., Saint Augustine, FL (800) 458-9960, www.tensolite.com.***
**Booth 2235** **RS 369**

# NEW WAVES

## Components and Subsystems

These millimeter-wave components and subsystems are designed for military and commercial systems worldwide. Products include transceivers, low noise and power amplifiers, frequency multipliers and switches in a core frequency range of 18 to 110 GHz, as well as radio links at 60 and 74 GHz. Fast prototyping services and custom-engineered products ranging from single functions to highly integrated assemblies are provided. Partnered with BTP Systems, the company provides repair and refurbishment services of Mil SATCOM and other military communication and radar systems.



***Terabeam/HXI,***
***Haverhill, MA (978) 521-7300,***
***www.terabeam-hxi.com.***
***Booth 1009*** ***RS 370***

## Drop-in Isolators and Circulators

This extended range of X-band packaged drop-in and substrate drop-in isolators and circulators combine small size and low mass with high power handling capabilities of 45 W peak or 20 W CW and low loss of 0.2 dB per junction. Options include: multi junction devices, surface-mount designs and integrated power sensors. These designs are being qualified for defense applications such as active arrays.

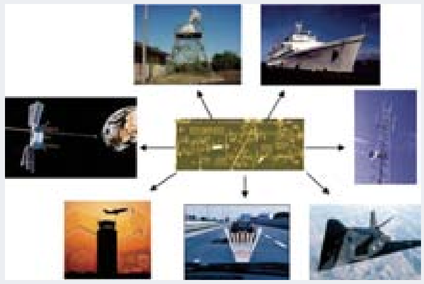
***Thales MESL Ltd.,***
***Newbridge, Edinburgh, Scotland***
***0131 333 2000, www.thales-mesl.com.***
***Booth 914*** ***RS 371***

## Hermetic SMT Packages

These hermetically sealed custom aluminum or aluminum alloy packages feature true surface-mount connections that perform through K-band. This unique approach offers several pin position options and delivers premium VSWR characteristics while ensuring low parasitic inductance. They can be supplied 100 percent hermetically tested and are available in a variety of plating options including nickel, silver or gold. A wide range of solder schedules is available.

***Thunderline-Z,***
***Hampstead, NH (603) 329-4050,***
***www.thunderlinez.com.***
***Booth 1305*** ***RS 372***

## MMIC Transceivers



These X- to W-band multi-frequency integrated transceiver (MINT) chips offer an $F_o$ tuning for 11 to 100 GHz applications. VCOs, amplifiers, multipliers and mixers are integrated into one MMIC for radar (Tx, Rx and $IF_{out}$) or communication ($IF_{in}$, Tx, Rx and $IF_{out}$) applications. On-chip reconfigurability of VSWR, amps to multipliers, multiplier to mixers, assures compatibility to most requirements.

***TLC Precision Wafer Technology Inc.,***
***Minneapolis, MN (612) 341-2795,***
***www.tlcprecision.com.***
***Booth 1611*** ***RS 373***

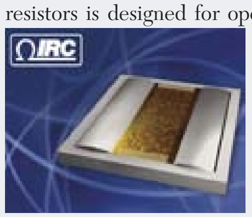
## K-band Power Amplifier

The model TGA4503 is a K-band power amplifier designed for 18, 23 and 26 GHz point-to-point radios. This power amplifier is available as MMIC or packaged. It features on-chip power detection (balanced design), good return loss and a robust passivation overcoat to protect against environmental effects. Key specifications include good TOI performance of 39 dBm, typical gain of 22 dB and P1dB of 29 dBm. P/N as MMIC, model TGA4503, is available in a compact design of 3.5 mm². Model TGA4503-SM is available in a 4×4 mm² QFN package. These power amplifiers are 100 percent DC/RF tested on-wafer.


***TriQuint Semiconductor Inc.,***
***Hillsboro, OR (503) 615-9000,***
***www.triquint.com.***
***Booth 1929*** ***RS 374***

## Chip Resistors

The MWR series of microwave/RF termination resistors is designed for operation at frequencies up to 40 GHz. These chip resistors are constructed using the company's proprietary TaN-Film® self-passivating thin film resistive element, providing an ultra-stable corrosion-resistant device suitable for use in harsh environments. The series features resistive resistance values of 50 and 75 Ω with tolerances down to ±1 percent. The chips offer absolute TCRs to ±25 ppm/°C, noise characteristics of < –20 dB and stray distributed capacitance of less than 0.05 pF.




***TT electronics***
***IRC Advanced Film Division,***
***Corpus Christi, TX (361) 992-7900,***
***www.irctt.com/microwave.***
***Booth 2019*** ***RS 375***

# NEW WAVES

## QFN Plastic Package

UMS has released numerous new products in RoHS compliant standard QFN plastic packaging for applications up to 30 GHz, including a full 24 GHz radar chipset and the CHT4690-QAG attenuator featuring high broadband, linearity and dynamic characteristics. LNAs are now targeting higher power and linearity as shown by the new CHA3666-QAG and CHA3688-QDG. These parts (LNAs, driver amplifiers, mixer, application specific chipsets) are ideal for microwave radio, automotive radars (SRR), V-SAT and military applications.

***United Monolithic Semiconductors,***
***Orsay, France +33 1 69 33 03 08,***
***www.ums-gaas.com.***
***Booth 918*** ***RS 376***

## Etching and Diffusion Bonding

The company is combining the technologies of its photochemical etching and diffusion bonding to create micro cooling cells and other custom miniature devices to aid in the electronics industry. This capability allows for the production of surface channels and features smaller than 100 µm. No application is too small in size or volume to develop.

***VACCO Industries,***
***South El Monte, CA (626) 443-7121,***
***www.vacco-etch.com.***
***Booth 611*** ***RS 377***

## Oven-controlled Crystal Oscillators

This series of low noise oven-controlled crystal oscillators (OCXO) is designed for wireless reference applications. With extremely low phase noise (–95 dBc at 10 Hz, –170 dBc at 100 kHz), stability of 0.1 ppm over –40° to +85°C, a frequency range of 25 to 100 MHz and a compact package (25.4 × 22 mm), this family of OCXOs offers a compelling cost-effective solution to the communications infrastructure market.

***Valpey Fisher Corp.,***
***Hopkinton, MA (508) 435-6831,***
***www.valpeyfisher.com.***
***Booth 2011*** ***RS 378***

## RF/Microwave Integrated Software

CONCERTO v6, the new version of its integrated software for RF and microwave design, now includes the Conforming FDTD analysis, Moment Method analysis and Finite Element analysis modules, all running within a single environment. New features are available in each of the modules, as well as enhancements to the shared Geometric Modeler.


***Vector Fields Inc.,***
***Aurora, IL (630) 851-1734,***
***www.vectorfields.com.***
***Booth 346*** ***RS 379***

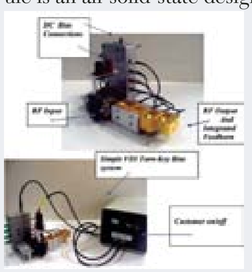
## YIG-based Synthesizer

The Hammerhead family of YIG-based frequency synthesizers meets the demanding requirements of high data-rate digital radios, satellite communications systems, fast switching radar and sensor systems that must be tunable over wide frequency ranges and secure military communications systems. The company's patented technologies provide the broad tuning bandwidth, spectral purity, extended temperature performance, microphonic and phase hit resistance, and ultra low phase noise performance required by next generation commercial and military systems.

***VIDA Products Inc.,***
***Santa Rosa, CA (707) 541-7000,***
***www.vidaproducts.com.***
***Booth 2632*** ***RS 380***

## 1.4 to 1.5 THz Frequency Extension Module

This 1.4 to 1.5 THz frequency extension module is an all-solid-state design that produces approximately 10 to 30 µW of CW RF output power over the 1.4 to 1.5 THz band. The customer RF input is approximately 14.5 to 15.5 GHz with an 18 dBm power level. The system includes an integrated RF output feedhorn and simple bias system.



***Virginia Diodes Inc.,***
***Charlottesville, VA (434) 297-3257,***
***www.virginiadiodes.com.***
***Booth 2420*** ***RS 381***

# NEW WAVES

## 3 dB Quadrature Combiner/Divider

This newly patented 3 dB quadrature coupler technology provides quadrature combining with 10:1 bandwidth capability. The model QH7349 is available connectorized and non-connectorized. This combiner/divider offers an insertion loss that measures 0.5 dB maximum, VSWR of 1.35 maximum, isolation of 18 dB minimum and amplitude balance of ±0.6 dB maximum. The divider/combiner operates in a frequency range from 100 to 1000 MHz. Size: 4.6" × 1.7" × 0.31".

***Werlatone Inc.,***
***Brewster, NY (845) 279-6187,***
***www.werlatone.com.***
**Booth 2204** **RS 382**

## Cable Assemblies

EYE-OPENER® DensiShield cable assemblies are designed to transmit high speed differential signals while reducing size and weight by 40 percent over other high speed cabling products currently on the market. Built with FCI DensiShield connectors, the cable assemblies utilize a wafer structure where each pair is shielded to lower cross-talk within the connector. Paired with lightweight cabling options, the cable is a smaller, more compact option to InfiniBand,™ CX4 and other high speed cabling products.

***W.L. Gore & Associates Inc.,***
***Elkton, MD (302) 292-5100,***
***www.gore.com.***
**Booth 1620** **RS 383**

## Doppler Ranging Sensor Heads

The SRU series of ranging sensor heads is designed for long range distance detection where the sensitivity is essential. These ranging sensors are used for moving target distance detection. Four configurations are offered for special applications. The single channel versions are used for speed and distance sensing only while dual-channel versions are offered for speed, distance and direction sensing. In addition, dual antenna versions are offered for high power versions to eliminate the limited Tx/Rx isolation problems due to the diplexer.

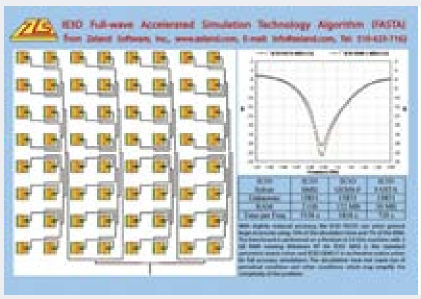
***WiseWave Technologies Inc.,***
***Torrance, CA***
***(310) 539-8882,***
***www.wisewave-inc.com.***
**Booth 437** **RS 384**

## Coaxial Resonator Oscillator

The model CRO1877A-LF is an RoHS compliant coaxial resonator based voltage-controlled oscillator (VCO) that operates in a frequency range from 1835 to 1920 MHz. This model offers phase noise performance of –111 dBc/Hz at 10 kHz offset from the carrier. This unique design offers good tuning linearity with a typical tuning sensitivity of 22 MHz/V and covers the entire band between 0.5 to 4.5 V. This model offers low pulling of < 0.5 MHz/V and pushing of < 0.5 MHz, which makes it an ideal choice for applications where signal stability, tuning linearity and low phase noise are critical. Size: 0.50" × 0.50" × 0.22". Price: $29.95/VCO (5 pcs min). Delivery: stock to four weeks.


***Z-Communications Inc.,***
***San Diego, CA***
***(858) 621-2700,***
***www.zcomm.com.***
**Booth 2307** **RS 385**

## High Performance EM Simulators



These high performance EM simulators are targeted for the design of MMIC, RFIC, RFID, PCB, RF circuits and antennas. The IE3D EM simulator is seamlessly integrated into Cadence Virtuoso, Cadence Allegro and AWR Microwave Office to improve designers' productivity. The recent release of IE3D full-wave accelerated simulation technology algorithm (FASTA) offers fast and reliable full-wave results.

***Zeland Software Inc.,***
***Fremont, CA***
***(510) 623-7162,***
***www.zeland.com.***
**Booth 1223** **RS 386**

# ERRATUM

In "Anechoic Chamber Measurement Improvement," an application note by G. Cottard and Y. Arien that appeared in the March issue of *Microwave Journal*, Mr. Cottard's affiliation was incorrectly listed. He is associated with ANTEM located in Saint-Maur-des-Fosses, France. Our apologies to Mr. Cottard for any inconvenience this error has caused.



# NEW LITERATURE

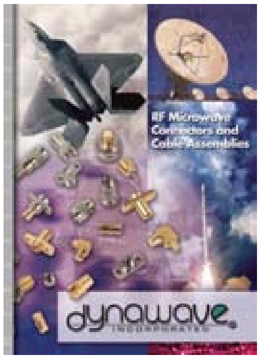
## PRODUCT BROCHURE


This brochure features the company's WAVE~X products that provide flexible, low profile EMI absorption that is readily conformable and easy to install in the area to be shielded. The WAVE~X family offers a frequency range from 10 MHz to 40 GHz, good near-field attenuation and mode suppression, space saving, thin materials and good mechanical conformability properties.

***ARC Technologies Inc.,***
***Amesbury, MA (978) 388-2993,***
***www.arc-tech.com.***

**RS No. 200**

## PRODUCT CATALOG

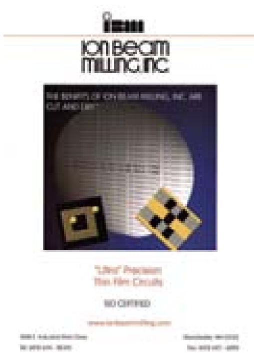



This catalog details the company's capabilities in the design and manufacture of RF microwave connectors and cable assemblies. The company is a provider of high quality, standard and special RF and microwave connectors, adapters, blindmate interconnecting components and cable assemblies for use in military applications and commercial microwave, RF and wireless industry components. Information on quote requests, ordering information and product warranty is also provided.

***Dynawave Inc.,***
***Haverhill, MA (978) 469-0555,***
***www.dynawave.com.***

**RS No. 201**

## PRODUCT BROCHURE

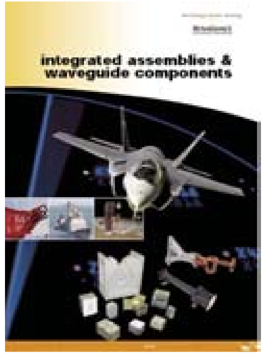



This brochure provides a compilation of the company's ultra high density micro-machined devices. The company utilizes photolithography and ion beam milling to fabricate electronic and mechanical elements for an array of commercial, industrial, military and satellite applications.

***Ion Beam Milling Inc.,***
***Manchester, NH (603) 644-2326,***
***www.ionbeammilling.com.***

**RS No. 202**

## PRODUCT BROCHURE




This brochure describes the company's high power capability for the design and manufacture of integrated waveguide subsystems and components. These components include ferrite circulators/isolators, bandpass filters/diplexers, power dividers/combiners, water loads, ceramic windows, arc sensors and orthomode tees. These products operate in frequency bands from 400 MHz through 50 GHz and from WR2100 to WR22 waveguide.

***Renaissance Electronics Corp.,***
***Harvard, MA (978) 772-7774,***
***www.rec-usa.com.***

**RS No. 203**

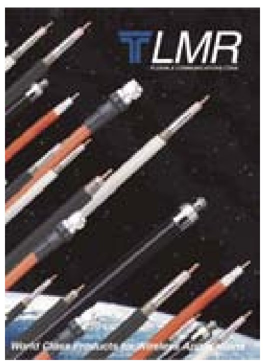
## POWER AMPLIFIERS DATA SHEET


This data sheet provides complete detail on the company's 20 to 25 W Ka-band power amplifiers, the MPC4-1530 ODU series. This series is ideal for SATCOM systems serving military and commercial airborne and mobile platforms. A product photograph, description, performance features, electrical and mechanical specifications, and outline drawings are also provided.

***Sophia Wireless Inc.,***
***Chantilly, VA (703) 961-9573,***
***www.sophiawireless.com.***

**RS No. 204**

## WIRELESS PRODUCTS CATALOG

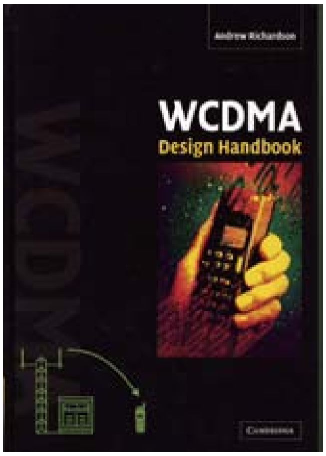



The 11th edition of the LMR® wireless products catalog includes the company's entire range of LMR cables. The latest connectors, accessories and installation tools have also been added as well as a handy pullout comparison reference chart detailing attenuation and power handling characteristics of LMR cables.

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

**RS No. 205**

## WCDMA Design Handbook

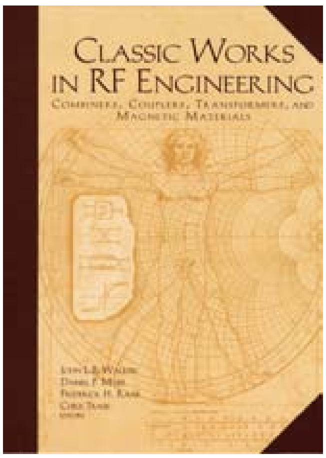



**Andrew Richardson**
**Cambridge University Press • 590 pages; $100**
**ISBN: 0-521-82815-5**

This book addresses the subject of wideband code division multiple access (WCDMA) as defined by the Third Generation Partnership Project (3GPP) and provides a detailed review of the architecture and the operation of the system. The focus is on the radio interface, from the physical layer through to the upper layers of the non-access stratum. This text offers a complete end-to-end explanation of the system operation, or alternatively allows the reader to focus on any aspects of the system, which are of interest and relevance. The material is presented in a modular fashion, with the overlap and interlinking of the chapters kept to a minimum to allow them to be as self-standing as possible. The book can be divided into four parts. Part 1, Chapters 1 to 3, is a general introduction; Part 2, Chapters 4 to 7, covers mainly the physical layer; Part 3, Chapters 8 to 12, covers layers 2 and 3 in the access stratum; and Part 4, Chapters 13 and 14, covers the non-access stratum protocol. The reading of these four parts will depend upon the specific interests of the reader. Parts 1 and 2 are recommended for RF, DSP, ASIC and hardware engineers. For protocol designers/software designers and protocol test engineers who are focusing on the operation of the access stratum of the WCDMA system, Parts 1 and 3 are the most appropriate. Protocol designers/software designers and protocol test engineers concentrating on the operation of the non-access stratum of the WCDMA system should read Parts 1 and 4. Finally, for an interested reader, or for a graduate or undergraduate course, the chapters can be taken in order. The book follows the 3GPP specifications; for completeness, the relevant specifications are outlined in the Appendix.

*To order this book, contact:*
Cambridge University Press
40 West 20th Street
New York, NY 10011-4211
(212) 337-5057

## Classic Works in RF Engineering: Combiners, Couplers, Transformers and Magnetic Materials




**John L.B. Walker, Daniel P. Myer, Frederick H. Raab and Chris Trask, Eds.**
**Artech House • 382 pages; $129, £55**
**ISBN: 1-58053-056-7**

Much of the groundbreaking developments of RF components occurred in the 1940s and many of these components still form the backbone of today's designs. The original work is hard to find as it was published in journals that are long gone or had limited circulation. The aim of this book is to make this wealth of information readily available. It focuses on passive signal processing components commonly used at RF, namely impedance conversion and power splitting/combining. Chapter 2 looks at the history of powdered iron materials before considering ferrite materials that use the oxides of magnetic materials, followed by a discussion on losses in magnetic materials caused by eddy currents and hysteresis, and concludes with noise and distortion considerations. Chapter 3 on baluns/hybrids/anti-phase power splitters initially discusses the distinction between these terms before detailing the fundamental performance limitations associates with this type of component. It continues with a description of lossless, two- and three-port baluns including the lattice (bridge), Marchand and Guanella baluns, and concludes with lossy three-port and lossless four-port baluns. Chapter 4 is concerned with impedance transformation and shows that, at RF, this is best done using a transmission line transformer. It concludes with a discussion on design, construction and application. Chapter 5 begins by discussing the basic terminology and then develops the theory of hybrid splitters and hybrid combiners. Chapter 6 describes quadrature combining of power amplifiers, a system otherwise known as a balanced amplifier. This chapter also considers aspects that are not normally addressed, such as the effect of arbitrary loads on the overall performance.

*To order this book, contact:*
Artech House
685 Canton St.
Norwood, MA 02062
(781) 769-9750 ext. 4030; or
46 Gillingham St.
London SW1V 1HH UK
+44 (0) 207-8750

# Advertising Index

| RS No. | Advertiser | Page No. | Phone | Fax | Web Address |
|---|---|---|---|---|---|
| 1 | A.J. Tuck Company | 108 | 203-775-1234 | 203-775-4705 | http://mwj.hotims.com/7959-1 |
| 2 | AA MCS | 365 | +33(0)8 11 09 76 76 | +33(0)1 76 91 50 31 | http://mwj.hotims.com/7959-2 |
| 3 | Accubeat Ltd. | 130 | | | http://mwj.hotims.com/7959-3 |
| 4 | Accumet Engineering Corporation | 140 | 978-568-8311 | 978-562-4384 | http://mwj.hotims.com/7959-4 |
| 5 | Advanced Power Technology RF | 82 | 408-986-8031 | 408-986-8120 | http://mwj.hotims.com/7959-5 |
| 6 | Advanced Switch Technology | 356 | 613-384-3939 | 613-384-5026 | http://mwj.hotims.com/7959-6 |
| 7 | Advanced Technical Ceramics Company | 90 | 423-755-5400 | 423-755-5438 | http://mwj.hotims.com/7959-7 |
| 8 | Aeroflex | 7 | 516-694-6700 | 516-694-2562 | http://mwj.hotims.com/7959-8 |
| 9 | Aeroflex/Inmet, Inc. | 287 | 734-426-5553 | 734-426-5557 | http://mwj.hotims.com/7959-9 |
| 10 | Aeroflex/KDI-Integrated Products | 263 | 973-887-8100 ext. 500 | 973-884-0445 | http://mwj.hotims.com/7959-10 |
| 11 | Aeroflex/Metelics, Inc. | 183 | 408-737-8181 | 408-733-7645 | http://mwj.hotims.com/7959-11 |
| 12 | Aeroflex/Weinschel, Inc. | 15 | 800-638-2048 | 301-846-9116 | http://mwj.hotims.com/7959-12 |
| 13 | Aerowave Inc. | 163 | 781-391-1555 | 781-391-5338 | http://mwj.hotims.com/7959-13 |
| 14 | Aethercomm | 143 | 760-598-4340 | 760-598-4342 | http://mwj.hotims.com/7959-14 |
| | Agilent Technologies, Inc. | 47,171 | 800-829-4444 | 415-857-5518 | www.agilent.com |
| 15 | Allrizon-Tongguang Communications Equipment (Shanghai) Co., Ltd. | 226 | +86-21-5219-2719 | +86-21-5218-6150 | http://mwj.hotims.com/7959-15 |
| 526 | Allwin Technology, Inc. | 294 | +86-25-84304950 | +86-25-84304959 | http://mwj.hotims.com/7959-526 |
| 16 | Amcom Communications Inc. | 204 | 301-353-8400 | 301-353-8401 | http://mwj.hotims.com/7959-16 |
| 17 | American Microwave Corporation | 355 | 301-662-4700 | 301-662-4938 | http://mwj.hotims.com/7959-17 |
| 18,19 | American Technical Ceramics | 94,185 | 631-622-4700 | 631-622-4748 | http://mwj.hotims.com/7959-18 |
| 20 | Ametek Specialty Metal Products | 246 | 203-949-8837 | | http://mwj.hotims.com/7959-20 |
| 21 | AML Communications Inc. | 55 | 805-388-1345 | 805-484-2191 | http://mwj.hotims.com/7959-21 |
| 22 | Amphenol | 195 | 800-627-7100 | 203-796-2032 | http://mwj.hotims.com/7959-22 |
| 23 | AmpliTech Inc. | 211 | 631-435-0603 | 631-435-0604 | http://mwj.hotims.com/7959-23 |
| 24 | AMTA | 290 | 425-868-2558 | | http://mwj.hotims.com/7959-24 |
| 25 | Ansoft Corporation | 207 | 412-261-3200 | 412-471-9427 | http://mwj.hotims.com/7959-25 |
| 26 | Applied Computational Sciences | 234 | | | http://mwj.hotims.com/7959-26 |
| 27 | Applied Engineering Products | 285 | 203-776-2813 | 203-776-8294 | http://mwj.hotims.com/7959-27 |
| 28 | Applied Thin Film Products | 99 | 510-661-4287 | 510-661-4250 | http://mwj.hotims.com/7959-28 |
| 29 | Applied Wave Research, Inc. | 11 | 310-726-3000 | | http://mwj.hotims.com/7959-29 |
| 30,31 | AR Worldwide | 45,164 | 215-723-8181 | 215-723-5688 | http://mwj.hotims.com/7959-30 |
| 32 | ARC Technologies Inc. | 122 | 877-24-WAVEX | | http://mwj.hotims.com/7959-32 |
| 33 | Arlon-Materials for Electronics Division | 305 | 800-635-9333 | 302-834-2574 | http://mwj.hotims.com/7959-33 |
| 34 | Artech House | 354 | 800-225-9977 | 781-769-6334 | http://mwj.hotims.com/7959-34 |
| 35,36 | Astrolab, Inc. | 115,338 | 732-560-3800 | 732-560-9570 | http://mwj.hotims.com/7959-35 |
| 37 | Auriga Measurement Systems, LLC | 91 | 978-441-1117 | 978-441-2666 | http://mwj.hotims.com/7959-37 |
| 38 | Avtech Electrosystems | 168 | 800-265-6681 | 613-226-2802 | http://mwj.hotims.com/7959-38 |
| 39 | Barry Industries, Inc. | 199 | 508-226-3350 | 508-226-3317 | http://mwj.hotims.com/7959-39 |
| 40 | BeckElec, Inc. | 108 | 623-435-6555 | 623-435-0013 | http://mwj.hotims.com/7959-40 |
| 41 | Bird Technologies Group | 261 | 866-695-4569 | | http://mwj.hotims.com/7959-41 |
| 526 | Caiqin Electronics Elements | 294 | +86-512-58339888 | +86-512-58331196 | http://mwj.hotims.com/7959-526 |
| 42 | CAP Wireless Inc. | 250 | 805-499-1818 | | http://mwj.hotims.com/7959-42 |
| 43 | Cernex, Inc. | 209 | 408-541-9226 | 408-541-9229 | http://mwj.hotims.com/7959-43 |
| 44 | Channel Microwave Corporation | 17 | 805-482-7280 | 805-987-8794 | http://mwj.hotims.com/7959-44 |
| 45 | Charter Engineering | 168 | 727-549-8999 | 727-549-8018 | http://mwj.hotims.com/7959-45 |
| 46 | Chelton & Telecom Microwave, a Cobham company | 41 | +33 (0) 1 69 02 25 60 | +33 (0) 1 69 02 25 99 | http://mwj.hotims.com/7959-46 |
| 47 | Ciao Wireless, Inc. | 144 | 805-389-3224 | 805-389-3629 | http://mwj.hotims.com/7959-47 |
| 48 | Cobham Defense Electronic Systems | 22–23 | 603-775-5200 | 603-775-5201 | http://mwj.hotims.com/7959-48 |
| 49 | Coilcraft | 16 | 800-322-2645 | 847-639-1469 | http://mwj.hotims.com/7959-49 |
| 50 | Colby Instruments | 190 | 425-452-8889 | 425-452-8802 | http://mwj.hotims.com/7959-50 |
| 51 | COM DEV Saw Products | 176 | 647-887-SAWS | 519-622-1691 | http://mwj.hotims.com/7959-51 |
| 52 | Commercial Microwave Technology, Inc. | 232 | 916-631-4363 | 530-642-9798 | http://mwj.hotims.com/7959-52 |
| 53 | Compex Corporation | 60 | 856-335-2277 | 856-335-7223 | http://mwj.hotims.com/7959-53 |
| 54 | Comtech PST Corp. | 205 | 631-777-8900 | 631-777-8877 | http://mwj.hotims.com/7959-54 |
| 55 | CPI Beverly Microwave Division | 32 | 978-922-6000 | 978-922-2736 | http://mwj.hotims.com/7959-55 |
| 56 | CPI Canada | 125 | 905-877-0161 | 905-877-5327 | http://mwj.hotims.com/7959-56 |
| 57 | Crane Aerospace & Electronics | 146 | 480-961-6269 | | http://mwj.hotims.com/7959-57 |
| 58 | CST of America, Inc. | 35 | 781-416-2782 | 781-576-5702 | http://mwj.hotims.com/7959-58 |
| 59,60 | CTT Inc. | 42,43 | 408-541-0596 | 408-541-0794 | http://mwj.hotims.com/7959-59 |
| 61 | Cuming Microwave Corporation | 229 | 800-432-6464 | 508-584-2309 | http://mwj.hotims.com/7959-61 |
| 62 | Daico Industries, Inc. | 101 | 310-507-3242 | 310-507-5701 | http://mwj.hotims.com/7959-62 |
| 63 | Damaskos Inc. | 358 | 610-358-0200 | 610-558-1019 | http://mwj.hotims.com/7959-63 |
| 64 | dBm, LLC | 84 | 973-709-0020 | 973-709-1346 | http://mwj.hotims.com/7959-64 |
| 65 | Delta Electronics Mfg. Corp. | 311 | 978-927-1060 | 978-922-6430 | http://mwj.hotims.com/7959-65 |
| 66 | Delta Microwave | 181 | 805-240-1044 ext. 122 | 805-240-9544 | http://mwj.hotims.com/7959-66 |
| 67 | Dielectric Laboratories Inc. | 89 | 315-655-8710 | 315-655-0445 | http://mwj.hotims.com/7959-67 |
| 68 | Dow-Key Microwave Corporation | 8 | 805-650-0260 | 805-650-1734 | http://mwj.hotims.com/7959-68 |
| 69 | Dynawave Incorporated | 148 | 978-469-0555 | 978-521-4589 | http://mwj.hotims.com/7959-69 |
| 70 | E2V Technologies | 162 | +44 (0) 1245 493 493 | | http://mwj.hotims.com/7959-70 |
| 71 | Eastern Wireless TeleComm, Inc. | 147 | 410-749-3800 | 410-749-4852 | http://mwj.hotims.com/7959-71 |
| 72,73 | Elcom Technologies | 196,198 | 201-767-8030 | 201-767-6266 | http://mwj.hotims.com/7959-72 |
| 74 | Electronika International Inc. | 360 | 440-743-7034 | 440-743-7035 | http://mwj.hotims.com/7959-74 |
| 75 | Elisra Electronic Systems Ltd. (Microwave Division) | 73 | 972(3)617-5655 | 972(3)617-5299 | http://mwj.hotims.com/7959-75 |
| 76 | EM Research, Inc. | 109 | 775-345-2411 | 775-345-1030 | http://mwj.hotims.com/7959-76 |
| 77 | Emerson & Cuming Microwave Products | 202 | 781-961-9600 | 781-961-2845 | http://mwj.hotims.com/7959-77 |
| 78 | Emerson Network Power | 317 | 800-247-8256 | | http://mwj.hotims.com/7959-78 |
| 79 | Emhiser Micro-Tech | 95 | 775-345-0461 | 775-345-1152 | http://mwj.hotims.com/7959-79 |
| 80,81 | Empower RF Systems, Inc. | 105,137 | 310-412-8100 | 310-412-9232 | http://mwj.hotims.com/7959-80 |
| 82 | Endwave Defense Systems | 25 | 408-522-3180 | 408-522-3181 | http://mwj.hotims.com/7959-82 |
| 83 | ET Industries | 134 | 973-394-1719 | 973-394-1710 | http://mwj.hotims.com/7959-83 |
| 84 | ETS-Lindgren | 299 | 512-531-6400 | | http://mwj.hotims.com/7959-84 |
| 85 | Eudyna Devices Inc. | 113 | +81-45-853-8156 | +81-45-853-8170 | http://mwj.hotims.com/7959-85 |

| RS No. | Advertiser | Page No. | Phone | Fax | Web Address |
|---|---|---|---|---|---|
| 86,87 | EuMW 2006 | 323,334 | + 44 20 7596 8742 | + 44 20 7596 8749 | http://mwj.hotims.com/7959-86 |
| 88 | EZ Form Cable Corporation | 213 | 203-785-8215 | 203-785-0466 | http://mwj.hotims.com/7959-88 |
| 89 | Fairchild Semiconductor | 65 | | | http://mwj.hotims.com/7959-89 |
| 90 | Filtel Microwave Inc. | 277 | 450-455-6082 | 450-424-5819 | http://mwj.hotims.com/7959-90 |
| 91,92 | Filtronic Compound Semiconductors, Ltd. | 51,275 | 408-850-5740 | 831-621-8074 | http://mwj.hotims.com/7959-91 |
| 93 | Flexco Microwave | 69 | 888-7-FLEXCO | 908-835-0002 | http://mwj.hotims.com/7959-93 |
| 94 | Flomerics | 224 | +44 (0) 20 8487 3000 | USA phone: 508-357-2012 | http://mwj.hotims.com/7959-94 |
| 95 | Florida RF Labs Inc. | 19 | 800-544-5594 | | http://mwj.hotims.com/7959-95 |
| 96 | Focus Microwaves Inc. | 53 | 514-684-4554 | 514-684-8581 | http://mwj.hotims.com/7959-96 |
| 97 | Freescale Semiconductor, Inc. | 119 | | | http://mwj.hotims.com/7959-97 |
| 98 | G.T. Microwave Inc. | 70 | 973-361-5700 | 973-361-5722 | http://mwj.hotims.com/7959-98 |
| 99 | Haverhill Cable & Manufacturing Corp. | 80 | 978-372-6386 | 978-373-8024 | http://mwj.hotims.com/7959-99 |
| 100 | Herley Industries, Inc. | 135 | 717-735-8117 | | http://mwj.hotims.com/7959-100 |
| 101 | Herotek, Inc. | 123 | 408-941-8399 | 408-941-8388 | http://mwj.hotims.com/7959-101 |
| 102,103 | Hittite Microwave Corporation | 167,169 | 978-250-3343 | 978-250-3373 | http://mwj.hotims.com/7959-102 |
| 104 | Huber + Suhner AG | 189 | +41 (0)71 353 41 11 | +41 (0)71 353 45 90 | http://mwj.hotims.com/7959-104 |
| | IEEE MTT-S International Microwave Symposium | 353 | 781-769-9750 | 781-769-5037 | www.ims2006.org |
| | IEEE MTT-S International Microwave Symposium – Hawaii | 306 | | | www.ims2007.org |
| | IEEE MTT-S Silicon Monolithic Integrated Circuits in RF Systems 2007 | 363 | | | www.ece.wisc.edu/sirf07 |
| | IEEE Radio and Wireless Symposium | 335 | 781-769-9750 | 781-769-5037 | www.radiowireless.org |
| | IEEE RFIC Symposium | 322 | | | www.rfic2006.org |
| 105 | Instruments for Industry Inc. | 351 | 631-467-8400 | 631-467-8558 | http://mwj.hotims.com/7959-105 |
| 106 | Insulated Wire Inc. | 255 | 203-791-1999 | 203-748-5217 | http://mwj.hotims.com/7959-106 |
| 107 | Integra Technologies, Inc. | 96 | 310-606-0855 | 310-606-0865 | http://mwj.hotims.com/7959-107 |
| 108 | Integrated Engineering Software | 86 | 204-632-5636 | | http://mwj.hotims.com/7959-108 |
| 109 | Interad Ltd. | 130 | 757-787-7610 | 757-787-7740 | http://mwj.hotims.com/7959-109 |
| 110 | International Crystal Manufacturing Co, Inc. | 114 | 800-725-1426 | | http://mwj.hotims.com/7959-110 |
| 111 | International Manufacturing Services, Inc. | 154 | 401-683-9700 | 401-683-5571 | http://mwj.hotims.com/7959-111 |
| 112 | Ion Beam Milling, Inc. | 225 | 603-644-2326 | 603-647-6889 | http://mwj.hotims.com/7959-112 |
| 113 | Isola Corp. | 215 | 800-845-2904 | | http://mwj.hotims.com/7959-113 |
| 114 | iTerra Communications | 173 | 650-424-1937 | 650-424-1938 | http://mwj.hotims.com/7959-114 |
| 115 | ITT Industries, Microwave Systems | 268 | 978-441-0200 | | http://mwj.hotims.com/7959-115 |
| 116,117,118 | J microTechnology | 356,358,360 | 503-614-9509 | 503-531-9325 | http://mwj.hotims.com/7959-116 |
| 119 | Jacket Micro Devices, Inc. | 136 | 404-526-6046 | | http://mwj.hotims.com/7959-119 |
| 120 | Jersey Microwave | 112 | 908-684-2390 ext. 23 | 908-684-2391 | http://mwj.hotims.com/7959-120 |
| 121 | JFW Industries, Inc. | 87 | 317-887-1340 | 317-881-6790 | http://mwj.hotims.com/7959-121 |
| 122 | K&L Microwave, Inc. | 9 | 410-749-2424 | 443-260-2268 | http://mwj.hotims.com/7959-122 |
| 123 | Krytar | 66 | 877-734-5999 | 408-734-3017 | http://mwj.hotims.com/7959-123 |
| 124 | Lark Engineering Company | 133 | 949-240-1233 | 949-240-7910 | http://mwj.hotims.com/7959-124 |
| 125 | Linear Photonics, LLC | 126 | 609-584-5747 | 609-631-0177 | http://mwj.hotims.com/7959-125 |
| 126 | LNX Corporation | 227 | 603-898-6800 | 603-898-6860 | http://mwj.hotims.com/7959-126 |
| 127 | Locus Microwave, Inc. | 316 | 814-861-3200 | 814-861-5195 | http://mwj.hotims.com/7959-127 |
| 128 | Logus Microwave Corporation | 279 | 561-842-3550 | 561-842-2196 | http://mwj.hotims.com/7959-128 |
| 129 | Lorch Microwave | 161 | 800-780-2169 | 410-860-1949 | http://mwj.hotims.com/7959-129 |
| 130 | Luff Research | 54 | 516-358-2880 | 516-358-2757 | http://mwj.hotims.com/7959-130 |
| 131,132 | M/A-COM, Inc. | 81,217 | 800-366-2266 | 978-442-5350 | http://mwj.hotims.com/7959-131 |
| 133 | M2 Global Technology, Ltd. | 26 | 210-561-4800 | 210-561-4852 | http://mwj.hotims.com/7959-133 |
| 134 | Marki Microwave, Inc. | 193 | 408-778-4200 | 408-778-4300 | http://mwj.hotims.com/7959-134 |
| 135,136 | Matrix Systems Corporation | 344 | 818-222-2301 | 818-222-2304 | http://mwj.hotims.com/7959-135 |
| 137 | Maury Microwave Corporation | 6 | 909-987-4715 | 909-987-1112 | http://mwj.hotims.com/7959-137 |
| 138 | MECA Electronics, Inc. | 124 | 973-625-0661 | 973-625-9277 | http://mwj.hotims.com/7959-138 |
| 139 | Merrimac Industries | 283 | 973-575-1300 | 973-575-0531 | http://mwj.hotims.com/7959-139 |
| 140 | MICA Microwave Corporation | 83 | 209-825-3977 | 209-825-3991 | http://mwj.hotims.com/7959-140 |
| 141 | MiCIAN GmbH | 286 | +49(421)16899351 | +49(421)16899352 | http://mwj.hotims.com/7959-141 |
| 142 | Micon Precise Corp. | 134 | 886-2-2917-7528 | 886-2-2912-1659 | http://mwj.hotims.com/7959-142 |
| 143 | Micro Lambda Wireless, Inc. | 127 | 510-770-9221 | | http://mwj.hotims.com/7959-143 |
| 144 | Micro-Coax Components | 309 | 800-223-2629 | 610-495-6656 | http://mwj.hotims.com/7959-144 |
| 145 | MicroMetrics Inc. | 257 | 603-641-3800 | 603-641-3500 | http://mwj.hotims.com/7959-145 |
| 146 | Microsemi Corporation | 82,293 | 949-221-7112 | 949-756-0308 | http://mwj.hotims.com/7959-146 |
| 147 | MicroTech Inc. | 349 | 203-272-3234 | 203-271-0352 | http://mwj.hotims.com/7959-147 |
| 148 | Microwave Circuit Technology Inc. | 254 | 631-845-1041 | | http://mwj.hotims.com/7959-148 |
| 149 | Microwave Communications Laboratories Inc. (MCLI) | 165 | 800-333-6254 | 727-381-6116 | http://mwj.hotims.com/7959-149 |
| 150 | Microwave Development Laboratories | 179 | 781-292-6680/6684 | 781-453-8629 | http://mwj.hotims.com/7959-150 |
| 151 | Microwave Device Technology | 52 | 978-692-7800 | | http://mwj.hotims.com/7959-151 |
| 152 | Microwave Filter Company, Inc. | 46 | 800-448-1666 | 315-463-1467 | http://mwj.hotims.com/7959-152 |
| | *Microwave Journal* | 307,332,352, 358,362,373 | 800-225-9977 | 781-769-5037 | www.mwjournal.com |
| 153 | Microwave Solutions, Inc. | 361 | 800-967-4267 | 619-474-4600 | http://mwj.hotims.com/7959-153 |
| 154 | MiG Microwave Innovation Group | 197 | +49 421 22 37 96 60/62 | +49 421 22 37 96 30 | http://mwj.hotims.com/7959-154 |
| 155 | Millennium Microwave Corporation | 200 | 410-742-8858 | | http://mwj.hotims.com/7959-155 |
| 156 | Millitech | 289 | 413-582-9620 | 413-582-9622 | http://mwj.hotims.com/7959-156 |
| 157 | Milmega Limited | 302 | +44 (0) 1983 618004 | +44 (0) 1983 811521 | http://mwj.hotims.com/7959-157 |
| 158 | Mimix Broadband, Inc. | 67 | 281-988-4600 | 281-988-4615 | http://mwj.hotims.com/7959-158 |
| 159,160,161, 162,163,164, 165,166,167, 168,169,170 | Mini-Circuits | 4–5,18,37, 76–77,151,152, 203,223,259, 271,301,369 | 718-934-4500 | 718-332-4661 | http://mwj.hotims.com/7959-159 |
| 171 | Mini-Systems, Inc. | 20 | 508-695-0203 | 508-695-6076 | http://mwj.hotims.com/7959-171 |
| 172,173,174 | MITEQ Inc. | 3,97,281 | 631-436-7400 | 631-436-7430 | http://mwj.hotims.com/7959-172 |

| RS No. | Advertiser | Page No. | Phone | Fax | Web Address |
|---|---|---|---|---|---|
| 175 | Modelithics, Inc. | 114 | 888-359-6359 | 813-558-1102 | http://mwj.hotims.com/7959-175 |
| 176 | Modular Components National, Inc. | 297 | 410-879-6553 | 410-638-7356 | http://mwj.hotims.com/7959-176 |
| 177 | Molex | 319 | 317-834-5600 | 317-834-5611 | http://mwj.hotims.com/7959-177 |
| 178 | MTI Wireless Edge | 210 | +972-3-9025050 | +972-3-9025051 | http://mwj.hotims.com/7959-178 |
| 179,180 | Narda Microwave-East, an L3 Communications Co. | 175,333 | 631-231-1700 | 631-231-1711 | http://mwj.hotims.com/7959-179 |
| 181 | Narda Microwave-West, an L3 Communications Co. | 117 | 916-351-4500 | 916-351-4550 | http://mwj.hotims.com/7959-181 |
| 182 | Neltec | 313 | 480-967-5600 | | http://mwj.hotims.com/7959-182 |
| 183 | Networks International Corporation | 120 | 913-685-3400 | 913-685-3732 | http://mwj.hotims.com/7959-183 |
| 184 | Nexyn Corporation | 326 | 408-982-9339 | 408-982-9275 | http://mwj.hotims.com/7959-184 |
| 185 | Noisecom | COV 2 | 973-386-9696 | 973-386-9191 | http://mwj.hotims.com/7959-185 |
| 186 | NoiseWave Corp. | 21 | 973-386-1119 | 973-386-1131 | http://mwj.hotims.com/7959-186 |
| 187 | OML Inc. | 273 | 408-779-2698 | 408-778-0491 | http://mwj.hotims.com/7959-187 |
| 188 | Pascall Electronics Limited | 212 | +44(0) 1983 817300 | +44(0) 1983 564708 | http://mwj.hotims.com/7959-188 |
| 189 | Peak Devices, Inc. | 291 | 978-422-7641 | 978-422-0011 | http://mwj.hotims.com/7959-189 |
| 190 | Phase One Microwave Inc. | 166 | 916-624-1445 | 916-624-0284 | http://mwj.hotims.com/7959-190 |
| 191 | Picosecond Pulse Labs Inc. | 129 | 303-209-8100 | 303-447-2236 | http://mwj.hotims.com/7959-191 |
| 192 | Planar Monolithic Industries, Inc. | 357 | 301-631-1579 | 301-662-2029 | http://mwj.hotims.com/7959-192 |
| 193 | Pole/Zero Corporation | 231 | 513-870-9060 | 513-870-9064 | http://mwj.hotims.com/7959-193 |
| 194 | Prewell Corporation | 276 | 82-31-420-8362 | 82-31-420-8301 | http://mwj.hotims.com/7959-194 |
| 195 | Pulsar Microwave Corporation | 150 | 800-752-3043 | 973-779-2727 | http://mwj.hotims.com/7959-195 |
| 196 | Quest Microwave Inc. | 102 | 408-778-4949 | 408-778-4950 | http://mwj.hotims.com/7959-196 |
| 197 | QuinStar Technology, Inc. | 110 | 310-320-1111 | | http://mwj.hotims.com/7959-197 |
| 198,199 | Radiall | 98,174 | 33-1-49-353535 | 33-1-48-546363 | http://mwj.hotims.com/7959-198 |
| 426 | Radio Research Instrument Co., Inc. | 364 | 203-753-5840 | 203-754-2567 | http://mwj.hotims.com/7959-426 |
| 427 | Reactel, Incorporated | 267 | 301-519-3660 | 301-519-2447 | http://mwj.hotims.com/7959-427 |
| 428 | RelComm Technologies, Inc. | 321 | 410-749-4488 | 410-860-2327 | http://mwj.hotims.com/7959-428 |
| 429 | Remcom | 329 | 814-861-1299 | 814-353-1420 | http://mwj.hotims.com/7959-429 |
| 430 | REMEC Defense & Space | 128 | 858-560-1301 | | http://mwj.hotims.com/7959-430 |
| 431 | Renaissance Electronics Corporation | 325 | 978-772-7774 | 978-772-7775 | http://mwj.hotims.com/7959-431 |
| 432 | Res-Net Microwave Inc. | 270 | 727-530-9555 | 727-531-8215 | http://mwj.hotims.com/7959-432 |
| 433 | RF Cable Assembly, Division of RF Industries | 126 | 800-233-1728 | 858-549-6340 | http://mwj.hotims.com/7959-433 |
| 434 | RF Micro Devices | 49 | 336-678-5570 | 336-931-7454 | http://mwj.hotims.com/7959-434 |
| 435.436.437 | RFHIC | 182,184,186 | 82-31-250-5011 | 82-31-250-5089 | http://mwj.hotims.com/7959-435 |
| 438 | RFMW Ltd. | 359 | 877-367-7369 | | http://mwj.hotims.com/7959-438 |
| 439 | Richardson Electronics, Ltd. | 331 | 800-737-6937 | 630-208-2550 | http://mwj.hotims.com/7959-439 |
| 440 | RLC Electronics, Inc. | 29 | 914-241-1334 | 914-241-1753 | http://mwj.hotims.com/7959-440 |
| 441 | Rodelco Electronics Corp. | 27 | 631-981-0900 | 631-981-1792 | http://mwj.hotims.com/7959-441 |
| 442 | Rogers Corporation | 85 | 480-961-1382 | 480-961-4533 | http://mwj.hotims.com/7959-442 |
| 443 | Rohde & Schwarz GmbH | 159 | +49-1805-124242 | +49-89-412913777 | http://mwj.hotims.com/7959-443 |
| 444 | Rosenberger | 111 | +49-8684-18-0 | +49-8684-18-499 | http://mwj.hotims.com/7959-444 |
| 445 | Roswin Inc. | 68 | +82-41-621-4450 | +82-41-621-4451 | http://mwj.hotims.com/7959-445 |
| 446 | RTx Technology Co., LTD. | 303 | 82-31-743-6275~7 | 82-31-743-6278 | http://mwj.hotims.com/7959-446 |
| 447 | Sarnoff Corporation | 100 | 609-734-2553 | | http://mwj.hotims.com/7959-447 |
| 448 | Satellink, Inc. | 360 | 972-487-1434 | 972-487-1204 | http://mwj.hotims.com/7959-448 |
| 449 | Sawtek, a TriQuint Company | 38–39 | 407-886-8860 | 407-886-7061 | http://mwj.hotims.com/7959-449 |
| 450 | Sector Microwave Industries, Inc. | 356 | 631-242-2300 | 631-242-8158 | http://mwj.hotims.com/7959-450 |
| 451 | Seekon Microwave | 216 | 0086-28-81700184 | 0086-28-81700845 | http://mwj.hotims.com/7959-451 |
| 452 | Semflex Inc. | 103 | 800-778-4401 | 480-985-0334 | http://mwj.hotims.com/7959-452 |
| 453 | SGMC Microwave | 337 | 321-409-0509 | 321-409-0510 | http://mwj.hotims.com/7959-453 |
| 454 | Sirenza Microdevices | 107 | 303-327-3030 | | http://mwj.hotims.com/7959-454 |
| 455 | Sivers IMA AB | 118 | 46 (0) 8 703 68 04 | 46-8-7519271 | http://mwj.hotims.com/7959-455 |
| 456 | Skyworks Solutions, Inc. | 155 | 781-376-3000 | | http://mwj.hotims.com/7959-456 |
| 457 | SM Electronics | 367 | 800-715-4396 | 972-984-1218 | http://mwj.hotims.com/7959-457 |
| 458,459 | Sonnet Software, Inc. | 59,61,COV 3 | 315-453-3096 | 315-451-1694 | http://mwj.hotims.com/7959-458 |
| 460 | Sophia Wireless Inc. | 132 | 703-961-9573 | 703-961-9576 | http://mwj.hotims.com/7959-460 |
| 461 | Spacek Labs | 251 | 805-564-4404 | 805-966-3249 | http://mwj.hotims.com/7959-461 |
| 462 | Special Hermetic Products, Inc. | 160 | 603-654-2002 | 603-654-2533 | http://mwj.hotims.com/7959-462 |
| 463 | Spectrum Elektrotechnik GmbH | 221 | +49-89-3548-040 | +49-89-3548-0490 | http://mwj.hotims.com/7959-463 |
| 464 | State of the Art, Inc. | 34 | 800-458-3401 | 814-355-2714 | http://mwj.hotims.com/7959-464 |
| 465 | Stealth Microwave, Inc. | 121 | 888-772-7791 | 609-538-8587 | http://mwj.hotims.com/7959-465 |
| 466 | Storm Products Company | 253 | 630-754-3300 | 630-754-3500 | http://mwj.hotims.com/7959-466 |
| | Strand Marketing, Inc. | 315 | 978-463-0780 | 978-463-0781 | www.strandmarketing.com |
| 467 | StratEdge Corporation | 48 | 858-569-5000 | 858-560-6877 | http://mwj.hotims.com/7959-467 |
| 468 | Summitek Instruments | 141 | 208-772-8515 | 208-762-6133 | http://mwj.hotims.com/7959-468 |
| 469 | Suss MicroTec AG | 88 | (+49) 35240/73-0 | | http://mwj.hotims.com/7959-469 |
| 470 | SV Microwave, Inc. | 93 | 561-840-1800 | 561-842-6277 | http://mwj.hotims.com/7959-470 |
| 471 | Swift & Associates | 249 | 818-989-1133 | 818-989-4784 | http://mwj.hotims.com/7959-471 |
| 472 | Symmetricom | 36 | 978-232-1497 | | http://mwj.hotims.com/7959-472 |
| 473,474,475 | Synergy Microwave Corporation | 157,327,371 | 973-881-8800 | 973-881-8361 | http://mwj.hotims.com/7959-473 |
| 476,477,478, 479,480 | Taconic | 44,50,56, 348,350 | 800-833-1805 | 518-658-3988 | http://mwj.hotims.com/7959-476 |
| 481 | Tecdia, Inc. | 106 | 408-453-0200 | 408-453-0220 | http://mwj.hotims.com/7959-481 |
| 482 | Tektronix, Inc. | 265 | 800-833-9200, Option 1 | | http://mwj.hotims.com/7959-482 |
| 483 | Teledyne Cougar | 79 | 408-522-3838 | 408-522-3839 | http://mwj.hotims.com/7959-483 |
| 484 | Teledyne Relays | 131 | 800-351-7368 | | http://mwj.hotims.com/7959-484 |
| 485 | Temp-Flex Cable Inc. | 104 | 508-839-5987 | | http://mwj.hotims.com/7959-485 |
| 486 | Tensolite | 13 | 800-458-9960 | 360-759-4016 | http://mwj.hotims.com/7959-486 |
| 487 | Terabeam/HXI | 187 | 978-691-7400 | 978-691-7401 | http://mwj.hotims.com/7959-487 |
| 488 | Texas Instruments | 219 | | | http://mwj.hotims.com/7959-488 |
| 489 | Thunderline-Z | 312 | 603-329-4050 | | http://mwj.hotims.com/7959-489 |
| 490 | Tiger Microwave Corporation | 288 | +86-28-66070208 | +86-28-66070496 | http://mwj.hotims.com/7959-490 |
| 491 | Times Microwave Systems | 243 | 203-949-8400 | 203-949-8423 | http://mwj.hotims.com/7959-491 |

# Advertising Index


| RS No. | Advertiser | Page No. | Phone | Fax | Web Address |
|---|---|---|---|---|---|
| 492 | TRAK Microwave Corporation | 138 | 813-901-7200 | | http://mwj.hotims.com/7959-492 |
| 493 | Trans-Tech Ceramic Materials | 347 | 301-695-9400 | 301-695-7065 | http://mwj.hotims.com/7959-493 |
| 494 | Trilithic Inc. | 239 | 800-874-5484 | 317-895-3612 | http://mwj.hotims.com/7959-494 |
| 449 | TriQuint Semiconductor, Inc. | 38–39 | 503-615-9000 | 503-615-8900 | http://mwj.hotims.com/7959-449 |
| 495 | TRM, Inc. | 72 | 603-627-6000 | 603-627-6025 | http://mwj.hotims.com/7959-495 |
| 496 | Tru Corporation | 62-63 | 800-262-9878 | 978-531-6993 | http://mwj.hotims.com/7959-496 |
| 497 | TTE Inc. | 140 | 310-478-8224 | 310-445-2791 | http://mwj.hotims.com/7959-497 |
| 498 | Tusonix | 247 | 520-744-0400 | 520-744-6155 | http://mwj.hotims.com/7959-498 |
| 499 | UltraSource, Inc. | 142 | 603-881-7799 | 603-881-9966 | http://mwj.hotims.com/7959-499 |
| 500 | United Monolithic Semiconductors | 295 | 33 (1) 69 33 02 26 | 33-(0)-1-69330309 | http://mwj.hotims.com/7959-500 |
| 501 | Universal Microwave Components Corporation | 316 | 703-642-6332 | 703-642-2568 | http://mwj.hotims.com/7959-501 |
| 502 | Universal Microwave Corporation | 71 | 877-862-9873 | | http://mwj.hotims.com/7959-502 |
| 503 | Universal Microwave Technology, Inc. | 188 | +886-2-2698-9969 | +886-2-2698-9968 | http://mwj.hotims.com/7959-503 |
| 504 | UTE Microwave Inc. | 241 | 732-922-1009 | 732-922-1848 | http://mwj.hotims.com/7959-504 |
| 505 | Valpey Fisher Corporation | 201 | 800-982-5737 | 508-435-6831 | http://mwj.hotims.com/7959-505 |
| 506 | Vector Fields Inc. | 245 | 630-851-1734 | 630-851-2106 | http://mwj.hotims.com/7959-506 |
| 507 | Vectron International | 58 | 1-88-VECTRON1 | 888-FAX-VECTRON | http://mwj.hotims.com/7959-507 |
| 508 | Voltronics Corporation | 237 | 973-586-8585 | 973-586-3404 | http://mwj.hotims.com/7959-508 |
| 509 | W.L. Gore & Associates, Inc. | 298 | 800-445-GORE | | http://mwj.hotims.com/7959-509 |
| 510 | Waveline Inc. | 282 | 973-226-9100 | 973-226-1565 | http://mwj.hotims.com/7959-510 |
| 511 | Wavetronix, Inc. | 269 | 727-530-9555 | | http://mwj.hotims.com/7959-511 |
| 512 | WCA International | 314 | 202-452-7823 | 202-452-0041 | http://mwj.hotims.com/7959-512 |
| 513 | Weinschel Associates | 180 | 877-948-8342 | 301-963-8640 | http://mwj.hotims.com/7959-513 |
| 514 | Wenzel Associates, Inc. | 235 | 512-835-2038 | 512-719-4086 | http://mwj.hotims.com/7959-514 |
| 515,516 | Werlatone, Inc. | 343,COV 4 | 845-279-6187 | 845-279-7404 | http://mwj.hotims.com/7959-515 |
| 517 | West Bond Inc. | 116 | 714-978-1551 | 714-978-0431 | http://mwj.hotims.com/7959-517 |
| 518 | Wide Band Systems, Inc. | 92 | 973-586-6500 | 973-627-9190 | http://mwj.hotims.com/7959-518 |
| 519 | Win Semiconductors Corp. | 191 | 310-530-8485 | 310-530-8499 | http://mwj.hotims.com/7959-519 |
| 520 | Winchester Electronics | 177 | 203-741-5400 | 203-741-5500 | http://mwj.hotims.com/7959-520 |
| 521 | Wisewave Technologies, Inc. | 139 | 310-539-8882 | 310-539-8862 | http://mwj.hotims.com/7959-521 |
| 522 | WJ Communications Inc. | 33 | 800-WJ1-4401 | 408-577-6621 | http://mwj.hotims.com/7959-522 |
| 523,524 | Z-Communications, Inc. | 57,345 | 858-621-2700 | 858-621-2722 | http://mwj.hotims.com/7959-523 |
| 525 | Zeland Software, Inc. | 233 | 510-623-7162 | 510-623-7135 | http://mwj.hotims.com/7959-525 |


*Visit* Microwave Journal *on the Web at* **www.mwjournal.com**

Visit mwjournal.com/info and enter RS# to request information from our advertisers

Microwave Journal

June 2006 Issue

**The Road from RFIC to SoC**

**UHF RFID and Tag Antenna Scattering**

**Power Amplifiers for RF and Microwave Applications**

## Sales Representatives

microwave journal

**Carl Sheffres**, Publisher

**Ed Johnson**, Associate Publisher

**Ken Hernandez**, Traffic Administrator

**Eastern and Central Time Zones**
Chuck Curley
*Eastern Reg. Sales Mgr.*
685 Canton Street
Norwood, MA 02062
Tel: (781) 769-9750
FAX: (781) 769-5037
ccurley@mwjournal.com

Michael Hallman
*Eastern Reg. Sales Mgr.*
4 Valley View Court
Middletown, MD 21769
Tel: (301) 371-8830
FAX: (301) 371-8832
mhallman@mwjournal.com

**Eastern and Central Time Zones**
Ed Johnson
*Associate Publisher*
PO Box 5962
Ocala, FL 34478-5962
Tel: (352) 620-2442
FAX: (352) 620-2443
ejohnson@mwjournal.com

**Pacific and Mountain Time Zones**
Wynn Cook
*Western Reg. Sales Mgr.*
PO Box 23200
San Jose, CA 95153
Tel: (408) 224-9060
FAX: (408) 224-6106
wcook@mwjournal.com

**International Sales**
Richard Vaughan
*International Sales Manager*
Tel: +44 207 596 8742
rvaughan@horizonhouse.co.uk

Michel Zoghob
*Deputy Publisher*
Tel: +44 207 596 8741
mzoghob@horizonhouse.co.uk

46 Gillingham Street
London SW1V 1HH, England
Tel: +44 207 596 8740
FAX: +44 207 596 8749

**Germany, Austria, and Switzerland (German-speaking)**
Juergen Wissling
Wissling Marketing Services
Riedstrasse 5
72813 St. Johann-Wuertingen
Germany
Tel: +49 7122 828140
FAX: +49 7122 828145
jwissling@horizonhouse.com

**Israel**
Oreet Ben Yaacov
Oreet International Media
15 Kineret Street
51201 Bene-Berak, Israel
Tel: +972 3 570 6527
FAX: +972 3 570 6526
obenyaacov@horizonhouse.com

**Korea**
Young-Seoh Chinn
JES Media International
2nd Floor, ANA Bldg.
257-1, Myungil-Dong
Kangdong-Gu
Seoul, 134-070 Korea
Tel: +82 2 481-3411
FAX: +82 2 481-3414
yschinn@horizonhouse.com

**Singapore**
Hoong-Mun Koo
Publicitas
02-01 Wellington Bldg.
20 Bideford Road
Singapore 229921
Tel: +65 6836 2272
FAX: +65 6735 9653