Vol. 49 • No. 12
December 2006

Microwave Journal

MTT-S RWS Show Issue

Long Beach, CA

Symposium and Exhibition Preview

Design of Microstrip Dual Behavior Resonator Filters

2006 Editorial Index

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DECEMBER 2006 VOL. 49 • NO. 12

2007 IEEE MTT-S RADIO AND WIRELESS SYMPOSIUM & EXHIBITION

GUEST EDITORIAL

SPECIAL REPORTS

FEATURES

TECHNICAL FEATURES

49 Years of Publishing Excellence

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Microwave Journal

FEATURES

TECHNICAL FEATURE

SPECIAL REPORT

PRODUCT FEATURES

DEPARTMENTS

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Ask Harlan

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 February issue. All responses must be submitted by **January 8, 2007**, to be eligible for the participation of the December 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.

October Question and Winning Response

The October question was submitted by Arun Kumar:

Dear Harlan,

I am involved in Schottky diode mixer design at microwave frequencies. For accurate design, I want to characterize the diode with the help of the text fixture and network analyzer. As the junction resistance varies with LO power level for characterization of the diode how much LO power should I give? Some literature says that the LO power should be such that the rectified current from the diode is in the order of 1 to 1.5 mA. How then should I measure the rectified current through the diode, which is mounted in the test fixture? Please help.

The winning response to the October question is from Scott Wartenberg of Booz Allen Hamilton:

It sounds like you are characterizing a Schottky diode for use in a mixer design. If so, characterize the diode at the RF power it will see during circuit operation. Otherwise set the input power to the lowest RF power that does not significantly modulate the junction yet still produces enough RF drive for a measurement with adequate dynamic range. Depending on whether it’s a high or low barrier Schottky, this is between –25 to –40 dBm, respectively. Reliably measuring a diode’s AC rectified current is difficult even when using precision source/monitor units, force/sense triaxial cables and high frequency bias tees. With no DC applied (as with a zero-bias Schottky), significant current flows only during positive AC voltage swings. During negative voltage swings, some capacitance is needed to continue sourcing an RMS current. External capacitance withstanding, the diode’s junction capacitance is very small (~100 fF). Driving the input RF power hard will eventually result in a rectified current of 1 to 1.5 mA RMS but the peak voltage may damage the device. To improve your measurement, there are a few points worth mentioning. At low current/voltage, a Schottky diode is highly reflective, its return loss near the right edge of the Smith Chart. Almost all of the –25 to –40 dBm power will be reflected back, making fine measurement resolution tricky. To increase measurement sensitivity, many vector network analyzers (VNA) come with a configurable S-parameter test set. This breaks out access to the forward (source output) and reverse (receiver input) signal paths. Inserting a low noise amplifier in the reverse path improves the VNA receiver’s dynamic range. An attenuator or isolator in the forward path ensures diode mixing products do not corrupt the RF source (remember S-parameters are single-tone measurements). Inserting a DC blocking capacitor at the VNA port also protects the receiver. A power flatness calibration is recommended. The alternative is to create a nonlinear Schottky diode model that is a function of both applied DC bias and RF power. This is a better solution but a lot more work.

Harlan’s response:

The actual design of the test fixture will depend on the style of the diode package. The diode manufacturer may be able to help. As for the bias level, 1 to 1.5 mA is normal for receiver applications. For modulators it can go up to 10 mA. In order to measure it, you will need a bias tee, either as part of the fixture or as a separate component in front of the fixture. There is a good discussion of Schottky diode characteristics in Chapter 2 of *The RF and Microwave Circuit Cookbook*, S. Maas, Artech House Inc., 1998, ISBN#0-89006-973-5.

This Month’s Question of the Month

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

Shanthi B. from Commercial Cellphone Makers has submitted this month’s question:

Dear Harlan,

Why is the open/short/thru method the most preferred calibration method for RF measurements?

If your response is selected as the winner,
you’ll receive a free book of your choice from Artech House.
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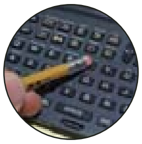

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JANUARY

POWER AMPLIFIER SYMPOSIUM
January 8–9, 2007 • Long Beach, CA
http://pasymposium.ucsd.edu/

IEEE RADIO AND WIRELESS SYMPOSIUM (RWS 2007)
January 9–11, 2007 • Long Beach, CA
www.radiowireless.org

7TH TOPICAL MEETING ON SILICON MONOLITHIC INTEGRATED CIRCUITS IN RF SYSTEMS (SIRF 2007)
January 10–12, 2007 • Long Beach, CA
www.ece.wisc.edu/sirf07

WCA INTERNATIONAL SYMPOSIUM AND BUSINESS EXPO
January 16–19, 2007 • San Jose, CA
www.wcai.com

FEBRUARY

IEEE INTERNATIONAL SOLID-STATE CIRCUITS CONFERENCE (ISSCC 2007)
February 11–15, 2007 • San Francisco, CA
www.isscc.org/isscc/

3GSM WORLD CONGRESS
February 12–15, 2007 • Barcelona, Spain
www.3gsmworldcongress.com

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

MARCH

MILITARY TECHNOLOGIES CONFERENCE
March 27–28, 2007 • Boston, MA
http://mtc07.events.pennnet.com

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

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

INTERNATIONAL WIRELESS COMMUNICATIONS EXPO (IWCE 2007)
March 28–30, 2007 • Las Vegas, NV
www.iwceexpo.com

APRIL

IEEE RADAR CONFERENCE 2007
April 17–20, 2007 • Waltham, MA
www.radar2007.org

JUNE

IEEE MTT-S IMS SYMPOSIUM AND EXHIBITION
June 3–8, 2007 • Honolulu, HI
www.ims2007.org

WCA 2007
June 11–14, 2007
Washington, DC
www.wcai.com/events.htm

JULY

IEEE EMC SYMPOSIUM
July 8–13, 2007
Honolulu, HI
www.emc2007.org

OCTOBER

2007 EUROPEAN MICROWAVE WEEK
October 8–12, 2007 • Munich, Germany
www.eumweek.com

NOVEMBER

ANTENNA MEASUREMENT TECHNIQUES ASSOCIATION (AMTA)
November 4–9, 2007 • St. Louis, MO
www.amta.org

Workshops & Courses

CST MWS 2006: Advanced Training and Co-simulation

■ **Topics:** This course will illustrate how to work efficiently with CST SUITE STUDIO™ 2006. Improve your performance in using CST MICROWAVE STUDIO® for signal integrity, power integrity, EMC applications, filters and waveguide structures. For more information, visit www.cst.com.
■ **Site:** San Bruno, CA
■ **Date:** December 14, 2006
■ **Contact:** CST of America Inc., 10 Laurel Avenue, Suite 300, Wellesley Hills, MA 02481 (781) 416-2782.

Practical RF and Microwave Design

■ **Topics:** This intensive, five-day course provides acceleration through the RF design learning curve by presenting a comprehensive introduction to RF and microwave design theory, techniques and measurements. Although the course includes necessary theoretical aspects, great emphasis is placed upon the practicalities of RF engineering. For more information, visit www.conted.ox.ac.uk.
■ **Site:** Summertown, Oxford, UK
■ **Dates:** January 22–26, 2007
■ **Contact:** University of Oxford Continuing Education, +44 (0) 1865 286958 or e-mail: anthony.santiago@conted.ox.ac.uk.

Phased Array Antennas and Adaptive Techniques

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

Practical Antenna Design

■ **Topics:** The course covers the important and timely issues involving modern antenna design and theory. Developed specifically for engineers and designers who work with radar and radio communications, this workshop will give participants the understanding of antenna theory and techniques, the skills to analyze, design and measure various antennas, and the knowledge of antenna measurements. For more information, visit www.conted.ox.ac.uk.
■ **Site:** Summertown, Oxford, UK
■ **Dates:** February 2007
■ **Contact:** University of Oxford Continuing Education, +44 (0) 1865 286958 or e-mail: anthony.santiago@conted.ox.ac.uk.

The Entrepreneurial Engineer

■ **Topics:** This short course is an efficient and memorable introduction to the personal, interpersonal, business and organizational skills necessary to help engineers of applied science and mathematics perform at high levels in today's increasingly opportunistic organizations and enterprises. For more information, visit http://online.engr.uiuc.edu/shortcourses/tee/index.html.
■ **Site:** Archived on-line course.
■ **Dates:** Archived on-line for anytime viewing.
■ **Contact:** University of Illinois at Urbana-Champaign, 117 Transportation Bldg., 104 S. Mathews Avenue, Urbana, IL 61801 (217) 333-0897 or e-mail: deg@uiuc.edu.

PCB Design Techniques for EMC and Signal Integrity

■ **Topics:** This course will assist practicing engineers who are responsible for PCB designs and system-level products. Disciplines include PCB layout, logic design, regulatory compliance and EMC. For more information, visit http://epdwww.engr.wisc.edu.
■ **Site:** For location information, please visit url.
■ **Dates:** For date information, please visit url.
■ **Contact:** University of Wisconsin Madison, Department of Engineering Professional Development, 432 North Lake Street, Madison, WI 53706 (800) 462-0876.

Welcome to the 2007 Radio and Wireless Symposium

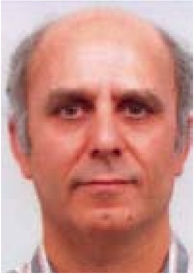
Mohammad Madihian
General Chairman, 2007 Radio and Wireless Symposium

Join us in Long Beach, CA, for the second Radio & Wireless Week (RWW) events January 7–12, 2007, not only to learn about the latest technological, scientific and commercial developments, but also to see friends and experience the Southern California lifestyle with its excellent climate, food and shoreline beauty, all wrapped in one package. The RWW collocates three prestigious conferences and one major commercial exhibition. The overall focus is on key technologies covering device level to system level for the advancement of current radio and wireless systems as well as creating new concepts and breakthroughs for next generation networks.

The centerpiece of the week is the IEEE Radio and Wireless Symposium (RWS), which continues the evolution of the successful Radio and Wireless Conference (RAWCON). Three IEEE Societies support the RWS—the ComSoc and AP provide technical co-sponsorship and the MTT-S provides sponsorship. The RWS brings together a unique mix of communications systems and RF implementations via high quality invited and contributed papers, a rump session, workshops and short courses. Don't miss our daily Special Invited Session on "Enabling Technologies for the Next Generation Radio and Wireless Networks," lectured by world-class speakers from industry and academia.

The IEEE Topical Symposium on Power Amplifiers for Wireless Communications (PAS) and Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems (SiRF) are also key parts of the program. The PAS has been bringing leading RF power amplifier engineers together for many years, and will continue that tradition. SiRF has for years presented the latest in silicon RF technologies and applications and will continue its strong tradition.

With these three conferences and a large commercial exhibition along with social events including free receptions and daily breakfast and lunch, we offer you a convenient opportunity to receive a comprehensive update in all the technical and commercial facets of the rapidly changing radio and wireless landscape. I look forward to seeing you in Long Beach!



Mohammad Madihian *joined NEC Central Research Laboratories, Kawasaki, Japan, in 1983, where he worked on research and development of Si and GaAs device-based digital as well as microwave and millimeter-wave monolithic ICs. In 1999, he moved to NEC Laboratories America Inc., Princeton, NJ, and is presently the department head where he conducts PHY/MAC layer signal processing activities for high speed wireless networks and personal communications applications. He has edited a book called* CMOS-RF and Its Application to Wireless Network Terminals *(Anthology), Tokyo, Japan: Toriceps, Nov. 2001. He has authored or co-authored more than 140 journal and conference publications including 25 invited talks, and holds 70 Japan/US registered or pending patents on device, circuit and system for wireless applications. Dr. Madihian received the IEEE MTT-S Best Paper Microwave Prize in 1988 and the IEEE Fellow Award in 1998. He holds eight NEC Distinguished R&D Achievement Awards. He has served as Guest Editor to the* IEEE Journal of Solid-State Circuits, Japan IEICE Transactions on Electronics, *and* IEEE Transactions on Microwave Theory and Techniques. *He is currently serving on the IEEE Speaker's Bureau, IEEE Compound Semiconductor IC Symposium Executive Committee, IEEE Radio & Wireless Symposium Executive Committee, IEEE International Microwave Symposium Technical Program Committee, IEEE MTT-S Editorial Board and Asia Pacific Microwave Conference Technical Program Committee. Dr. Madihian is an adjunct professor in the electrical and computer engineering department at Drexel University, and the Editor-in-Chief,* International Journal of Microwave Science and Technology.

2007 IEEE
RADIO AND WIRELESS SYMPOSIUM

Long Beach Convention Center
Long Beach, CA
January 9–11, 2007
http://www.radiowireless.org

Attending the Conference

Harlan Howe, Jr.
Editor, Microwave Journal

The 2007 IEEE MTT-S Radio and Wireless Symposium will be held in conjunction with the 7th Topical Meeting on Silicon Monolithic ICs, the IEEE Topical Symposium on Power Amplifiers for Wireless Communications, and the Radio and Wireless Exhibition. All of the technical meetings and the exhibition will be held in Halls A, B and associated meeting rooms at the Long Beach Convention and Entertainment Center, 300 E. Ocean Blvd., Long Beach, CA. On-site registration will open at noon on Saturday, January 6, 2007.

The technical program for RWS includes 135 papers, six workshops, two short courses and a rump session. Panel sessions have been eliminated this year in order to allow the delegates time to visit the exhibition during the noon lunch break. Workshops will be held on Sunday and Monday, RWS technical sessions on Tuesday through Thursday and two short courses on Friday. The exhibition will open on Tuesday and run until Thursday mid-afternoon. In addition, the Power Amplifier Symposium meeting will be held on Monday and Tuesday. The Silicon RF IC meetings will start on Wednesday and continue through Friday. A full program is available at www.radiowireless.org or you can request a printed copy via e-mail at kdednah@mwjournal.com.

Travel to Long Beach

The Long Beach area is served by three airports: Los Angeles International (LAX), John Wayne (SNA) and Long Beach (LGB), the last of which is the closest and most convenient.

Cab fares from LAX, SNA and LGB are about $45, $50 and $20, respectively. Super-

shuttles are available from all three airports at slightly lower rates. Rental car counters are located at each airport. Driving instructions are printed in the advance program.

Hotels

While there are many nearby hotels within walking distance, there are two hotels with convention rates. The headquarters hotel is the Hyatt Regency Long Beach, located next to the convention center. The Westin Long Beach is about two blocks away. For on-line booking information, go to www.radiowireless.org and click on "Hotel Information." Transportation from the hotels will not be provided. The outlying hotels are served by a trolley service that stops in front of the convention center.

Social Highlights

A complimentary daily breakfast will be served in the convention center from 7:00 to 8:30 AM. In addition, a complimentary lunch for all delegates will be served in the exhibition hall on Tuesday, Wednesday and Thursday from 12:00 NOON to 1:00 PM. Morning and afternoon coffee breaks will also be in the exhibition hall. On Tuesday afternoon from 5:00 to 7:00 PM there will be an exhibitor-hosted reception in the exhibition hall. Complimentary beverage tickets will be included in the delegate packages.

The Power Amplifier Symposium Banquet will be held on Monday evening. The RWS Reception and Banquet will be held on Wednesday evening and the SiRF banquet will be held on Thursday evening. These events will be at the Hyatt and purchased tickets are required.

Plenary Session

The Plenary Session will be held on Tuesday starting at 8:30 AM. After welcoming remarks from Mohammad Madihian, general chairman, and Aly Fathy, technical program chairman, and addresses by Nim Cheung, president – IEEE Communications Society, and Steve Kenney, president – IEEE Microwave Theory and Techniques Society, the plenary session presentation, "Mobile Terminal – Today and Future" by Dr. Kiyohito Nagata, will be given. Nagata is currently the vice president and managing director of the Product Division at NTT DoCoMo, and has been engaged in the company's R&D strategy planning since 1999.

Exhibition

The Radio and Wireless Exhibition will feature new products and services for wireless design engineers from principle suppliers in the industry, including devices, components, materials, test equipment, software, subsystems and systems. The exhibition is open Tuesday and Wednesday from 9:00 AM to 5:00 PM and Thursday from 9:00 AM to 3:00 PM in exhibition halls A and B on the lower level of the convention center. Please note that children under the age of 14 will not be admitted to the exhibition halls at any time.

Cyber Café

A wireless cyber café will be available in the lobby area at the front of the building.

General Information

There will be an information booth in the registration area as well as an IEEE MTT-S membership booth. Free coffee, tea and soft drinks will be available in the refreshment area on the exhibition floor. IEEE policy prohibits recruiting of attendees during the symposium, which means that exhibitors may not post information on job opportunities or recruit for prospective employees. Smoking and personal food or beverages are not permitted anywhere in the building.

2007 IEEE MTT-S RWS Exhibitor Showcase

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Antenna Systems & Technology **PubBin**
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AR Worldwide **312**
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Publications, Software

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Mountain View, CA
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Publications, Services

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Software

Cambridge University Press **437**
New York, NY
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Publications

Cascade Microtech 627
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CST of America Inc. 418
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High Frequency Electronics 630
Bedford, NH

S. Spencer, G. Breed, T. Burkhard, N. Breed

High Frequency Electronics is the monthly magazine for design engineers and managers seeking ideas and solutions involving analog, digital, RF, microwave, mm-wave and optical technologies. The market-driven content covers materials, devices, components, test equipment, computer-aided design, systems, subsystems, and the latest information on design techniques, applications and solution-oriented new products.
Publications

IEEE Communications PubBin
New York, NY

Publications

IEEE Microwave Magazine 628
Piscataway, NJ

S. Schneiderman, M. Rubin

IEEE Microwave Magazine is issued bimonthly and the only magazine sponsored by IEEE Microwave Theory and Techniques Society (IEEE MTT-S) concentrating on technical, general-interest and applications-oriented articles. The markets covered include communications systems and equipment, navigation and guidance systems, aircraft, missiles, space and ground support equipment, industrial equipment, controls and systems, ICs and microprocessors, semiconductors, and more.
Publications

JFW Industries Inc. 615
Indianapolis, IN

B. Walker, S. Leonard

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Minneapolis, MN

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W. Strickler, M. Millhaem

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R. Dudzinski

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RFICs, Services, Software, Transceivers

M/A-COM Inc. **313**
Lowell, MA

D. Pierro, P. Hindle

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J. Adamson, J. Sevic, R. Wallace, E.Kueckels

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MECA Electronics Inc. **632**
Denville, NJ

C. Davo, E. Schiebler

Since 1961, MECA has designed and manufactured an extensive line of RF/microwave components with industry leading performance including fixed attenuators, directional and hybrid couplers, isolators/circulators, power dividers/combiners, RF loads, DC blocks and bias tees. MECA has long been the "backbone" of high performance wired and air-interfaced networks including in-building and BTS applications. Made in USA.
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Micrometrics Inc. **537**
Londonderry, NH

J. Morgan, D. Langan

Offering tuning varactors, step recovery diodes, Schottky, PIN/limiter and BeamLead

PIN diodes, capacitors, spiral inductors, thin film resistors, attenuator pads and epitaxial growth and coating services for the semiconductor fabrication market.
Attenuators, Diodes/FETs/Transistors, Resistors/Capacitors/Inductors, Services

Microwave Communications Labs **526**
St. Petersburg, FL

K. D'Amato, T. Nguyen, E. Roecker

Microwave Communications Laboratories Inc. (MCLI) is a leader in the manufacturing of RF/microwave components. Since 1988, MCLI has built a solid reputation for high quality and fast delivery. MCLI is ISO 9001:2000 certified with an inspection system that ensures high quality and reliable products. At MCLI, we are committed to providing exceptional service to our customers throughout the world and throughout the 21st century.
Amplifiers, Attenuators, Connectors/Cables/Cable Assemblies, Couplers, Diodes/FETs/Transistors, Filters, Hybrids, Isolators/Circulators, Mixers/Modulators/Detectors, Oscillators, Phase Shifters, Power Dividers, Services, Signal Processing Components, Switches, Terminations

Microwave Journal **331**
Norwood, MA

C. Sheffres, E. Johnson, W. Cook, M. Hallman, C. Curley, H. Howe, F. Bashore, K. Moore

Microwave Journal is THE resource for working RF, microwave and wireless engineers, with 50,000 subscribers worldwide and the most respected editorial content in its field. The redesigned web site features unique resources, hundreds of archived articles, expanded event coverage and a dynamic on-line Buyers Guide. Weekly e-mail newsletters deliver timely news, industry analysis, the latest product announcements and expert advice. See us on-line at www.mwjournal.com.
Publications

Microwave Product Digest **438**
Englewood Cliffs, NJ

Publications

Modelithics Inc. **643**
Tampa, FL

L. Dunleavy

Modelithics Inc. was formed in 2001 to address the industry-wide need for high accuracy RF and microwave active and passive models. Our current products include commercial device model libraries that support multiple simulation tools. Modelithics also satisfies a wide range of custom linear and nonlinear measurement and modeling requirements.
Services, Software

Northwest EMC Inc. **431**
Irvine, CA

D. Maynard

Northwest EMC Inc. is the largest independent, accredited commercial EMC compliance test laboratory in the United States. Northwest EMC has convenient locations in California, New York, Oregon and Washington. Our facilities include FCC listed 10 meter and 3 meter chambers, as well as a full compliment of immunity and wireless testing capabilities. For additional information, please visit our web site at www.nwemc.com.
Services

Octagon Communications **438**
Englewood Cliffs, NJ

D. Harway

Octagon Communications publishes *MPD/Microwave Product Digest*, a new product tabloid serving engineers working in the RF and microwave industry involving frequencies from RF to light. Our affiliate, RD Communications, publishes *MIL/COTS Digest*, a product tabloid dedicated to presenting defense electronic products designed for use in aerospace and defense systems.
Publications

Park Electrochemical Corp. **424**
Melville, NY

B. Nichols, J. Spiegel, M. Carlson, D. Dahlquist

Park Electrochemical Corp. is an advanced materials company which develops and manufactures Nelco® RF/microwave and high technology digital printed circuit materials and Nelcote™ advanced composite materials. Park is listed on the NYSE as "PKE" and based in Melville, NY, with global manufacturing facili-

ties in Singapore, China, France, Connecticut, New York, Arizona and California.
Antennas, Materials, Printed Circuit Boards

Passive Microwave Technology 436
Camarillo, CA

QUEST Microwave Inc. 436
Morgan Hill, CA

A. Campbell, B. Campbell, N. Khayat, G. Grund, C. Grund

QUEST Microwave Inc. manufactures ferrite products (isolators and circulators) for cellular/PCN/PCS communications, point-to-point radios, LMDS, and SATCOM/VSAT transceivers and converters.
Isolators/Circulators

RelComm Technologies Inc. 433
Salisbury, MD

J. Tinkler, M. Magda

RelComm Technologies Inc. designs and manufactures design enhanced application specific RF coaxial relays for mission critical communications including security, safety and intelligence, commercial telecom infrastructure, military defense fixed/mobile/shipboard, as well as test and measurement instrumentation from DC to 40 GHz.
Switches

RF Design 440
Overland Park, KS

RF Design is the only publication written exclusively for RF and microwave design engineers to provide the latest practical information needed to design leading-edge radio frequency products that work across the spectrum.
Publications

RF Globalnet PubBin
Sewickley, PA

RF Globalnet is the Internet's leading source of technical information for the RF/microwave design industry, serving the needs of engineering professionals since 1996. The site offers technical articles, white papers, application notes, software tools, industry news, product information, discussion forums and much more. Visit www.rfglobalnet.com.
Publications

RF Industries/RF Connectors Div. 439
San Diego, CA

R. La Fay, D. McReynolds

RF Industries' RF Connector Division designs and manufactures coaxial connectors, adapters, cable assemblies and preparation/installation tools used in radio communications, wireless devices, broadcast installations, LANs and WLANs, antenna devices and cellular infrastructure.
Attenuators, Connectors/Cables/Cable Assemblies

RFHIC 219
Suwon, Korea

K. Kim

Active device and hybrid manufacturer. Best in custom design super fast development. MMIC, PA, LNA, CATVHIC, PLL. New 2.5G/3.5G WiMAX component solution.
Amplifiers, Attenuators, Couplers, Filters, Hybrids, Mixers/Modulators/Detectors, MMICs, RFICs, Switches, Transceivers

RFMD 513
Greensboro, NC

K. Ingram

RFMD® (NASDAQ: RFMD) is a global leader in the design and manufacture of high performance radio systems and solutions for applications that drive mobile communications. Holding over 50 percent market share in PAs and the leading position in merchant market EDGE transceiver shipments, RFMD is a trusted solution provider to major handset manufacturers worldwide.
Amplifiers, Filters, MMICs, Switches, Transceivers

Rogers Corp. 421
Chandler, AZ

Worldwide supplier and high volume manufacturer of leading edge circuit materials that are widely adopted in the wireless, antenna and telecommunication industries. Key product families include RO4000®, RO3000®, RT/duroid® and ULTRALAM® 3000 high frequency laminates.
Materials

Rohde & Schwarz Inc. 413
Columbia, MD

R. Pieciak

Rohde & Schwarz is one of the world's leading manufacturers of test and measurement, radio and broadcasting equipment with 6000 employ-

ees and worldwide sales topping $1 billion. In America, we have locations from coast to coast. We're known for responsive support and service infrastructure for fast calibrations and service turnaround. 1-888-837-8772, www.RSA.rohde-schwarz.com/USA.
Test and Manufacturing Equipment

Sigma Systems Corp. **620**
El Cajon, CA
R. Freiwald, S. Hoover, D. Fennessy, E. Moore

Manufacturer of precision environmental, temperature, humidity, and thermal vacuum chambers, hot/cold plates, and wafer chucks, temperature cycling tool ovens, precision temperature controllers. Specializing in high accuracy, small footprint, high production, laboratory thermal test/conditioning equipment. Exceptional quality since 1956. Standard, semi-custom, and custom applications—engineering creative solutions for unique thermal challenges.
Test and Manufacturing Equipment

Sonnet Software Inc. **619**
North Syracuse, NY
Y. Chase, M. Kobasa, J. Rautio, R. O'Rourke

Sonnet Software Inc. announces the new Sonnet Suites Release II. In Release II, Sonnet introduces a simultaneously calibrated internal port that can be used for highly accurate attachment points of active and passive components. The new ports also enable full co-simulation of external components and SMD models within the EM analysis environment. Sonnet also releases a redesigned and seamless interface to the Agilent ADS suite, and a new 64-bit EM analysis engine.
Software

Sources East Inc. **645**
Campbell, CA
D. Hanes, J. Hyde, W. Pittman

This year SEI is stressing our antennas, GPS antennas, as well as our die cast waterproof microwave enclosures. We provide aggressively priced high frequency interconnect technology. Today's specials are tomorrow's standard products so both low and high volume specials tailored to the individual requirements of our customers are always welcome.
Antennas, Connectors/Cables/Cable Assemblies, Isolators/Circulators, Terminations

SUSS MicroTec Inc. **533**
Waterbury Center, VT
T. Schivo

SUSS MicroTec Test Systems is a world leader in premium performance on-wafer test solutions, and has been designing and manufacturing innovative probe systems for over 30 years. With the increasing complexity of IC devices, our systems are designed to streamline the testing process by leveraging our application expertise to provide complete solutions tailored to your needs. For more information, visit www.suss.com.
Software, Test and Manufacturing Equipment

CW Swift & Associates Inc. **212**
Van Nuys, CA
A. Swift, S. Swift

Distributor and manufacturer's rep of precision RF, microwave and millimeter-wave adapters, connectors, cable assemblies and components: 1.85 mm, 2.4 mm, 2.9 mm, 3.5 mm, SMA, MCX, MMCX and other interfaces. Fixed attenuators and terminations up to 50 GHz. All available from stock except on St. Patrick's Day.
Amplifiers, Attenuators, Connectors/Cables/Cable Assemblies, Couplers, Isolators/Circulators, Oscillators, Power Dividers, Resistors/Capacitors/Inductors, Terminations

Synergy Microwave Corp. **319**
Paterson, NJ
A. Almeida

Low phase noise planar resonator oscillators rivaling the phase noise performance of expensive SAW and CRO/DRO oscillators, YIG-like VCOs offering ultra-wide bandwidth and low power consumption, highly versatile synthesizers in optimized and higher than octave bandwidths, high IP3 FET mixers, wideband microwave mixers up to 18 GHz, high power signal processing couplers and 90 degree hybrids.
Attenuators, Couplers, Filters, Hybrids, Mixers/Modulators/Detectors, Oscillators, Phase Shifters, Power Dividers, Signal Processing Components, Synthesizers

Taconic **520**
Petersburgh, NY
E. Sandor, S. McGinty

Taconic manufactures TacLam,® ORCER, and TacPreg® PTFE substrate materials for microwave frequency and high speed digital applications. Our products range in dielectric constant from 2.17 to 10 and laminate lengths up to 106" are supplied. For more information, call Taconic headquarters at +800-833-1805 or visit us on the web at www.taconic-add.com.
Materials

Tektronix Inc. **631**
Beaverton, OR
D. McCarthy
See the new RSA6100A Real-Time Spectrum Analyzer, especially if you are looking at purchasing the Agilent PSA E4440A series or the Rohde & Schwarz FSQ series. Also participate in the RFIQ Challenge for a chance to win a trip to Hawaii for MTT-S 2007 or a $100 Radio Shack gift certificate.
Test and Manufacturing Equipment

Telecommunications **331**
Norwood, MA
Publications

Trilithic Inc. **611**
Indianapolis, IN
S. Johnson, M. Burton
Trilithic is an innovative provider of RF and microwave solutions. Our product line includes custom filters for military and commercial applications, subsystems for test/verification and production environments, and in stock attenuators, switches and other signal control components for most requirements. A new series of high "Q" cavity filters will be featured at this exhibition.
Attenuators, Filters, Power Dividers, Systems/Subsystems, Switches, Terminations

TTE Inc. **532**
Los Angeles, CA
D. Zavac, S. Sodaro, J. Gilmore
Since 1956, TTE Inc. has led the way in the design, development and manufacture of active and passive filters from 0.1 Hz to 26 GHz. Most LC filters are available in one week ARO for 10 or less units, four weeks for 100 units ARO. Visit our web site at www.tte.com.
Filters

Via Satellite **PubBin**
Rockville, MD
Via Satellite, the satellite industry's leading magazine, keeps its 22,000 global subscribers "in the know" by providing essential news and analysis on the commercial communications, broadcast, military and enterprise sectors of the satellite industry. Every issue includes information on current and evolving applications, infrastructure issues, technology, procurement reports and business and regulatory developments around the world. Visit us on-line at www.viasatellite.com
Publications

Wiley **420**
Hoboken, NJ
Wiley is a global publisher of professional, consumer, scientific and technical books, journals, textbooks and education materials. Among it's many imprints are the world renowned "For Dummies" line as well as Webster's New World, CliffNotes, Frommers, Betty Crocker books, and Jossesy-Bass. To see more about these and our other imprints, visit Wiley at www.wiley.com.
Publications

Wireless Design & Development **442**
Rockaway, NJ
Wireless Design & Development (WDD) is a portfolio of publications and products that offers articles, product information and news in all sectors of wireless, covering all frequencies. *WDD* is "wider wireless" covering emerging technologies and markets. *WDD* offers its monthly publication, *WDD Asia*, *WDD Asia China Edition*, multiple e-Newsletters, webcasts and more. *WDD* is an Advantage Business Media publication.
Publications

Zeland Software Inc. **521**
Fremont, CA
J. Zheng
IE3D EM Simulation and Optimization Package Release 12 with FastEM Design Kit for real-time full-wave EM tuning, optimization and synthesis, multi-fold speed improvement and multi-CPU support, Boolean enabled equation-based geometry editing and automated equivalent circuit extraction and optimization.
Antennas, Filters, MMICs, Printed Circuit Boards, RFICs, Software

Northrop Grumman Awarded $357 M USCIS Contract

Northrop Grumman has been awarded a $357 M, indefinite delivery, indefinite quantity contract by the US Citizenship and Immigration Services (USCIS), an agency within the Department of Homeland Security (DHS), to continue providing biometric capture services in support of US citizenship applications and green card renewals. The contract is for one base year with four one-year options and has a potential value of $750 M over a five-year period.

Biometric capture services involve electronic scanning and recording of fingerprints and photograph and signature collection for identification purposes. The contract work will be performed in all 50 US states at 136 Application Support Centers (ASC), with possible future expansion overseas. Northrop Grumman has provided these services to USCIS since 1999. "Northrop Grumman is proud of its past performance and continued opportunity to significantly contribute to our nation's homeland security," said James Cameron, president of Northrop Grumman's Technical Services sector. "Whether supporting our Department of Defense warfighters in the field or the Department of Homeland Security here in the United States, our goal remains the same: to provide innovative solutions and services to our valued customers."

Under Northrop Grumman's management of the biometric program, USCIS has reduced its fingerprint rejection rate from 20 to 1.5 percent, the lowest such rate at DHS. Rejections are caused by improper finger print recording. Factors that have led to the reduction in the reject rate include additional fingerprint technician training, the creation of a certification-training program for quality assurance and improvements USCIS made to the fingerprinting computer systems. Northrop Grumman's teammates include USE Inc., Orlando, FL, Pinkerton Government Services Inc., Mansfield, MA, and International Organization for Migration, Geneva, Switzerland.

Raytheon to Demonstrate Aircraft Protection System

Raytheon Co. has been awarded a $4.1 M contract by the Department of Homeland Security, to demonstrate the suitability of its Vigilant Eagle Airport Protection System to function in a civilian environment and protect aircraft from the threat of shoulder-fired missiles.

Vigilant Eagle provides an invisible dome of protection around airports or airfields, offering all aircraft—international or domestic commercial flights as well as military and private planes—protection from terrorist surface-to-air missiles including Man-portable Air-defense System (MANPADS). Vigilant Eagle aims a focused, precisely steered beam of electromagnetic energy at a terrorist's missile, diverting the threat away from the targeted aircraft. Because Vigilant Eagle is ground-based rather than installed on individual aircraft, it can protect all aircraft inside an airport area. Vigilant Eagle consists of three interconnected primary components: a distributed missile detect and track system, a command and control system, and the active electronically scanned array, which is a billboard-sized array of efficient antennas linked to solid-state amplifiers that provide the beam that diverts the missile.

"Raytheon's Vigilant Eagle defeats man-portable missiles in seconds, without an alteration to or involvement by the aircraft using the airport," said Mike Booen, vice president of Directed Energy Weapons at Raytheon Missile Systems in Tucson, AZ. "Not only has our Vigilant Eagle system proven effective, but it protects all aircraft using an airport and can be rapidly deployed at a reasonable cost."

Ground-based Vigilant Eagle provides anti-MANPADS protection for a fraction of the cost of airborne systems being developed. Vigilant Eagle also has a far lower false alarm rate than other systems and uses proven, mature technologies.

Raytheon plans to conduct validation activities and implement a unique interoperability test bed at a site determined by DHS to provide data for DHS's assessment of Vigilant Eagle's capability to defeat MANPADS. The test bed is an initial step to implementing counter-MANPADS to protect flights at airports.

Raytheon's airport security solutions also include a contract with the Port Authority of New York and New Jersey to provide a Perimeter Intrusion Detection System (PIDS) to safeguard the region's four airports: John F. Kennedy International, Newark Liberty International, La Guardia and Teterboro. The Raytheon-led team will design, develop and deploy the security system; provide complete infrastructure development; integrate existing and future access controls and intrusion detection systems; and provide training and maintenance. PIDS is the first large scale, fully integrated design and built project at any major domestic airport.

Harris Corp. Achieves Uplink to Milstar Using AEHF Navy Terminal

Harris Corp. announced that it is the first company to successfully uplink to a Milstar satellite using an Advanced Extremely High Frequency (AEHF) Navy Multiband Terminal prototype system. This milestone follows the company's announcement last month that it was the first to acquire and track low- and medium-data-rate waveforms on Milstar 6 using the same prototype terminal. An SCA 2.2.1 compliant software programmable modem developed by Harris was instrumental in both successful demonstrations. Once fielded, the terminal will serve as the common element of naval information networks, providing interconnection of individual naval assets with other services and eventually with the Global Information Grid.

In 2003, Harris won a contract to develop four prototypes for the next-generation AEHF Navy Multiband Terminal. The US Space and Naval Warfare Systems Command is scheduled to perform a competitive downselect and issue a contract in June 2007 for the engineering, manufacture and development (EMD) phase of the program. Should Harris win the EMD phase competition, the overall value of the program for the Harris team could exceed $1 B by 2015. "This uplink demonstration marks another defining milestone in the development of next generation, Navy protected SATCOM terminals that offer multiband communication capabilities in a single terminal," said Sheldon Fox, vice president and general manager of the Department of Defense Program business unit of Harris Government Communications Systems Division. "We now have successfully achieved both uplink and downlink capabilities ahead of schedule—key steps in demonstrating that our next-generation AEHF terminal can communicate successfully with Milstar satellites."

Acquisition of and uplink with the Milstar satellite was performed at Harris Naval SATCOM Integration and Test Facility in Palm Bay, FL, utilizing a KGV-136, the newest generation cryptographic unit. The successful demonstration was the culmination of two years of Harris-sponsored waveform design and hardware/software development as part of the prototype competition sponsored by the Navy Program Executive Office for C^4I.

Coupled with an earlier demonstration of the new, extended data rate (XDR) waveforms and the Milstar downlink capability, this latest demonstration confirms that Harris is on plan to provide US Navy ship, submarine and shore installations with full access to the communications capacity provided by the AEHF satellite constellation. This approach offers the Navy better access to SATCOM assets and increased bandwidth, as well as protection from jamming and interception of transmissions.

The Navy Multiband Terminal Phase 1 program is a 43-month effort to design and develop prototype Q-band SATCOM submarine and shipboard terminals in support of the US Navy's FORCEnet concept. Additional phases will add high performance Ka- and X-band capabilities to the common terminal. The resulting system will replace current single- and dual-band terminals, yielding significant life-cycle cost reductions and improved reliability. ■

Biofuelling Wireless Networks in Africa

The GSM Association, Ericsson and multinational telecommunications group MTN have teamed up to establish biofuels as an alternative source of power for wireless networks in the developing world. The three organisations have set up a pioneering project in Nigeria to demonstrate the potential of biofuels to replace diesel as a source of power for mobile base stations located beyond the reach of the electricity grid.

The project comprises the setting up of a pilot biodiesel powered base station solution in Lagos and will later deploy biodiesel fuelled base stations in rural regions of southeastern and southwestern Nigeria. The three organisations are setting up a supply chain designed to benefit the local population by sourcing a variety of locally produced crops and processing them into biofuel. Groundnuts, pumpkin seeds, jatropha and palm oil will be used in the initial pilot tests. The GSMA and Ericsson will draw on the findings of the pilot to help operators across the developing world determine whether they can use biodiesel to power their networks in rural areas.

Karel Pienaar, CTIO of the MTN Group, proffered, "The early adoption of biofuel powered mobile networks would place Africa at the forefront of a new wave of innovation that is making mobile communications affordable and accessible across the developing world."

Alcatel Accepts PRISMA Space Mission

Alcatel Alenia Space will develop and supply the S-Band Formation Flying Radio Frequency (FFRF) sensor for the Prototype Research Instruments and Space Mission technology Advancement (PRISMA) mission. PRISMA is an eight-month flight mission funded by the Swedish National Space Board (SNSB), with the Swedish Space Corp. (SSC) as prime contractor and developed in cooperation with the German Aerospace Centre (DLR), the Danish Technical University (DTU) and the French Space Agency (CNES).

Its primary goal is to perform guidance, navigation and control demonstrations as well as in-flight validation of sensor technologies for future missions in which rendezvous and formation flying are a prerequisite. Alcatel Alenia Space's French and Spanish subsidiaries will design, develop, manufacture, test and supply the FFRF sensor, under the frame of the bilateral Earth science missions agreement signed between CNES and CDTI (the Spanish space agency).

The FFRF sensor, which will comprise two FFRF terminals, two sets of antennas and two associated test benches, will provide real time relative positioning and inter-vehicle communication services with a dynamic range between 3 m to 30 km and a positioning accuracy of 1 cm. It will be used for the European Space Agency's and CNES' next generation formation flying missions.

Vitelec and Midwest Merge

Vitelec Electronics Ltd., part of Emerson Connectivity Solutions, is combining its operation with Midwest Microwave International Ltd., a supplier of low loss RF cable assemblies and microwave components. The merger follows Emerson's recent acquisition of Midwest Microwave Inc. of Saline, MI, US, and Midwest Microwave International Ltd, based in Chelmsford, Essex, UK. It is a move intended to bring significant benefits to customers both in the UK and Europe.

Supplying an extensive range of standard and custom low loss cable assemblies, together with microwave components including attenuators, power dividers, couplers, terminations, precision connectors and adaptors, Midwest's product offering combines perfectly with Vitelec's high quality range of RF cables and connectors. As well as the clear synergies between the product ranges, Vitelec will also be relocating to Midwest's expanded Chelmsford facility, bringing increased capacity and development of custom solutions.

Customers of the new combined Connectivity Solutions are likely to benefit in a number of areas. Indeed, the new business will provide a wider RF product offering, all supported by a world class manufacturing and assembly facility, together with a sophisticated European warehouse and logistics operation. As a result, levels of customer service will be further enhanced while the move illustrates Emerson's long-term commitment to the UK and European marketplace.

European Satellite Interference Location Service

Responding to increased demand from commercial satellite operators and government organisations, QinetiQ is launching a European satellite interference geolocation service. This service will assist in the fight against malicious or accidental disruption to satellite communications services. Hosted in the UK and operating on a 24/7 basis the service will allow customers to rapidly identify, and accurately locate, the source of interference to their satellites.

Provided on a pay-as-you-go annual contract the service is based on QinetiQ's state-of-the-art satID® system and exploits advanced patented techniques to deliver a highly accurate and fast service. The company has already secured its first European customer for the service, which mirrors a similar geolocation operation based in Singapore and serving Asia.

Rob Rideout, QinetiQ's satID Business Group manager, said: "This European service launch will complement our existing Asian service and provide customers with access to a dedicated geolocation service capability that is unique in Europe. We now provide a cost-effective, service-based alternative to satellite operators who do not wish to commit to purchasing a system but still want to promote a satellite communications service that includes the added protection and piece of mind of a geolocation capability."

Wireless Collaboration for ST and Nanotron

STMicroelectronics and Nanotron Technologies GmbH have announced a definitive, non-exclusive agreement under which the two companies will jointly develop complete solutions for the Real Time Location Systems (RTLS) market. These solutions offering robust communication, precision ranging and high accuracy positioning will operate on emerging low data rate (LDR) networks that meet the recently begun efforts to establish a low data rate wireless personal area network (IEEE 802.15.4a) standard. Nanotron brings to the initiative its expertise and intellectual property in the design and manufacture of RF systems using the Chirp Spread Spectrum radio hardware and software, while STMicroelectronics will contribute world class capabilities in semiconductor technology and development, as well as its global manufacturing and marketing resources.

The work will involve joint development of components and reference designs for a complete roadmap of next-generation location awareness solutions with hardware, software and tools, for the industrial and the active RFID asset tracking market. A first joint Chirp product from the partners is planned for launch in early 2007.

"The continued growth of active RFID applications depends upon advancements in RF technologies, like Chirp and symmetric double-sided two-way ranging, to enable solutions that are highly robust, highly accurate and simple to deploy at low cost," said Jim Nicholas, general manager of ST's Microcontroller Division. "By working with Nanotron, we intend to complement our RF LDR products with new high performance reliable communications platforms that will dramatically improve our customers' time-to-market." ■

China's Consumer Electronics Manufacturing Will More Than Double by 2010

Low labor costs and a fast-growing domestic market will spur China's consumer electronics manufacturing industry to more than double by 2010, reports In-Stat. The industry will grow from $71.5 B in 2006 to $167 B by 2010, the high-tech market research firm says. China's mature supply chain, a skilled labor force and convenient logistics are the key factors to attract outsourcing manufacturers from abroad.

"About two-thirds of China's electronic manufacturing revenue comes solely from foreign-funded or Sino-foreign joint ventures," says Anty Zheng, In-Stat analyst. "The world's top ten electronics manufacturers have all invested in China and consider China to be a key region in their global manufacturing facility layout."

Recent research by In-Stat found the following:

- China-based electronics manufacturing companies contributed about 8 percent of China's total $425 B electronics manufacturing revenue in 2005.
- Compared to its mature manufacturing environment, China's R&D ability, especially in chip design and solutions, is still weak: over 90 percent of chips for electronics manufacturing still depend on imports.
- A few Chinese fabless IC companies have set up successful models to win in niche markets like the video/audio chip market in mobile communications and MP3.

The research, "Electronics Manufacturing in China," covers the market for consumer electronics production in China. It examines China's current electronics manufacturing industry and development trends, with forecasts on electronics manufacturing revenue by several product categories through 2010. Companies interested in cooperating with Chinese electronics manufacturing companies or fabless companies will find the marketing intelligence necessary to penetrate the country's electronics manufacturing industry. The report provides valuable references related to electronics manufacturing for any IC companies looking to sell chips in China.

This research is part of In-Stat's China Semiconductor and Electronics Manufacturing Service. Semiconductor consumption by application for China is at the core of this service and it forecasts semiconductor consumption in crucial segments, including 3G mobile devices and infrastructure, IC cards and consumer electronics devices. Semiconductor consumption for all of Asia is also addressed by country and an additional step toward presenting the whole picture is taken with an assessment of electronics manufacturers in China.

A related In-Stat report, "Semiconductor Manufacturing Capacity by Country in Asia, 2006," details the semiconductor manufacturing capacity of various countries in Asia, and also looks at the capital spending trends in this industry. A separate section deals with the DRAM manufacturing in Asia.

Wi-Fi and Active RFID Vying for Healthcare Asset Management

Wi-Fi and active radio frequency identification (RFID) technologies are locked in a long battle to capture the burgeoning market in healthcare asset tracking, according to a new study by ABI Research. With less than five percent of North American healthcare facilities currently equipped with asset-management systems, this market, says industry analyst Sara Shah, "is up for grabs."

Hospitals own lots of expensive equipment, from basic items such as wheelchairs to the most sophisticated medical machinery. At any given time, much of it is hard to find: either in use or in storage. The result: over-inventory and under-utilization of assets. Both Wi-Fi and active RFID systems allow hospitals to know where their equipment is, nearly in real time.

"Wi-Fi location system vendors are focusing on healthcare," says Shah, "because most hospitals have Wi-Fi networks in place and many medical devices are Wi-Fi-equipped for patient monitoring. The value proposition is that they can keep their existing infrastructure and add new elements." Wi-Fi location vendors such as Aeroscout, Ekahau and Pan-Go will also argue that their technology is standard-based and non-proprietary. On the other hand, RFID vendors such as RF Code and Radianse point to the wide application of RFID for asset tracking and their longevity in the industry.

Wi-Fi is a viable solution for hospitals but most hospitals will need to install extra access points because their networks were not designed for this purpose. "The integration process can also be more difficult than many seem to believe," says Shah, "and requires extensive system configuration in order to determine accurate location."

"Active RFID and Wi-Fi in the RTLS Market" analyzes the impact Wi-Fi vendors will have on the market and explains the differences between RFID and Wi-Fi systems, including both applications and vertical markets. It forms part of ABI Research's RFID, M2M and Wi-Fi research services.

Much Greater Growth Potential in Wireless Markets Worldwide

Survey data collected from US customers in the past year reveals how the growth potential of global wireless markets is being seriously underestimated. Aside from the US, markets with a high percentage of prepaid services also contribute to this misjudgment.

The term that has caused the most confusion is "wireless penetration," which was intended to mean the percent of the population that used (was penetrated) by wireless phones. An example of this deep confusion was found in one research firm's declaration that "one third of the world's population now has a cellular phone." That conclusion was based on dividing the number of phone lines by the world's population. Since there are three times as many people as there are mobile phones, obviously one-third of the people have mobile phones. The math behind the assumption was elegant, simple and wrong.

During the past year, In-Stat has asked thousands of wireless subscribers in the US and Canada if they have more than one mobile phone number. Fifteen to over 17 percent responded that they did, indeed, use more than one mobile phone; most had one for personal use and one for business; many use a standard cell phone for most voice calls and have a second device—usually a Blackberry—as their second phone.

Here is the effect of these multi-line subscribers: at the end of August 2006, the Cellular Telephony and Internet Association (CTIA) stated there were 218.4 million wireless subscribers in the US. The CIA Factbook on-line states that the US population at the time was approximately 298.4 million people. The simple math (lines divided by people) finds 73.2 percent "penetration" in the US. The incorrect conclusion is that nearly three-quarters of the people in the US have mobile phones.

However, using data from In-Stat surveys that suggests that about 15 percent of those users have two cell phone subscriptions (or more) changes that figure substantially.

- 218.4 million total subscribers
- 15 percent dual ownership
- 32.7 million users with two phones

That means there are 32.7 million fewer people in the US who have cell phones than the so-called "penetration rate" suggests. True penetration is closer to 60 percent and there are over 30 million potential new wireless subscribers that have not been recognized in the past. Outside the US, the over counting is even greater. Because many users, especially those using prepaid wireless services, purchase multiple SIM cards from different carriers, "penetration rates" exceed 100 percent in several countries. Tiny Luxembourg takes the prize with over 1.3 wireless phone lines per resident or 130 percent "penetration."

Without an accurate count of the number of subscribers using multiple devices, it is impossible to accurately estimate the number of people who still do not have mobile phones. The highly desirable "total addressable market" is larger—perhaps much larger—than it appears.

During 2006 and into the future, In-Stat is expanding a broad range of consumer surveys to include more respondents in Europe, Asia and elsewhere. These data will be used throughout In-Stat in developing accurate estimates of wireless users worldwide and will provide even more accurate forecasts of wireless subscribers, handsets and infrastructure as well as applications such as mobile video and multimedia those subscribers will use. ■

INDUSTRY NEWS

■ **Symmetricom Inc.**, a leader in precise time and frequency products and services, announced the acquisition of **Timing Solutions Corp.**, a privately held company based in Boulder, CO, that provides high performance time and frequency products and services for government, aerospace and military markets. Under the terms of the agreement, Symmetricom paid approximately $8 M in cash.

■ **Andrew Corp.**, a leader in communications systems and products, has agreed to acquire **EMS Wireless**, a Norcross, Georgia-based division of EMS Technologies Inc. Under the agreement, Andrew will pay $50.5 M in cash for EMS Wireless, a major designer and manufacturer of base station antennas and repeaters for cellular networks in North America. Its customers include the major wireless operators in the US.

■ **Kulicke & Soffa Industries Inc.** announced the signing of an agreement to acquire **Alphasem**, a supplier of die bonder equipment, from Dover Technologies International Inc., a subsidiary of Dover Corp. The purchase price is $30 M, subject to a working capital adjustment.

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

■ **Vishay Intertechnology Inc.** and **International Rectifier Corp.** (IR) announced they have reached an agreement for the sale of IR's Power Control Systems (PCS) business to Vishay. The PCS business includes IR's Non-focus Products business and certain product revenue from its Focus Products business, including certain discrete planar MOSFETs, discrete diodes and rectifiers, discrete thyristors, and automotive modules and assemblies. The PCS business accounted for revenue of approximately $300 M, or 26 percent of revenues in IR's June-ending fiscal year 2006. The PCS business is expected to be sold for approximately $290 M in cash.

■ **RF Monolithics Inc.** (RFM) announced it will offer its recently acquired asset management software through and under the name of its subsidiary, **Aleier Inc.**, and discontinue use of the Caver-Morehead Systems brand. The new name reflects the expanded scope that RFM plans for Aleier.

■ **Interplex NAS**, a manufacturer of metal stamping, insert molding and a full line of solder and flux bearing edge clips, has announced the completion and move to its new corporate headquarters in Northvale, NJ. The new 54,000 square foot facility allows the company to further its streamlined design philosophy by having all aspects of the engineering process under one roof. For more information, contact Joseph Praino, national sales manager, Interplex NAS, 232 Pegasus Avenue, Northvale, NJ 07647 (201) 768-8388 or e-mail: joe.praino@us.interplex.com.

■ **Applied Wave Research Inc.** (AWR®) announced that in order to better serve the company's rapidly expanding Japanese customer base, it has opened a dedicated sales, marketing and support center in Japan, and has appointed Michiyoshi Endo as managing director. A graduate of the Tohoku Institute of Technology with a BS degree in electronics engineering and telecommunications, Endo-san worked as an applications engineer at Kyocera Co. Ltd., before moving into sales and marketing, strategic planning, customer service and business development for various high technology software and hardware companies in Japan and Asia.

■ **D2 Technologies** announced that it has opened a Design Center in Maynard, MA, just outside of Boston. The center will be focused on the development of software products for mobile communication devices. Zigurd Mednieks, chief software architect, heads the Design Center. Mednieks is a widely respected technologist, and the author of books and book chapters on telephony and programming published by leading publishers.

■ **EDO Corp.** announced it has opened a new facility to manufacture state-of-the-art battlefield communications systems in Charleston, SC. The operation employs 50 people, with a projected growth to 70 in 2007. The new facility is responsible for supporting the Transition Switch Module (TSM) program, a key component of the Marine Corps network-centric battlefield communications strategy. In 2005, EDO was awarded a contract with a maximum value of $240 M for the procurement of multiple configurations of TSMs.

■ **UltraSource Inc.**, a supplier of custom thin film circuits and ceramic interconnect devices, has announced the expansion of the company's cleanroom facilities at its corporate headquarters and manufacturing facility in Hollis, NH. Citing increased customer opportunities and business expansion, UltraSource has commenced building an additional 1500 square feet of cleanroom manufacturing space. The added cleanroom space brings the total cleanroom space at UltraSource to 6000 sq. ft. and will allow for optimization of lean manufacturing cells to enhance manufacturing productivity and product flow.

■ **Endwave Corp.**, a provider of high frequency RF modules for telecommunications networks, defense electronics and homeland security systems, announced the completion of the relocation of its corporate headquarters. The new address is: Endwave Corp., 130 Baytech Drive, San Jose, CA 95134 (408) 522-3100, fax: (408) 522-3197, www.endwave.com.

■ **CPS Technologies**, a leader in the design and production of metal matrix composites, has announced a strategic partnership with **sp^3 Diamond Technologies Inc.** (sp^3), a supplier of DiaTherm™ diamond heat spreaders and diamond products for solving thermal management challenges in high performance applications. Geared towards meeting the growing market need for electronics packages with enhanced thermal dissipation requirements, the two companies are partnering to provide AlSiC packages with diamond pins.

■ **Tektronix Inc.** announced that it is working with **LitePoint Corp.**, a provider of advanced wireless test solutions, to create an end-to-end test solution for WiMAX. The effort between LitePoint and Tektronix, including new test tools for troubleshooting WiMAX application design utilizing a Tektronix Real-Time Spectrum Analyzer, will address the full value chain of test needs from pre-development through to final production test. The collaboration will provide fast time to production and low cost per test manufacturing solution for WiMAX.

■ **Skyworks Solutions Inc.** announced that **Broadcom** has selected its WLAN 802.11n 2 × 2 multiple input, multiple output (MIMO) front-end module (FEM) reference design to complement its Intensi-fi™ draft-802.11n chipsets. The proposed 802.11n Wi-Fi® specification significantly increases the wireless range and speeds the transfer of data, empowering more robust applications to be effectively run over public hotspots and private networks.

■ **BAE Systems**, **National Instruments** and **Phase Matrix Inc.** (PMI) announced a joint initiative to develop a PXI Express-based synthetic instrument for military and commercial RF and microwave applications. PMI is currently developing a 100 kHz to 26.5 GHz family of downconverter modules in a 3U PXI Express-compatible format to support PXI RF and microwave applications. BAE Systems, a leader in synthetic instrument systems, plans to build a next-generation synthetic instrument based on the new downconverter module family, using National Instruments PXI Express chassis, controllers and intermediate frequency (IF) digitizer modules as well as National Instruments LabVIEW graphical development software for host and FPGA-based signal processing.

■ **Tyco Electronics** and **Versatile Systems Inc.** announced the expansion of the SyncSeer™ system capabilities by adding **M/A-COM** RFID components to the SyncSeer system. The SyncSeer system is an intelligent, technology infrastructure and information management system comprised of hardware and software for companies in the entertainment, retail, health care, government and education marketplaces. Under the terms of the alliance, M/A-COM Inc. will provide multi-protocol fixed and embedded UHF RFID readers and antennas.

■ A Development Test Mode for the WiMAX 802.16e protocol conformance test solution has been released by **Aeroflex** and **AT4 Wireless** (formerly known as CETECOM Spain) on behalf of the WiMAX Forum. The availability of the Development Test Mode gives first-line WiMAX equipment manufacturers, chipset developers and protocol stack developers an early opportunity to test both subscriber and base station functionality and interoperability throughout the development phase of their products.

■ **Harris Corp.**'s Broadcast Communications Division Radio Business Unit has donated its Platinum Series® Z5, 5 kW, solid-state, FM transmitter to the first independent Iraqi women's radio station, Radio Al-Mahaba. The new Harris transmitter will transmit within a 60 to 90 mile radius of the station's Baghdad location and will reach people in approximately half of the 18 provinces.

■ **Silicon Laboratories Inc.**, a leader in high performance, analog-intensive, mixed-signal ICs, recently celebrated ten years of mixed-signal innovation. By fundamentally changing semiconductor architectures, Silicon Laboratories has achieved multiple industry firsts in the communications, wireless, networking, power and microcontroller markets. Silicon Laboratories has built a portfolio of market leading products leveraging mixed-signal trade secrets, a world-class engineering team and more than 700 issued or patent pending innovations.

■ **WJ Communications Inc.** announced that it has successfully achieved certification from the South Korean government Ministry of Information Communication (MIC) for its RFID UHF WJR7090 reader module and is now approved for sale in Korea.

■ **Palomar Technologies**, a supplier in precision automation equipment and process development for microelectronic assembly, announced that it has been recertified as meeting the requirements of ISO 9001/ANSI-ASQ Q9001:2000 and is registered by SGS.

■ **PSI-TEC Corp.**, a wholly-owned subsidiary of PSI-TEC Holdings Inc., announced that the company's independent laboratory results came back positive, confirming the thermal stability of its Perkinamine electro-optic materials. Thermal stability as high as 350°C was confirmed.

CONTRACTS

■ **Lockheed Martin** has been awarded a contract valued at approximately $120 M to provide the US Army with five Enhanced AN/TPQ-36 radars. The contract was awarded by the Army's Program Executive Officer-Intelligence, Electronic Warfare and Sensors (PEO-IEW&S); the radars—also known as the EQ-36 Counterfire Target Acquisition Radar—will be delivered within 36 months.

■ The **Evans Capacitor Co.** has won a $3.03 M contract from **Lockheed Martin** Missiles and Fire Controls, Orlando, FL, to supply capacitor banks for Lot III production of the Apache helicopter Arrowhead Program. Arrowhead is the Modernized Target Acquisition and Designation Sight/Pilot Night Vision System (MTADS/PNVS) for AH-64 Apache attack helicopters. Evans will supply two specially built and packaged capacitor banks for the system. It will manufacture approximately 250 Arrowhead ship sets by the end of 2007.

■ **Microsemi Corp.**, a manufacturer of high performance analog/mixed-signal integrated circuits and high reliability semiconductors, has announced that Congress has appropriated $1.8 M to allow Microsemi's Power Products Group (formerly Bend, Oregon-based Advanced Power Technology) to develop technology related to the use of silicon carbide semiconductor components in military avionics applications. It is expected that the program will be administered by the Air Force Research Laboratory (AFRL).

■ **Agilent Technologies Inc.** and **AT4 Wireless** (formerly known as CETECOM Spain) announced that Agilent's Measurement Systems Division and Wireless Business Unit have won a contract valued at more than US $1 M jointly with AT4 Wireless for fixed and mobile WiMAX conformance test and regulatory test systems with Telecom Technology Center Taiwan.

■ **RF Industries’** RF Neulink Telemetry Division announced it has been awarded a $77,000 order for modified models of its flagship NL6000 wireless modem from Lockheed Martin.

■ **IKE Micro**, a build-to-print contract manufacturer serving the defense and commercial markets, announced that it was awarded a large order from a division of Tyco Electronics. IKE Micro received an order from **M/A-COM**, Lowell, MA, for 13,500 amplifier assemblies to support a military radar program. The order will be completed in 2007.

FINANCIAL NEWS

■ **Credence Systems Corp.** reports sales of $109.6 M for the third quarter of fiscal 2006 ended July 31, 2006, compared to $111.9 M for the same period in 2005. Net loss for the quarter was $461.4 M ($4.61/per share), compared to a net loss of $41.7 M ($0.43/per share) for the third quarter of last year.

■ **PulseWave RF™ Inc.** (formerly PropheSi Technologies™ Inc.), a fabless semiconductor company providing modules for the wireless infrastructure market, announced that it closed a $30 M Series C funding round led by Oak Investment Partners. Existing PulseWave RF investors, including Austin Ventures, Bay Partners and Genesis Campus, also participated in the round. PulseWave RF will use the funding to commercialize its Class M power amplifier module, a digital power amplifier architecture for wireless base stations. In addition, the investment will support the company’s expansion of its operations, sales and marketing and engineering teams.

■ **Jacket Micro Devices** (JMD), a supplier of small, high performing RF modules, announced it has received $12 M in venture funding. New investor Intersouth Partners led the round with participation from existing investors Noro-Moseley Partners, Sevin Rosen Funds and Imlay Investments. The new round of financing will be used to expand product development and ramp production of the company’s recently introduced products for 802.11n applications.

■ **Chip Estimate Corp.**, a provider of architectural-level chip planning solutions, announced that it has raised $3.5 M in expansion financing in two closings. ITU Ventures, who participated in the original seed funding of the company, led this round. The company has raised $5.5 M since its inception in 2003, and will use the latest round to fund working capital growth and accelerate the product roadmap for establishing tight and meaningful integration of architectural plans with industry-leading EDA implementation systems.

NEW MARKET ENTRY

■ ElectroMagneticCareers.com, a new career web site focused exclusively on RF and microwave, antenna, radar, EMC and related test engineers, was launched in October 2006. Bringing together employers and engineers within the industry, ElectroMagneticCareers.com facilitates talent hunt for employers and job search for microwave and RF engineers. With the variety of related expertise categories, one can now pin-point the exact skill set matching a project’s needs.

PERSONNEL

▲ Steve Karlovic

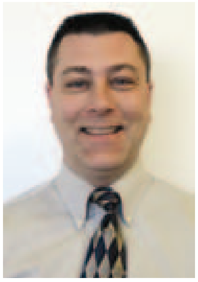
■ EADS North America Defense Test and Services announced the appointment of **Steve Karlovic** to vice president of business development and customer support, with responsibility for worldwide business development, sales and customer support in addition to corporate communications. Prior to joining the company, Karlovic was responsible for related logistics programs at Lockheed Martin Simulation, Training and Support in Orlando, FL.

■ Micronetics Inc. announced that **Kevin Beals** has joined the company as vice president of business development. Beals brings nearly 25 years of related design and sales experience with highly integrated technologies for military and commercial electronic markets. Most recently, Beals served as district sales manager at M/A-COM Inc., where he had contributed for the past 15 years.

■ Paratek Microwave has opened a new advanced engineering Design Center in the Chicago suburb of Crystal Lake, IL, naming **Keith Manssen**, vice president of engineering for commercial products, to run the operation. Manssen comes to Paratek with over 25 years of wireless and mobile phone industry experience, most notably with Motorola where he spearheaded the development of its highly successful StarTAC and GSM phones.

▲ Alfredo Perez

■ Technical Communities Inc. announced that **Alfredo Perez** will join the company as a vice president-business development. Perez, who will be based in the Washington, DC-area, comes to Technical Communities from IPIX Corp., Reston, VA, where he was vice president of sales. As a vice president-business development, Perez will assume responsibility for a strategic approach to the company's continued business expansion of GSA distribution of IT products and services. He will be directly responsible for the establishment of agreements between Technical Communities and manufacturers as well as ongoing sales strategy.



▲ Mark Perhacs

■ Advanced Control Components Inc. announced that **Mark Perhacs** has joined the company as the director of sales and marketing. Perhacs has spent the last 18 years in the RF and microwave industry. His experience includes sales and business development for companies focused on the commercial and military industries. Most recently he was the sales manager for Aeroflex-KDI Integrated Products in Whippany, NJ. Perhacs will be managing all of the foreign and domestic representatives, as well as setting marketing strategy for the company's products. He may be reached via phone at (732) 460-0212 x267 or e-mail: mperhacs@advanced-control.com.

■ Centerline Technologies announced the appointment of **Robert Naugler** to the position of operations manager. In this capacity, Naugler is responsible for the day-to-day operation of Centerline Technologies' lapping, polishing and dicing operations. His responsibilities also include the supervision of quality, production and statistical process control. Naugler has extensive experience in operations management, process development, and research and development.

■ Auriga Measurement Systems LLC announced the addition of **Agostino Augie Papetti** as director of global marketing. Papetti has 40 years of experience focusing on global marketing and building strong customer relations. Previous to Auriga, Papetti was employed by Agilent Technologies and Hewlett Packard in a variety of sales and marketing positions focusing on the microwave and millimeter-wave business segments, the aerospace and defense market, and the GaAs Foundry Infrastructure. At Auriga, Papetti will refine the company's strategy to grow the global marketing enterprise to support the three core Auriga business lines of modeling and design services, characterization instruments, and test and measurement systems, and to expand into related fields.

■ Elcoteq SE announced that **Richard Appleby** has joined Elcoteq as director, America Operations. Formerly vice president of North America Manufacturing for Foxconn, Appleby has over 25 years of experience in the electronics manufacturing industry. At Elcoteq, Appleby will be responsible for all aspects of operations management.


▲ *David Hsiao*

■ Fox Electronics announced **David Hsiao** has been hired as its new manager of sales and marketing for Fox Asia Pacific. Hsiao will manage Fox's rapid growth in this area, which includes Taiwan and China. He will also open a new Fox office in Taiwan. In addition, Hsiao will be responsible for the marketing and sales of Fox's full range of frequency control products. Before joining Fox, Hsiao worked as managing director of sales for Hosonic Electronic Ltd. at the Hosonic headquarters, and as vice president at Hosonic (HK) International Co. Ltd. The Fox Asia Pacific's sales headquarters is located at 4/7 Gold & Silver, Commercial Building, 12-18 Mercer St., Central, Hong Kong.

■ XMA Corp. announced the appointment of **Thomas Kuhn** as senior microwave component engineer. In this position, he will be responsible for expanding XMA's new product design introductions along with fresh inputs for the manufacturing teams at XMA's Manchester, NH, and Tianjin, China facilities. Kuhn has several years experience in New Product Design and Technical Support of Manufacturing.

■ RFMW Ltd. announced it has appointed **Richard Sisterson** as the new sales engineer for the San Diego, CA territory. Sisterson comes to RFMW Ltd. from CK Associates, the manufacturer's rep for M/A-COM, MuRata, Intersil and Honeywell. Prior to that, he spent five years with Future Electronics as a technical solutions manager and the regional analog and RF specialist for the San Diego region.

REP APPOINTMENTS

■ Electronic component distributor **Digi-Key Corp.** and **Antenova Ltd.** announced the signing of a global distribution agreement. Based in Cambridge, UK, Antenova is a developer and supplier of high performance integrated antenna solutions for a wide range of wireless applications for mobile handsets, portable devices and other consumer electronics. Antenova products are available for purchase directly from Digi-Key and are featured in its print and on-line catalogs.

■ **Aethercomm Inc.** announced it has appointed **K-Tech Sales** as the company's exclusive sales representative covering northern California. K-Tech Sales will represent and support Aethercomm's entire product offering. The company can be reached at: 100 Century Center Court, Suite 405, San Jose, CA 95112 (408) 437-1808 or visit www.ktechsales.com.

■ **Teledyne Relays** has added **Mouser Electronics Inc.** as an authorized global distributor of its switching products.

■ **Palco Connector** announced the appointment of **Jaytech Sales** as the company's newest sales representative, covering the New England states. Palco designs and manufactures catalog and custom RF and microwave coax connectors, contacts and cable assemblies. Jaytech is located in Dracut, MA, and may be reached by phone (978) 453-8797 or e-mail: richjerome@comcast.net.

■ **Reactel Inc.**, a manufacturer of RF and microwave filters, multiplexers, switched filter banks and sub-assemblies to the commercial, military, industrial and medical industries, announced the appointment of **VP Electronics** as the company's representative in Maryland, Virginia and Washington, DC. For more information about VP Electronics, visit www.vpelectronics.com or call Vince Pirro at (410) 489-9554.

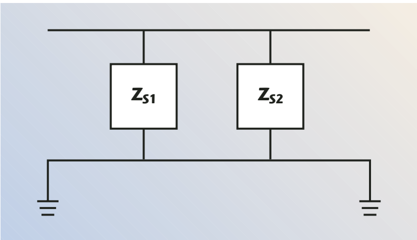
■ **LNX Corp.** announced the appointment of **Special-Ind** as its representative in Italy. Special-Ind brings 50 years experience in the marketing of microwave products for the defense and commercial business. LNX designs and manufactures microwave and millimeter-wave products combined with digital technology for the same markets. Special-Ind can be reached at 02-6074741, fax: 02-66800493 or e-mail: specialind@specialind.it.

■ **G.T. Microwave Inc.**, Randolph, NJ, announced the company's appointment of domestic representative, **Odyssey 1**, to cover Colorado and Utah. The members of Odyssey 1 were allotted the task of covering prospective customers in the Midwest region of the United States. The company's headquarters is stationed at 970 East 3300 South #7A, Salt Lake City, UT 84106. The company's web site can be located at www.odyssey1.biz.

DESIGN OF MICROSTRIP DUAL BEHAVIOR RESONATOR FILTERS: A PRACTICAL GUIDE

RF filters are commonly implemented inside receivers, with rigorous specifications about rejection of the adjacent transmitted frequency band, in order to preserve them from possible damage and degradation due to high transmit power.[1] Nowadays, these difficult problems are the subject of intensive studies in microwave planar filters.[2–5] For such applications, the use of dual behavior resonators (DBR) appears to be a very convenient solution because they allow the control of two attenuated bands on either side of one bandpass.[6,7] A DBR results from the association of two different parallel bandstop structures. Each of them brings its own transmission zero with respect to its fundamental resonant condition. At the same time, their association is transparent within a given operating frequency once the bandstop structures have been properly connected under constructive recombination criteria. It results in a bandpass response created between the above-mentioned lower and upper rejected bands. Quite often, a DBR filter can be an alternate solution whenever classical planar solutions are unable to solve a given problem.[8–18] This tutorial is aimed at showing how to benefit from this particular planar topology. The basic principles of DBR are recalled before describing in detail the design of a microstrip DBR filter in Ku-band.

Fig. 1 The basic resonant structure of a DBR.



WHAT IS A DBR

The generic structure, shown in ***Figure 1***, can be described as a parallel association of two different bandstop structures of equivalent input impedances, Z_{S1} and Z_{S2}. Obviously, the impedance of the whole structure is defined as

$$Z = \frac{Z_{S1}Z_{S2}}{Z_{S1} + Z_{S2}} \quad (1)$$

This equation shows that the stub association has no effect on the frequencies of the transmission zeros that always appear when Z = 0, that is when $Z_{S1} = 0$ or $Z_{S2} = 0$. The individual incidence of each bandstop structure is

E. RIUS, C. QUENDO, A. MANCHEC, Y. CLAVET, C. PERSON AND J.F. FAVENNEC
LEST-UMR CNRS no. 6165
Brest, France
G. JARTHON, O. BOSCH, J.C. CAYROU, P. MORONI AND J.L. CAZAUX
Alcatel Alenia Space
Toulouse, France

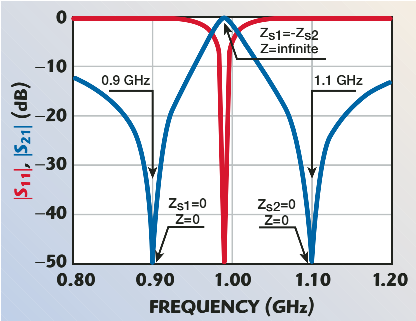
then preserved. Nevertheless, a bandpass can be created when the equivalent input impedances Z_{S1} and Z_{S2} have the same modulus, but become out-of-phase. Indeed, in this case, the total impedance, Z, tends towards infinity. According to the number of available parameters and to the initial behavior of each bandstop structure, a DBR allows the independent control of:

- 1 pole in the operating bandwidth
- 1 transmission zero in the lower attenuated band
- 1 transmission zero in the upper attenuated band

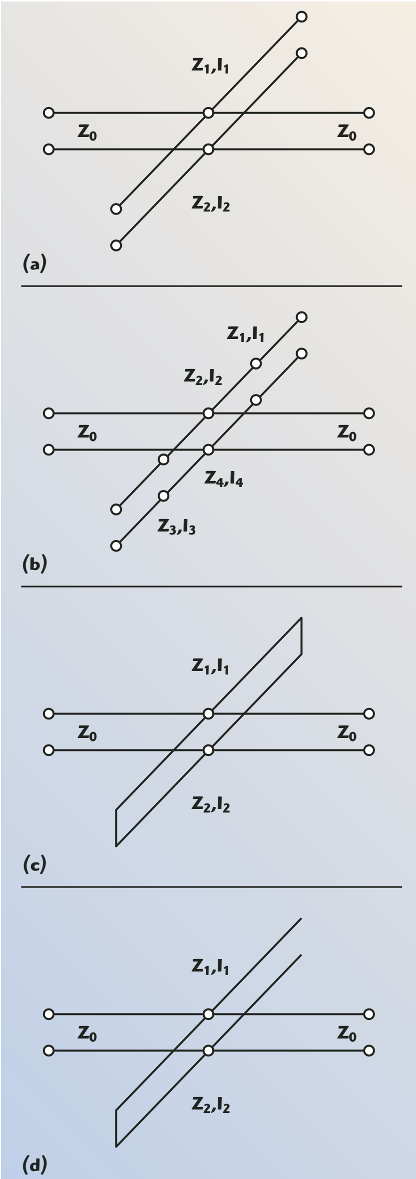
Such a structure can produce a response like the one shown in ***Figure 2***. One should nevertheless keep in mind that spurious resonances appear on each side of the bandpass. Consequently, this kind of resonator is only usable over a limited frequency range.

DBR FILTER SYNTHESIS

In planar technology, conventional bandstop structures can be easily implemented by using open stubs or short-circuited stubs, with or without stepped-impedances. ***Figure 3*** shows



▲ *Fig. 2 Ideal transmission line response of a DBR.*



▲ *Fig. 3 Examples of DBRs.*

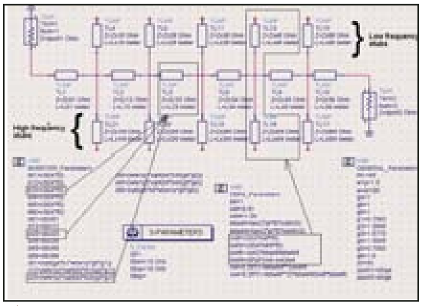
some examples of DBRs. The first one, (a), is made of uniform open-circuited stubs of different lengths,[7,19] whereas the second one, (b), results from the combination of stepped-impedance stubs and open-circuited ones.[6,7] The third DBR structure, (c), is composed of uniform short-circuited stubs of different lengths,[7] and the last one, (d), corresponds to an association of short-circuited stubs and open-ended ones.[7] General syntheses, all based on classical slope parameter formalism, have been proposed.[7] To illustrate the potential of a DBR filter, an ideal transmission line circuit (see ***Figure 4***) has been simulated with Agilent-ADS.™

The simulated response produced (see ***Figure 5***) is similar to that of a fifth-order DBR filter based on uniform-length, open-circuited stubs: a 4 percent fractional bandwidth centered at 1 GHz, with transmission zeros distributed symmetrically on each side of the bandpass. As an example, only the equations relative to the DBR n° 4 are given (see Figure 4), characterized by the parameters k_{4lf} and k_{4hf} equal to 0.91 and 1.09, respectively. These parameters define the position of the transmission zeros with respect to the central frequency. The proper slope parameter of this DBR is denoted by b4 and set to 1 here; b4 acts as a degree of freedom. Of course, the equations for the other DBRs are similar. It is worth noting that, because of the independence of DBRs, the transmission zeros are also independent. Flexibility is one of the great advantages of such a particular topology.

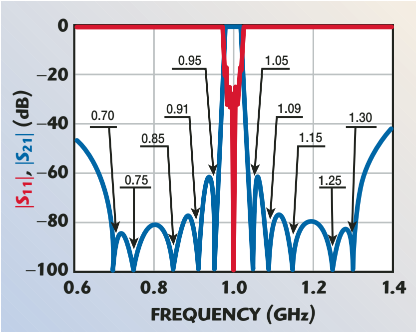
DESIGN OF A KU-BAND ALUMINA MICROSTRIP DBR FILTER

Fourth-order Ku-band DBR Filter

The design of a DBR Ku-band filter in microstrip technology will now be considered. This example will allow making explicit the design methodology, from the ideal transmission line model and associated synthesis to the manufactured circuit and final measurements. The focus will be on the particular features of this filter as well as on the difficulties met during the design. The proposed

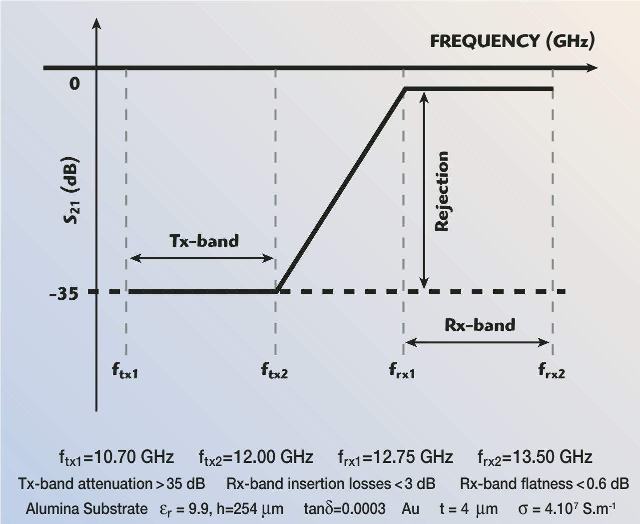


▲ *Fig. 4 Ideal transmission line scheme of a fifth-order DBR filter based upon uniform-length, open-circuited stubs.*

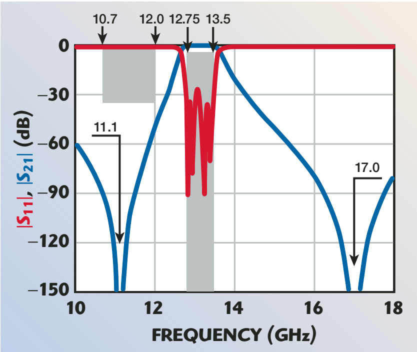


▲ *Fig. 5 Ideal transmission line response of a fifth-order DBR filter based upon uniform-length, open-circuited stubs.*

DBR Ku-band microstrip filter is slated to be incorporated in a receiver aboard a telecommunications satellite. ***Figure 6*** gives its precise specifications with respect to frequency. This filter must be able to eliminate the transmit (Tx)-band without seriously affecting the very close receive (Rx)-band. The attenuation within the Tx-band, between 10.7 and 12 GHz, must be better than 35 dB. For the bandwidth defined within 12.75 and 13.5 GHz, the losses and flatness need to be better than 3 and 0.6 dB, respectively. No specifications are given for the frequencies located before the Tx-band and after the Rx-band. Therefore, the main problem here is to get better rejection while restricting the number of resonators to be used so as to reduce both the level of insertion losses and the structure size. Filter topologies including transmission zeros are obviously well suited to this kind of problem. Moreover, the lack of specifications outside the frequency band between 10.7 and 13.5 GHz makes the DBR topology appear as a good candidate.



▲ *Fig. 6 Ku-band filter specification.*



▲ *Fig. 7 Simulated response of the fourth-order Ku-band DBR filter.*

Until now, designers have usually developed classical hairpin filter solutions. Indeed, the electrical performance of a fifth-order hairpin filter built on alumina substrate ($\varepsilon_r = 9.9$, h = 254 µm) was found to meet the desired specifications for insertion losses, flatness and Tx-band attenuation equal to 2.30, 0.5 and better than 47 dB, respectively. With this solution, the overall size of the structure (6.6×2.9 mm^2) remains small. However, this filter is very sensitive to technological variations because the smallest width for the slots is only 46 µm. Not only the sensitivity to dimensional variations, but also the influence of packaging must be considered with great attention. Since a fourth-order DBR filter should be sufficient to give the required out-of-band rejection, uniform-length stubs are chosen because of the availability of general synthesis[7] and

TABLE I

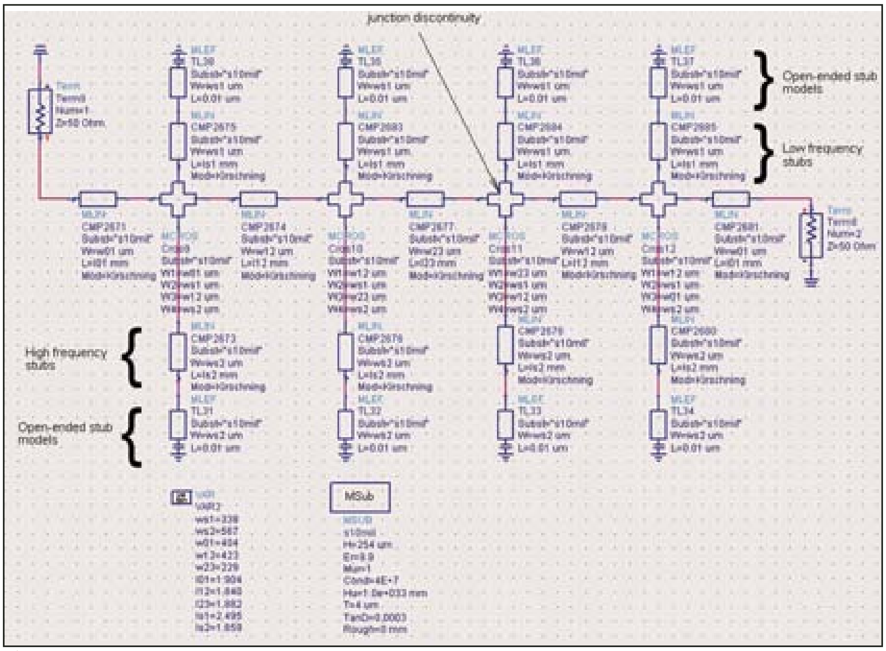
INPUT PARAMETERS OF THE FOURTH-ORDER, IDEAL TRANSMISSION LINE DBR FILTER SIMULATION

General Input Parameters	*Dual Behavior Resonators i=1, 2, 3 and 4*
$f_0 = 13.08$ GHz $w = 5.5\%$ $g_a = g_b = 1$ S $w_{1p} = 1$ Rad.s^{-1} $A_m = 0.01$ dB	$k_{ilf} = 0.85$ $k_{ihf} = 1.30$ $b_i = 22.3$

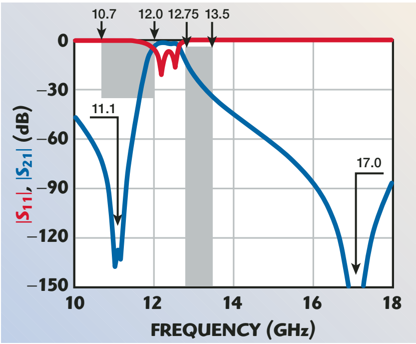
TABLE II

OUTPUT PARAMETERS OF THE FOURTH-ORDER, IDEAL TRANSMISSION LINE DBR FILTER SIMULATION

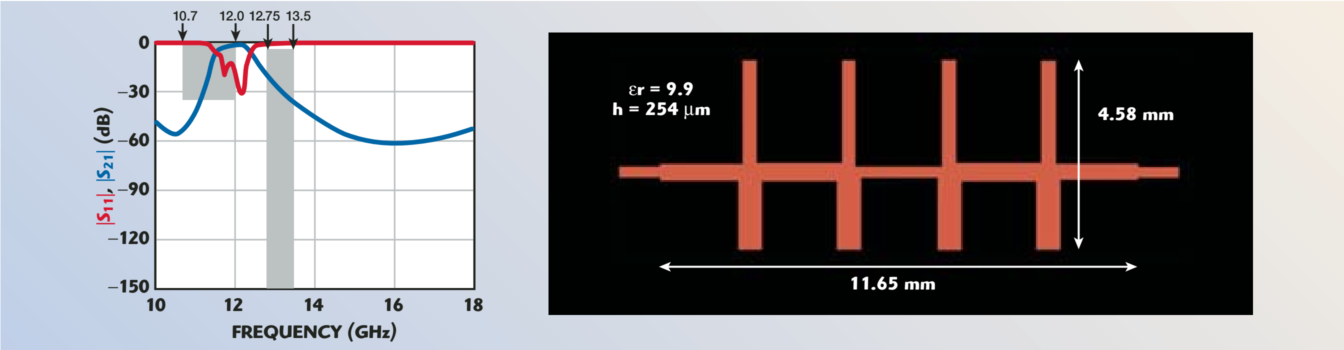
Dual Behavior Resonators i=1, 2, 3 and 4	*Inverters i–1,i*
$l_0 = c_0/4.f_0$ $l_{ilf} = l_0/k_{sbf}$ mm $l_{ihf} = l_0/k_{shf}$ mm $Zs_{ilf} = 42.0\ \Omega$ $Zs_{ihf} = 31.5\ \Omega$	$l_{i-1,i} = 5.730$ mm $Zc_{01} = 38.1\ \Omega = Zc_{56}$ $Zc_{12} = 37.7\ \Omega = Zc_{45}$ $Zc_{23} = 51.3\ \Omega = Zc_{34}$



▲ *Fig. 8 Microstrip transmission line model of the fourth-order Ku-band DBR filter.*

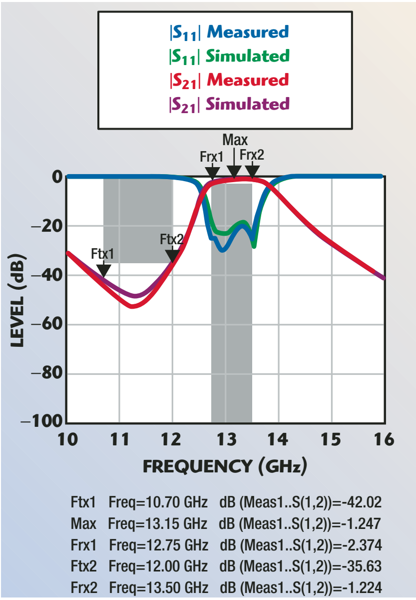


▲ *Fig. 9 Microstrip transmission line simulated response of the fourth-order Ku-band DBR filter.*

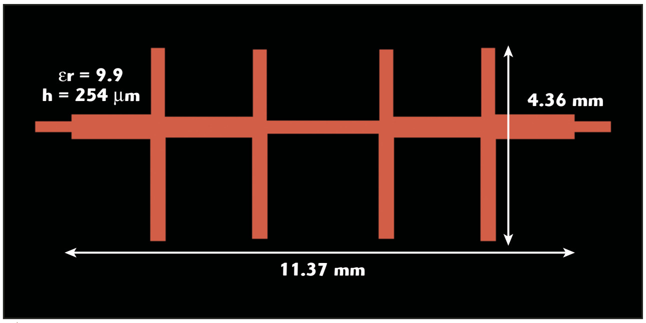


▲ *Fig. 10 Electromagnetic simulation and layout of the fourth-order Ku-band DBR filter.*

specific efforts are made to prevent the layout from having strong discontinuities. ***Tables 1*** and ***2*** give the input and the output parameters chosen for the synthesis. Since no specifications were given for the frequencies located beyond the bandwidth, the high frequency transmission zeros were kept free. In order to simplify the design, all the DBRs were chosen identical. Finally, the degrees of freedom of the synthesis were used so that the stub- and inverter-impedances fell within 30 and 50 Ω. Such an impedance range provides a good compromise between insertion losses, rejection, dimensional sensitivity and junction-discontinuity size. ***Figure 7*** shows the simulated response of the DBR filter with the input parameters given in Table 1. The next step is to build the equivalent microstrip circuit model, based on using an alumina substrate (ε_r = 9.9 and h =



▲ *Fig. 11 Fourth-order Ku-band DBR filter's electromagnetic simulation and experimental response.*



▲ *Fig. 12 Layout of the fourth-order Ku-band DBR filter.*

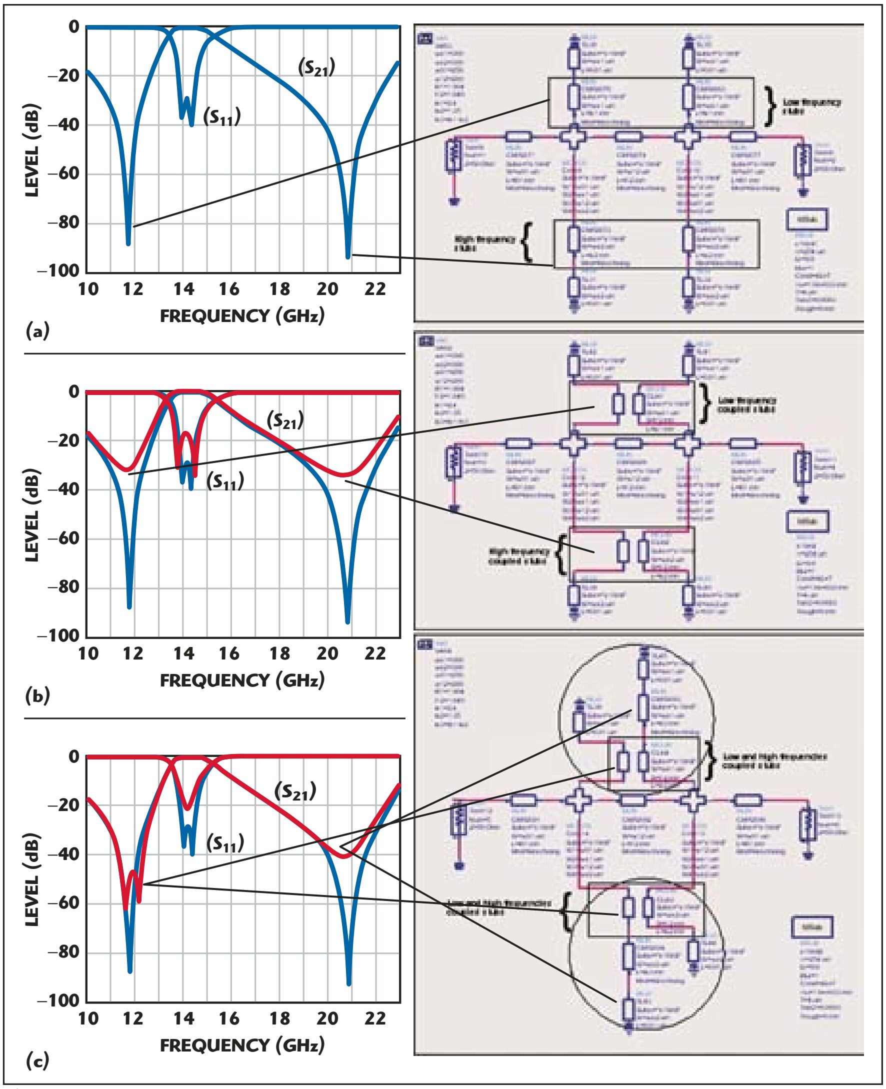
254 μm) and shown in ***Figure 8***. This model takes into account discontinuity effects, such as cross-junctions and open-end effects, as well as metallic and dielectric losses. ***Figure 9*** shows the simulated response of the circuit and highlights the importance of the discontinuity effects to be overcome. The frequency of the transmission zeros can be adjusted by modifying the stub length, but this change is insufficient to tune the electrical characteristics in the bandpass. Moreover, such an electrical circuit model is not suitable in the present case, because it is unable to take into account the couplings between stubs, which strongly affect the response at these frequencies.

Figure 10 shows the electromagnetic simulation and the associated layout. The parasitic coupling effects clearly appear on the response. Transmission zeros are eliminated. Nevertheless, the electrical response can be improved to meet the desired specifications by carrying out an optimization procedure to correct the layout. This operation is easily done by changing the stub's length to directly adjust the bandwidth and the attenuated band; the matching level is adjusted by modifying the impedances of stubs and inverters. The lengths of the inverters can be also used as tuning parameters.

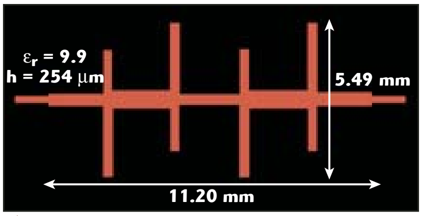
Figure 11 shows that an acceptable matching level can be easily obtained, but with no full removal of the damages noticed on the attenuated band and flatness. It also compares experimental results with those of the electromagnetic simulation and shows that the insertion losses in the bandwidth are within 1.2 and 2.3 dB; moreover, attenuation in the Tx-band is better than 35 dB. So, even though the rejection satisfies the specifications, it is not true for the flatness value found to be 1.17 dB, and which must be improved. ***Figure 12*** shows the layout obtained after further improvement. The filter size is 11.2 × 4.4 mm^2, and the smallest strip width is approximately 300 μm. It is worth noting that this layout is not significantly different from the one used in the original electromagnetic simulation.

MODIFIED FOURTH-ORDER KU-BAND DBR FILTER

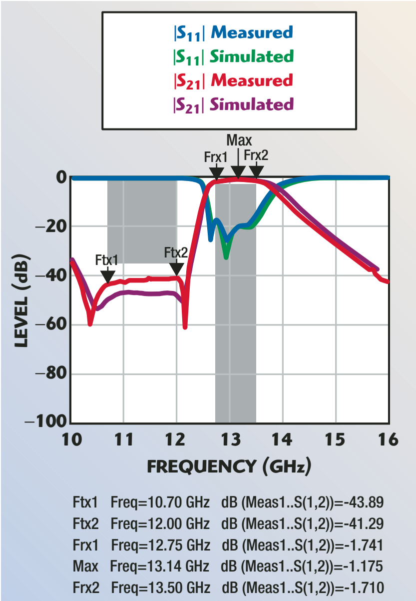
By strongly affecting the electrical response, the couplings between adjacent stubs are at the origin of a true limitation. It is clear that the change in the attenuation of the lower attenuated band is caused by the coupling between the low frequency stubs. It is the same for the upper attenuated



▲ *Fig. 13 Qualitative analysis of the coupling phenomena.*



▲ *Fig. 14 Modified layout of the fourth-order Ku-band DBR filter.*



▲ *Fig. 15 Electromagnetic simulated and measured responses of the modified fourth-order Ku-band DBR filter.*

band because of the coupling between the high frequency stubs. These effects are illustrated by substituting the stubs with microstrip coupled-line models in a circuit simulator. ***Figure 13*** shows the frequency response obtained for a symmetrical second-order filter where symmetrical means two identical DBRs (a); the electrical response obtained after replacing the stubs with a coupled-line model (b); it makes clear the changes occurring in the response, especially those in the frequency regions of transmission zeros. Thus, a very convenient way to overcome damage in the lower attenuated band is to interchange the stubs; it results in the suppression of coupling phenomena in this frequency range (c). This action moves away the low frequency transmission zeros and, thus, widens the attenuated band. The difference of length between low and high frequency stubs now appears as a new tuning parameter. ***Figure 14*** shows the layout obtained after a two by two exchange of the DBR stubs positions. Obviously, as in the previous case, a slight optimization phase is needed to adjust the response correctly. As shown in ***Figure 15***, the new possibilities offered by such a configuration are used to improve the rejection in the lower attenuated band, and thus to significantly improve flatness in the bandpass. Once again, experimental and electromagnetic simulated results are in good agreement. The insertion loss within the bandwidth lies between 1.2 and 1.75 dB, and the attenuation in the Tx-band is greater than 40 dB. No significant change in the global size of the structure ensues from the geometrical change. Finally, this filter meets easily the required specifications.

CONCLUSION

The design of a DBR filter in Ku-band was described with rigorous specifications in terms of insertion losses, flatness and rejection. The solution offered sounds very convenient when there is no constraint outside of a limited frequency band of interest. The efforts were concentrated on the strong isolation between the adjacent Tx and Rx frequency bands, considered as the main critical point. The present study was aimed at describing the design methodology and demonstrating the possibilities offered by the DBR topology while focusing on the previously mentioned critical point. Compared to a classical hairpin topology, the proposed solution appears very attractive in terms of insertion losses, rejection level and sensitivity to dimensional variations. An improvement of approximately 1.2 dB in insertion loss was obtained by only lowering the order in the case of a DBR filter compared to that of a hairpin, that is a fourth-order (DBR) against a fifth-order (hairpin). Indeed, as the electrical specifications are met with a very large margin, the structure can withstand dimensional variations and dielectric permittivity tolerance over a large range of temperature amplitude; a spatial application may undergo temperature variations from –20° to 60°C. The study of the possible effects induced on the structure by packaging showed that, in the present case study, the addition of a metallic cover (h = 3 mm) made corrections unnecessary. Similar studies carried out for different frequency specifications, such as 10.7 to 12.75 GHz for the Tx-band and 13.75 to 14.8 GHz for the Rx-band, have led to similar overall performance. Moreover, the use of over-sizing techniques enables one to significantly reduce the size of a DBR structure to get closer to an equivalent hairpin structure or even smaller.[20] The main drawback of DBR structures is spurious resonances. Since they were not detrimental for the receiver case discussed here, however, no specific effort was done to suppress them. Nevertheless, in the prospect of other applications, this point has been the subject of thorough investigations, particularly through the integration of low pass structures in bandpass structure and coupled inverters.[21] Among the other issues to be considered in the future, one should mention the stub coupling phenomena. They are not taken into account in the present synthesis, and doing it would simplify design and enhance performances. Alcatel Alenia Space has selected DBR solutions for use in telecommunications satellite receivers. The first one is used in a satellite, which is planned to launch in 2006. ■

References

1. I. Hunter, *Theory and Design of Microwave Filters*, The Institution of Electrical Engineers, Stevenage, Herts, UK, 2000.
2. J.T. Kuo, M.J. Maa and P.H. Lu, "A Microstrip Elliptic Function Filter With Compact Miniaturized Hairpin Resonators," *IEEE Microwave and*

Guided Wave Letters, Vol. 10, No. 3, March 2000, pp. 94–95.
3. G. Machiarella and A. Bovatti, "Single-sided Filters in Microstrip Technology," *2001 European Microwave Conference Proceedings*, pp. 45–48.
4. D.C. Rebenaque, A.A. Melcon and M. Guglielmi, "A New Simple Microstrip Open-loop Resonators Filter for High Selectivity Applications," *2003 IEEE International Microwave Symposium Digest*, Vol. III, pp. 1603–1606.
5. S. Amari, G. Tadeson, J. Cihlar and U. Rosenberg, "New Parallel λ/2-Microstrip Line Filters With Transmission Zeros at Finite Frequencies," *2003 IEEE International Microwave Symposium Digest*, Vol. I, pp. 543–546.
6. C. Quendo, E. Rius and C. Person, "Narrow Bandpass Filters Using Dual Behavior Resonators," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 51, No. 3, March 2003, pp. 734–743.
7. C. Quendo, E. Rius and C. Person, "Narrow Bandpass Filters Using Dual Behavior Resonators (DBRs) Based on Stepped-impedance Stubs and Different-length Stubs," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 52, No. 3, March 2004.
8. G. Prigent, E. Rius, F. Le Pennec, S. Le Maguer, C. Quendo, G. Six and H. Happy, "Design of Narrowband DBR Planar Filters in Si-BCB Technology for Millimeter-wave Applications," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 52, No. 3, March 2004.
9. C. Quendo, E. Rius and C. Person, "An Original Topology of Dual-band Filter with Transmission Zero," *2003 IEEE International Microwave Symposium Digest*, Vol. II, pp. 1093–1095.
10. A. Manchec, E. Rius, C. Quendo, C. Person, J.F. Favennec, P. Moroni, J.C. Cayrou and J.L. Cazaux, "Ku-band Microstrip Diplexer Based on Dual Behavior Resonator Filter," *2005 IEEE International Microwave Symposium Session WE1F*.
11. C. Quendo, E. Rius, A. Manchec, Y. Clavet, B. Potelon, J.F. Favennec and C. Person, "Planar Tri-band Filter Based on Dual Behavior Resonator (DBR)," *2005 European Microwave Conference Digest*, pp. 269–272.
12. V. Palazzari, S. Pinel, J. Laskar, L. Roselli and M. Tentzeris, "Design of an Asymmetrical Dual-band WLAN Filter in Liquid Crystal Polymer (LCP) System-on-package Technology," *IEEE Microwave and Wireless Components Letters*, Vol. 15, No. 3, March 2005.
13. W.H. Tu and K. Chang, "Compact Microstrip Bandstop Filter Using Open Stub and Spur-line," *IEEE Microwave and Wireless Components Letters*, Vol. 15, No. 4, April 2005.
14. H.S. Wu, H.J. Yang, C.J. Peng and C.K.C. Tzuang, "Miniaturized Microwave Passive Filter Incorporating Multilayer Synthetic Quasi-TEM Transmission Line," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 53, No. 9, September 2005.
15. M.I. Lai and S.K. Jeng, "A Microstrip Three-port and Four-channel Multiplexer for WLAN and UWB Coexistence," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 53, No. 3, October 2005.
16. G. Macchiarella and S. Tamiazzo, "Design Techniques for Dual-passband Filters," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 53, No. 11, November 2005.
17. M. Ohira, H. Deguchi, M. Tsuji and H. Shigesawa, "Novel Waveguide Filters with Multiple Attenuation Poles Using Dual Behavior Resonance of Frequency-selective Surfaces," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 52, No. 11, November 2005.
18. C.M. Tsai, H.M. Lee and C.C. Tsai, "Planar Filter Design with Fully Controllable Second Passband," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 53, No. 11, November 2005.
19. P. Rizzi, *Microwave Engineering, Passive Circuits*, Prentice Hall, Upper Saddle River, NJ, 1988, pp. 466–468.
20. A. Manchec, R. Bairavasubramanian, C. Quendo, S. Pinel, E. Rius, C. Person, J.F. Favennec, J. Papapolymerou and J. Laskar, "High Rejection Planar Diplexer Based on Liquid Crystal Polymer Substrate Using Oversizing Techniques," *2005 European Microwave Conference Digest*, pp. 101–104.
21. A. Manchec, C. Quendo, E. Rius, C. Person and J.F. Favennec, "Design Synthesis of Dual Behavior Resonator (DBR) Filters with Integrated Low Pass Structures for Spurious Responses Suppression," *IEEE Microwave and Wireless Components Letters*, Vol. 16, No. 1, January 2006.

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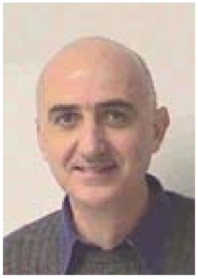

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MICROWAVE NOISE MODELING FOR ALGAAS/INGAAS/GAAS PHEMTS

Analytical expressions for the noise parameters of microwave pseudomorphic high electron mobility transistors (PHEMT) are presented in this article. These expressions are derived from an accurate small-signal and noise equivalent circuit model, which takes into account the influences of the intrinsic elements and gate leakage current. The scaling rules for the noise parameters of the intrinsic part are determined based on these analytical expressions. The experimental and theoretical results show that at the same bias condition, good scaling of the noise parameters up to 26 GHz can be achieved between the large-size devices (2 × 40 μm and 260 μm gate width PHEMTs) and the elementary cell (2 × 20 μm gate width PHEMT).

Pseudomorphic high electron mobility transistors (PHEMT) have shown excellent microwave and noise performance and are very attractive for millimeter-wave and optoelectronic applications. The complete characterization of these devices, in terms of noise and scattering parameters, is necessary for computer-aided design (CAD) of monolithic microwave integrated circuits (MMIC) or optoelectronic integrated circuits (OEIC).[1–3] The full noise characterization of a PHEMT requires the determination of four noise parameters: minimum noise figure F_{min}, noise resistance R_n, optimum source conductance G_{opt} and optimum source susceptance B_{opt}. The determination of the noise parameters is typically performed by analyzing the variation of the measured noise figure as a function of the source impedance. A minimum of four independent measurements is required. However, for increasing accuracy, more than four measurements are usually performed and curve-fitting techniques are then used to determine the noise parameters.[4–7] Several authors[8–10] have proposed improved methods, using the equivalent transistor noise model, to provide additional information to reduce the complexity of the measurement procedure. The noise models can be broadly obtained by numerical and experimental ap-

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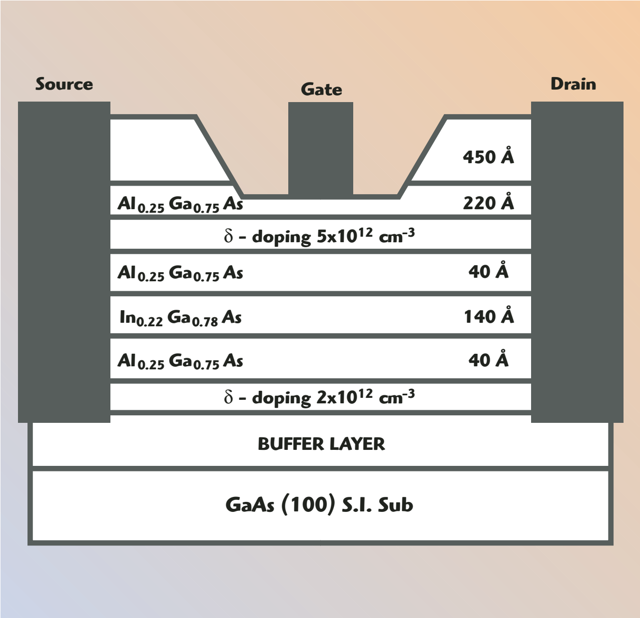


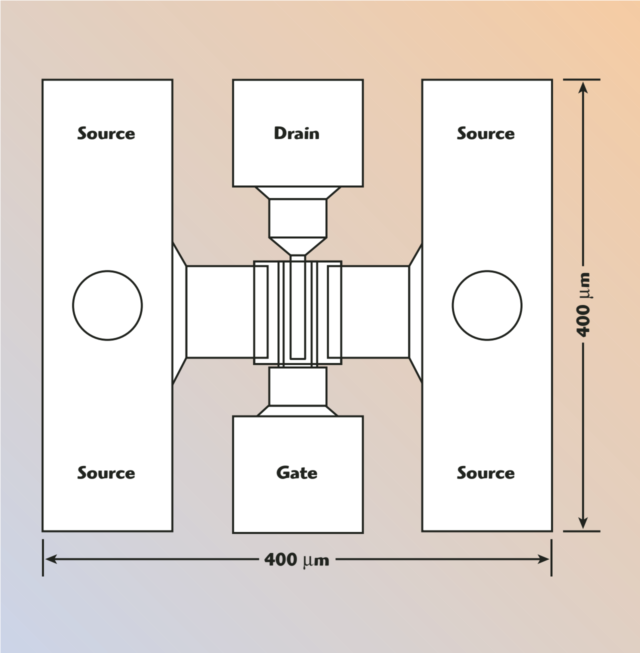
▲ *Fig. 1 Device cross-section of a double heterojunction δ-doped PHEMT.*

proaches, both of which could lead to an equivalent-circuit representation with adequate parameterization. These measured noise parameters can be coupled with S-parameter measurements into an equivalent-circuit model, an approach that is common for microwave devices.[11–16] An empirical relation between the noise figure and the circuit parameters, employing fitting parameters, was proposed for GaAs FETs by Fukui.[12] More quantitative equivalent-circuit modelings have been pursued by Statz, et al.[13] and Pospieszalski,[14] where the noise was equivalently represented as gate and drain temperature or resistance/conductance using Nyquist noise sources.

In order to optimize the noise performance of PHEMTs for low noise applications, fully scalable analytical expressions for the noise parameters, which can provide good accuracy and be scalable based on the layout structure as well as gate width, are very attractive for MMIC design and have a number of advantages. These advantages include:

- The noise parameters of different size devices using the same process can be readily obtained using scalable normalization model parameters, so low cost and time savings can be achieved
- They are useful for understanding the physical mechanisms and for evaluating the influence of the different parameters of the small-signal equivalent circuit model

A. Cappy derived simple analytic expressions for the minimum noise figure, noise conductance and the optimum source impedance based on an equivalent circuit, considering only the intrinsic gate-to-source capacitance and extrinsic gate and drain resistances.[17] Unfortunately, fully scalable analytical expressions for the noise parameters have not been discussed yet. In this article, a set of new expressions for the four noise parameters of AlGaAs/InGaAs/GaAs PHEMTs are derived from an accurate noise equivalent circuit model without any assumptions and approximations. The effects of all intrinsic elements and gate leakage current are taken into account.



▲ *Fig. 2 Layout of the interdigitated double heterojunction δ-doped PHEMT.*

The scaling rules for the noise parameters of intrinsic part are determined, based on these analytical expressions.

THEORETICAL ANALYSIS

Device Structure

The AlGaAs/InGaAs/GaAsPHEMT with 0.25 µm mushroom gates have been grown and fabricated using Nanyang Technological University's (NTU) developed process technology. The layer structure of the wafer, from bottom to top, consists of a GaAs undoped buffer layer, a 140 Å undoped $In_{0.22}Ga_{0.78}As$ strained layer, a 40 Å $Al_{0.25}Ga_{0.75}As$ spacer layer, a 5×10^{12}cm^{-2} Si δ-doping plane, a 220 Å I–$Al_{0/25}Ga_{0.75}As$ source layer and a Si-doped 450 Å n$^+$–GaAs cap layer. Here, a PI-gate PHEMT has been used, which has a 2 × 40 µm gate width (number of gate fingers × unit gate width) and a pinch off voltage of approximately –0.8 V. The double heterojunction δ-doped PHEMT structure considered in this study is shown in ***Figure 1***. ***Figure 2*** shows the layout of the interdigitated double heterojunction δ-doped PHEMT.

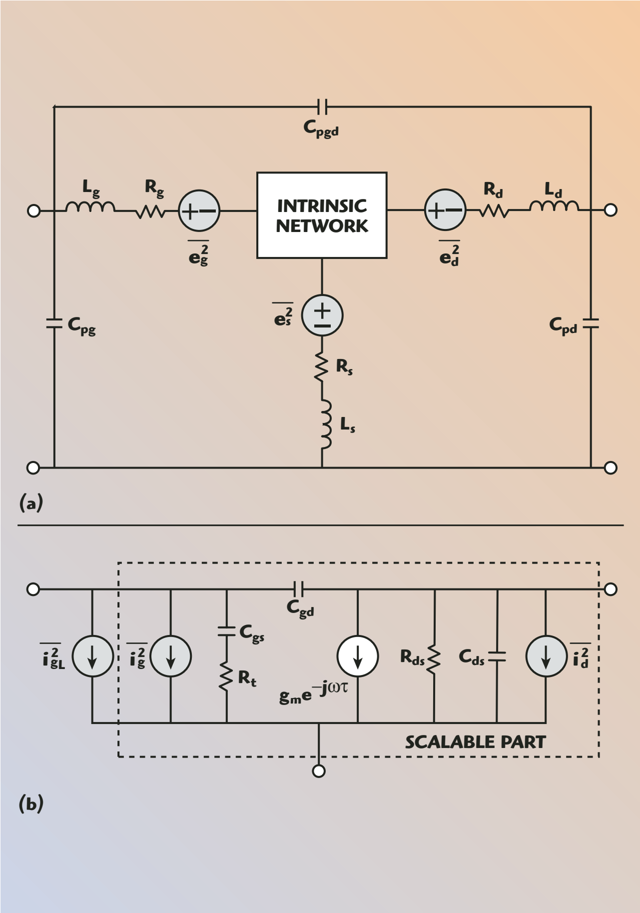
Noise Model

From the circuit point of view, the FET device can be treated as a black box of a noisy two-port. As is well known, the noise behavior of a linear noisy two-port network can be characterized by the four noise parameters, F_{min}, R_n, G_{opt} and B_{opt}, with

$$F = F_{min} + \frac{R_n}{G_s}\left[\left(G_s - G_{opt}\right)^2 + \left(B_s - B_{opt}\right)^2\right] \quad (1)$$

where

F = noise figure
$Y_s = G_s + jB_s$ = source admittance
F_{min} = minimum noise figure
R_n = noise resistance
$Y_s = G_s + jB_s$ = optimum source admittance



▲ *Fig. 3 Noisy small-signal equivalent circuit model of PHEMT; (a) extrinsic part and (b) intrinsic part.*

The complete PHEMT small-signal and noise equivalent circuit model, including the intrinsic and extrinsic parts, is shown in ***Figure 3***. The circuit model comprises the well-known small-signal equivalent circuit, and six noise sources $\overline{e_g^2}$, $\overline{e_d^2}$, $\overline{e_s^2}$, $\overline{i_g^2}$, $\overline{i_d^2}$ and $\overline{i_{gL}^2}$. The three noise sources $\overline{e_g^2}$, $\overline{e_d^2}$, $\overline{e_s^2}$ represent the noise behavior of the access resistances R_g, R_d and R_s, and are simply given by: $\overline{e_i^2} = 4kTR_i\Delta f$, where k is the Boltzmann constant, T is the absolute temperature, R_i is the resistance value and Δf is the bandwidth. The two correlated current noise sources $\overline{i_g^2}$ and $\overline{i_d^2}$ represent the internal noise sources of the intrinsic PHEMT. These two noise sources are characterized by their mean quadratic value in a bandwidth Δf centered on the frequency f, and can be given by the following expressions[1]

$$\overline{i_g^2} = 4kT\frac{\left(\omega C_{gs}\right)^2 R}{g_m}\Delta f \tag{2}$$

$$\overline{i_d^2} = 4kTg_m P\Delta f \tag{3}$$

The cross correlation between $\overline{i_g^2}$ and $\overline{i_d^2}$ can be expressed as

$$\overline{i_d^* i_g} = 4kT\omega C_{gs} C\sqrt{PR}\Delta f \tag{4}$$

where R and P are the gate and drain noise model parameters, and C is the correlation coefficient.

$\overline{i_{gL}^2}$ represents the gate leakage current noise source, and is given by[18,19]

$$\overline{I_{gL}^2} = 2\alpha q I_{gL} \tag{5}$$

where

I_{gL} = gate leakage current
α = fitting factor

In the small-signal and noise equivalent circuit model, L_g, L_d and L_s represent the inductances of the gate, drain and source feed-lines, respectively, C_{pg}, C_{pd} and C_{pgd} represent the gate, drain and isolation between gate and drain pad capacitances, R_s and R_d are the source and drain resistances, R_g is the distributed gate resistance, C_{gs}, C_{gd} and C_{ds} are the gate-to-source, gate-to-drain and drain-to-source capacitances, respectively, and R_i is the channel resistance. g_m is the transconductance, g_{ds} is the drain conductance and τ is the time delay associated with transconductances.

DERIVATION OF THE NOISE PARAMETERS

New Expressions for the Noise Parameters

From the intrinsic part of the small-signal model, it can be found that it consists of seven elements: g_m, g_{ds}, C_{gs}, C_{gd}, C_{ds}, R_i and τ. The corresponding short circuit Y-parameters of the intrinsic small-signal equivalent circuit can be expressed as[20]

$$Y = \begin{bmatrix} \dfrac{j\omega C_{gs}}{1 + j\omega R_i C_{gs}} + j\omega C_{gd} & -j\omega C_{gd} \\ \dfrac{g_m e^{j\omega\tau}}{1 + j\omega C_{gs} R_i} - j\omega C_{gd} & g_{ds} + j\omega\left(C_{ds} + C_{gd}\right) \end{bmatrix} \tag{6}$$

The corresponding admittance noise correlation matrix can be expressed as

$$C_Y = 4kT\begin{bmatrix} \alpha I_{gL} / 2V_T + \left(\omega C_{gs}\right)^2 R / g_m & j\omega C_{gs} C\sqrt{PR} \\ -j\omega C_{gs} C\sqrt{PR} & g_m P \end{bmatrix} \tag{7}$$

where V_T represents the thermal voltage ($V_T = kT/q$).

Based on the noise correlation matrix technique,[21] the four noise parameters can be directly calculated from the chain noise correlation matrix

$$R_n = C_{A11} \tag{8}$$

$$G_{opt} = \sqrt{\frac{C_{A22}}{C_{A11}} - \left(\frac{\mathrm{Im}\left(C_{A12}\right)}{C_{A11}}\right)^2} \tag{9}$$

$$B_{opt} = \frac{\mathrm{Im}\left(C_{A12}\right)}{C_{A11}} \tag{10}$$

$$F_{min} = 1 + 2\left[\mathrm{Re}\left(C_{A12}\right) + G_{opt} C_{A11}\right] \tag{11}$$

where

$$C_{A11} = \frac{C_Y 22}{|Y_{21}|^2} \quad (12)$$

$$C_{A12} = \frac{(Y_{11})^* C_{Y22} - (Y_{21})^* C_{Y21}}{|Y_{21}|^2} \quad (13)$$

$$C_{A22} = C_{Y11} + \frac{|Y_{11}|^2 C_{Y22}}{|Y_{21}|^2} - 2\,\mathrm{Re}\left(\frac{Y_{11}}{Y_{21}} C_{Y21}\right) \quad (14)$$

with Equations 5 and 6 substituted in Equations 7 to 10, one gets

$$F_{min} = 1 + 2k_3 + \frac{2}{g_m k_1}\sqrt{\omega^2 C_{gs}^2 PR\left(1-C^2\right) + g_{mk_1k_2}} \quad (15)$$

$$R_n = \frac{P}{g_m k_1} \quad (16)$$

$$G_{opt} = \sqrt{\omega^2 C_{gs}^2 \frac{R}{P}\left(1-C^2\right) + \frac{g_m k_1 k_2}{P}} \quad (17)$$

$$B_{opt} = -\omega\left[\left(C_{gs} + C_{gd}\right) - C\sqrt{\frac{R}{P}} C_{gs}\right] \quad (18)$$

where

$$k_1 = \frac{g_m + 2\omega^2 C_{gd}\left(\tau + C_{gs} R_i\right)}{g_m\left(1 + C_{gs}^2 R_i^2\right)}$$

$$k_2 = \frac{\alpha I_{gL}}{2V_T}$$

$$k_3 = \frac{\omega^2 C_{gs}}{g_m k_1}\left[PC_{gs}R_i - C\sqrt{PR}\left(\frac{C_{gd}}{g_m} + C_{gs}R_i + \tau\right)\right]$$

Scaling Rules

According to the scaling rules of PHEMTs, the intrinsic small-signal model parameters have a standard scaling:[22] the intrinsic capacitances, transconductance and output conductance are proportional to the gate width and the intrinsic resistance is inversely proportional to the gate width, that is

$$\begin{bmatrix} C_{gs} \\ C_{gd} \\ C_{ds} \\ g_m \\ g_{ds} \\ R_i \end{bmatrix} = \begin{bmatrix} n & 0 & 0 & 0 & 0 & 0 \\ 0 & n & 0 & 0 & 0 & 0 \\ 0 & 0 & n & 0 & 0 & 0 \\ 0 & 0 & 0 & n & 0 & 0 \\ 0 & 0 & 0 & 0 & n & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{n} \end{bmatrix} \begin{bmatrix} C_{gs}^c \\ C_{gd}^c \\ C_{ds}^c \\ g_m^c \\ g_{ds}^c \\ R_i^c \end{bmatrix} \quad (19)$$

where n represents the number of the elementary cells for the larger gate width size device, which is defined by

$$n = \frac{W}{W^c} \quad (20)$$

and the superscript c denotes the elementary cell.

Assuming that the time delay remains invariant at the same bias condition for the same device process, that is $\tau = \tau^c$, with Equation 18 substituted in Equation 5, one gets

$$Y = nY^c \quad (21)$$

From Equation 20, it can be found that a large gate width size PHEMT can be viewed as consisting of n elementary cells with the same gate width connected in parallel. Based on the noise correlation matrix technique,[21] the admittance noise correlation matrix for a large gate width size PHEMT can be expressed as

$$C_Y = nC_Y^c \quad (22)$$

Because the gate leakage current is not scalable, all the scaling rules for the noise parameters n this article will not include the effect of gate leakage current (dashed box in the intrinsic part of the noisy small-signal equivalent circuit model). With Equations 18 and 21 substituted in Equation 6, one gets

$$P = P^c \quad (23)$$

$$R = R^c \quad (24)$$

$$C = C^c \quad (25)$$

TABLE I

PARASITIC PARAMETERS FOR DIFFERENT SIZE PHEMTS

Elements	2 × 20 μm	2 × 40 μm	2 × 60 μm
C_{pg} (fF)	25.5	25.5	25.5
C_{pd} (fF)	28	28	28
C_{pgd} (fF)	4.5	4.5	4.5
L_g (pH)	75	60	40
L_d (pH)	80	65	50
L_s (pH)	10	8	4
R_g (Ω)	8.5	5	1
R_d (Ω)	10.5	5	3.5
R_s (Ω)	6	2.5	1.2

TABLE II

INTRINSIC PARAMETERS FOR DIFFERENT SIZE PHEMTS

Elements	2 × 20 μm	2 × 40 μm	2 × 60 μm
C_{gs} (fF)	33.0	63.5	85.0
C_{gd} (fF)	13.5	22.5	35.0
C_{ds} (fF)	2	4	6
g_m (pH)	16	31	45
τ (ps)	0.65	0.7	0.7
g_{ds} (mS)	1	2	3
R_i (Ω)	28	12	6

TABLE III

NOISE MODEL PARAMETERS FOR DIFFERENT SIZE PHEMTS

Elements	*2 × 20 μm*	*2 × 40 μm*	*2 × 60 μm*
p	1.50	1.50	1.55
R	1.10	1.10	1.15
C	0.30	0.32	0.35
αI_{gL}	5×10^{-6}	4×10^{-6}	2×10^{-6}

With Equations 22 to 24 substituted in Equations 14 to 17, it can be found that the scaling rules of the noise parameters for the intrinsic part are as follows: the minimum noise figure F_{min} remains invariant, the noise resistance R_n is inversely proportional to the number of elementary cells, and the optimum source conductance G_{opt} and the optimum source susceptance B_{opt} are proportional to the number of the elementary cells, that is

$$F_{min} = F^c_{min} \tag{26}$$

$$R_n = \frac{1}{n} R^c_n \tag{27}$$

$$G_{opt} = nG^c_{opt} \tag{28}$$

$$B_{opt} = nB^c_{opt} \tag{29}$$

Determination of Noise Model Parameters P, R, C and α

Once the small-signal elements are extracted from the S-parameter measurements, the extraction of the four unknown noise model parameters can be carried out using the procedure based on the noise correlation matrix technique as follows[23]

1. Calculation of the chain noise correlation matrix for PHEMT.

$$C_A^T = 4kT \begin{bmatrix} R_n & \dfrac{F_{min}-1}{2} - R_n Y^*_{opt} \\ \dfrac{F_{min}-1}{2} - R_n Y_{opt} & R_n \left|Y_{opt}\right|^2 \end{bmatrix} \tag{30}$$

2. Transformation of the chain noise correlation matrix to the admittance noise correlation matrix and subtraction of pad capacitances (C_{pb}, C_{pc} and C_{pbc}). Because the pad network is a noiseless network, the admittance noise matrix remains invariant.
3. Transformation of the admittance noise correlation matrix to the impedance noise correlation matrix and subtraction of extrinsic inductances and resistances.
4. Transformation of the impedance noise correlation matrix to the impedance noise correlation matrix.

The noise model parameters can then be determined as

$$P = \frac{C_{Y22}}{4kTg_m\Delta f} \tag{31}$$

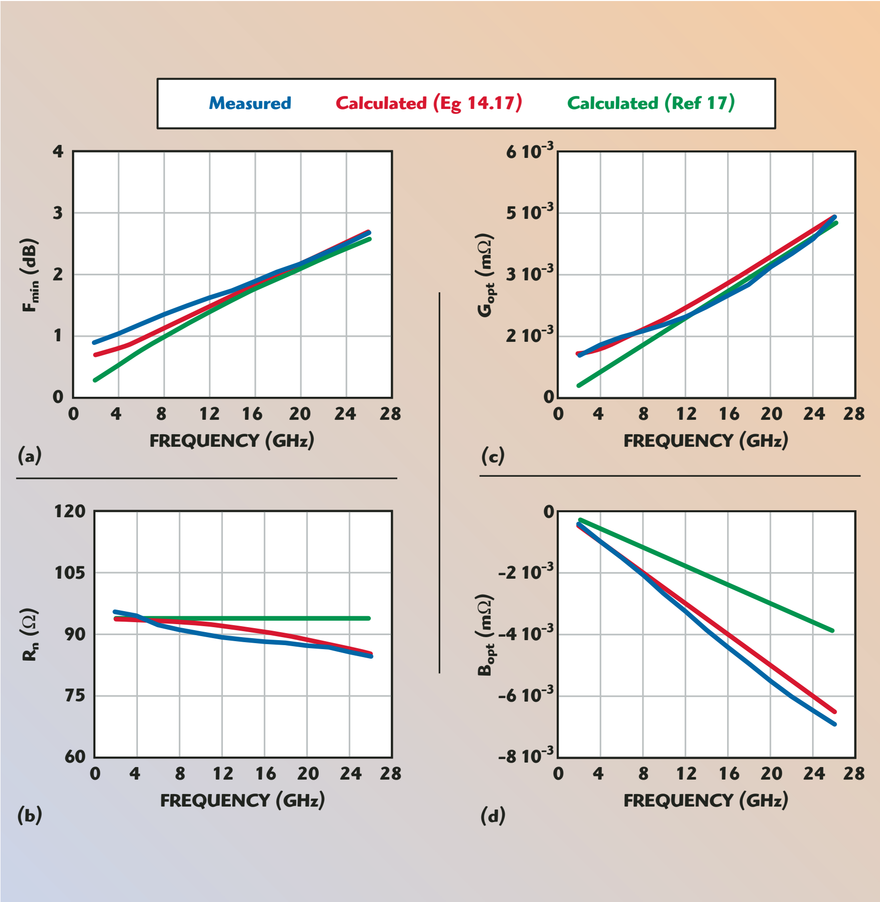
$$R = \frac{C_{Y11} - 2\alpha q I_{gL}}{4kT\left(\omega C_{gs}\right)^2 \Delta f} g_m \tag{32}$$

$$C = \frac{\mathrm{Im}\left(C_{Y12}\right)}{4kT\omega C_{gs}\sqrt{PR}} \tag{33}$$

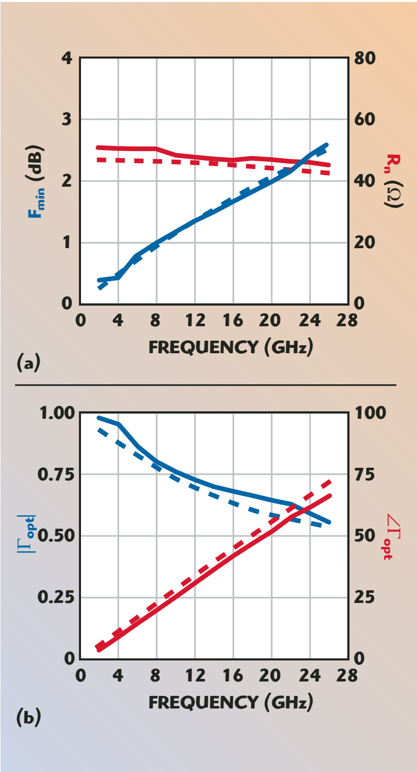
$$\alpha = \frac{1}{2qI_{gL}} C_{Y11}\Big|_{\omega \to o} \tag{34}$$

EXPERIMENTAL VERIFICATION

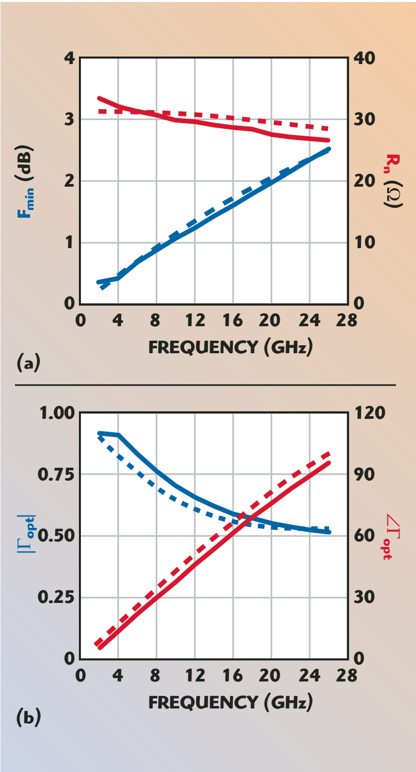
In order to verify the equations derived for the four noise parameters, 0.25 μm AlGaAs/InGaAs/GaAs double heterojunction δ-doped PHEMTs, with 2 × 20 μm, 2 × 40 μm and 2 × 60 μm gate widths, have been characterized. The S-parameters for model extraction and verification were measured up to 40 GHz using an Agilent 8510C network analyzer. The DC bias was supplied by an Agilent 4156A. The microwave noise parameter measurements were carried out on wafer over the frequency range of 2 to 26 GHz using an ATN microwave noise measurement system NP5. The extracted values of the bias-independent small-signal elements for the 2 × 20 μm, the 2 × 40 μm and the 2 × 60 μm PHEMTs are summarized in ***Table 1***. Once the values of the parasitic elements are known, all bias-dependent elements can be easily determined by using a direct extraction technique.[22] The corresponding intrinsic parameters g_m, τ, C_{gs}, C_{gd}, C_{ds}, R_{bi} and g_{ds} at a constant drain-source voltage V_{ds} = 2.0 V and I_{ds} = 6 mA, 12.2 mA, and 18 mA for 2 × 20 μm, 2 × 40 μm and 2 × 60 μm PHEMTs are given in ***Table 2***. It can be observed that the time delays τ are nearly constant for different size devices. The extracted noise model parameters P, R, C and α are summarized in ***Table 3***. It can be found that P, R and C remain invariant for four different gatewidth size PHEMTs under the same bias condition. However, the gate leakage current cannot be scalable. The measured and computed noise parameters versus frequency are compared in ***Figure 4*** for a 2 × 20 μm PHEMT under the single bias conditions V_{gs} = 0 V, V_{ds} = 2 V. A good agreement is observed. The new expressions are also compared with the model proposed by A. Cappy[17] (green lines). The red lines correspond to the values calculated from Equations 14 to 17. The new expressions are clearly more accurate than Cappy's. Because of the gate leakage current effect, the minimum noise figure does not cross the zero point. To illustrate the efficiency of the scaling rules for noise parameters, the measured and predicted results for larger size PHEMTs (2 × 40 μm and 2 × 60 μm) are compared in ***Figures 5*** and ***6***. The 2 × 40 μm and 2 × 60 μm PHEMTs can be viewed as consisting of two and three elementary cells (2 × 20 μm PHEMT) connected in parallel. The measured data for the intrinsic part of the 2 × 40 μm and 2 × 60 μm PHEMTs are obtained after de-embedding the extrinsic elements from the measured noise parameters and the predicted data are obtained via the scaling process (Equations 25 to 28) from the elementary cell (2 × 20 μm PHEMT). Good agreement is obtained between measured and predicted data to validate the scaling approach for noise parameters.



▲ *Fig. 4 Comparison of measured and calculated noise parameters for a 2 × 20 µm PHEMT.*



▲ *Fig. 5 Comparison of measured (solid line) and predicted (dashed line) noise parameters for a 2 × 40 µm PHEMT.*



▲ *Fig. 6 Comparison of measured (solid line) and predicted (dashed line) noise parameters for a 2 × 60 µm PHEMT.*

CONCLUSION

In this article, a set of new analytical expressions for the noise parameters of PHEMTs in the microwave frequency range is proposed. These expressions are derived on the basis of an accurate small-signal and noise equivalent circuit model. The scaling rules for the noise parameters are determined for different gatewidth PHEMTs under the same process condition. The experimental and theoretical results show that for the same bias conditions, good scaling of the noise parameters can be achieved between the large-size device and the elementary cell. ■

References

1. H. Ikeda, T. Ohshima, M. Tsunotani, T. Ichioka and T. Kimura, "An Auto-gain Control Transimpedance Amplifier with Low Noise and Wide Input Dynamic Range for 10 Gb/s Optical Communication Systems," *IEEE Journal of Solid-State Circuits*, Vol. 36, No. 9, September 2001, pp. 1303–1308.
2. Q.Z. Liu and R.I. MacDonald, "Sensitivity Analysis of Integrated InGaAs MSM-PDs and HEMT Optoelectronic Receiver Array," *IEEE Transactions on Electron Devices*, Vol. 42, No. 7, July 1995, pp. 1221–1226.
3. N.R. Das, P.K Basu and M.J. Deen, "A New Approach to the Design Optimization of HEMT and HBT for Maximum Gain-bandwidth of MSM-based Integrated Photoreceiver and its Noise Performance at 1.55 µm," *IEEE Transactions on Electron Devices*, Vol. 47, No. 11, November 2000, pp. 2101–2109.
4. R.Q. Lane, "The Determining of Device Noise," *IEEE Proceedings*, Vol. 57, 1969, pp. 1461–1462.
5. G. Caruso and M. Sannino, "Computer-aided Determination of Microwave Two-port Noise Parameters," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 26, No. 9, September 1978, pp. 639–642.
6. A.C. Davidson, B.W. Leake and E. Strid, "Accuracy Improvements in Microwave Noise Parameter Measurements," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 37, No. 12, December 1989, pp. 1973–1978.
7. J.M. O'Callaghan and J.P. Mondal, "A Vector Approach for Noise Parameter Fitting and Selection of Source Admittance," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 37, No. 8, August 1989, pp. 1376–1382.
8. J. Gao, C.L. Law, H. Wang, S. Aditya and G. Boeck, "A New Method for PHEMT Noise Parameter Determination Based on 50 Ω Noise Measurement System," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 51, No. 10, October 2003, pp. 2079–2089.
9. M. Rudolph, R. Doerner, P. Heymann, L. Klapproth and G. Boeck, "Direct Extraction of FET Noise Models from Noise Fig-

ure Measurements," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 50, No. 2, February 2002, pp. 461–464.
10. R. Hu and S. Weinreb, "A Novel Wideband Noise Parameter Measurement Method and its Cryogenic Application," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 52, No. 5, May 2004, pp. 1498–1507.
11. G. Martines and M. Sannino, "The Determination of the Noise, Gain and Scattering Parameters of Microwave Transistors (HEMT) Using Only Automatic Noise Figure Test-set," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 42, No. 7, July 1994, pp. 1105–1113.
12. H. Fukui, "The Noise Performance of Microwave Transistors," *IEEE Transactions on Electron Devices*, Vol. 13, No. 3, March 1966, pp. 329–341.
13. H. Statz, H.A. Haus and R.A. Pucel, "Noise Characteristics of Gallium Arsenide Field-effect Transistors," *IEEE Transactions on Electron Devices*, Vol. 21, No. 9, September 1974, pp. 549–562.
14. M.W. Pospieszalski, "Modeling of Noise Parameters of MESFETs and MODFETs and their Frequency and Temperature Dependence," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 36, No. 1, January 1988, pp. 1–10.
15. F. Danneville, G. Dambrine and A. Cappy, "Noise Modeling in MESFET and HEMT Using a Uniform Noisy Line Model," *IEEE Transactions on Electron Devices*, Vol. 45, No. 10, October 1998, pp. 2207–2212.
16. B.U.H. Klepser, C. Bergamaschi, M. Schefer, C.G. Diskus, W. Patrick and W. Bachtold, "Analytical Bias-dependent Noise Model for InP HEMTs," *IEEE Transactions on Electron Devices*, Vol. 42, No. 11, November 1995, pp. 1882–1889.
17. A. Cappy, "Noise Modeling and Measurement Techniques," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 36, No. 1, January 1988, pp. 1–10.
18. D.S. Shin, J.B. Lee, H.S. Min, J.E. Oh, Y.J. Park, W. Jung and D.S. Ma, "Analytical Noise Model with the Influence of Shot Noise Induced by the Gate Leakage Current for Submicrometer Gate-length High-electron-mobility Transistors," *IEEE Transactions on Electron Devices*, Vol. 44, No. 11, November 1997, pp. 1883–1887.
19. P. Heymann and H. Prinzler, "Improved Noise Model for MESFETs and HEMTs in Lower Gigahertz Frequency Range," *Electronics Letters*, Vol. 28, March 1992, pp. 611–612.
20. G. Dambrine, A. Cappy, F. Heilodore and E. Playez, "A New Method for Determining the FET Small-signal Equivalent Circuit," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 36, No. 7, July 1988, pp. 1151–1159.
21. H. Hillbrand and P. Russer, "An Efficient Method for Computer-aided Noise Analysis of Linear Amplifier Networks," *IEEE Transactions on Circuits and Systems*, Vol. 23, No. 4, April 1976, pp. 235–238.
22. S.W Chen, O. Aina, W. Li, L. Phelps and T. Lee. "An Accuracy Scaled Small-signal Model for Interdigitated Power PHEMT up to 50 GHz," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 45, No. 5, May 1997, pp. 700–703.
23. R.A. Pucel, W. Struble, R. Hallgren and U.L. Rohde, "A General Noise De-embedding Procedure for Packaged Two-port Linear Active Devices," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 40, No. 11, November 1992, pp. 2013–2024.

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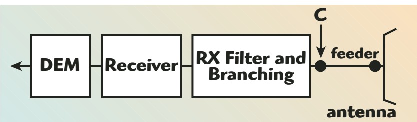
INTERFERENCE DETECTION AND MEASUREMENTS FOR MICROWAVE RADIO LINK PLANNING

The development of 3G services is requiring a constant increase in network capacity from the mobile operator. Dense access microwave networks, in terms of links per square kilometer and spectrum occupancy, are needed to connect UMTS nodes to the core network. Any introduction of a new link or any capacity upgrade needs careful planning and the choice of the RF channel is crucial. When looking for a vacant channel in the radio frequency spectrum, the normal practice suggests the use of small and portable field measurement setups, normally consisting of a simple receiver (antenna, low noise amplifier and spectrum analyzer). More complex systems can be conceived, of course, but the radio network engineer is mainly driven by operative and economic constrains. Nevertheless, the radio link planner should be aware of the limits of these measurement systems.

In this article, these specific measurement benches will be analyzed in terms of sensitivities achievable in the field and their limitations with regards to interference detection and their impact on system planning. It is meaningful to have some basis for comparison between interferer levels that could degrade the link quality and the effective levels that it is possible to detect when assessing radio spectrum occupancy. Hence, how interferences affect digital radio links will be reviewed first.

Fig. 1 Receiving section of a radio relay system.



THE "VICTIM" OF INTERFERENCE

A single radio terminal, part of a point-to-point digital radio link, will be considered as the potential victim of other digital interferers. Each of the two equipment terminals can be affected by interference in different ways, depending on the radio network environment into which the link itself is embedded. Generally, when referring to power levels, some reference points in the radio link plant are defined; the usual point corresponds to the connection between the branching network and the antenna feeder (point C in ***Figure 1*** of the receiver chain). For split mount equip-

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TABLE I

EXAMPLE OF TYPICAL RADIO EQUIPMENT PARAMETERS

Capacity	Modulation	S/N (BER=10^{-6}) (dB)	Threshold at Point C (BER=10^{-6}) (dBm)	Receiver Noise N (dBm)
16 × E1	4 QAM	13.5	–83	–98
STM-1	32 TCM	17.6	–76	–95
STM-1	128 MCLM	24.5	–71	–97
2 × STM-1	128 TCM	23.6	–69	–94

ment (indoor plus outdoor units) this is the only RF point available from outside the unit.

THE RECEIVER THRESHOLD

The thermal threshold of a receiver system is the minimum power level, at the apparatus input, that guarantees a bit error rate (BER) better than a certain value (typically BER = 10^{-6}). The threshold is an important receiver parameter in link budget analysis since it impacts on the link performance. The receiver threshold level P_{RX0} (at point C) depends on the system's modulation scheme, bit rate, front-end noise figure and implementation losses

$$P_{RX0} = \left(\frac{S}{N}\right)_{10^{-6}} + N_{RX} + L_{imp} \text{ dBm} \qquad (1)$$

$$N_{RX} = 10\log_{10}\left(R_s\right) + F_{noise} - 114 \qquad \text{dBm} \qquad (2)$$

where

- $(S/N)_{10^{-6}}$ [dB] = signal-to-noise ratio required at the demodulator input in order to have BER=10^{-6}
- N_{RX} [dBm] = thermal noise level
- L_{imp} [dB] = a positive term that includes noise figure and modem implementation losses (industrial margin); typically in the range 0.5 to 2 dB
- R_S [MHz] = symbol rate
- F_{noise} [dB] = receiver noise figure

Examples of threshold values are reported in ***Table 1***, for point-to-point microwave systems operating in the 18 GHz frequency band. The European Telecommunications Standard Institute (ETSI) also gives values for various equipment types in different frequency bands.[1]

EFFECTS OF INTERFERENCES

The effects of interferences on a digital radio relay system are normally quantified in terms of threshold degradation (see ***Figure 2***). If no interference is affecting the receiver, the BER curve corresponds to the additive white Gaussian noise (AWGN) channel condition ($I = -\infty$ dBm). In the presence of interference, the BER curve widens ($I = I(\delta)$) since the receiver needs more power to maintain the same S/N ratio at the demodulator in order to have the same target BER. Hence, the operating point with BER = 10^{-6} will be found at the degraded threshold $P_{RX0}+\delta$.

The signal-to-noise ratio for this new point corresponds to the degraded threshold over the power sum of the receiver noise level N_{RX} (dBm), plus the interference level I (dBm), which must be equal to $(S/N)10^{-6}$, that is

$$\underbrace{P_{RX0} + \delta - 10\log_{10}\left(10^{\frac{N_{RX}}{10}} + 10^{\frac{I}{10}}\right)}_{\frac{S}{N}} = \underbrace{P_{RX0} - N_{RX}}_{\left(\frac{S}{N}\right)_{10^{-6}}} \text{ dB} \qquad (3)$$

that is

$$\delta = 10\log_{10}\left(1 + 10^{\frac{I - N_{RX}}{10}}\right) \text{ dB (1)} \qquad (4)$$

This formula gives the threshold degradation δ in terms of the receiver noise and the interference level at point C. If more interference sources are present, I is the power sum of all components, supposed uncorrelated.

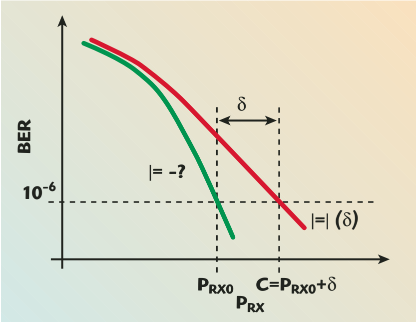


Fig. 2 The effect of interference.

A $\delta = 3$ dB degradation is obtained when the interferer level is equal to the receiver noise ($I = N_{RX}$), while $\delta = 1$ dB degradation is obtained when the interferer level is 6 dB below the receiver noise level. A degradation equal or lower than 1 dB is normally accepted, especially in a much polluted electromagnetic environment. Undue degradations (above 3 dB, for example) mean that some further optimization in the design of the link has to be considered.

Compare now the working C/I ratio with respect to the target S/N ratio, for a fixed BER. The carrier level for the degraded case is

$$C = P_{RX0} + \delta = \left(\frac{S}{N}\right)_{10^{-6}} + N + \delta \text{ dBm} \qquad (5)$$

Then, the C/I ratio, the S/N target and the threshold degradation are combined as

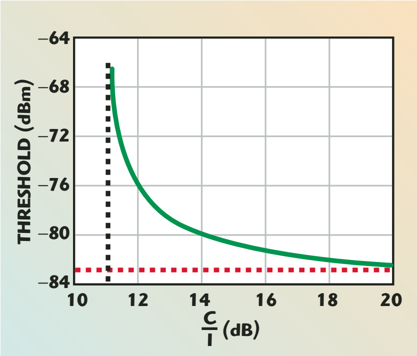
$$\frac{C}{I} = \left(\frac{S}{N}\right)_{10^{-6}} - 10\log_{10}\left(10^{\frac{\delta}{10}} - 1\right) + \delta \text{ dBm} \qquad (6)$$

The threshold degradation is given by

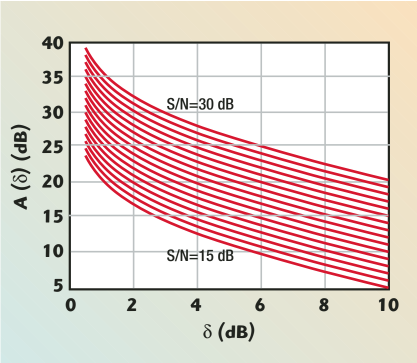
$$\delta = -10\log_{10}\left(1 - 10^{\frac{\left(\frac{S}{N}\right)_{10^{-6}} - \left(\frac{C}{I}\right)}{10}}\right) \text{ dB} \qquad (7)$$

in terms of $(S/N)_{10^{-6}}$ (equipment parameter) and C/I ratio (link working point).

For instance, the C/I ratio corresponding to a 1 dB degradation is



▲ *Fig. 3 Threshold degradation for BER=10⁻⁶.*



▲ *Fig. 4 Threshold degradation term.*

$$\left.\frac{C}{I}\right|_{\delta=1\mathrm{dB}} = \left(\frac{S}{N}\right)_{10^{-6}} + 6.9\ \mathrm{dB} \qquad (8)$$

This particular C/I value is often given as a system specification for co-channel and adjacent-channel interference rejection[1] and it is sometimes useful to relate it to the $(S/N)_{10^{-6}}$. From Equation 7 it is clear that, as C/I approaches $(S/N)_{10^{-6}}$, the threshold degradation increases with no limit; the system cannot work with a BER better than or equal to 10^{-6} at $C/I = (S/N)_{10^{-6}}$. ***Figure 3*** shows the effects of the interference in terms of the degradation curve for a 4QAM system with a receiver thermal threshold equal to –83 dBm at BER = 10^{-6} ($16 \times E_1$ capacity).

In order to design the test bench to be used in the field to detect dangerous interferer levels, the interferer levels that can be considered to effectively degrade the receiver threshold of a radio link must be found. From Equation 7, the interferer level that gives a fixed maximum accepted degradation δ is

$$I(\delta) = P_{RX0} - A(\delta)\ \mathrm{dBm}$$

$$A(\delta) = 10\log_{10}\left(10^{\frac{\delta}{10}} - 1\right) - \left(\frac{S}{N}\right)_{10^{-6}} \qquad (9)$$

Figure 4 shows the term A(δ), which indicates the difference (in dB) between the interferer level and the thermal threshold, in order to give δ dB degradation. For instance, if $(S/N)_{10^{-6}} = 26$ dB and $P_{rx0} = -70$ dBm, A = 31.8 dB for δ = 1 dB, so an interferer of about –102 dBm is sufficient to give a 1 dB degradation on the receiver threshold.

For the two commonly used degradation values, the practical rules are

$$\delta = 1\ \mathrm{dB} \Rightarrow I = P_{RX0} - \left(\frac{S}{N}\right)_{10^{-6}} - 6\ \mathrm{dBm} \qquad (10a)$$

$$\delta = 3\ \mathrm{dB} \Rightarrow I = P_{RX0} - \left(\frac{S}{N}\right)_{10^{-6}}\ \mathrm{dBm} \qquad (10b)$$

To some extent, this analysis is a little pessimistic. In Equation 4, the thermal noise and the digital modulation interferer are combined in a fashion that is correct only if the interferer is assumed to be a Gaussian stochastic signal. This is the case when the interference term I is the sum of many independent interferers. Normally a single digital interferer has a non-Gaussian statistic and the threshold of degradation is slightly less. In other terms, the same threshold degradations as in Equation 10 shall be produced by a single digital interferer 1 or 2 dB higher.

FIELD DETECTION OF INTERFERERS

A trustworthy way to measure the real impact of the interfering environment on a certain radio link is to use the radio link equipment itself. A typical procedure to evaluate the threshold degradation is to simulate a fading on the transmitting side and measure at the receiver the power level that corresponds to BER = 10^{-6}. The degradation is the difference between the threshold measured in the field and the value obtained from laboratory measurements or system specifications. This procedure is reliable, but needs the radio link to be already installed. It can be used at the commissioning of the link as a further test, but it is very impractical in the link-planning phase. A measurement bench built with a portable spectrum analyzer, a low noise amplifier and a small antenna is a much more flexible and cost-effective system.

The Measurement System

The measurement system to be investigated is shown in ***Figure 5***. The system is composed of a microwave antenna tuned in the relevant frequency band, a low noise amplifier (LNA) and a portable spectrum analyzer (SA). The antenna, typically a small horn reflector, and the LNA are connected by a RF cable that should be as short as possible. Another cable connects the LNA to the analyzer.

Noise Analysis

In order to evaluate the minimum interferer signal that the system can detect, the overall system noise is evaluated. The noise sources affecting the system sensitivity include: the antenna noise (electromagnetic noise coming from the environment and captured by the antenna), the transmission line noise (mainly due to passive electric losses of the first cable) and the LNA noise (electronic and thermal noise). The SA input RF attenuator is not included in the analysis since it is generally set to 0 dB in order to have best displayed average noise level (DANL). ***Figure 6*** shows all the noise sources in terms of noise temperature at the system input. The total system noise temperature T_{SYS} is

$$T_{SYS} = T_A + T_{L_1} + T_{LNA} + T_{L_2} + T_{SA}\ [K] \quad (11)$$

where

T_A = antenna noise temperature ($T_A = T_0 = 290$ K is assumed)

T_{L1} = first transmission line noise temperature

$$T_{L1} = T_0\left(10^{L1/10} - 1\right)[K] \quad (12)$$

T_{LNA} = LNA noise temperature at the antenna output

$$T_{LNA} = T_0\left(10^{Flna/10} - 1\right)10^{L1/10}[K] \quad (13)$$

T_{L2} = second transmission line noise temperature

$$T_{L2} = T_0\left(10^{L2/10} - 1\right)10^{(L1-Glna)/10}[K] \quad (14)$$

T_{SA} = SA's front-end noise reported at the system input

$$T_{AS} = T_0 \bullet 10^{\frac{DANL_{1kHz}+L_1+L_2-G_{LNA}+144}{10}}[K] \quad (15)$$

expressed in terms of DANL at 1 kHz resolution bandwidth.

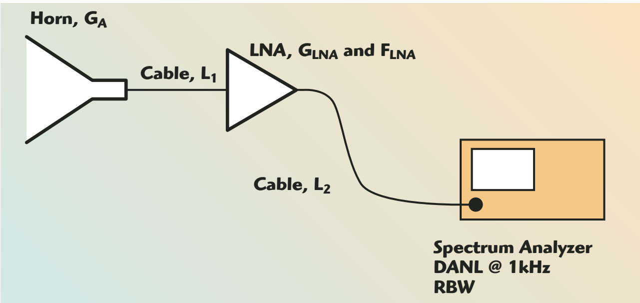


Fig. 5 Interferer detection system.

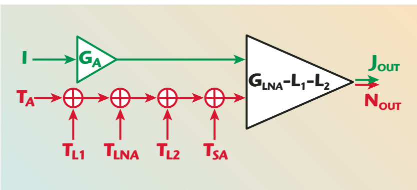


Fig. 6 System noise sources.

The antenna noise temperature, being at the starting point of the receiver chain, is one of the leading components of the system temperature. This term is the geometrical convolution of the brightness temperature of the surrounding environment and the antenna radiation pattern.

For instance, supposing a narrow beam width antenna pointed toward a region of uniform background noise temperature T_{bg}, then $T_A = T_{bg}$. In Earth-Space communications, this could be the case of a ground station antenna directed to the sky (T_A = 3 to 30 K in the microwave region up to 40 GHz) or the case of a satellite antenna pointed to the earth (T_A = 290 K). Measurements of brightness temperature for a ground station receiver have been reported.[2] For clear air conditions, at 0° elevation, the brightness temperature is approximately 90 K at 5 GHz, increases almost linearly to 290 K at approximately 20 GHz and then remains constant. For this specific case, considering that the measurements are made with a wide beam antenna (such as a 30° HPBW horn antenna) with no significant elevation angle, the antenna temperature is usually taken to be $T_A \sim T_0 = 290$ K.

Keeping in mind that G_{LNA} is generally much higher than the total losses $L_1 + L_2$, the system temperature simplifies to

$$T_{SYS} = T_0 10^{\frac{L_1}{10}}\left(10^{\frac{F_{LNA}}{10}} + 10^{\frac{DANL_{1kHz}+L_2-G_{LNA}+144}{10}}\right)[K] \quad (16)$$

Furthermore, if the following condition is fulfilled

$$G_{LNA} + F_{LNA} - L_2 \geq DANL_{1kHz} + 154\ [dB] \quad (17)$$

the system noise temperature is simply

$$T_{SYS} \cong T_0 10^{\frac{F_{LNA}+L_1}{10}}[K] \quad (18)$$

The total output thermal noise, displayed by the spectrum analyzer in a resolution bandwidth RBW (MHz), is

$$N_{OUT} = 10\log_{10}(RBW) + G_{LNA} + F_{LNA} - L_2 - 114\left[\frac{dBm}{RBW}\right] \quad (19)$$

Equation 17 means that the noise provided by the LNA to the SA shall be at least 10 dB higher than the SA effective noise. This condition is often fulfilled by a good amplifier chain.

THE MINIMUM DETECTABLE LEVEL

Searching for digital radio sources, it is very likely to come across noise-like signals with a flat power spectrum density. The emitted power of these interferers is spread over the entire signal bandwidth and their spectral density tends to be buried in the noise. The interferer level measured by the SA is

$$J_{OUT} = I + 10\log_{10}\left(\frac{RBW}{F_S}\right) + G_A + G_{LNA} - L_1 - L_2 \; [dBm] \qquad (20)$$

where

RBW (MHz) = SA resolution bandwidth
F_S (MHz) = Nyquist symbol rate of the interferer signal
I (dBm) = interferer level captured by the antenna

The level of the interferer captured by the measurement antenna is

$$I = J_{OUT} - 10\log_{10}\left(\frac{RBW}{F_S}\right) - G_A - G_{LNA} + L_1 + L_2 \; [dBm] \qquad (21)$$

The level is referred to a virtual point before the measurement antenna. To evaluate its effect on the microwave link, it must be scaled to the reference point C, adding the link antenna gain GRL and the feeder losses L_F

$$I_{@C} = I + G_{RL}(\theta,\phi) - L_F \; [dBm] \qquad (22)$$

where (θ,Φ) is the polar direction of the incoming interferer. The interferer-to-noise ratio referred at the SA is

$$\left(\frac{J}{N}\right)_{OUT} = I - 10\log_{10}(F_S) + G_A - F_{LNA} - L_1 + 114 \; [dB] \qquad (23)$$

which is valid according to Equation 17.

To be detectable with respect to the system noise floor, the $(J/N)_{OUT}$ ratio should be at least zero. In this situation, the detected signal appears on the SA as a 2 dB spectrum bump over the average background noise.[3] The minimum detectable interferer level I_{MDL} at the antenna is then

$$I_{MDL} = 10\log_{10}(F_S) - G_A + F_{LNA} + L_1 - 114 \; [dBm] \qquad (24)$$

For wideband signals, with a symbol rate much wider than the resolution bandwidth, the sensitivity of the measurement system is determined by the interferer bandwidth, the LNA noise figure and the net antenna gain (including the first cable loss). The RBW has no influence, since it processes wideband signals and noise the same way. Furthermore, if Equation 17 is fulfilled, even the LNA gain has no impact on the bench sensitivity. I_{MDL} has be be scaled as well to the reference point C

$$I_{MDL@C} = I_{MDL} + G_{RL}(\theta,\phi) - L_F \; [dBm] \qquad (25)$$

A "BAD" VARIATION ON THE THEME

If the performance of a bench is analyzed without the LNA, the SA is connected directly to the measurement antenna via a single RF cable (loss L_1) and the output noise displayed on the SA is

$$N_{OUT} = 10\log_{10}(RBW) + DANL_{1kHz} + 30 \left[\frac{dBm}{RBW}\right] \qquad (26)$$

The measured interferer-to-noise ratio is

$$\left(\frac{J}{N}\right)_{OUT} = I - 10\log_{10}(F_S) + G_A - DANL_{1kHz} - L_1 - 30 \; [dB] \qquad (27)$$

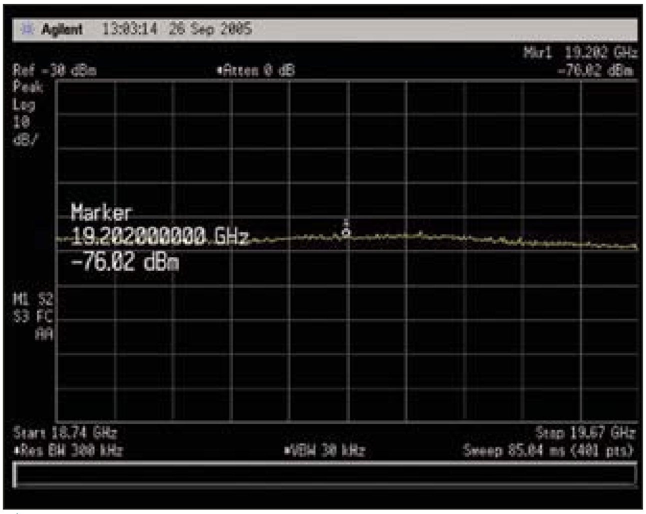
Then, the minimum detectable interferer level I_{MDL} at the antenna is

$$I_{MDL} = 10\log_{10}(F_S) - G_A + \underbrace{(DANL_{1kHz} + 144)}_{F_{SA}} + L_1 - 144 \; [dBm] \qquad (28)$$

It is clear that the term F_{LNA} of Equation 24 has been replaced by the term $F_{SA} = DANL_{1kHz} + 144$, the former being the SA noise figure. The test bench without LNA has a drastically reduced sensitivity by $F_{SA} - F_{LNA}$. This severe reduction may correspond to dozens of dBs (30 dB or more); benches without a proper LNA could not detect strong interferers and the measurement session may become meaningless.

SOME MEASUREMENT ASPECTS

When searching for wideband digital interferers, reducing RBW does



▲ *Fig. 7 System noise displayed on the spectrum analyzer.*

not significantly help the system sensitivity. So the choice of RBW is mainly driven by the sweep time of the SA. A complete interference search at each radio site often means scanning the whole spectrum band (both lower and upper sidebands) from 0° to 360° azimuth at both polarizations, at steps equal to the measurement antenna half power beam width. This corresponds to hundreds of SA snapshots and the time consumed for each of them is crucial. From a practical experience, a RBW of 300 kHz seems to be a suitable trade off between spectral resolution and sweep time, at least for microwave digital radio relay systems. If narrowband signals are to be investigated (that is analog signals with discrete spectrum lines or non-modulated carriers), smaller resolution bandwidths can be a better choice.

Video bandwidth (VBW) is another SA setting. It does not affect the noise floor but averages the display trace, making the inspection easier. Since it affects the sweep time, a good choice can be VBW = 30 kHz.

If DANL is not known at 1 kHz, it is possible to scale it from

$$DANL_{1kHz} = DANL_{XkHz} - 10\log_{10}\left(\frac{XkHz}{1kHz}\right)\left[\frac{dBm}{1kHz}\right] \quad (29)$$

With the equipment at hand, it is a good idea to measure DANL in the frequency range of interest using a 50 Ω load to terminate the SA input. The level of the flat trace indicated by the SA with RBW set to 1 kHz is exactly $DANL_{1kHz}$. Equation 17 can be verified by terminating the LNA input with a 50 Ω load just before the antenna flange. If the new background noise level measured is at least 10 dB above the SA $DANL_{1kHz}$, Equation 17 is verified and Equation 24 is valid.

A PRACTICAL EXAMPLE

Consider a test bench used in the field for real radio spectrum analysis in the 18 GHz frequency band. Specifically, a 55 MHz free channel is identified in order to deploy a 1×STM-1 32 TCM link with radio parameters taken from Table 1 and with 0.6 m parabolic integrated antennas on each side.

The measurement system is composed of a horn antenna (G_A =23 dBi) and an LNA (G_{LNA} =45 dB, F_{LNA} =2 dB) directly connected to the antenna flange (L_1 = 0 dB). The SA (Agilent E4407B) is connected to the LNA via a coaxial cable (L_2 = 2 dB).

Equation 17 is fulfilled ($DANL_{1kHz}$ =–112 dBm); from Equation 19, the predicted noise background is –74.2 dBm. The system noise is measured closing the LNA input with a matched attenuator and the average noise background is about –76 dBm in 300 kHz RBW, as shown in ***Figure 7***. Taking into account a –2.5 dB factor (due to the under-response of the SA log-scale) and an over-response of +0.5 dB (ratio of the equivalent noise bandwidth to the –3 dB bandwidth), the corrected measurement agrees with the predicted value (–76 +2.5 – 0.5). With this setup, the maximum interferer level IMDL is reported in ***Table 2*** for different interferer bandwidths.

It is interesting now to compare these values with interferer levels that can be considered dangerous for the planned radio link. Assuming that an interferer is considered dangerous if δ =3 dB, from Table 1 and Equation 10a, the maximum interferer level I_{MAX} that it can tolerate is –93.6 dBm. If the δ = 1 dB criteria is used, the I_{MAX} level would be 6 dB lower.

The I_{MAX} level is referred at point C, while measurement setup sensitivity I_{MDL} is the level detected prior to the measurement antenna. Equation 25 must be used to compare the two of them.

In this example, G_{RL} = 38 dBi at the antenna boresight and L_{FC} =0 dB. For a gain at an angle direction the antenna radiation pattern has to be used. Here, an approximation of the beam, valid for small angles, was used. The I_{MDL} at C is reported in ***Table 3*** (link direction). All the values referred to the direction of the link are greater than the maximum acceptable interferer level. Angled interferers will be discriminated by the radio link antenna. The difference between the bench sensitivity I_{MDL} at C and the maximum acceptable interferer level I_{MAX} is sig-

TABLE II

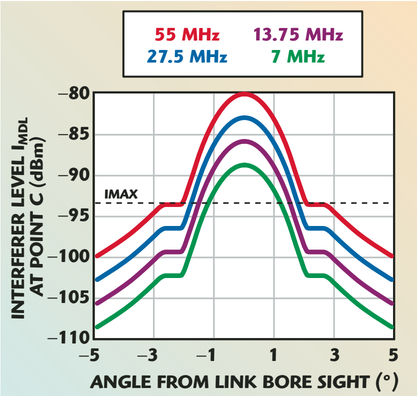
MINIMUM INTERFERER LEVEL FOR TWO DIFFERENT INTERFERER BANDWIDTHS

Capacity	Modulation	Max Interferer I_{MAX} (δ ≤ 3 dBm)	Max Interferer I_{MAX} (δ ≤ 1 dBm)
16 × E1	4 QAM	–96.5	–102.5
STM-1	32 TCM	–93.6	–99.6
STM-1	128 MCLM	–95.5	–101.5
2 × STM-1	128 TCM	–92.6	–98.6

TABLE III

I_{MDL} REPORTED AT C (LINK DIRECTION)

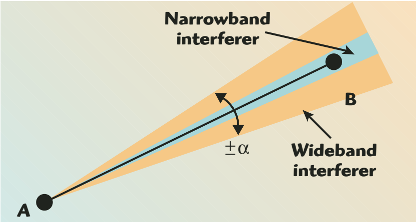
Interferer Bandwidth (MHz)	I_{MDL} (dBm)	I_{MDL} at C (Link Direction) (dBm)
7	–127	–89
13.75	–124	–86
27.5	–121	–83
55	–118	–80



▲ *Fig. 8 Angular region of "dangerous" undetected interferers.*

nificant only in the angular region close to the link direction. ***Figure 8*** shows the I_{MDL} at C of Table 3, scaled by the angular discrimination of the antenna link.

Consider the 55 MHz interferer (the hardest to detect because of more spread over the bandwidth). In the angular sector of ±2° with respect to the link direction, the I_{MDL} is greater than I_{MAX}. In other words, the antenna link is not able to discriminate those "hidden" (undetected) interferers. If they



▲ *Fig. 9 "Hidden" interferers angular region.*

are present, they can effectively degrade the link (see ***Figure 9***). Outside this region, possible undetected interferers reaching terminal A will be reduced down to values that will respect the threshold degradation criteria. For narrower band interferers, the indeterminate angular region is also narrower (that is ±1° at 7 MHz). From Equation 24, it can be seen that not much can be done in order to increase the sensitivity except by changing the measurement antenna. For instance, a 30 cm parabolic antenna could be used, at least for the measurements along the link direction. With this new antenna, the sensitivity could have been increased by 11 dB. However, when performing measurements in the field, it is not always feasible to use a high gain antenna; this is especially true for the lower frequency bands such as 7 or 11 GHz. It is then up to the radio network designer to investigate the hidden interferer's geographical region, in order to find distant interfering sources (radio towers, microwave hubs, etc).

CONCLUSION

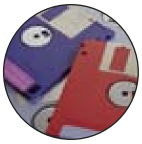
In this article, a specific measurement bench was analyzed for in field interference detection used in the planning and design of microwave digital radio links in a polluted electromagnetic environment, where detailed spectrum analysis is needed. The test bench considered is composed of a simple portable receiver scheme suitable for field operation. A quick noise analysis has been provided in order to evaluate the measurement performance in terms of achievable sensitivities. With equipment commercially available, it is possible to achieve good confidence in the search of interferers.

Nevertheless, these systems have inherent limitations that should be understood by the radio link designer in order to perform correct radio link planning and spectrum management. The impact of these limitations has been investigated in terms of angular regions, where the antenna link is not able to discriminate "hidden" interferer signals that can effectively degrade the link. ■

References

1. *Generic Wordings for Standards on DFRS Characteristics – Part 1*, European Telecommunications Standard Institute, TR 101 0361-1, 2002.
2. *Recommendation P.327, Radio Noise*, International Telecommunication Union-Radiocommunications, Geneva, Switzerland, 2001.
3. C. Brown, *Spectrum Analysis Basics Seminar*, Hewlett-Packard, 1997.

Luca Stroppolo *received his MS degree in electronic engineering from the II University of Rome Tor Vergata in 1993. In 1995, he received his postgraduate degree from the SSGRR School of Telecommunication of STET, where he subsequently taught courses on wireless systems aspects. From 1995 to 2001, he was with the network engineering department of Telecom Italia, where he was involved with the specifications and system analysis of wireless systems (point-to-multipoint systems and wireless LAN) including testing and field trials. During that time he was also a member of the ETSI TM4 standardization group. From 2001 to 2002, he was with Edisontel, responsible for the deployment of the radio access network. From 2002 to 2005, he was with 3 Italia in the radio network-planning department, responsible for microwave radio link design and system engineering. Since 2006, he has been working with Ericsson NSI, responsible for radio access network planning and design.*



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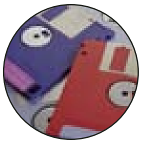

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2006 MTT-S CONFERENCE

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SUPPLEMENT FEATURES

SOFTWARE ANALYSIS THAT GOES FAR BEYOND ELECTROMAGNETICS

Analysis performed with traditional electromagnetic-field software might give a good sense of the operation of a microwave component from the perspective of pure electromagnetics under ideal conditions. Real-world operating conditions are not ideal, however, and the physical phenomena that affect a component's performance often go beyond electromagnetics alone—effects from heat, stress and even chemical processes might degrade a component's performance or even lead to failure. Furthermore, operating conditions could make the retrieval of a malfunctioning component very expensive if not impossible, especially if the device is severely damaged or destroyed. In those cases, other than trying to recreate the problematic operating conditions in the laboratory, the only chance an engineer has to evaluate system performance and determine the cause of catastrophic failure is through software simulation.

A new generation of software features well-proven methods for microwave analysis that engineers can combine with virtually any other type of physics. One such tool, COMSOL Multiphysics, makes this possible by basing its computational engine on the solution of systems of partial differential equations. A well-known example of such a set of PDEs is, of course, Maxwell's equations—the basis of any computer simulation for RF and microwave design. Multiphysics software can augment Maxwell's equations with other equations such as those for heat transfer and structural deformation for a strongly coupled simulation. Advanced software tools even allow investigators to start with a clean slate, allowing them to build a physics model from first principles and optionally combine them with ready-made physics models.

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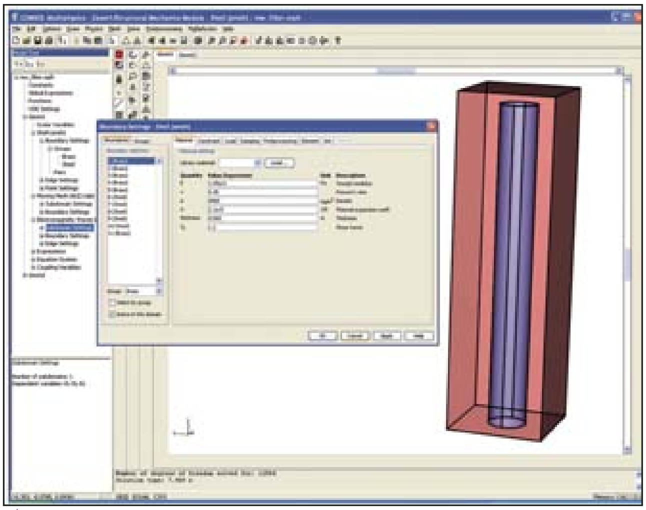
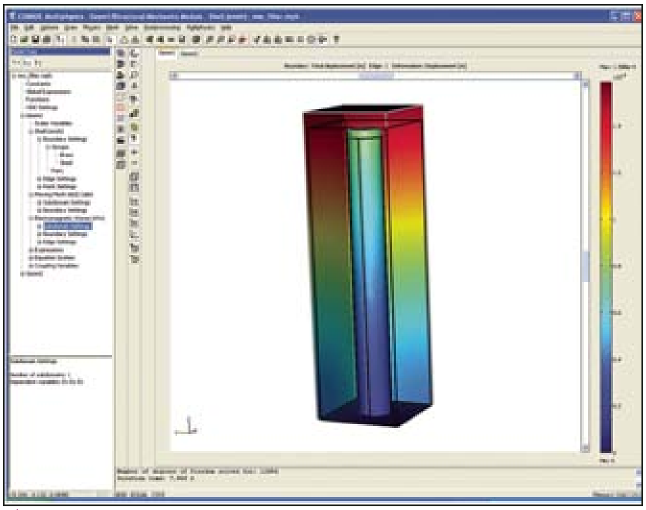
Burlington, MA



▲ *Fig. 1 A microwave filter modeled in COMSOL Multiphysics.*



▲ *Fig. 2 Thermal expansion of the filter cavity at 100°C above the reference temperature.*

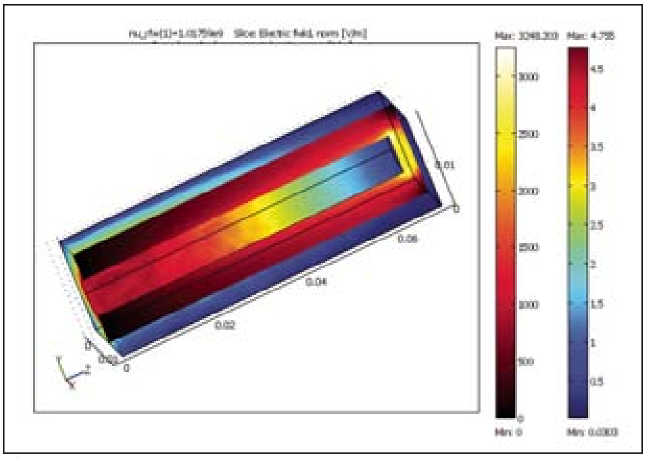
THERMAL DRIFT IN A CAVITY PASSBAND FILTER

As an example of a microwave simulation where multiphysics capabilities are beneficial, consider a microwave cavity passband filter exposed to intense sunlight. The result is significant heating and subsequent thermal expansion, which might be large enough to change the cavity's shape and thus shift its resonant frequency, a phenomena known as thermal drift. This leads to poor frequency stability in the entire system. System engineers need to estimate possible drift in the passband frequency and try to compensate for it.

Figure 1 shows a microwave filter modeled in COMSOL Multiphysics consisting of a box with a cylindrical post centered on one face. It is typically made of brass and is covered with a thin layer of silver to minimize losses. The silver layer is sufficiently thin to have a negligible influence on the device's thermal and mechanical properties.

The thermal expansion and the associated drift in resonant frequency are caused by a uniform increase in the temperature of the cavity walls. With COMSOL Multiphysics one can readily compute the thermal expansion. Specifically it is the shell template, which handles mechanical structures that are too thin to be explicitly meshed throughout their thickness. Furthermore, the mode analysis of the electromagnetic cavity is done in such a case using the 3D Electromagnetic Waves template in the RF Module, a specialized add-on for COMSOL Multiphysics.

To achieve optimal accuracy, a special method is needed that smoothly deforms the original mesh according to the thermal expansion. The Moving Mesh capability for handling a deformed geometry in COMSOL Multiphysics is used to map the thermal expansion to the geometry used for the electromagnetic wave analysis. This approach accounts for any changes in shape and volume of the domain used for the computation of the resonant frequency. The filter's temperature can rise due to power dissipation in the filter itself, in the surrounding electronics, or due to external heating. ***Figure 2*** shows the thermal expansion results for a filter



▲ *Fig. 3 The magnitude of the electric field for the fundamental mode of a microwave filter cell as part of a larger cascaded system.*

made entirely of brass. The original shape is shown as a wire frame with an overlayed exaggerated display of the expansion.

MODE ANALYSIS

Although an actual filter usually consists of multiple cascaded cavities, this discussion limits the analysis to one cell. The cell consists of a thin brass shell with a cylindrical post. ***Figure 3*** shows the filter's lowest eigenmode. The typical quarter-wave resonance of the cylindrical post is clearly visible. A strong capacitive coupling between the top of the post and the top surface of the box is also visible.

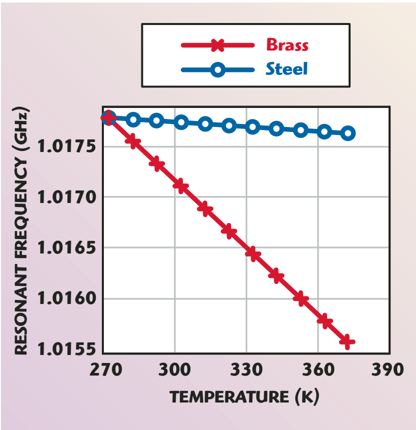
RESONANT FREQUENCY vs. TEMPERATURE

By repeating the structural and electromagnetic analysis for a number of operating temperatures it is easy to obtain a plot of resonance frequency versus temperature. A comparison of two different designs—one with the entire filter made of brass and one with the post made of steel-appears in ***Figure 4***.

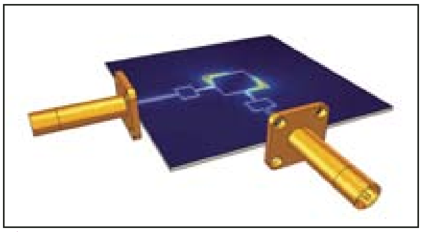
The design with a brass hull and a steel post proves superior with much less thermal drift and hence improved frequency stability for the entire system. The reason is the reduced capacitive coupling between the top of the post and the nearby top surface of the box, which results from the different coefficients of thermal expansion for the two materials. This coupling has a strong influence on the resonant frequency and, when reduced, counteracts the effect of an overall increase in cavity size.

RF MULTIPHYSICS ANALYSIS OUTLOOK

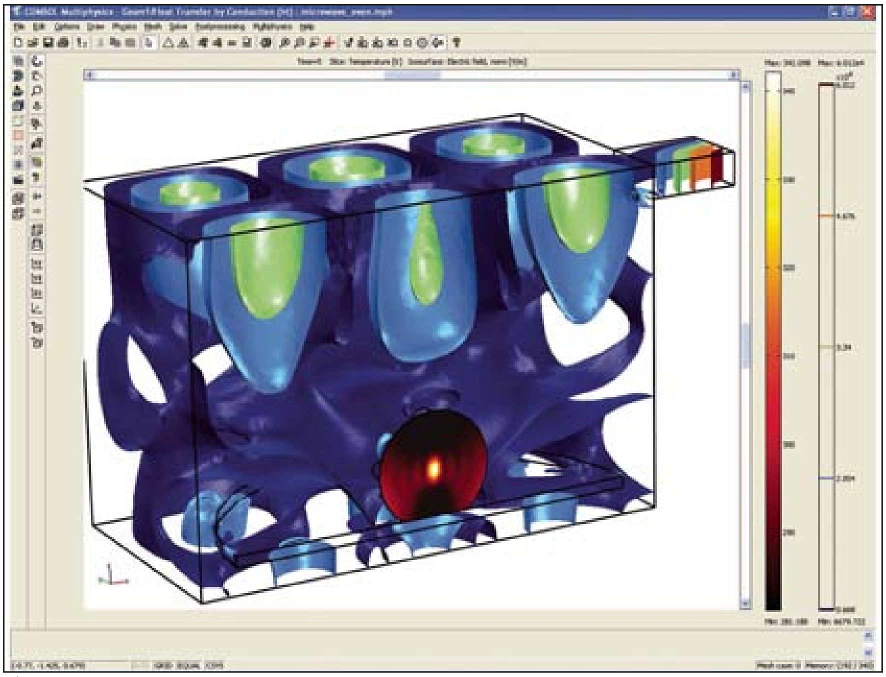
Thermo-mechanical-microwave analysis, such as that of the brass-steel cavity filter case just examined, is merely one of many possible multiphysics applications in the RF arena. Other practical examples include the study of surface acoustic wave (SAW) filters and radio-frequency identification (RFID) systems. Computing the frequency characteristics of a SAW filter requires a combined RF/mechanical/piezoelectric analysis where 64-bit solver technology is required to accurately resolve both mechanical and electrical phenomena and possibly also include heating effects. For RFID systems, government regu-



▲ *Fig. 4 Resonant frequency versus temperature for two different designs: one with the entire filter made of brass and the other with the post made of steel.*



▲ *Fig. 5 Microwave analysis of a microstrip patch antenna with a visualization of the total energy density.*



▲ *Fig. 6 Microwave heating of a potato in a microwave oven.*

lations require vendors to perform combined RF and thermal analysis to ensure that effects on the human body are below given threshold values.

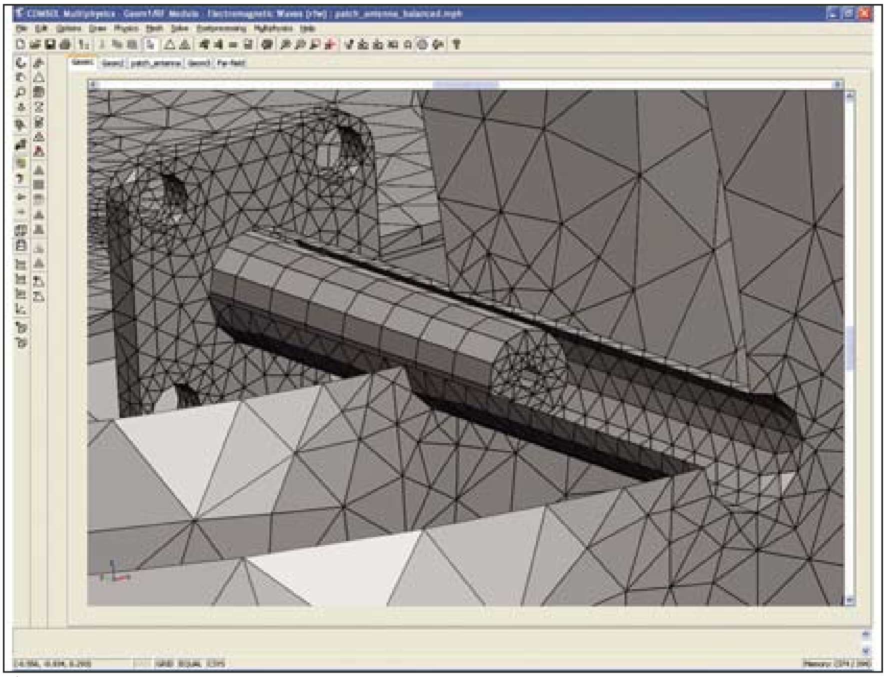
Intense competition suggests that forward-looking companies involved with research and engineering in RF and microwaves will turn to multiphysics for their modeling and virtual prototyping needs. In many markets such software tools can dramatically slash overall development time, costs and time to market. When working with military and defense systems, though, the stakes are much higher, and so is the need for the most capable tools available on the market.

A SIMULATION ENVIRONMENT FOR MULTIPHYSICS

COMSOL Multiphysics is a finite-element analysis (FEA) modeling environment for simulation of virtually any physical process in 1D, 2D or 3D. Users can model most phenomena through predefined application templates, but they can also modify these templates for very specific requirements or adaptation to the very latest research findings. In addition, optional modules add discipline-specific tools for analysis in the areas of AC/DC, RF and microwave, heat transfer, MEMS, structural mechanics, acoustics, chemical engineering, and earth science. A wide-range of coupled analyses are possible by combining any set of modules. Bidirectional interfaces to MATLAB,® from The MathWorks Inc., and COMSOL Script give access to multiphysics FEA from these programming environments for further optimization, pre- and post-processing. A FEA model can be saved as a MATLAB® compatible M-file and then used to create nested for loops over parameters controlling boundary conditions, materials settings, frequency and CAD geometry dimensions.

RF MODULE

The RF Module provides tailored user interfaces and solvers for time-domain, frequency-domain and mode analysis for RF, microwave and photonics applications. The user-interfaces support 2D, axisymmetric 3D and full-wave 3D analysis. It can be used for traditional EM-wave simulations such as that of a balanced microstrip patch antenna (see ***Figure 5***) or for strongly-coupled multiphysics applications such as the heating of a potato in a microwave oven where the permittivity and equivalent conductivity are functions of tempera-



▲ *Fig. 7 The assembly meshing of the coaxial feed of a microwave patch antenna combines tetrahedral and pentahedral vector finite elements for efficiency.*

ture. ***Figure 6*** simultaneously shows the standing electromagnetic wave in the oven and the temperature field within the potato. This particular simulation shows a "hot spot" in the center of the potato.

COMSOL Multiphysics provides a set of automatic and semi-automatic finite-element meshing utilities for the creation of triangular, quadrilateral, tetrahedral, pentahedral and hexahedral vector (also known as "edge") elements of order 1, 2 and 3. These can seamlessly be combined with elements used for other types of physics.

The ability to mesh assemblies (combinations of CAD parts) allows users to combine different element shapes in the same model, as shown in ***Figure 7*** in a magnification of a meshed part from the aforementioned microstrip antenna simulation.

Using different-shaped element types in different parts of a CAD geometry lets the mesh better adapt to a geometrical shape that, in turn, minimizes the number of finite elements used and thereby speeds up the solution process.

KEY FEATURES

COMSOL Multiphysics key features include:

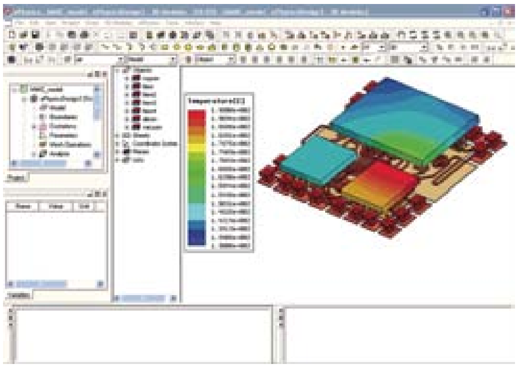
- Strongly coupled FEA physics simulations: thermal, structural, fluid, chemical, semiconductor and more
- Bidirectional MATLAB/COMSOL Script interface with automatic generation of M-files
- State-of-the-art 64-bit meshing and solver technology
- Moving Mesh for deformable domains
- User-defined differential equations can be added to an FEA simulation
- Add-on modules for advanced analysis: Heat Transfer, Structural Mechanics, AC/DC, RF, Acoustics, Chemical Engineering, MEMS, Earth Science

RF Module key features include:

- 3D and 2D frequency-domain and time-domain simulations
- Material properties can be complex valued, anisotropic, discontinuous, frequency dependent, time dependent
- Perfectly Matched Layers (PML) for wide frequency band truncation of the computational domain
- Couples seamlessly with any COMSOL Multiphysics Module.

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

RS No. 301



MULTI-DOMAIN SIMULATOR COUPLES THERMAL AND STRESS ANALYSES TO 3D ELECTROMAGNETIC SIMULATION

Most of today's wireless applications call for a reduction in the physical size and an increase in the functionality of RF and microwave components, forcing designers to adopt a host of new materials and structures. These densely packed circuits present a number of engineering challenges from increased electromagnetic coupling to increased dissipated power. Integration and miniaturization exacerbate the interdependency between electrical, thermal and mechanical behavior, calling for engineering tools that not only simulate each domain accurately but capture the coupling between them. ePhysics version 2.0 from Ansoft does just that by dynamically coupling thermal and stress analysis to HFSS for electromagnetic-based multi-physics analysis. The combination of ePhysics with HFSS allows engineers to investigate quantities such as temperature, stress and electrical performance for an arbitrary 3D structure without the need to build and test a physical prototype.

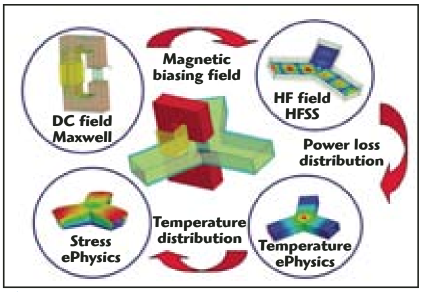
COUPLED ANALYSES

ePhysics v2 provides powerful multi-disciplinary analysis within an electromagnetic-based design flow. A unique dynamic link mechanism supports automated data exchange between dedicated solvers. Through this coupling between the ePhysics and HFSS solvers, a device's behavior can be fully investigated. With these coupled simulators, engineers can account for the mechanical and thermal consequences of the electromagnetic fields that contribute significantly to a design's overall performance. There is no limit to the number of projects and analyses that can be coupled in a "daisy chain" fashion to reproduce the desired application. In such linked designs, variables can be exchanged between any two adjacent designs and used wherever needed along the daisy chained designs. For example, a multi-domain capability is exer-

ANSOFT CORP.
Pittsburgh, PA

cised as temperature distributions resulting from HFSS derived electromagnetic fields that are then channeled into the ePhysics electrostatic solver to evaluate the induced mechanical stress and resulting deformation, as shown in ***Figure 1***. Note that in this application the magnetostatic solver in Ansoft's Maxwell product provides the distribution of the nonlinear biasing DC field in the ferrite component such that HFSS can accurately calculate the corresponding HF fields and losses in the ferrite.

In this multi-domain analysis, the thermal analysis provides the temperature distribution source used in the stress target design for the computation of the resulting deformation and stress. The thermal capability in ePhysics provides nonlinear steady-state and transient thermal analyses, including all heat transfer mechanisms: conduction, convection and radiation (which can be coupled to Ansoft electromagnetic solvers), and stress solvers. The power loss with volumetric or surface density distribution information obtained by the 3D electromagnetic solver HFSS serves as a highly accurate heat source for thermal analysis. This allows engineers to obtain a complete thermal profile of a device including the overall temperature distribution and location of hot and cold spots in a steady-state thermal analysis or for any instant in time if the thermal analysis is transient. In addition to using thermal sources based on HFSS derived losses, independent thermal sources may also be applied to the same or different objects in ePhysics. For example, this is very useful to model additional heat sources that are not of electromagnetic nature.

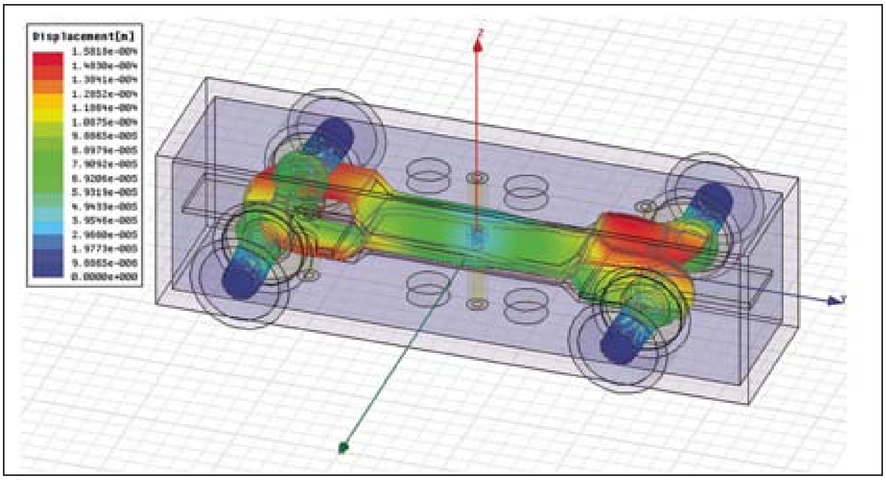


▲ *Fig. 1 Multi-domain analysis couples electrical, thermal and stress simulations.*

The linear stress-analysis engine in ePhysics is especially useful for analyzing deformation and stress due to electromagnetic force density distribution, thermal deformation, structural stress due to temperature distribution and more. Power losses computed by HFSS for microwave and RF applications are used to determine the corresponding temperature distribution; subsequently, the temperature distribution at selected time steps is used to calculate the corresponding deformation and structural stress in a microwave/RF component.

DESIGN AUTOMATION

To reduce engineering set-up time and enhance usability, the new user interface for ePhysics v2 is based on the same Ansoft desktop that is common to HFSS, Q3D Extractor and Ansoft Designer, implementing numerous automation features specific to an electromagnetic-centric design flow. For instance, parameterization of model geometries and materials is easily defined for all model design objects and design optimization is available through Optimetrics. To assist the engineer in defining complex multi-domain analyses, multiple links may be used in the same solution setup. In the example of a thermal transient design, apart from selecting the power loss distribution calculated in the "source design," there are two additional links that can be created and used in the solution process. The first is a mesh link to indicate the source of mesh (based on a design with identical geometry) and a link to a thermal static design that allows the use of an existing static solution as the distributed initial condition (temperature distribution in the model at Time =0).



▲ *Fig. 2 Stress analysis of high power stripline coupler with displacement magnified for easy visualization (maximum displacement is 0.15 mm).*

Further automation supports design and/or project variables being used in coupled projects. For instance, a variable that has been defined in the source design can be controlled in the target design. This capability allows a user to perform parametric sweeping of an HFSS object directly from within an ePhysics simulation. Thus, the whole range of simulations in HFSS and ePhysics are performed such that data flow between coupled solvers occurs automatically, without stopping the global solution process. The results of the parameter sweep are available in the post processor for viewing without any additional intervention from the user. Additionally, coupled designs utilize data caching technology to eliminate the need for re-simulating previously solved structures.

The link between simulators includes various mechanisms that automate simulator-to-simulator coupling for multi-domain analysis. Key automation features include:

- import a starting mesh from the coupled simulator of any eligible design (designs must share a common geometry)
- import the initial temperature distribution from a static thermal solution (if thermal transient solution is used)
- usage of adaptive mesh refinement (insures the mapping of the applicable fields and automatically monitors between different meshes in the coupled designs)
- automatic mapping of parameters between coupled designs
- power loss density from HFSS is mapped automatically to any ePhysics coupled thermal designs

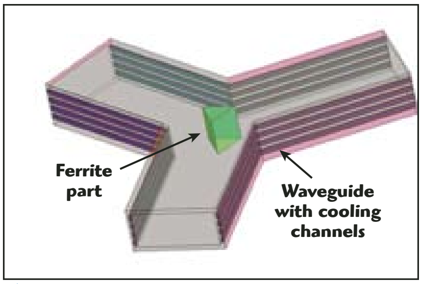


Fig. 3 Geometry of the device with cooling channels in the walls of the waveguide.

NEW ANALYSIS CAPABILITIES

The latest release of ePhysics supports a new solution sequence from HFSS "transient" to ePhysics thermal transient solver. This new capability is demonstrated in an example of a high power ferrite circulator wherein the power loss distribution corresponding to the power loss peak calculated by HFSS is channeled to ePhysics for simulation of the transient temperature.

The ePhysics coupling supports HFSS arbitrary excitation sequencing such that an arbitrary sequence of power pulses can be efficiently generated to create the desired ePhysics input as a function of time, based on a single HFSS solution. The user definable parameter setup allows the thermal solver to calculate global quantities such as object-wise average temperature, hot spot and cold spot temperatures and their respective locations. Also, field distributions and other calculations can be performed using the post processing. Additional multi-domain analysis can be used to simulate the stress and deformation at user-specified moments and the corresponding temperature distributions, as shown in ***Figure 2***.

The features available in the thermal transient solution sequence are exhibited in the following formulation

$$\rho c \partial_t \vartheta = -\nabla \vec{q} + Q_v(t, \vec{x})$$
$$\vec{q} = -k \nabla \vartheta$$

In this formulation, Q_v represents the power loss distribution, k is the thermal conductivity tensor, ρ is the mass density and c is the specific heat. The thermal diffusion equation is solved using the initial temperature distribution throughout the model and the boundary conditions specified by the user.

$$\vartheta(0, \vec{x}) = \vartheta_0(\vec{x})$$

Advanced convective and radiative boundary conditions can be defined by the user to account for free and forced convection and thermal radiation effects.

Forced convection is often used in real life applications to cool down the high temperatures present in devices operating under high power steady-state or transient (pulsed) conditions. A structure with forced cooling can be simulated in ePhysics via the dedicated forced convection and radiation boundary conditions. Forced convection is reflected in a model featuring user-specified convection channels that allow the flow of a variety of cooling fluids at user specified velocity, such as the case of the liquid cooled ferrite circulator with cooling channels located in the walls of the waveguide structure, as shown in ***Figure 3***. The setup of the forced convection on the walls of the channels allows the user to choose among a few available fluids or specify newly defined ones.

Other analysis capabilities introduced in ePhysics v2 include the ability to handle nonlinear thermal properties (conductivity vs. temperature), a new anisotropic stress solution and the optional distributed analysis that provides distributed computation of parametric sweeps for multi-physics applications resulting in a drastic acceleration of overall simulation time for large parametric studies and design optimization.

CONCLUSION

Growing concern over optimal design, reliability and shortened design cycles demands simulation technology that provides the utmost insight into the electrical, thermal and mechanical behavior of complex microwave/RF components. Linking dedicated simulators provides an unprecedented look into the true nature of the hardware being developed by engineers today. Simulation technology and automation are critical factors in establishing a multi-domain analysis capability. Such capability is especially important to designers working with high density and high power applications where thermal and stress considerations are no longer insignificant contributors to overall device performance.

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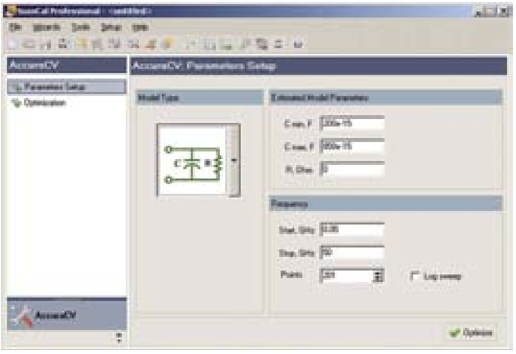


A SOFTWARE TOOL ADDRESSING CHALLENGES OF SEMICONDUCTOR MINIATURIZATION

Current trends in the design of semiconductor devices are forcing design and test engineers to reevaluate the status quo and to realize that it is no longer possible to use traditional design rules and test methods with new semiconductor systems. More and more frequently it is becoming necessary to implement methods involving frequencies in the gigahertz range, which can be daunting for engineers who up until now have had nothing to do with RF or microwaves.

That is why AccuraCV,™ now available in the SussCal® Professional calibration and measurement software suite, has been introduced. It addresses the challenges resulting from shrinking device sizes by making accurate impedance measurements of physically small elements. Having the capability to make such measurements is becoming increasingly important—for instance, the International Technology Roadmap for Semiconductors (ITRS) reports that in 2012 the thickness of gate oxides, characterized using impedance measurements, is predicted to be about half as thick as it is today.

Impedance measurements are critical in process control, but traditional DC methods for making impedance measurements suffer inaccuracies when used on small components. As a solution, impedance characterization can be done using scattering (S)-parameter measurements at microwave frequencies. Thus, AccuraCV is an intuitive tool for optimizing the frequency of impedance measurements that will provide the most accurate results. In addition, it can be used to optimize device design by reducing the costs incurred during process control.

CURRENT STATUS

There are several different conventional methods for measuring device under test (DUT) impedance. The most commonly used are those available from commercial impedance analyzers (based on the measurement of the DUT current over the applied voltage). These are widely used in the semiconductor industry and provide an accurate impedance measurement at frequencies up to 110 MHz. However, for very small devices, extracting the modeling parameters of a

SUSS MICROTEC TEST SYSTEMS
Dresden, Germany

DUT is becoming difficult in this frequency range, and unwanted effects such as current leakage significantly reduce measurement accuracy.

To overcome this problem, additional effort must be put into the measurement procedure. This includes using more complicated three-, four- or five-element DUT equivalent circuits, in which the parasitic elements—those elements used to describe effects such as current leakage—must be characterized accurately. This reduces the practical application range of conventional impedance measurement methods for characterization of advanced semiconductor components. These limitations can be overcome by selecting S-parameter-based impedance measurement techniques and increasing the measurement frequency to the microwave range.

MICROWAVE MEASUREMENT METHODS

The S-parameters (reflection and transmission coefficients) of the DUT can be obtained with the help of a vector network analyzer (VNA). The main advantage of a VNA-based measurement system is that it is relatively simple to measure S-parameters in a very wide frequency range in one sweep, from some hundreds of megahertz to beyond 110 GHz. A very simple relationship between the reflection coefficient Γ_{DUT} of the DUT and its impedance Z_{DUT} allows the measurement software to extract the desired model parameters easily and at any frequency:

$$Z_{DUT} = Z_0 \left(\frac{1+\Gamma_{DUT}}{1-\Gamma_{DUT}} \right)$$

where

Z_0 = measurement system reference impedance

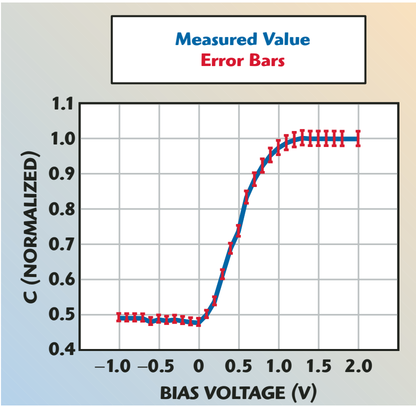
However, the reflection coefficient is a relative parameter. It is derived in a measurement system with fixed reference impedance Z_0, which is set at 50 Ω for most applications. It is simple to show that the constant error $\Delta\Gamma$ introduced in the reflection coefficient measurements due to the VNA measurement uncertainty leads to a nonlinear error function for measured DUT impedance. This fact limits the accuracy of the impedance characterization method based on the S-parameter measurements.

ACCURATE MODELING

AccuraCV was developed to meet the challenge of making accurate impedance measurements using S-parameters. It provides accurate modeling of the expected measurement error from the VNA-based measurement system. The mathematical model takes into account the estimated value of the measured impedance of the DUT as well as the measurement uncertainty of the system. As a result, the patent-pending AccuraCV algorithm calculates a value of the impedance measurement error over the specified frequency range.

Typically, most test elements can be measured at different frequencies. This requires the test engineer to find the optimum frequency for accurate impedance measurements either by trial and error or daunting mathematical calculations. With the help of this new tool, the optimal frequency can be found and the measurement error can be reduced to less than five percent, depending on the measurement setup and the DUT.

Figure 1 demonstrates the measurement results of microwave capacitance/voltage (C/V) characterization of the gate oxide capacitance of a next-generation semiconductor component optimized and analyzed with AccuraCV. To achieve the highest measurement accuracy for the region of smallest capacitance, the algorithm calculated the optimal measurement frequency as 1.3 GHz. At this frequency, the expected measurement error is reduced to two percent. Additionally, the capacitance extraction error is evaluated over the whole bias range and displayed as error bars.



▲ *Fig. 1 Results of the gate oxide capacitance characterization of a next-generation semiconductor element optimized with the help of the AccuraCV tool.*

Testing impedance of bias-dependent semiconductor components, such as transistors and varactors, the optimum frequency can be calculated for each bias point, increasing the measurement accuracy over the whole range of the impedance variation of the DUT.

Additionally, the AccuraCV algorithm optimizes test elements used in process monitoring during fabrication. The design of the verification element and its estimated electrical characteristics can be easily adjusted to the measurement equipment type and the uncertainty of the measurement method. As a result, the quality of process monitoring during production is increased.

It is recognized that the cost of testing increases proportionally with the test frequency. Therefore, from a cost-effectiveness perspective, the test should be kept at the lowest feasible frequency. By doing this, the new tool increases the effectiveness in device design, making it possible for test elements to be designed to optimize the required measurement frequency range.

For example, limiting the test frequencies at which process monitoring elements are tested to 6 GHz will reduce the cost of test because a less expensive measurement setup is required. AccuraCV easily calculates the required impedance of the test element at the specified frequency (< 6 GHz) that will result in the least amount of measurement error. The test element can then be designed according to these specifications.

CONCLUSION

To decrease the manufacturing costs of semiconductor devices, more and more elements are being put on the wafer, decreasing the size of the components and increasing chip density. Due to the miniaturization of devices, S-parameter-based impedance measurement methods are becoming more commonplace at both the design and production phase. AccuraCV optimizes S-parameter-based methods by determining the test frequency that will significantly improve measurement accuracy.

The tool also finds the balance between the often competing requirements of decreasing the cost of test and increasing the test accuracy. From specifications calculated using the software, the test structures can be designed for accurate characterization at lower frequencies.

Last but not least, AccuraCV is integrated into the SussCal Professional calibration and measurement software suite, providing a full set of tools required for accurate S-parameter test at the engineer's fingertips—from automated system calibration to measurement optimization. As such, the wizard-driven design of the software guarantees that a user with little or no RF or microwave measurement experience can make accurate measurements in a matter of minutes.

SUSS MicroTec Test Systems, Dresden, Germany +49 35240 730, www.suss.com.

RS No. 302

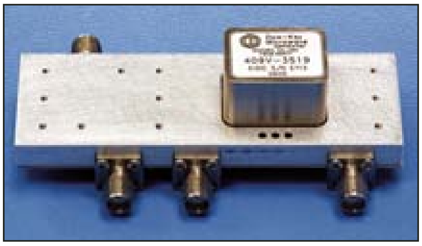
BREAKTHROUGH SWITCH BLENDS SMALL SIZE WITH HIGH POWER HANDLING CAPABILITY AND DURABILITY

The growing trend toward the use of smaller components in high-end microwave applications is being driven fervently by end-user demand for easier mobility and serviceability of equipment. Within the military realm especially, tactical agility in the field correlates directly to the use of certain types of equipment that are rugged and powerful, yet lightweight and compact.

Unfortunately, when it comes to performance, the design of smaller-size components oftentimes has meant that a certain amount of power and durability has been sacrificed. The challenge to microwave engineers has been to find the best balance of component size, weight and performance characteristics that will meet or exceed the required specifications for a given application.

Recognizing the critical need for more powerful, reliable and miniaturized microwave components, Dow-Key Microwave Corp. recently released its 409 Series single-pole, double-throw (SPDT) switch designed for drop-in microstrip or coplanar circuit applications.

Fig. 1 The 409 switch mounted in a PCB fixture.

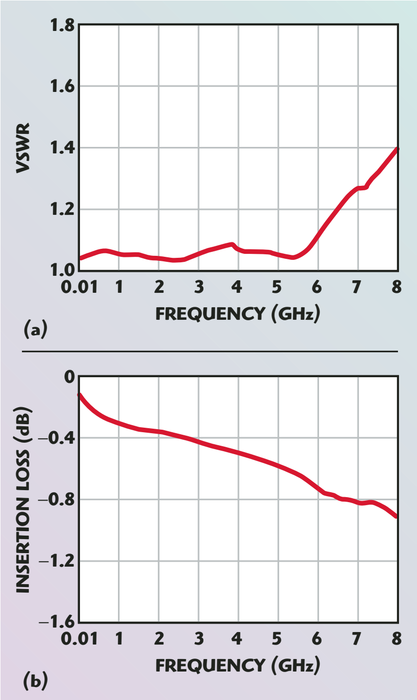


SMALL FOOTPRINT, LIGHT WEIGHT

In response to key user demands, the 409 switch has been designed to provide extreme durability and high power handling characteristics in a highly compact footprint—0.800" × 0.600" × 0.640"—that can be mounted directly onto a microstrip or coplanar circuit assembly, as shown in ***Figure 1***.

Weighing in at a mere 11.25 grams, the hermetically sealed 409 switch is almost seven times lighter and one-third the size of its 401 Series predecessor, which had served as the industry-standard miniature SPDT switch for many years. Where switches like Dow-Key's 401 Series connectorized switches had in the past been used in applications required RF cables, the new compact 409 directly launches the RF signal to the microstrip or coplanar transmission lines, and provides virtually the

DOW-KEY MICROWAVE CORP.
Ventura, CA



▲ *Fig. 2 The 409 switch's typical (a) VSWR and (b) insertion loss performance.*

same electrical and power handling characteristics of the venerable 401 but in a small, 310 mm^2 area of the RF circuit space.

FOCUS ON POWER HANDLING

The design process of the 409 switch was a complex engineering task, starting with an intended military application, and working through numerous trade-offs between the power handling and size reduction of the switch.

Military applications demand much from microwave components: exposure to moisture, humidity, dirt and sand; the ability to operate reliably within extreme temperature variations between –55° to +85°C; and the capability to withstand high levels of shock and vibration. Thus, the two most critical aspects in the creation of the 409 miniature switch were to enable it to operate reliably in harsh environments while affording it the capacity to handle high levels of power.

HERMETIC SEALING

Metal-to-metal/glass-to-metal hermetic sealing (1×10^{-6} atm-cc He/sec) of the housing was the obvious choice to enable the switch to perform reliably in harsh conditions. However, hermetic sealing presents certain power handling challenges to a small switch, as the properties of the glass used in the sealing process present relatively significant losses for high-frequency signals.

Additionally, as the switch miniaturization is limited by the level of power it must handle, balanced heat dissipation must be present in the design. The operating temperature of all switch components is not only impacted by the external environment but also increased as a result of the heat generated by the power transmitted through the device. Without excellent heat dissipation characteristics, any hot spots on the interface between the switch and the remainder of the assembly could be problematic for the parts inside the unit, potentially melting some of its critical dielectrics.

THERMAL MANAGEMENT

Dow-Key designed the 409 switch with a focus on thermal management so as to enable the miniature switch to dissipate the heat created by high-frequency RF signals. The dimensions of the 409 switch, particularly the surface areas that come into direct contact with the microstrip ground plane, were carefully designed to provide a balanced exchange of heat between the unit and the overall assembly. The company has also developed a very detailed application for the microstrip circuit design, taking full advantage of the switch power handling. The result is a switch that provides extremely low insertion loss, high-integrity routing of high-power RF signals up to 6 GHz and 100 W. ***Figure 2*** shows the 409 switch VSWR and insertion loss performance vs. frequency.

BUILT TO LAST

In terms of materials, the 409 switch is made from aluminum and electroless nickel with kovar gold-plated contacts. An extremely robust latching drive mechanism enables the 409 to be used in high-vibration and mechanical shock applications. Rated at an operating life of one million cycles, the 409 is rated to operate at frequency ranges between DC and 6 GHz.

MYRIAD APPLICATIONS

Ideal for redundancy, filter and amplifier switching in applications where high isolation is required, the main uses for the 409 Series switch will be primarily high-end military in nature, though it also can be used in ATE environments. From airborne, shipboard, amphibious, or land-based vehicles—or anywhere there exists a high level of vibration, shock and exposure to extreme temperatures—the 409 is suited for deployment wherever SPDT action is required.

Engineers looking for switch solutions in portable radio applications, for example, will find the 409 switch particularly useful due to its small size and low weight.

For airborne applications in which vehicles operate in high-vibration environments, the use of the 409 switch is attractive due to its ability not only to withstand high temperature variations and shock, but because it also affords high-power capability with low insertion loss. Further, at a little over 11 grams each, numerous 409 switches can be outfitted to provide redundancy and higher performance levels with a negligible addition of weight to the aircraft.

In land-based military vehicle applications, the amount of equipment that must be carried on board puts real estate at an extreme premium. Here, the 409's small size has the potential to reduce some of the hardware requirements inside the vehicle, thus helping to maximize space while achieving the required operational benefits of the vehicle.

A high-quality alternative to solid-state devices, Dow-Key's 409 Series switch provides microwave engineers with breakthrough performance and easy serviceability in an extremely compact unit for use in high-end, mission-critical applications. While other miniature microwave switches exist on the market, none offer the 409's level of high-power handling capacity combined with hermetic sealing. This unique design opens up the doors for new applications that previously had been difficult or impossible to build. For more information, visit Dow-Key Microwave's web site at www.dowkey.com.

Dow-Key Microwave Corp., Ventura, CA (805) 650-2329, www.dowkey.com.

RS No. 300

● **Broadband, Microwave and Wireless Components**

"Click to Quote" and "Click to Buy" are new features of the newly updated Aeroflex/Inmet web site. The site now allows a user to obtain a quote for any one of the listed products simply by clicking on the quote button pictured next to the particular model number. In addition, a "Buy Now" button has been added next to each item that is available for immediate purchase.

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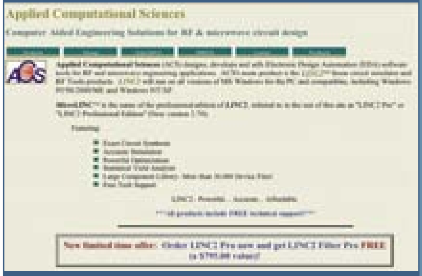
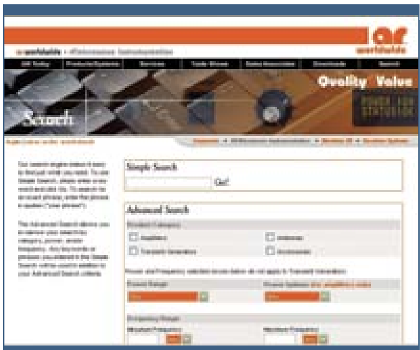


● **Circuit Design Software**

The ACS web site highlights new features of the LINC2 RF and microwave circuit design software suite. LINC2 combines high performance RF and microwave circuit design, synthesis, simulation and optimization into a single integrated program at an affordable cost. The software includes a comprehensive suite of design tools for the exact synthesis of a wide variety of active and passive circuits.

Applied Computational Sciences (ACS),
1061 Dragt Place,
Escondido, CA 92029

www.appliedmicrowave.com



● **On-line Ordering**

Ordering from AR Worldwide has become easier with the addition of on-line ordering to the company's web site. Registered users are able to select products, enter billing and payment information, and receive acknowledgment of the order. The web site also features detailed product pages with downloadable specification sheets, software demos and application notes. The web site includes a search that allows users to search by amplifier, keyword, power and/or frequency.

AR Worldwide RF/Microwave Instrumentation,
160 School House Road,
Souderton, PA 18964

www.ar-worldwide.com

● **On-line Part Locator**

This on-line part locator allows engineers to type key requirements into an intuitive on-line form to output a reference table of suitable oscillators, with quick links to the full specification sheet for each. The part locator covers the company's entire range of standard crystal oscillator products, including OCXOs, TCXOs, VCXOs, SPXOs, factory programmable oscillators for fast delivery, and oscillators approved by communications chipset manufacturers Semtech and Zarlink Semiconductor.

C-MAC MicroTechnology,
Endeavour House, Mercury Park,
Wycombe Lane, Wooburn Green,
Buckinghamshire HP10 0HH, UK

www.cmac.com

● **Ultra Precision Lapping, Polishing and Finishing Services**

This site features the company's high quality, ultra-precision surface finishing in the telecommunication, semiconductor, communication, micro-electronic, defense and security markets. Services include grinding, lapping, polishing, diamond sawing and laser machining of metals, ceramic, sapphire and other materials.

Centerline Technologies,
577 Main Street, Suite 270,
Hudson, MA 01749

www.centerlinetech-usa.com

● **RF and Microwave Components**

This web site features the company's wide range of RF and microwave components such as cable assemblies, connectors and adapters, power dividers, attenuators, amplifiers, bias tees, and isolators and circulators. Data sheets and pricing are also available on-line. The company's products are designed for markets that include telecommunications, wireless and SATCOM, military, instrumentation, consumer electronics, computers and computer peripherals, commercial aircraft, industrial equipment and medical equipment.

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www.electronikainc.com

Components and Subsystems

Endwave's innovative components and subsystems enable the transmission, reception and processing of RF, microwave and millimeter-wave signals in next generation wireless communications networks, defense and homeland security systems. Featured on the company's web site are a variety of single and multi-function solutions including: JCA amplifiers, oscillators, multipliers, up/downconverters, synthesizers, transceivers, switch arrays and custom multi-function assemblies.

Endwave Corp.,
130 Baytech Drive,
San Jose, CA 95134

www.endwave.com

Electromagnetic Measurement, Shielding and Control

The company's web site has recently gone through a major renovation. User-friendly improvements include: a more robust search engine, graphically enhanced and streamlined navigation, print-friendly pages and dedicated solutions areas related to users interests. Cross-referenced information such as documentation, standards, related products and information enable the user to more efficiently access the information they need.

ETS-Lindgren,
1301 Arrow Point Drive,
Cedar Park, TX 78613

www.ets-lindgren.com

Custom and Standard Filters

KR Electronics designs and manufactures high quality filters for the commercial and military markets. The web site features bandpass, low pass, high pass, notch, root cosine, diplexers, group delay networks, wideband 90° phase splitters, coils and transformers. In addition to design and manufacturing services, the company offers extensive test and measurement capabilities including environmental testing.

KR Electronics,
91 Avenel Street,
Avenel, NJ 07001

www.krfilters.com

RF/Microwave Filters and Assemblies

This redesigned web site provides a dynamic environment for customers to quickly learn about the company's products and capabilities. Key highlights include: A Product Finder tool to search a database of existing designs; a Package Finder tool to search standard package outlines and download PDF data sheets; and a Spotlight section on the home page to showcase new product updates and news about NIC.

Networks International Corp.,
15237 Broadmoor,
Overland Park, KS 66223

www.nickc.com

Web Update

ICs, Modules and Subsystems

This comprehensive, versatile web site has recently added new product pull-down menus and RoHS compliant component pages. The web site details full specifications for over 430 products, application notes, quality assurance and product support tools including Product Cross Reference, Parametric Search, PLL Phase Noise and Mixer Spur Chart Calculators, and expanded e-commerce. The company's new product selection guide, newsletter and CD can also be requested from the site.

Hittite Microwave Corp.,
20 Alpha Road,
Chelmsford, MA 01824

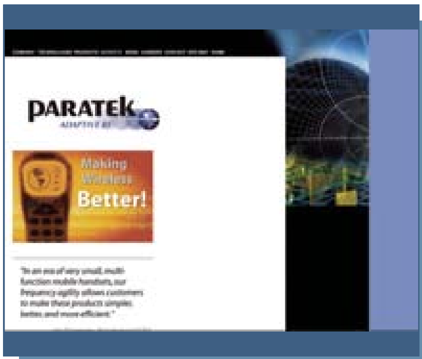
www.hittite.com

Amplifiers, Integrated Assemblies and Subsystems

This newly designed web site offers several new features. The new search tool allows a user to instantly find any of the company's products within the database and the new drop down menus allow a user to narrow a search to the items that one is most interested in. The company's Orderstat systems allow a user to track the progress of an order daily with automatic e-mail notification regarding an order.

Planar Electronics Technology,
5715 Industry Lane, Unit 11,
Frederick, MD 21074

www.planarelec.com



Adaptive RF Tuning Solutions

This web site features the company's adaptive RF tuning solutions for government and commercial wireless applications. Products include the Adaptive Impedance Matching Module (AIMM), which is a closed-loop, self-contained circuit that senses impedance mismatches in wireless handsets and instantly corrects for them. Paratek is headquartered in Columbia, MD, with additional offices in Nashua, NH and Crystal Lake, IL.

Paratek Microwave Inc.,
22 Technology Way,
Nashua, NH 03060

www.paratek.com

Filters, Diplexers and Subassemblies

The company has recently enhanced its web site to include an on-line filter RFQ tool. Filter quotes have never been easier, and are now just a click away. The site also features the company's full-line of RF/microwave filters, diplexers and subassemblies. Additionally, in support of customers worldwide, Reactel's product catalog and data sheets are available by download.

Reactel Inc.,
8031 Cessna Avenue,
Gaithersburg, MD 20879

www.reactel.com

Digital RF Amplifiers

PulseWave RF™ is a fabless semiconductor company that develops digital RF power amplifier modules. The company's proprietary Class M Power technology produces a multicarrier power amplifier (MCPA) with a 50 percent reduction in cost and size, and a 40 percent increase in power efficiency. By implementing Class M Power, the overall base station cost is reduced by 20 percent.

PulseWave RF,
110 Wild Basin Road, Suite 100,
Austin, TX 78746

www.pulsewaverf.com

RCS Measurement Systems

QuarterBranch Technologies Inc. provides technical support and design services to the radar cross section (RCS) measurement community. The web site includes the company's new flagship system, RadarMan, which is a high speed, broadband pulsed-IF radar system covering 2 to 18 GHz in a single, 7-inch high by 13-inch deep rack-mount chassis with most of the capabilities and features of much larger, more expensive competing systems.

QuarterBranch Technologies Inc.,
4 North Berlin Pike,
Lovettsville, VA 20180

www.quarterbranch.com

RF MEMS Switches

This recently updated web site features the company's commercially available RF MEMS switch. Site features include a technology section on the advantages of MEMS, as well as descriptions and literature for the company's product line. Order on-line with TeraVicta or through its worldwide distributor, Richardson Electronics.

TeraVicta Technologies Inc.,
2535 Brockton Drive,
Austin, TX 78758-4411

www.teravicta.com

Engineering Tools Aid in Packaging Design

On the Thunderline-Z web site you will find an advanced search engine of the company's entire database of previously designed feedthrus. Search over 2000 models of RF/50 Ω, DC and capacitor/filter feedthrus to find the model that most closely resembles your application. In addition, you will find an impedance reference calculator. Use this tool to calculate the opposing dimension of glass-to-pin, or pin-to-glass, that will achieve optimal impedance in your RF or microwave package.

Thunderline-Z,
11 Hazel Drive, Hampstead, NH 03841

www.thunderlinez.com

NEW WAVES: RWS Product Showcase

Signal Generator

The Agilent N9310A RF signal generator reinforces Agilent's entry into the low cost test instruments market and delivers on the company's commitment to provide leading-quality and cost-effective products to customers. The N9310A RF signal generator covers ranges from 9 kHz to 3 GHz and full range of modulation types, including AM, FM, phase modulation, pulse modulations and an optional IQ modulator. With external IQ source, it can easily generate various types – even I/Q modulated signals such as GSM, CDMA and OFDM signals as seen in modern digital communications systems.

Agilent Technologies Inc.,
Santa Clara, CA (800) 829-4444,
www.agilent.com.
Booth 637 **RS No. 216**

RF System-in-Package Kit

The RF System-in-Package (SiP) Kit includes new Cadence SiP RF products and methodologies for automating and accelerating the entire design process of RF SiPs for wireless communications applications. It also provides customer-proven SiP implementation methodologies based on an 802.11 b/g wireless local area network (WLAN) design. This enables fast and streamlined adoption of the SiP design technique with low risk. This Cadence Kit, along with the previously released Cadence RF Design Methodology Kit, expands Cadence's RF design offerings in the wireless segment.

Cadence Design Systems Inc.,
San Jose, CA (408) 943-1234,
www.cadence.com.
Booth 621 **RS No. 220**

40 W Power Amplifier

These new SCPA linear solid-state power amplifier modules are designed for CDMA applications. Model CMW1042 delivers 40 W of power over 869 to 894 MHz and offers a nominal 54 dB gain. This module meets the FCC specifications for digital modulation and is rugged and unconditionally stable, making it suitable for all types of applications. Model CMW1042 is part of AR Worldwide's extensive new family of power amplifier modules for wireless amplifiers such as CDMA, HDTC and WiMAX.

AR Worldwide Modular RF,
Bothell, WA (425) 485-9000,
www.ar-worldwide.com.
Booth 312 **RS No. 218**

Laser Powered Probe

The newest addition to the AR Worldwide RF/Microwave Instrumentation family of laser powered probes is the revolutionary new 3 MHz to 18 GHz probe. Model FL7018 designed and manufactured by AR operates continuously without recharging or battery replacement. All AR laser powered probes feature an internal microprocessor to provide linearization, temperature compensation, control and communication functions. Other laser powered probes available include the FL7030 (5 kHz to 30 MHz) and the FL7006 (100 kHz to 6 GHz).

AR Worldwide RF/Microwave Instrumentation,
Souderton, PA (215) 723-8181,
www.ar-worldwide.com.
Booth 312 **RS No. 219**

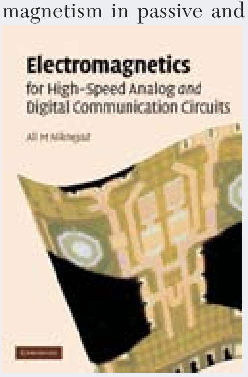
Simulation Software

The latest version of HFSS™ is a software program designed for electromagnetic field simulation and S-parameter/full-wave SPICE extraction of high frequency and high speed components. Learn about the latest developments in distributed processing for HFSS that deliver significant productivity gains for designers of on-chip embedded passives, PCB interconnects, antennas, RF/microwave components and high frequency IC packages.

Ansoft Corp.,
Pittsburgh, PA (412) 261-3200,
www.ansoft.com.
Booth 523 **RS No. 217**

Electromagnetics for High Speed Analog and Digital Communication Circuits

This book reviews the fundamentals of electromagnetism in passive and active circuit elements, highlighting various effects and potential problems in designing a new circuit. The author begins with a review of the basics – the origin of resistance, capacitance and inductance – then progresses to more advanced topics such as passive device design and layout, resonant circuits, impedance matching, high speed switching circuits, and parasitic coupling and isolation techniques. Using examples and applications in RF and microwave systems, the author describes transmission lines, transformers and distributed circuits.



Cambridge University Press,
New York, NY (212) 924-3900,
www.cambridge.org/us/engineering.
Booth 437 **RS No. 221**

3D EM Time Domain Tool

CST MICROWAVE STUDIO® 2006B offers enhanced performance and robustness particularly in the Time Domain solver, due to the new Fast PBA mesher and the new flexible subgridding scheme with drastically reduced memory requirements. Alongside increased mesher and solver performance, users of the Frequency Domain solver now benefit from numerous new features and improvements such as the facility to excite structures by plane waves and slanted ports. Coupled simulation between CST MWS' Frequency Domain TET solver and CST EM STUDIO™'s magneto-static solver has been implemented in order to simulate realistic biasing of ferrites. The interoperability between the high frequency solvers and the thermal solver has been further improved.

CST of America® Inc.,
Wellesley Hills, MA (781) 416-2782,
www.cst.com.
Booth 418 **RS No. 222**

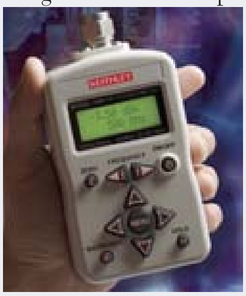
Synthesized Signal Generator

The model SSG 10/4000 is a synthesized signal generator that operates from 10 MHz to 4 GHz. The SSG is targeted towards applications that need low cost, simplicity of operation, connectivity and excellent RF performance. The SSG can be controlled via the front panel or remotely controlled via IEEE-488.2, RS-232 and 10/100BaseT Ethernet. The instrument weighs only 7 lb. and measures 10" × 10.5" × 2.75". Key specifications include a settling time of 200 µs, spurious rejection of at least 55 dB and output noise floor is –145 dBm/Hz.

dBm LLC,
Wayne, NJ (973) 709-0020,
www.dbmcorp.com.
Booth 625 **RS No. 223**

Handheld RF Power Meter

The model 3500 is a handheld RF power meter designed to make RF power measurements in both field and R&D lab environments. With a wide frequency range of 10 MHz to 6 GHz, the model 3500 is useful in a variety of applications, including test of mobile phone and cellular infrastructures, WLAN devices, RFID readers, WiMAX devices and wireless sensors. Its large dynamic range of –63 to +20 dBm enables the model 3500 to measure signals either directly from the device under test or through layers of cabling and fixtures. Price: $1500.00.



Keithley Instruments Inc.,
Cleveland, OH (800) 688-9951,
www.keithley.com.
Booth 527 **RS No. 224**

NEW WAVES

24 GHz UWB Radar Sensors

This new generation of 24 GHz ultrawideband (UWB) radar sensors is designed for military autonomous vehicles, leader/follower sensing and driver-assistance automotive applications. The short-range radar sensor is a highly-integrated "smart sensor" designed to improve safety and driver comfort functions in military and automotive applications by providing object detection and tracking up to within a few centimeters of the sensor with a range up to 30 m. These radar sensors are designed to operate in harsh weather and environmental conditions better than other sensing technologies, such as infrared devices.

M/A-COM Tyco Electronics,
Lowell, MA (978) 442-4825,
www.macom.com.
Booth 313 **RS No. 225**

Component Model Library

The Modelithics Library,™ an accurate tool set for RF and microwave designers, features several updates, including new models for active and passive devices manufactured by Avago (formerly Agilent), ATC, Advanced Power Technology (APT), Freescale, Johanson, Murata, Micrometrics, NEC, Philips and Sirenza. The new releases also offer significantly increased flexibility in pad geometry modeling.

Modelithics Inc.,
Tampa, FL (813) 866-6335,
www.modelithics.com.
Booth 643 **RS No. 227**

Inner DC Blocks

This family of RoHS compliant, DC blocks covers wireless band applications from 0.400 to 3.000 GHz. 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 making them ideal for eliminating unwanted DC voltages or surges to tower top amplifiers. Delivery: stock to two weeks. Made in the USA.

MECA Electronics Inc.,
Denville, NJ (973) 625-0661,
www.e-meca.com.
Booth 632 **RS No. 226**

Hot Switchable Relay

The 1P2T "hot switchable" relay's configuration utilizes standard type 'N' connectors and mechanical package outline. Its internal contacts employ special arc-quenching alloys and are complimented with a make-before-break switching configuration. Exceptional RF performance is rated to 8 GHz with hot switch power levels rated at 100 W CW to 2 GHz field tested beyond 100K cycles, 80 W CW to 4 GHz and 60 W CW to 8 GHz. The p/n RDL-2N3A8-HI is available to ship from stock.

RelComm Technologies Inc.,
Salisbury, MD (410) 749-4488,
www.relcommtech.com.
Booth 433 **RS No. 228**

Crimp Connectors

These two crimp connectors are designed for LMR-400 and Belden 9913 cables. The BNC, RFB-1106-I, is designed to perform to a minimum of 4 GHz and the TNC, RFT-1202-I, to a minimum of 7 GHz, dependent upon the coaxial cable used in the assembly. Both connectors feature gold-plated contacts, which can be soldered or crimped, Teflon® insulation and nickel-plated brass bodies.

RF Industries/RF Connectors Division,
San Diego, CA (800) 233-1728,
www.rfindustries.com.
Booth 439 **RS No. 229**

Power Amplifier

The RF3266 power amplifier is the latest addition to RFMD's 3G front-end portfolio targeting the Region 1, IMT Band, transmit path. With energy conservation in mind, the RF3266 incorporates the company's innovative power saving technology enabling enhanced low-power-mode efficiency while simultaneously meeting the stringent linearity requirements of HSDPA modulation. RFMD has neatly packaged this innovation into a 3 × 3 × 0.9 mm QFN package giving manufacturers the best MSL capability available in WCDMA power amplifiers. Combined with an integrated power detector, the RF3266 delivers a small, low profile solution size enabling the form factors needed to differentiate these solutions in the 3G mobile devices marketplace.

RFMD,®
Greensboro, NC (336) 664-1233,
www.rfmd.com.
Booth 513 **RS No. 230**

Low Gradient Temperature Chambers

These low gradient chambers are a replacement for constant temperature oil bath systems. The "Basic" low gradient package offers temperature gradients of ±1.0°C, and the "Ultra" low gradient chambers can achieve ±0.4°C, or better predicated on the DUT load. Both versions of Sigma's low gradient chambers operate in a temperature range of –70° to +150°C. These low gradient temperatures are achieved using Sigma's special high CFM blowers strategically positioned to maximize cross flow and turbulence in the convective airstream within the chamber interior.

Sigma Systems Corp.,
El Cajon, CA (619) 258-3700,
www.sigmasystems.com.
Booth 620 **RS No. 231**

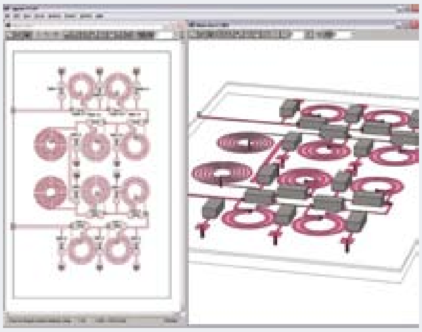
NEW WAVES

Public Safety and SMR Filter

The model CFB6-815 is a public safety and SMR filter that features a passband of 806 to 824 MHz and is ideally suited for in-building bidirectional amplifier applications that require a compact mechanical package. Isolation is specified at 90 dB at Fc ±36 MHz and the insertion loss is 1 dB. The design provides high "Q" and stable temperature performance and provides an excellent building block for compact diplexers and multiplexers. Size: 1.90" × 3.063" × 6.094".

Trilithic Inc.,
Indianapolis, IN (317) 895-3600,
www.trilithic.com.
Booth 611 ***RS No. 235***

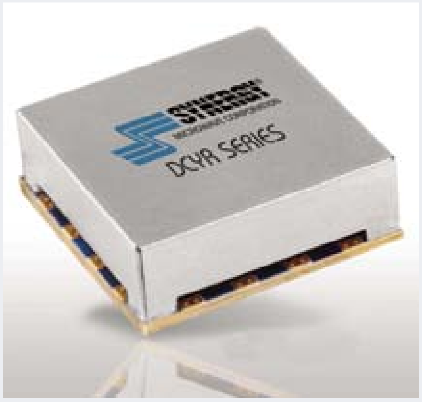
High Frequency EM Simulation



The company has recently announced the new Sonnet Suites Release 11. In Release 11, Sonnet introduces a Co-calibrated Internal Port that exhibits exceptional dynamic range, and can be used for accurate attachment points of active or passive components. The new ports also enable full co-simulation of surface-mount part models within the EM analysis environment. Sonnet also announces a redesigned and seamless GUI interface to the Agilent ADS suite.

Sonnet Software,
North Syracuse, NY (315) 453-3096,
www.sonnetsoftware.com.
Booth 619 ***RS No. 232***

Voltage-controlled Oscillator



This ultra low phase noise, broadband voltage-controlled oscillator (VCO) is designed for signal sources operating fundamentally from 200 to 600 MHz. The DCYR2060-5 is based on the company's proprietary patented and other patents pending technology, which increases bandwidth, lowers phase noise, responds to fast tuning and highly improves immunity to phase hits. The phase noise is typically –119 dBc/Hz at 10 kHz offset from the carrier and reaches the noise floor of –165 dBc/Hz at approximately 4 MHz. Size: 0.75" × 0.75" × 0.2", RoHS compliant packaging and can be delivered in tape and reel for automatic assembly processes.

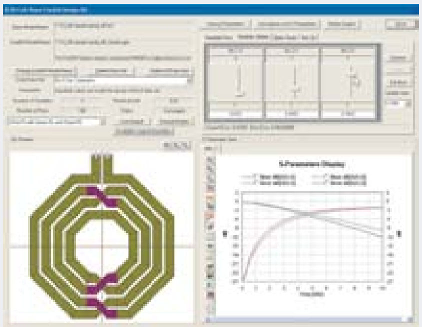
Synergy Microwave Corp.,
Paterson, NJ (973) 881-8800,
www.synergymwave.com.
Booth 319 ***RS No. 233***

Real-time Spectrum Analyzer

To address highly complex digital RF environments, the RSA6100A series of real-time spectrum analyzers offers the industry's leading combination of 110 MHz real-time bandwidth simultaneous with 73 dB spurious-free dynamic range. The RSA6100A series are the most capable and effective instruments available for solving even the most demanding digital RF test challenges. The DPX™ waveform image processor technology transforms volumes of real-time data to produce a live RF spectrum presentation that reveals previously unseen RF signals and signal anomalies.

Tektronix Inc.,
Beaverton, OR (800) 835-9433,
www.tektronix.com.
Booth 631 ***RS No. 234***

EM Simulation and Optimization Package

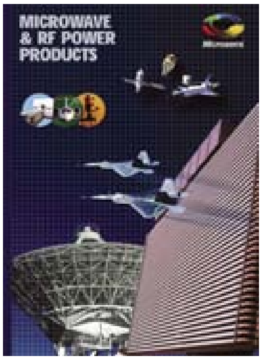


The release of IE3D V12 features a FastEM Design Kit for real-time full-wave EM synthesis; multi-fold speed improvement and multi-CPU support for improved efficiency; an equation based schematic-layout editor with Boolean operations for easy and flexible geometry editing; and lumped equivalent circuit automatic extraction and optimization for convenient circuit designs.

Zeland Software Inc.,
Fremont, CA
(510) 623-7162, www.zeland.com.
Booth 521 ***RS No. 236***

New Literature

Power Products Brochure



This 36-page brochure features the company's line of microwave PIN diodes and modules for small signal/high speed switching, large signal switching/attenuators, limiters and Schottky mixers in a variety of surface-mount and high-rel packages, plus its new line of RF power semiconductors for avionics, radar, microwave, broadband, HF/VHF/UHF communications and high voltage MOSFETs. Includes useful selector guides and case style outlines.

Microsemi Corp., Irvine, CA (949) 221-7100, www.microsemi.com.

RS No. 200

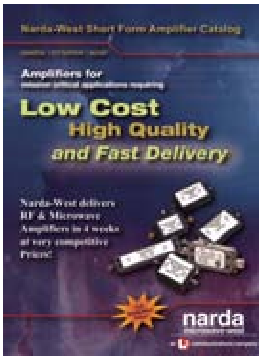
Spaceborne Products Data Sheet

This newly updated "Products for Spaceborne Applications" data sheet includes an explanation of the facilities, manufacturing flow processes, programmatic and quality requirements, as well as a listing of the company's Space Heritage since 1982. The company's emphasis is predominantly in technically challenging spaceborne requirements.

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

RS No. 201

Short Form Amplifier Brochure

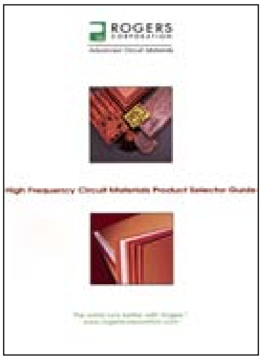


This catalog highlights the company's new amplifier product line that offers low cost, high quality and quick turnaround ("off the shelf" on some products and four weeks from time of order in most cases). These amplifiers are suitable for use in commercial, military, test equipment, prototype and laboratory applications.

Narda Microwave-West, Folsom, CA (916) 351-4500, www.nardamicrowave.com.

RS No. 202

Product Selector Guide

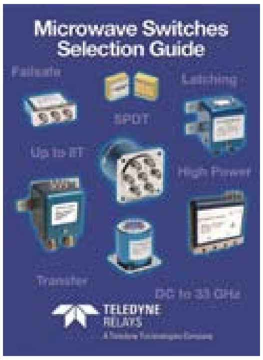


This product selector guide highlights the company's extensive selection of high frequency circuit materials for many types of applications. The materials range from low loss, others are temperature stable, some are rigid while others are suited for low cost commercial applications. The information contained in this guide assists the reader in designing with the company's laminates.

Rogers Corp., Rogers, CT (860) 774-9605, www.rogerscorporation.com.

RS No. 203

Selection Guide

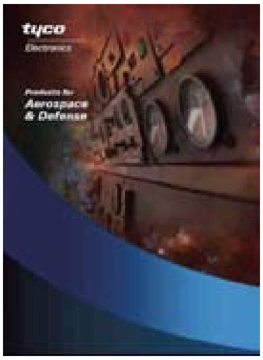


The microwave switches selection guide features 20 families of coaxial switches and relays in a tabular format. The guide provides detailed information about the company's switches and relays, which span the range from DC to 26.5 GHz and cover SPDT (single-pole, double-throw) up to SP8T and transfer switches. The brochure includes 21 listed parameters such as frequency range, coil voltage, connector type, temperature range, contact life, RF performance, available options, shock and vibration.

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

RS No. 204

Components Catalog

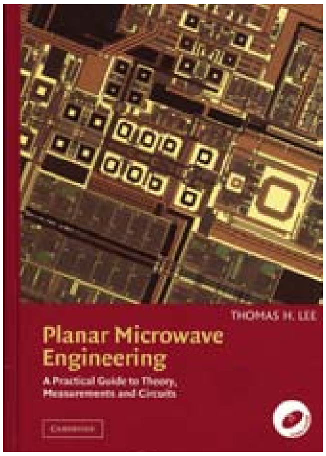


The aerospace and defense product catalog combines the company's core product offering for space, commercial aircraft, aerospace electronics, defense electronics and in-flight networking applications. The catalog provides nearly 700 pages of detailed information on products suitable for or specially designed for the aerospace and defense electronics industry.

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

RS No. 205

Planar Microwave Engineering: A Practical Guide to Theory, Measurements and Circuits



Thomas H. Lee
Cambridge University Press • 880 pages; $80, £45
ISBN: 0-521-83526-7

This book is a response to the students, hobbyists and practicing engineers who have complained about the lack of a modern reference that balances theory and practice. Chapter 1 provides a short history of RF and microwave circuits. Chapter 2 introduces some definitions and basic concepts. Chapter 3 provides a brief introduction to the Smith chart and S-parameters. Chapter 4 presents a number of impedance matching methods. Chapter 5 surveys a number of popular connectors, their domain of applications and the proper way to take care of them. Chapter 6 examines the characteristics of lumped, passive elements at microwave frequencies. The most common way of building a microwave circuit, microstrip, is introduced in Chapter 7. Chapter 8 presents several methods for making impedance measurements, ranging from time-domain reflectometry to vector network analysis. Chapter 9 is devoted to microwave diodes. Chapter 10 builds on that foundation to describe numerous mixers. Since active circuits are more interesting, Chapter 11 presents a survey of transistors, providing a somewhat unified treatment of these transistors and focusing on just two types (MOSFETs and bipolars). Chapter 12 considers how to squeeze the most of whatever transistor technology is used. Chapter 13 shifts from broadband to low noise amplification and Chapter 14 describes the principles underlying noise figure measurements. Chapter 15 shows how to produce instability to build oscillators. Chapter 16 describes phase-locked loop synthesizers. Chapter 17 analyzes the important subject of phase noise while Chapter 18 describes phase noise measurement methods. Chapter 19 describes spectrum analyzers, oscilloscopes and probes. Chapter 20 presents numerous ways to implement power amplifiers. Chapter 21 is dedicated to antennas, while Chapters 22 and 23 focus on the design of passive filters.

To order this book, contact:
Cambridge University Press
100 Brook Hill Drive
West Nyack, NY 10994-2133
(845) 353-7500

Parallel Finite-difference Time-domain Method

Wenhua Yu, Raj Mittra, Tao Su, Yongjun Liu and Xiaoling Yang
Artech House • 270 pages; $119, £72
ISBN: 1-58053-085-3

Computational electromagnetics has found broad applications in scientific research and engineering. The finite-difference time-domain (FDTD) method is well suited for analyzing problems with complex geometrical features as well as those containing arbitrarily inhomogeneous materials, but the technique places a relatively heavy burden on computer resources. One approach to circumvent this problem is to resort to a parallel processing technique. The focus of this book is on parallel implementation of the FDTD method. To provide some necessary background on the FDTD method, the reader is referred to the existing literature, where details in the background material can be found. However, some code segments are included in both the C and Fortran programming languages that are designed to help the reader understand the structure of parallel code and the programming method on which the code is based. The book is divided in two parts. In the first part, Chapters 1 to 8, the basis concepts of the 3D Cartesian FDTD method are introduced, such as the boundary conditions, near-to-far field transformation and enhancements to the FDTD, which is followed by a discussion of the parallel implementation of the FDTD method. In the second part, Chapters 9 and 10, the basic concepts of the body of revolution (BOR) FDTD method are introduced. The topics of absorbing boundary condition, near-to-far-field transformation, singular boundary condition and simulation technique for the partially symmetric problem are discussed, followed by the parallel implementation of the BOR/FDTD method. Finally, two appendices introduce the basic routines pertaining to the MPI library, its installation, the configuration of this library and that of the MPICH, and how to set these up on a PC cluster.

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

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3	Advanced Switch Technology	179	613-384-3939	613-384-5026	http://mwj.hotims.com/7966-3
4	Aeroflex/Inmet, Inc.	132	734-426-5553	734-426-5557	http://mwj.hotims.com/7966-4
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