May 2001

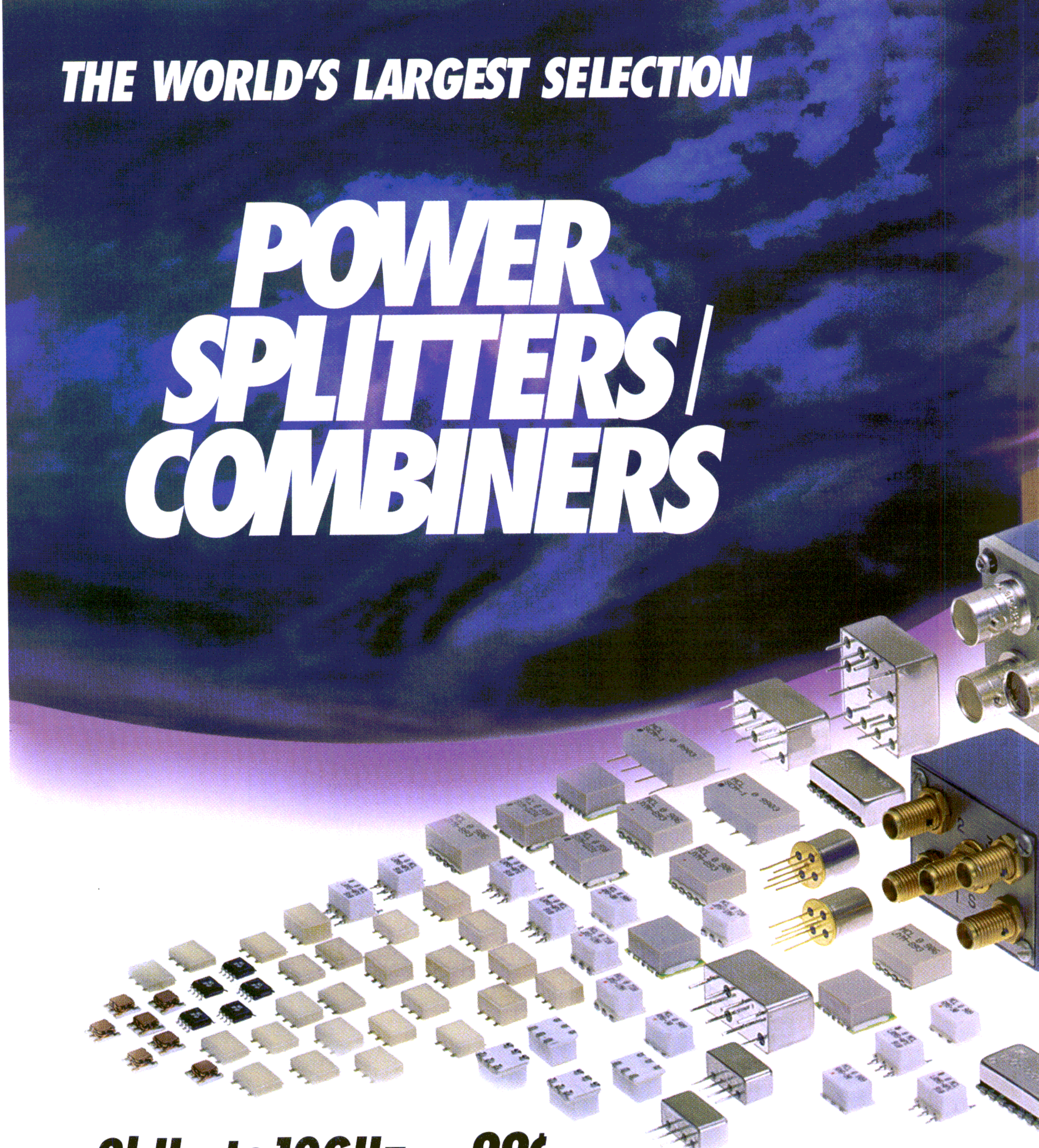
Applied MICROWAVE & WIRELESS

www.amwireless.com

Product Focus
New Products On Display at the MTT's IMS2001

Circuit Design
A Broadband Coupled-Line N-Way Power Combiner/Splitter

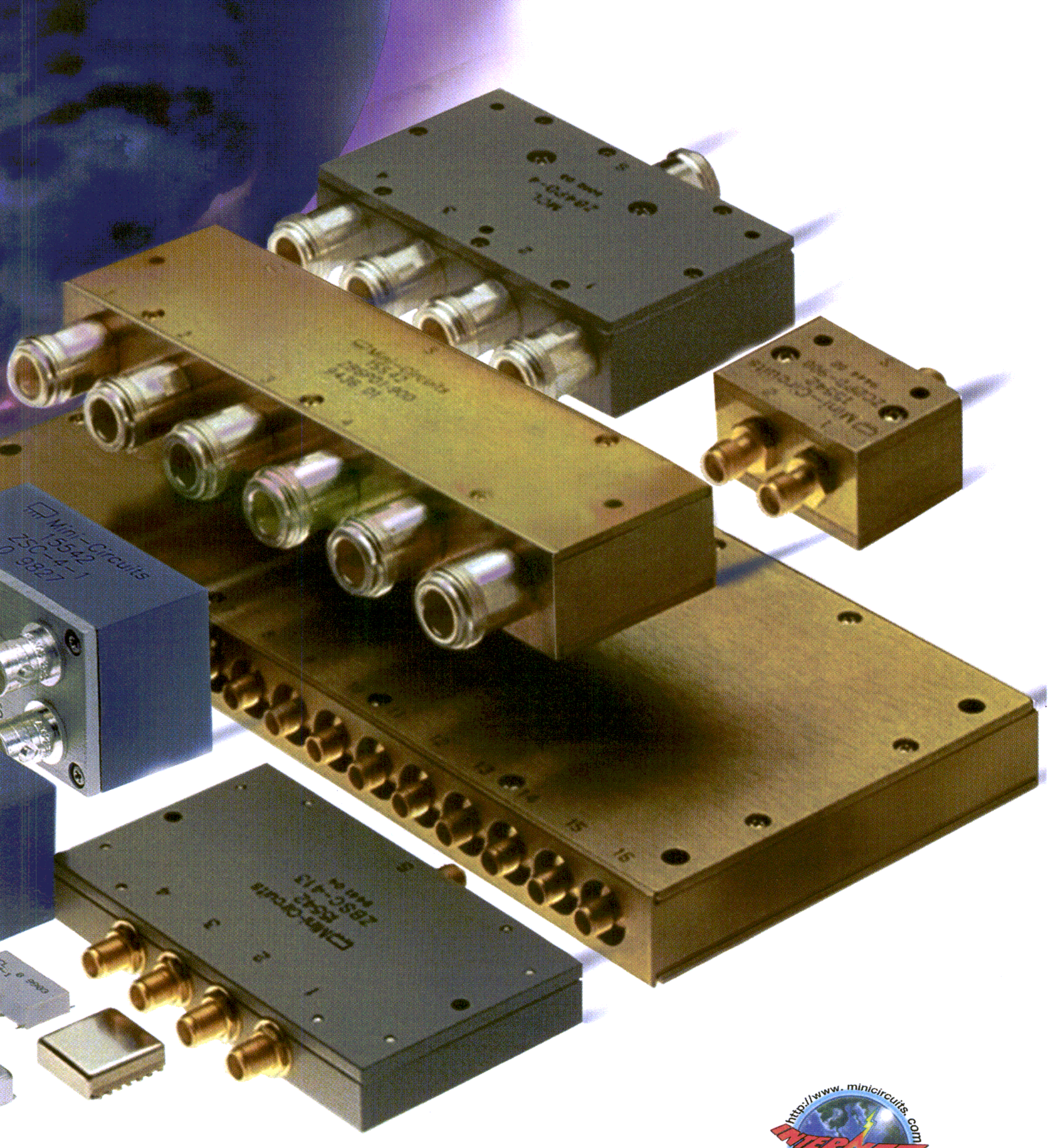
Market Update
Wireless Internet Services — How Much, How Fast?



2kHz to 10GHz *from* 99¢

Choose from over 550 standard off-the-shelf models from 2way and 3way to 48way; 0°, 90°, and 180°; 50 and 75 ohms covering 2kHz to 10GHz. Mini-Circuits will also supply your special needs and custom designs such as wider bandwidths, higher isolation, lower insertion loss and phase matched ports...all at catalog prices with rapid turnaround time. Case styles include surface mount, plug-in, flat pack, and coaxial connectorized... and custom case styles are no problem! Super-miniature and ultra-low profile surface mount units provide excellent solutions in cellular communications, cable systems, and countless wireless applications. And all units come with a 1 year guarantee and skinny 4.5 sigma performance repeatability unit-to-unit and production run to production run. Add fast delivery, unsurpassed applications support and value pricing, and the decision is easy. Call Mini-Circuits today!

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



see us on the web
http://www.minicircuits.com

Mini-Circuits®

US 101 INT'L 111
CIRCLE READER SERVICE CARD

P.O. Box 350166, Brooklyn, New York 11235-0003 (718) 934-4500 Fax (718) 332-4661 ***INTERNET*** http://www.minicircuits.com

For detailed specs on all Mini-Circuits products refer to • 760- pg. HANDBOOK • INTERNET • THOMAS REGISTER • MICROWAVE PRODUCT DATA DIRECTORY • EEM

ISO 9001 *CERTIFIED*

F 194 Rev B

See us at MTT-S — Booth #333

PACKAGING

VARIETY

Applied MICROWAVE & WIRELESS

May 2001
Vol. 13 No. 5

C O N T E N T S

TECHNICAL FEATURES

PRODUCTS & TECHNOLOGIES

Applied MICROWAVE & WIRELESS

May 2001
Vol. 13 No. 5

PRODUCTS & TECHNOLOGIES

MARKET UPDATE

DEPARTMENTS

Publisher
Gary A. Breed
Associate Publisher
Scott Spencer
Director of Operations
Dennis Ford
Managing Editor
Shannon O'Connor
Senior Consulting Editor
Dr. Joseph F. White
Editorial Advisors
Dr. Peter Staecker
Dr. James C. Rautio
Dr. Frederick H. Raab
Dr. Les Besser
Dr. Peter Rizzi
Dr. T.B. Ramachandran
Ben Robinson
Art Director
Joan Clipp
Assistant Editor
Kristine Phillips
Associate Editor
Martina Voigt
Data Manager
Nancy Breed
Office Assistant
Stephanie Hayden
Advertising Sales — East
Scott Spencer
Tel: 603-472-8261
Fax: 603-471-0716
Advertising Sales — West
Tim Burkhard
Tel: 707-544-9977
Fax: 707-544-9375
Classified & Spotlight Ads, Reprints and List Rentals
Aileen Kronke
Tel: 770-449-6774
Fax: 770-448-2839
New Subscriptions and Address Changes
Mail: 630 Pinnacle Court
Norcross, GA 30071
Fax: 770-448-2839
Back Issues
Tel: 770-449-6774

BPA INTERNATIONAL®

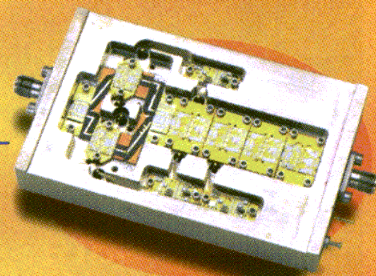
NOBLE PUBLISHING
Applied Microwave & Wireless
Noble Publishing Corporation
630 Pinnacle Court
Norcross, GA 30071
Tel: 770-449-6774
Fax: 770-448-2839
E-mail: amw@amwireless.com
www.amwireless.com

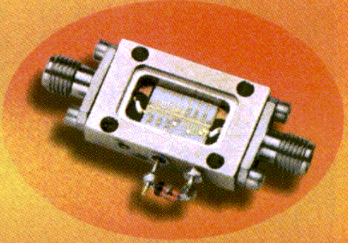
AMPLIFIERS

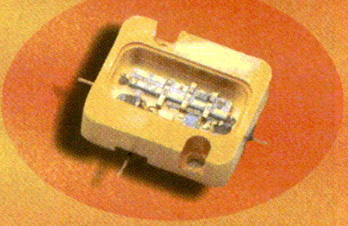
FOR EVERY APPLICATION

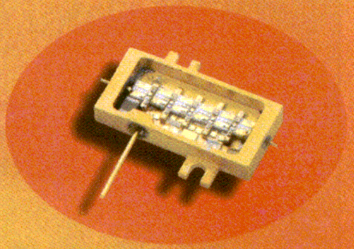
- HIGH RELIABILITY
- COMPETITIVELY PRICED
- QUICK DELIVERY

Model#	Freq Range (GHz)	Gain (dB min)	N/F (dB max)	Gain Flat (+/-dB)	1 dB comp. pt. (dBm min)	3rd Order ICP min	VSWR In/Out max	DC Current (mA)
MEDIUM POWER AMPLIFIERS (UP TO 2 WATTS)								
JCA01-P01	0.5-1.0	25	3.5	1	30	40	2.0:1	250
JCA12-P01	1.0-2.0	32	3	1	30	40	2.0:1	800
JCA34-P01	3.7-4.2	30	3	1	30	40	2.0:1	750
JCA56-P01	5.9-6.4	30	3	1	30	40	2.0:1	850
JCA78-P01	7.9-8.4	30	4	1	30	40	2.0:1	900
JCA812-P02	8.3-11.7	40	5	1.5	33	40	2.0:1	1700
JCA910-P01	9.5-10.0	30	4	1	33	40	2.0:1	1300
JCA1011-P01	10.7-11.7	30	4	1	30	40	2.0:1	950
JCA1819-P01	18.1-18.6	30	5	1	27	37	2.0:1	800
RADAR & COMMUNICATION BAND LOW NOISE AMPLIFIERS								
JCA23-302	2.2-2.3	30	0.8	0.5	10	20	2.0:1	80
JCA34-301	3.7-4.2	30	1	0.5	10	20	2.0:1	80
JCA56-502	5.4-5.9	50	1	0.5	10	20	2.0:1	160
JCA78-305	7.25-7.75	27	1.2	0.5	13	23	2.0:1	100
JCA910-305	9.0-9.5	27	1.4	0.5	13	23	1.5:1	150
JCA1112-305	11.7-12.2	27	1.5	0.5	13	23	1.5:1	150
JCA1415-305	14.0-14.5	26	1.6	0.5	13	23	1.5:1	160
JCA1819-305	18.1-18.6	22	2.0	0.5	10	20	1.5:1	160
JCA2021-600	20.2-21.2	30	2.2	1	13	23	1.5:1	240
TRI-BAND AMPLIFIERS (5.85 TO 14.5)								
JCA514-201	5.85-14.5	8	7	1.5	10	20	2.0:1	100
JCA514-300	5.85-14.5	14	6	1.5	10	20	2.0:1	150
JCA514-302	5.85-14.5	22	6	1.5	20	30	2.0:1	350
JCA514-400	5.85-14.5	25	6	1.5	10	20	2.0:1	250
JCA514-403	5.85-14.5	32	6	1.5	23	33	2.0:1	500
JCA514-501	5.85-14.5	35	6	1.5	16	26	2.0:1	375
JCA514-503	5.85-14.5	41	6	1.5	23	33	2.0:1	500
ULTRA-BROAD BAND AMPLIFIERS (2.0 TO 18 GHZ)								
JCA218-200	2.0-18.0	15	5	2.5	10	20	2.0:1	90
JCA218-300	2.0-18.0	23	5	2.5	10	20	2.0:1	110
JCA218-400	2.0-18.0	29	5	2.5	10	20	2.0:1	150
JCA218-500	2.0-18.0	39	5	2.5	10	20	2.0:1	180









JCA's catalog can now be downloaded from the Web at www.jcatech.com

JCA TECHNOLOGY

DELIVERY IN 2-4 WEEKS ARO

4000 Via Pescador, Camarillo, CA 93012
Phone: (805) 445-9888 • Fax: (805) 987-6990
Email: jca@jcatech.com

Circle 49

See us at MTT-S — Booth #2611

Kudos to Schools that Get EE Students Excited about RF and Microwaves

By Gary A. Breed
Publisher

I recently attended the annual advisory board meeting and technical conference of the Wireless and Microwave (WAMI) program at the University of South Florida (USF). This is one of only a few programs in the country with a strong connection between the RF/microwave/wireless industry and academia — at the *undergraduate* level as well as with graduate research.

Although the industry/education connection is extremely important, the most heartening aspect of the WAMI program is how it reaches students at a practical level. The WAMI Lab is a required undergraduate lab, with a curriculum that combines RF system design principles with lots of hands-on work interconnecting and measuring building-block RF components. Students learn first-hand about the difference between frequency domain and time domain, linear and non-linear behavior, modulation, frequency conversion and other concepts that are at the core of this area of engineering.

Another program with a similar undergraduate hands-on approach is in place at the other end of the country. Although it has a reputation at the highest levels of academic research, California Institute of Technology (Cal Tech) also reaches undergrads with courses that teach the basic principles of RF. Cal Tech's class has been built around a simple amateur radio transceiver kit. As students learn the concepts of RF systems, they build and test a portion of a real radio. At the end of the class, they have the most tangible understanding possible: a working RF transmitter/receiver. If they have an amateur radio license (some students get them during the term), they can then complete the experience with actual on-the-air conversations with other ham radio operators.

I am writing this on the 40th anniversary of Yuri Gagarin's history-making flight into earth orbit. This event is a reminder of both the excitement of space exploration and the urgency of developing technological superiority during the Cold War. It was 1961 and public awareness of technology was at its peak. I was 12 years old and already involved in radio, receiving my first amateur radio license later the same year.

Today, that kind of excitement over technology just doesn't exist. Young potential engineers have grown up using technology without really investigating how it works. Hopefully, more schools will develop hands-on lab programs like those at USF and Cal Tech to help students discover what many of us found out 40 years ago — RF is fun and fascinating!

Calendar

CONFERENCES

MAY

May 13-16, 2001
Fourth Conference on Electromagnetic Wave Interaction with Water and Moist Substances
Information: Dr. Klaus Kupfer
Tel: +49 3643 564361; Fax: +49 3643 564 202 or 204
E-mail: klaus.kupfer@mfpa.de
Internet: http://www.mfpa.de

May 13-17, 2001
International Symposium on Electromagnetic Theory
Victoria, British Columbia, Canada
Information: Secretariat
Tel: 613-993-9431; Fax: 613-993-7250
E-mail: URSI-B2001@nrc.ca
Internet: http://www.nrc.ca/confserv/URSI-B2001

May 20-25, 2001
2001 IEEE MTT-S International Microwave Symposium
Phoenix, AZ
Information: LRW Associates
Tel: 704-841-1915; Fax: 704-845-3078
E-mail: lrwassoc@carolina.rr.com
Internet: http://www.ims2001.org

May 22-24, 2001
Automated Manufacturing Exposition
Greenville, SC
Information: Marlene Cobia
Tel: 803-779-7123, x. 17; Fax: 803-779-7167
E-mail: mcobia@tecinconline.com
Internet: http://www.am-expo.com

May 22-24, 2001
Military Sensing Symposium 47th Annual Tri-Service Radar Symposium
Laurel, MD
Information: Lorraine Kohler
E-mail: lorraine.kohler@mail1.monmouth.army.mil
Internet: http://csdnta.erim-int.com/iria/iriscp.nsf

May 25, 2001
57th ARFTG Microwave Measurements Conference
Phoenex, AZ
Information: David Walker
Tel: 303-497-5490; Fax: 303-497-3970
E-mail: dwalker@boulder.nist.gov
Internet: http://www.arftg.org

May 28-June 1, 2001
51st Electronic Components & Technology Conference
Lake Buena Vista, FL
Information: ECA
Tel: 703-907-7547
Internet: http://www.ec-central.org

JUNE

June 4-9, 2001
Fourth International Kharkov Symposium — Physics and Engineering of Millimeter and Submillimeter Waves (MSMW'2001)
Kharkov, Ukraine
Information: Prof. Vladimir M. Yakovenko
Tel/Fax: +380 572 441105
E-mail: msmw2001@ire.kharkov.ua
Internet: http://www.ire.kharkov.ua/MSMW2001/msmw.htm

June 6-8, 2001
IEEE International Conference on Third Generation Wireless and Beyond (3Gwireless'01)
San Francisco, CA
Information: H. Janny
E-mail: janny@delson.org
Internet: http://www.3Gwireless.com/3Gwireless01

June 6-8, 2001
IEEE Frequency Control Symposium & PDA Exhibition
Seattle, WA
Information: ECA
Tel: 703-907-7547
Internet: http://www.ec-central.org

June 6-8, 2001
2001 Virginia Tech Symposium on Wireless Personal Communications
Blacksburg, VA
Information: Jenny Frank
Tel: 540-231-2971
E-mail: mprg@vt.edu

June 11-14, 2001
The IEEE International Conference on Communications (ICC2001)
Helsinki, Finland
Information: TSG-Congress Ltd.
Kaisaniemenkatu 3B12
Helsinki, Finland FIN-00100
Tel: +358 9 628 044; Fax: +358 9 6667 675
E-mail: icc2001@tsgcongress.fi
Internet: http://www.icc2001.com

June 18-20, 2001
Topical Workshop on Flip Chip Technology
Austin, TX
Information: IMAPS
Tel: 703-758-1060; Fax: 703-758-1066
E-mail: imaps@imaps.org

Calendar

SHORT COURSES

Besser Associates

RF Wireless System Design Fundamentals
Mountain View, CA . . . . . .May 7-9, 2001
Mountain View, CA . . . . . .August 22-24, 2001
Bluetooth: Operation and Use
Mountain View, CA . . . . . .May 10-11, 2001
3G Made Simple
Mountain View, CA . . . . . .May 14, 2001
RF and Wireless Made Simple
Mountain View, CA . . . . . .May 15-16, 2001
San Diego, CA . . . . .July 12-13, 2001
Mountain View, CA . . . . . .August 7-8, 2001
RF and Wireless Made Simple II
Mountain View, CA . . . . . .May 17-18, 2001
Mountain View, CA . . . . . .August 9-10, 2001
Applied RF Techniques I
Mountain View, CA . . . . . .June 4-8, 2001
Mountain View, CA . . . . . .August 13-17, 2001
RF Test Equipment Operation (laboratory course)
Mountain View, CA . . . . . .June 12, 2001
RF Testing for the Wireless Age (laboratory course)
Mountain View, CA . . . . . .June 13-15, 2001
Receiver and Transmitter Circuit Design
Mountain View, CA . . . . . .June 18-22, 2001
Frequency Synthesis and Phase-Locked Loop Design
Mountain View, CA . . . . . .June 25-26, 2001
RF CMOS Design
Mountain View, CA . . . . . .June 28-29, 2001
Moutnain View, CA . . . . . .August 23-24, 2001
Fiber Optics Made Simple
San Diego, CA . . . . .July 10-11, 2001
Advanced RF Power Amplifiers Techniques
Mountain View, CA . . . . . .July 10-13, 2001
Short Range Wireless and Bluetooth
San Diego, CA . . . . .July 10-13, 2001
DSP Made Simple for Engineers
Mountain View, CA . . . . . .July 16-18, 2001
RF Transceiver Design
Mountain View, CA . . . . . .July 24-27, 2001
Wireless Digital Communications
Mountain View, CA . . . . . .July 30-August 3, 2001
Practical Design of Integrated and Discrete Wireless Circuits
Mountain View, CA . . . . . .August 20-22, 2001
Information: Annie Wong, Tel: 650-949-3300; Fax: 650-949-4400; E-mail: info@bessercourse.com; Internet: www.bessercourse.com.

RTT Programmes Limited

SMR/PMR Design
London, England . . . . . . .May 14-16, 2001
Information: Lorraine Gannon, Tel: +44 181 844 1811; Fax: +44 181 751 2616; E-mail: seminars@rttsys.com; Internet: www.rttsys.com.

TTi Technology Training Initiative (Tustin Technical Institute, Inc.)

Mechanical Design for Product Reliability
Santa Barbara, CA . . . . . .May 3-4, 2001
Grounding and Shielding for EMI/EMC/ESD
Ottawa, ON, Canada . . . .May 7-9, 2001
DSP: Digital Signal Processing
Ottowa, ON, Canada . . . .May 9-11, 2001
Digital Data Acquisition
Lexington Park, MD . . . . .May 21-23, 2001
Telemetry
Lexington Park, MD . . . . .May 24-25, 2001
Fundamentals of Vibration for Test
Santa Barbara, CA . . . . . .June 4-6, 2001
Package and Product Fragility and Mechanical Shock
Santa Barbara, CA . . . . . .June 6-8, 2001
Vibration and Shock Test Control Techniques
Santa Barbara, CA . . . . . .June 11-13, 2001
Information: Brian P. Slatery, Tel: 805-682-7171; Fax: 805-687-6949; E-mail: brian@ttiedu.com; Internet: www.ttiedu.com.

Agilent Technologies

RF & Microwave Fundamentals
Winnersh, UK . . . . .May 15-17, 2001
Network Analysis Measurements
Winnersh, UK . . . . .May 29-30, 2001
Spectrum Analysis Measurements
Winnersh, UK . . . . .May 31-June 1, 2001
Information: Tracey Bull, Tel: +44 118 9276741; Fax: +44 118 9276862; E-mail: tracey_bull@agilent.com.

Henry Ott Consultants

Electromagnetic Compatibility Engineering
East Hanover, NJ . . . . . . .May 15-17, 2001
Information: Henry Ott Consultants, Tel: 973-992-1793; Fax: 973-533-1442.

Northeast Consortium for Engineering Education

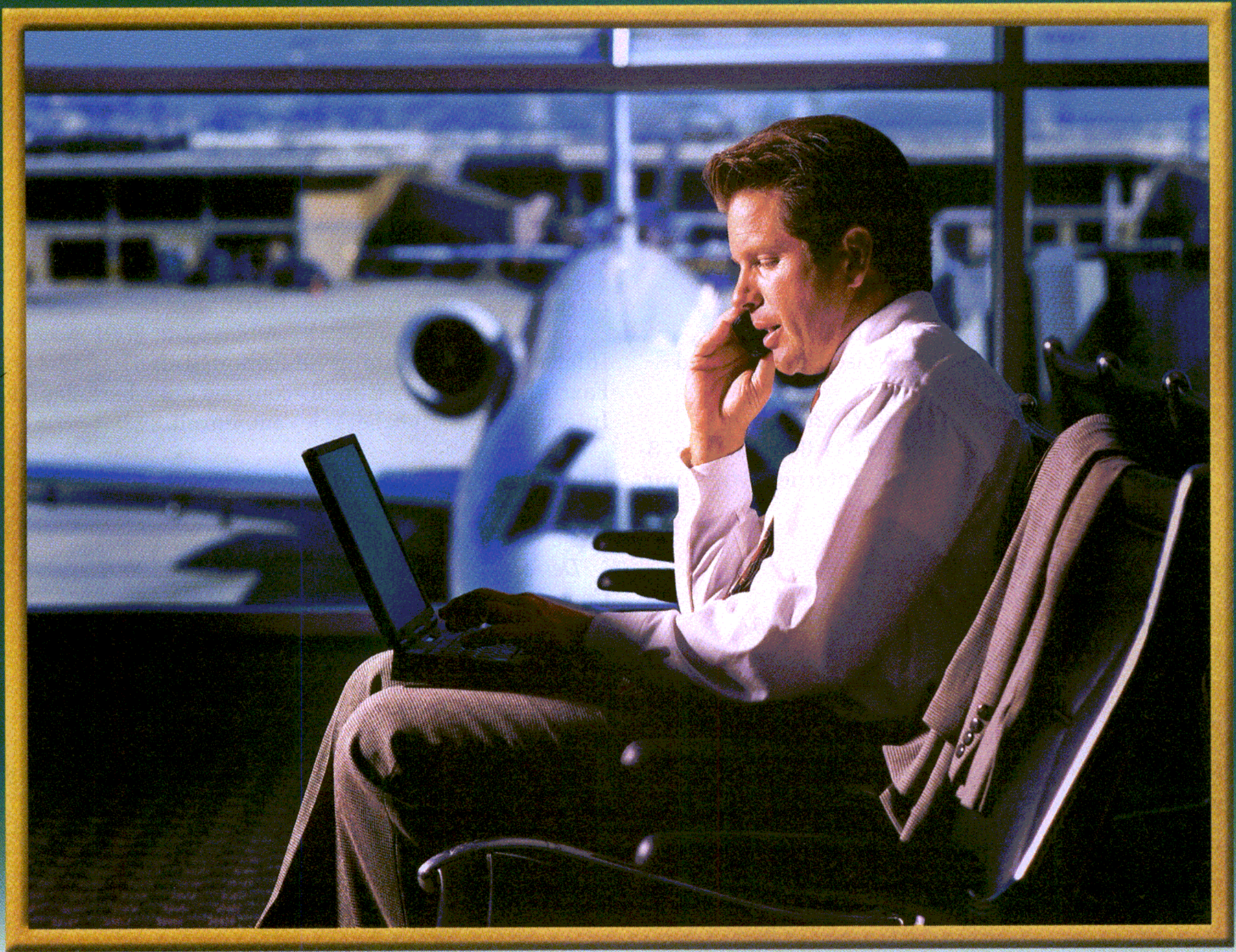
Antennas: Principles, Design and Measurements
Orlando, FL . . . . .May 21-24, 2001
Information: Kelly Brown, Tel: 407-892-6146; Fax: 407-892-0406; E-mail: stcloudof1@aol.com; Internet: www.usit.com/antenna.

Georgia Institute of Technology

RF and Wireless Principles and Practice
Atlanta, GA . . . . .May 21-25, 2001
Information: Georgia Tech Distance Learning, Continuing Education and Outreach, Tel: 404-894-2547; Fax: 404-894-7398; E-mail: conted@gatech.edu; Internet: www.conted.gatech.edu.

California State University, Northridge

Far-Field, Near-Field, Compact Ranges and Anechoic Chambers



Tough Environment. Top Performance.

Stanford Microdevices has expanded its industry-leading silicon-germanium (SiGe) amplifier line with two new power devices ideally suited for driver-amplifier functions in wireless equipment operating in the most demanding signal environments.

SOT-89 Package

Offering the wireless system designer typical GaAs linearity at silicon prices, these cost-effective heterojunction bipolar transistor (HBT) units produce high output IP3 performance across the DC-3000 MHz frequency band. SGA power devices are excellent choices for wireless infrastructure driver amplifiers, CATV amplifiers, as well as wireless-data and wireless-local-loop amplifiers. Stanford Microdevices delivers the power you need for your toughest operating environment.

For more information, visit us at stanfordmicro.com.

Part Number	Frequency Range (MHz)	Device Voltage (V)	Id (mA)	P1dB (dBm)	IP3 (dBm)	Gain @ 1 GHz (dB)	Gain @ 2 GHz (dB))	NF @ 1 GHz (dB)
SGA-9189	DC-3000	5	180	26	39	18	12	2.5
		3	165	22.5	35	18	12	2.2
SGA-9289	DC-3000	5	270	28	41	18	11	2.9
		3	315	26	39	17	11	2.6

*Data at 2 GHz unless otherwise noted

STANFORD MICRODEVICES

Circle 25

See us at MTT-S — Booth #445

www.stanfordmicro.com • 800.764.6642

Northridge, CA . . . . .June 12-15, 2001
Information: Shirley Lang, Tel: 818-677-2146; Fax: 818-677-5982; E-mail: shirley.lang@csun.edu; Internet: www.ecs.csun.edu/~crs/mam/.

University of Missouri-Rolla
Grounding and Shielding Electronic Systems
Boston, MA . . . . .June 19-20, 2001
Circuit Board Layout to Reduce Noise Emission and Susceptibility
Boston, MA . . . . .June 21, 2001
Information: Sue Turner, Tel: 573-341-6061; Fax: 573-341-4992; E-mail: suet@umr.edu; Internet: www.umr.edu/~conted.

University of Wisconsin at Madison
Basic Telephony and Digital Switching
Madison, WI . . . . .June 19-22, 2001
Engineering and Planning Telecommunication Local Loop Facilities
Madison, WI . . . . .June 28-29, 2001
Information: Katie Peterson, Tel: 1-800-462-0876; Fax: 608-263-3160; E-mail: custserv@epd.engr.wisc.edu; Internet: http://epd.engr.wis.edu.

University of California at Berkeley Extension
MOSFET Physics, Technology and BSIM Models
Berkeley, CA . . . . .June 20-22, 2001
Low-Power Circuits and Systems for Digital Wireless Communications
Berkeley, CA . . . . .June 28-29, 2001
Advanced Digital Integrated Circuits
Berkeley, CA . . . . .August 1-3, 2001
Information: Continuing Education, Tel: 510-642-4111; Fax: 510-642-0374; E-mail: course@unex.berkeley.edu; Internet: www.unex.berkeley.edu/enroll.

International Institute of Connector and Interconnection Technology (IICIT)
Basic Connector Technology
Detroit, MI . . . . .July 16-17, 2001
Connector Failure Mechanisms
Detroit, MI . . . . .July 19, 2001
Connector Testing
Detroit, MI . . . . .July 18, 2001
Bandwidth, High Frequency and RF Effects
Detroit, MI . . . . .July 19, 2001
Information: Suzanne Romeo, Tel: 1-800-854-4248; E-mail: sromeo@iicit.org; Internet: www.iicit.org.

CALLS FOR PAPERS

Antenna Measurement Techniques Association 23rd Annual Meeting and Symposium

October 21-26, 2001 — Denver, CO

Topics: Theory and applications of measurement techniques; new absorber designs; data acquisition and processing methods for test ranges; measurement standards and laboratory comparisons; antennas for automobiles, satellites, cellular and PCS; EMI/EMC/PIM chamber design, measurements and instruments; radio astronomy antenna measurement requirements; testing of millimeter- and submillimeter-wave antennas; new instruments for testing; diagnotic methods; advances in indoor/outdoor test ranges; imaging techniques; phase-array antenna testing; testing of low-frequency antennas; and aircraft and ship antenna measurements.

Authors should submit a 200-word abstract with name, organization, address, telephone number and e-mail address to:

AMTA Technical Coordinator
E-mail: technical-coordinator@amta.org

Deadline: May 4, 2001

Antenna Applications Symposium

September 19-21, 2001 — Monticello, IL

Topics: Arrays, packaging, interconnects, fixed and mobile communications, vehicular antennas, signal processing antennas, ultrawideband arrays, photonics and reconfigurable antennas.

Authors should submit a 200-word abstract with all contact information to:

Daniel H. Schaubert
Electrical & Computer Engineering
113 Knowles Engineering Building
University of Massachusetts
Amherst, MA 01003
Tel: 413-545-2530
Fax: 413-545-4652
E-mail: allerton@ecs.umass.edu

Deadline: May 11, 2001

Specialist Meeting on Microwave Remote Sensing

November 6-8, 2001 — Boulder, CO

Topics: Ground-based remote sending of the atmosphere and ocean; satellite- and aircraft-based remote sensing of the atmosphere, ocean, land surface and vegetation; radiometric and radar polarimetry, including imaging; radiometric and radar calibration; advanced instrument techniques; special campaigns and field experiments (TRMM); and radiometric/radar modeling of scattering, emission and radiative transfer.

Authors should submit three copies of a one-page abstract (approximately 500 words) in English, typed single spaced using 12 point Times Roman or equivalent typeface, with 1-inch margins and 0.14-inch paragrah indention. The author name, affiliation, address, telephone, fax and e-mail should be centered directly below the title, with the corresponding author noted with an asterisk (*). Mail, fax or e-mail as a Microsoft Word or plain text attachment.

Submit to:

Dr. Ed R. Westwater
Cooperative Institute for Research in the Environmental Sciences (CIRES)
University of Colorado
NOAA, Environmental Technology Laboratory
325 Broadway, MS R/E/ET1
Boulder, CO 80303
Tel: 303-497-6527
Fax: 303-497-3577
E-mail: Ed.R.Westwater@noaa.gov
Internet: http://www.etl.noaa.gov/mrs01

Deadline: May 15, 2001

IMAPS Brazil Technical Symposium 2001

August 1-3, 2001 — Sao Paulo, Brazil

Topics: Ball grid arrays, chip scale packaging, flip chip technology, fine pitch soldering, chip-on-board, desgin process and characterization technology, lead-free developments, conductive adhesives and new inorganic materials developments, quality and reliability, thick film technoloyg, MEMS, design for manufacturability, quality and reliability, economics and marketing, market and market treands and technology roadmaps and trends for electronic assembly (personal computer, wireless and telecommunication products).

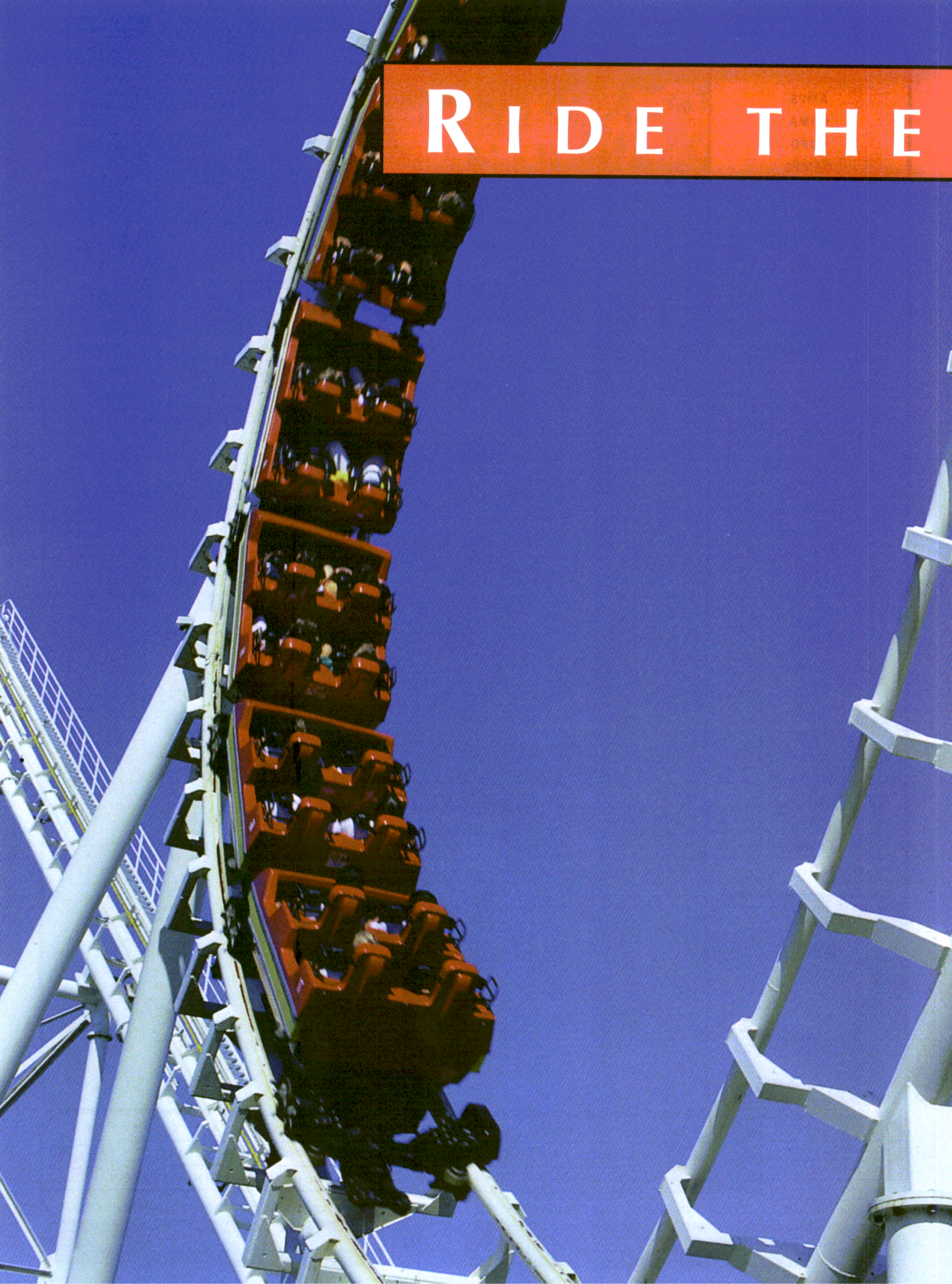
Authors should submit completed papers in English to:

Marcio Biasoli
Electronic Packaging Laboratory
National Institute of Technological Information
Tel: +55 19 3746 6062
Fax: +55 19 3289 7875
E-mail: biasoli@im.cti.br
Internet: http://www.imaps.org

Deadline: May 25, 2001

Companies, organizations and institutions may submit information for our Conference and Short Courses Calendar to Shannon O'Connor via e-mail at amw@amwireless.com

More events listed at www.amwireless.com


RIDE THE

BRIEFS

• The Motorola Applications Global Network (MAGNET) program has launched a series of online symposia targeted to software application developers. The site's interactive forums will provide training and seminars on topics such as Wireless Application Protocol (WAP) and General Packet Radio Service (GPRS), as well as application development information. The forums are available at MAGNET Web site, www.motorola.com/developers/wireless.

• M/A-COM, a unit of Tyco Electronics, has launched a Web site for its OpenSky Wireless Private Network at www.opensky.com. The site includes both product and ordering information.

• UltraRF has announced the establishment of an application engineering design center in Twyford, England. The center, targeted to European customers, will be equipped to make complex RF measurements on the entire range of UltraRF bipolar and LDMOS RF power transistors and modules.

• UMC has broken ground for a 300-mm semiconductor wafer fab in Singapore. The facility, to be operated by UMC affiliate UMCi Pte Ltd., will have a total capacity of 40,000 wafers per month. Production will focus on large die-size system-on-chip chips and is scheduled to begin in 2003.

• Microsemi Corp. has opened a new facility in Irvine, CA, to house its corporate offices and an advanced semiconductor design center. The design center will focus on Microsemi's lines of power management, RF and optoelectronic circuit designs.

• ST Assembly Test Services Ltd. has opened a new test development center in Surrey, England. The facility provides dedicated test engineering development and a quick ramp up to volume testing, designed to assist the company's customers in Europe.

Ericsson, Chartered demonstrate Bluetooth™ transceiver chip

Ericsson Microelectronics and Chartered Semiconductor Manufacturing have announced the successful implementation of a high-performance 0.25-micron radio frequency RF CMOS chip. Designed by Ericsson, this Bluetooth transceiver was verified as fully functional at first-pass design and first silicon.

Ericsson's present Bluetooth offering is based on the company's 0.35-micron BiCMOS technology. Using this same chip architecture, Ericsson developed the Bluetooth transceiver chip with Chartered's RF CMOS technology, enabling a smooth transition from BiCMOS to a foundry-based RF CMOS process at 0.25 microns. In future applications, the target is 0.18-micron system-on-chip solutions.

The jointly developed 0.25-micron process offers a core voltage of 2.5 volts and extremely high performance, with peak f_T of 39 GHz and f_{max} of 45 GHz. The 0.25-micron RF CMOS chip is optimized for Bluetooth protocol 1.1, Class 2 products. A design kit is now available.

Ericsson, based in Stockholm, Sweden, supplies microelectronic components for wireless applications, broadband communications, fixed access and optoelectronics. Chartered, based in Singapore, operates five semiconductor fabrication facilities at its headquarters.

New logic process offered by UMC

UMC has introduced a new logic process option that combines high speed and low power logic transistors into a single-chip design. The process, called Fusion, was designed using the company's WorldLogic℠ system-on-chip platform, which integrates a low-k dielectric material at the 0.13-micron generation (SiLK, k = 2.65).

The WorldLogic platform enables a variety of design options, such as analog and RF transistors, high-performance passive components and embedded DRAM and SRAM, to be assembled together with logic in a system-on-chip design. This process produces a performance advantage of up to 30 percent over other processes for wire speed delay and power reduction.

UMC, based in Sunnyvale, CA, manufactures wafers and ICs for semiconductor applications.

Ashvattha announces new silicon technology

Ashvattha Semiconductor has announced a new technology using a 0.25-micron silicon germanium BiCMOS process that integrates multiple complete RF front ends on a single chip. The chip includes wireless, GPS and Bluetooth™ transmitters and receivers, as well as Ashvattha's multi-mode synthesizer and isolation mechanisms that prevent the several on-chip radios from interfering with each other.

Ashvattha Semiconductor, Inc., based in Jacksonville, FL, provides highly integrated RF chips for wireless telecommunications markets.

Alpha launches switch/filter technology

Alpha Industries has introduced a new switch/filter technology that integrates multiple RF semiconductor components into a single, module-based platform. Products manufactured using this technology are based on the Alpha Integration Platform™, a proprietary technique for the design, simulation, packaging and testing of RF modules.

Alpha Industries, Inc., based in Woburn, MA, provides RF integrated circuit-based solutions, including semiconductors and ceramic components, for the broadband and wireless communications markets.

Companies, organizations and institutions may submit information for our News section to: Shannon O'Connor, *Applied Microwave & Wireless*, 630 Pinnacle Court, Norcross, GA, 30071; Fax: 770-448-2839; E-mail: amw@amwireless.com.

Agilent announces partnerships

Agilent Technologies has announced partnerships with two companies, one focused on silicon germanium product development and the other targeting the aerospace-defense and satellite markets.

Agilent and Atmel Corporation have teamed up to offer a complete design kit for Agilent's Advanced Design System (ADS) software. Based on Atmel's advanced silicon germanium (SiGE) bipolar technology, the design kit helps engineers speed up the development of RFICs for mobile communications.

Under a separate agreement, Agilent has selected SED Systems, a division of Calian Ltd., as a provider of custom test systems that use Agilent test instruments for the aerospace-defense and satellite markets. The designation named SED a Premier Solution Partner, which are providers who are certified by Agilent as best-in-class systems integrators in specific industries and application areas.

Agilent, based in Palo Alto, CA, provides services in communications, electronics and other markets.

General Semiconductor introduces new MOSFET production process

General Semiconductor has announced the production of power MOSFETs with a new proprietary silicon process using 200 million cell per square inch technology.

This new generation of GENFET™ yields a four-fold improvement over current cell density, enabling the production of smaller, highly efficient silicon MOSFET devices. They will be manufactured using General Semiconductor's 0.35 micrometer trench process technology, with initial samples to be available in the second quarter of 2001.

General Semiconductor, Inc., based in Melville, NY, manufactures power semiconductor components for the automotive, computer, consumer and wireless telecommunications equipment markets.

ASME to hold MEMS seminar

The American Society of Mechanical Engineers (ASME) has scheduled a two-day seminar on Micro-Electro Mechanical Systems (MEMS) on May 31 and June 1 at the Sheraton Universal Hotel in Universal City, CA.

The seminar will combine discussion of optical switching systems with breakthroughs in manufacturing, as well as the industry's business and marketing demands. Panel discussions, workshops and lectures on these subjects are planned.

Registration information is available from the ASME at 1-800-843-2763 or online at www.asme.org.

BUSINESS AND FINANCE

Air Force awards Harris contract for field radios

Harris Corporation has been awarded an $11 million contract from the U.S. Air Force's Electronics System Center to equip its Tactical Air Control Party squadrons with Falcon™ II AN/PRC-117F(C) multiband, multimission manpack radios. This is the second order Harris has received for the radio systems within 18 months.

The lightweight radios are designed to allow soldiers on the ground to request air support using satellite communications and to direct aircraft using VHF and UHF modes, using just one radio.

Harris provides product, systems and services for wireless, broadcast, network support and government markets.

▲ **Harris will provide radios designed for use by soldiers in the field under a contract with the U.S. Air Force.**

Nokia to supply 3G mobile network in Australia

Nokia has announced an agreement with Cable & Wireless Optus that provides for the supply of a comprehensive third-generation (3G) mobile network in Australia. The agreement covers the supply of 3G Radio Access Network (RAN) for both WCDMA and EDGE, as well as the complete 3G Circuit and Packet Core network.

The initial value is estimated at more than $452 million ($900 million Australian) over seven years.

Under the agreement, Nokia will provides its full end-to-end 3G solution, covering applications, charging, security, network management, packet and circuit switched core infrastructure and radio access network. Nokia's existing GSM BSS infrastructure supply agreement with Optus will also be continued and extended.

Nokia, based in Helsinki, Finland, supplies mobile phones and mobile, fixed and IP networks worldwide.

Motorola wins network contract

Motorola's Global Telecom Solutions Sector has received a $29 million contract from Jordan Mobile Telephone Services to expand the Global System for Mobile Communications (GSM) digital wireless network in Jordan.

Under the agreement, Motorola will install additional cellular base station equipment and increase switching capacity for the existing network, which serves Amman, Aqaba and several other cities.

Motorola, based in Schaumburg, IL, provides semiconductors, integrated communications solutions, embedded electronic systems and components.

P-Com receives broadband orders

P-Com has announced orders in excess of $5 million from Airstream Broadband Corporation for its point-to-multipoint broadband wireless access system.

The fixed wireless system, operating in the 10 GHz band, will be deployed in the Philippines.

P-Com Inc., based in Campbell, CA, manufactures point-to-multipoint, point-to-point and spread spectrum wireless access systems and provides related services for the telecommunications market.

Andrew announces NEC order

Andrew Corporation has received a $1.369 million order from NEC for wireless infrastructure equipment.

Under the agreement, Andrew will supply its HELIAX® VXL5 coaxial cable and connectors, base station antennas for Specialized Mobile Radio (SMR), and ValuLine® and terrestrial microwave antennas. NEC will use the equipment for its buildout of Nextel Communications' all-digital wireless network in Brazil.

Andrew, based in Orland Park, IL, supplies communications systems equipment and services for wireless, broadcast and common carrier.

Merrimac receives network order

Merrimac Industries has announced an initial order from Astrium to provide a low-frequency, highly integrated redundant distribution network. The network will be used for system clocks in the digital signal processors on board the three Inmarsat I-4 satellites Astrium is building. The total value of this and future orders for the systems is projected at $1 million.

The satellite system is being designed to support a Broadband Global Area Network services, planned for launch in 2004, that will allow high-speed internet access for notebook computers and handheld devices.

Merrimac, based in West Caldwell, NJ, manufactures RF and microwave components, assemblies and modules for the wireless telecommunications industry.

DMC Stratex announces orders

DMC Stratex Networks has received $500,000 in follow-on orders from Crown Castle UK Ltd. for its Altium and XP4 products. The orders were placed under a two-year provider agreement between the companies.

DMC Stratex Networks, based in San Jose, CA, provides products and solutions for cellular and broadband

A New Broadband Coupled-Line N-Way Power Combiner/Splitter

Simple interconnected coupled transmission lines provide greater bandwidth than conventional designs

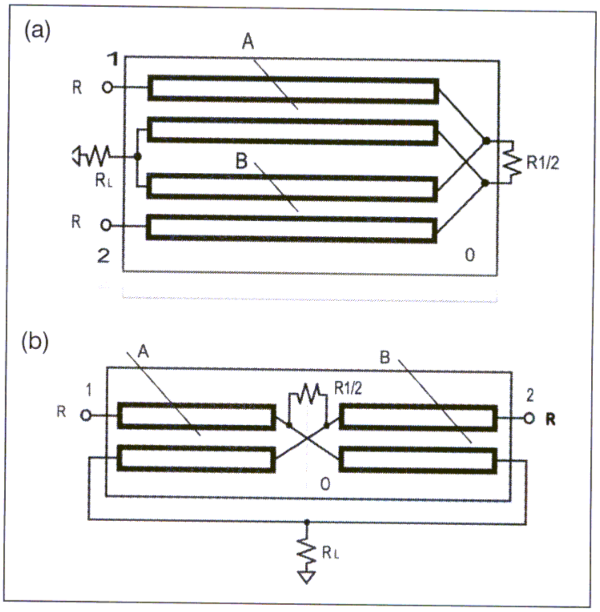
By Simon Y. London
Advanced Power Technologies, Inc.

In this article, a new broadband N-way power combiner/splitter is proposed and analyzed. This coupled transmission line combiner uses two-conductor quarter-wavelength coupled lines and achieves about twice the bandwidth of previous devices within the same overall length. Multi-conductor coupled lines, as well as lumped or distributed elements, and coupled-line sections can be used to further extend the bandwidth up to a decade or more. The needed coupling coefficients are easily realizable. A significant decrease in size over conventional designs enables its realization using MEMS technology, as well as at high power.

Typically, at microwave frequencies, broadband operation requires enlarged overall device size. For example, the use of two or more sectional Wilkinson power combiners is needed if the operational bandwidth is to exceed two octaves [1, 2]. As the number of sections increases, the insertion losses and complexity of device also increase. Similarly, the increase in the number of combining amplifiers complicates overall structure, making its realization difficult for high power or MEMS technology. In an N-way and M-sectional structure, there are N × M transmission lines and N × M isolating resistors, if N > 2 (M resistors if N = 2).

In recent years, other devices have been developed that achieve significantly broader bandwidth in a reasonable size. For example, a two-way power combiner (hybrid) has been described that has a two-octave bandwidth and occupies an area of about $\lambda/2 \times \lambda/2$ at center frequency [3].

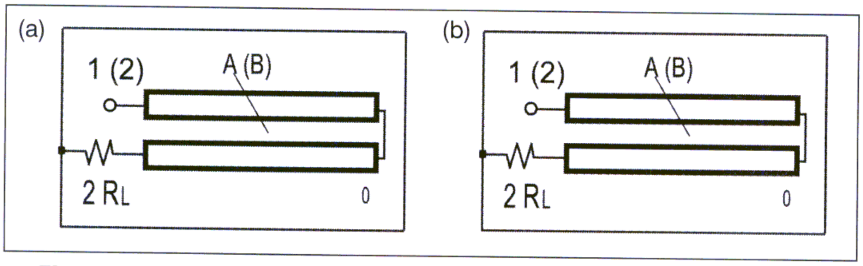
In the combiner/divider presented here, the size and insertion loss limitations are circumvented by the effective use of quarter-wavelength coupled transmission lines.



▲ **Figure 1. (a) Two-way, two-conductor coupled transmission line power combiner; (b) with vertical line of symmetry.**

Performance of simple combiners

The simplest version of the coupled transmission line two-way power combiner considered below is shown in Figure 1(a) [4]. It consists of two identical quarter-wavelength coupled transmission lines A and B, with respect to common ground 0, load resistance R_L and isolating resistor R1/2. Due to the symmetry with respect to input ports 1 and 2, it is preferable to analyze this circuit using the well-known even-odd modes approach. To make this analysis clear, redraw the circuit shown in Figure 1(a) in the form shown in Figure 1(b), which is typical for analysis of circuits with simple symmetry.



▲ **Figure 2. (a) Even-mode decomposition circuit and (b) odd-mode decomposition circuit.**

For equal magnitude and in-phase sources at ports 1 and 2, the isolating resistor R1/2 can be short-circuited. The operating circuit for each source is shown in Figure 2(a). For equal magnitude and out-of-phase sources at ports 1 and 2, the crossed conductors at the line of symmetry could be replaced by a 1:–1 ideal transformer, according to Bartlett bisection theorem [5]. The corresponding operating circuit is shown in Figure 2(b).

The first circuit, Figure 2(a), is known as a meander-line impedance transformer [6]. It defines the output reflection coefficient of combiner, or the operating in-phase reflection coefficient, at each of ports 1 and 2. For this combiner and for all that will be considered in this article, we neglect the losses in lines and assume that phase velocities are the same for all modes of propagation in the coupled transmission lines.

In the simplest case, when the transformation ratio of this meander-line transformer is equal 1:1, we have $R_L = R/2$. This is a well-known phase shifter (all-pass circuit), i.e., the even-mode reflection coefficient $\Gamma_+ = 0$. For this particular case, the bandwidth of the combiner is limited theoretically only by the isolation between ports 1 and 2, as defined by circuit Figure 2(b). The common case isolation between ports 1 and 2 is defined as

$$a_{12} = 20\log\frac{2}{|\Gamma_+ - \Gamma_-|}\ \text{dB} \qquad (1)$$

where Γ_- is the odd-mode reflection coefficient defined by circuit Figure 2(b). When $\Gamma_+ = 0$,

$$a_{12} = 20\log\frac{2}{|\Gamma_-|}\ \text{dB} \qquad (1a)$$

Condition $\Gamma_+ = 0$ will be satisfied if each coupled transmission line is symmetrical, and

$$R = \sqrt{Z_e \times Z_0} \qquad (2)$$

where Z_0 is the odd-mode characteristic impedance and Z_e is the even-mode characteristic impedance of the symmetrical coupled line [1, 2]. To minimize $|\Gamma_-|_{max}$, only one parameter (Z_0 or Z_e) could be varied, since the second one is defined by (2). For practical reason, it is important to know the correlation between Z_e, Z_0 and coupling coefficient of lines [1, 2].

$$k = \frac{Z_e - Z_0}{Z_e + Z_0} \qquad (3)$$

Using Equation (2), we find

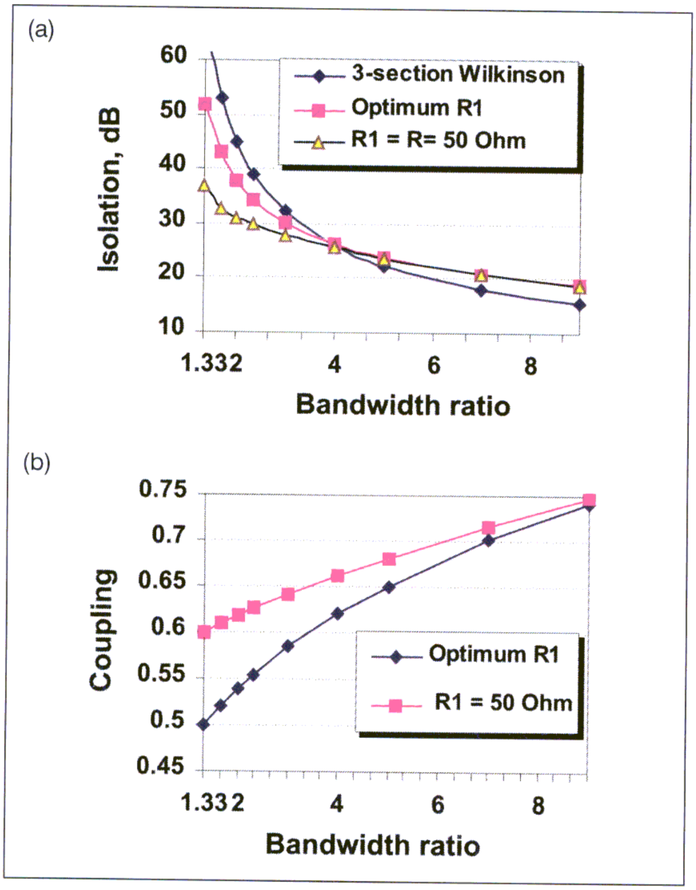
$$k = \frac{Z_e^2 - R^2}{Z_e^2 + R^2} = \frac{R^2 - Z_0^2}{R^2 + Z_0^2} \qquad (4a)$$

or

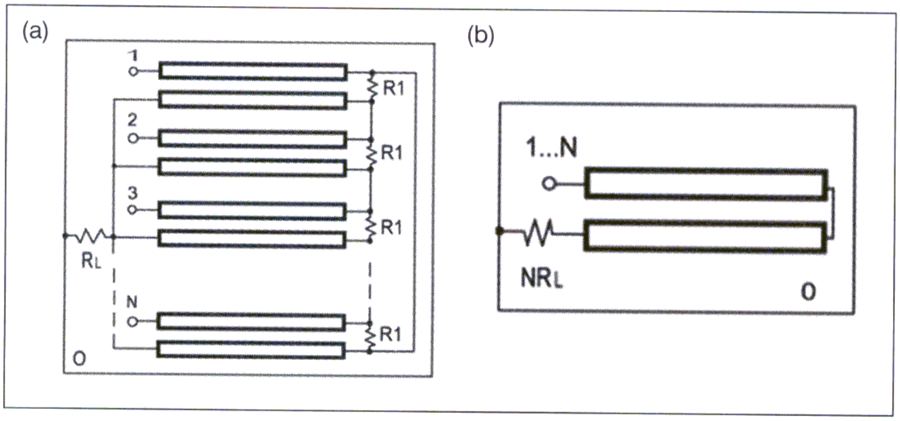
$$Z_e = R\sqrt{\frac{1+k}{1-k}},\ Z_0 = R\sqrt{\frac{1-k}{1+k}} \qquad (4b)$$

The second variable parameter is the value of isolating resistor R1.

For the circuit shown in Figure 1(a), which should satisfy Equation (2), the optimum values of R1 and of



▲ **Figure 3. Optimized characteristics of a two-way combiner; (a) isolation; (b) coupling.**



▲ **Figure 4. (a) Single-section N-way combiner with two-conductor coupled lines; (b) in-phase decomposition circuit.**

the line impedances for any given bandwidth ratio, $\alpha = f_{max}/f_{min}$, can be obtained numerically and analytically as well. Since numerical solutions are simpler for more complex circuits, only results of numerical solutions will be presented. The software GENESYS Version 6.5 from Eagleware Corporation has been used as a suitable tool for optimization of such circuits.

The procedure of characteristics calculation for all considered combiners includes the first step, in-phase (or output) VSWR minimization, and the second step, isolation maximization, using constraints on line parameters defined in the first step and freedom in the isolating elements.

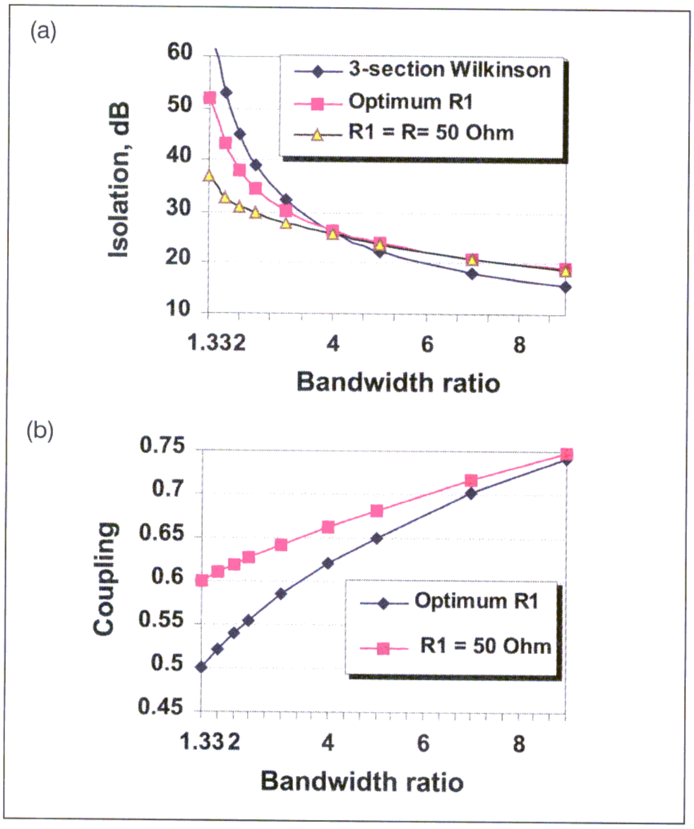
The results of optimization for circuit Figure 1 when $R = 2R_L = 50$ ohms are shown in Figure 3. These curves show that for bandwidth ratios above four, where the isolation becomes critical, the new combiner (a structure about one third the size of a three-section Wilkinson) achieves better performance. At a bandwidth ratio below four, there is non-significant penalty in isolation, but this is high in any case.

The basic Figure 1(a) design can be extended to an N-way combiner in a straightforward way. An N-way combiner with identical two-conductor coupled lines is shown in Figure 4(a). In the particular case of Figure 1(a), two resistors R1 are connected in parallel and shown as R1/2

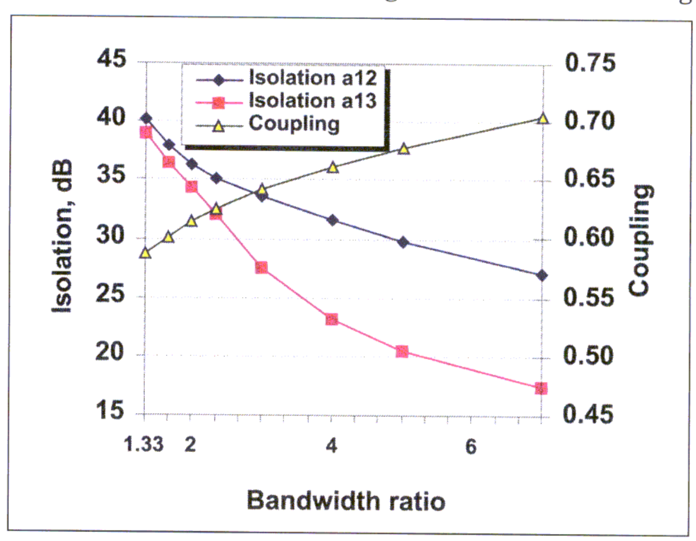
The in-phase mode decomposition circuit shown in Figure 4(a) corresponds to Figure 2(a) for N = 2. Decomposition circuits for N – 1 modes analogous to the odd-mode for N = 2 also exist. They correlate to Figure 2(b) but are not presented, due to the necessity of specific explanation away from the aim of this article, and because they are not used directly in numerical optimization.

The optimized characteristics of a single-section, three-way combiner for the particular case $R_L = R/3$ (typically $R = 50$ ohms) are shown in Figure 5. Similar results of optimization for a four-way combiner are shown in Figure 6.

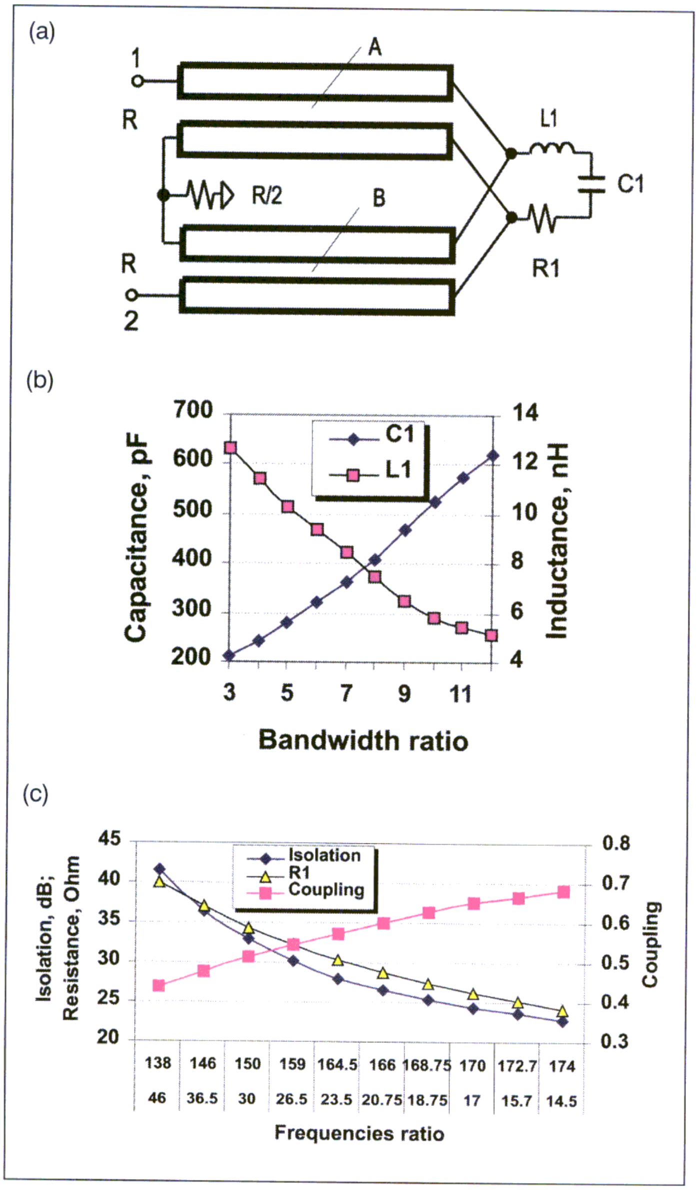
In both cases (N = 3 and N = 4), only a small effect in isolation will be seen using non-standard isolating



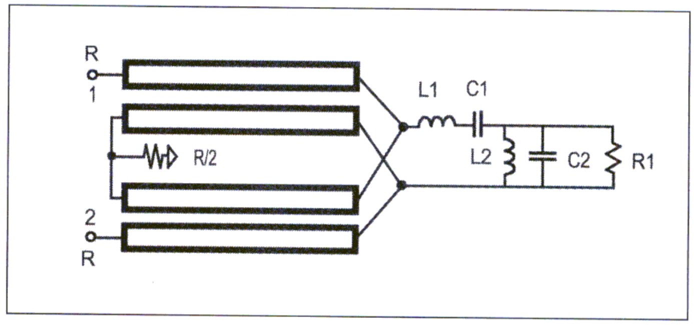
▲ **Figure 5. (a) Characteristics of isolation ($a_{12} = a_{23} = a_{13}$) for a three-way combiner and (b) the corresponding coupling coefficient.**



▲ **Figure 6. Characteristics of isolation ($a_{12} = a_{23} = a_{34} = a_{41}$; $a_{13} = a_{24}$) and coupling coefficient for a single-section four-way combiner with $R_L = R/4$ and R1 = R.**



▲ **Figure 7. Two-way combiner with (a) series LC-correction; (b) LC values; (c) characteristics.**



▲ **Figure 8. Two-way combiner with second order band-pass LC-correction.**

resistors when R1 ≠ R, assuming typical impedance at inputs R = 50 ohm. The optimum value of R1 is varied with bandwidth ratio.

In most practical cases, it is preferable to have impedances at all ports (inputs and output) to be equal. This means that the power combiner should affect an internal impedance transformation. The price for this additional property is narrowed bandwidth, which is true for the Wilkinson design and others.

Simple combiners with correction

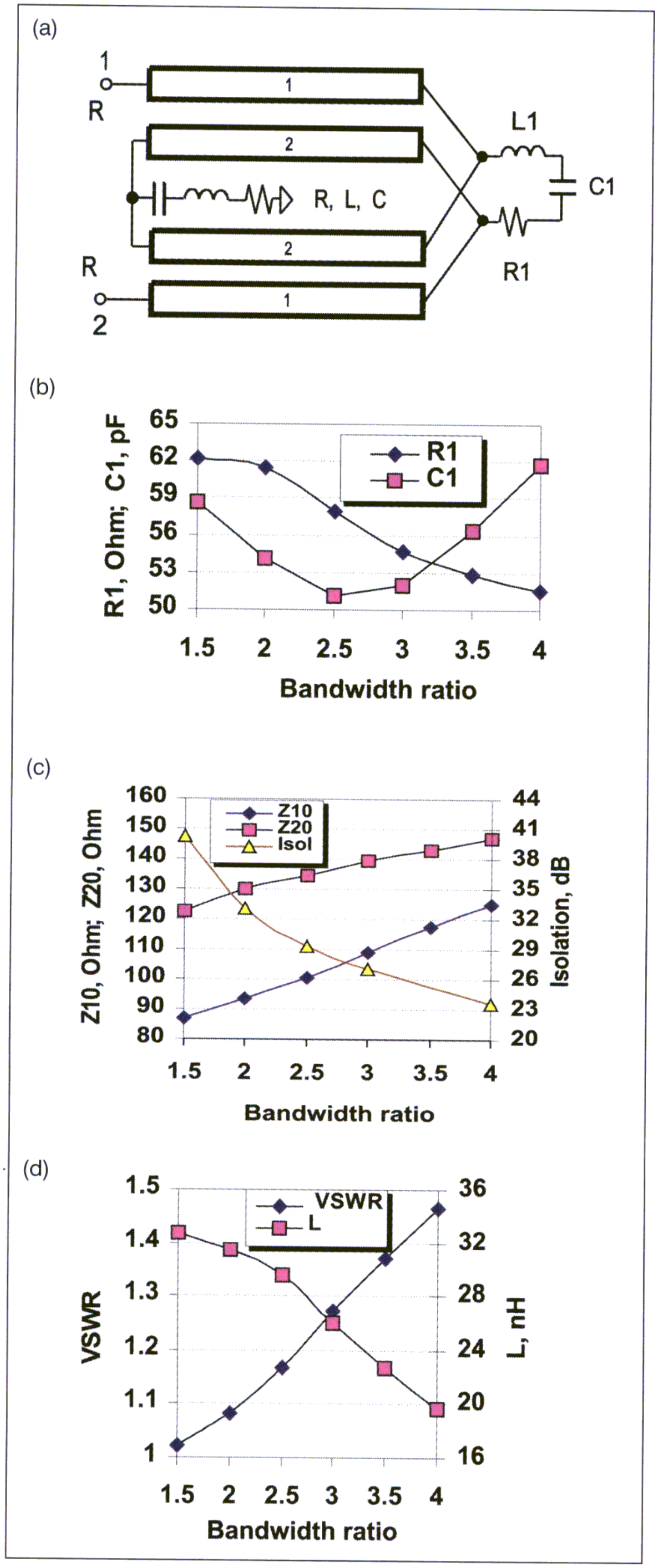
Simple correction networks effectively provide extended operating bandwidth [7]. In particular, a series LC-circuit may be connected with isolating resistors. This type of correction can be used also for increasing the isolation between inputs of an N-way combiner. An example of a two-way combiner with this LC-correction is shown in Figure 7. In this example, R = 50 ohms, and the electrical length of symmetrical coupled transmission line (for even and odd modes) equals 90 degrees at a central frequency of f_0 = 100 MHz. The values of elements L1, C1 and R1 for any central frequency f_0 and R could be calculated using a typical procedure.

For optimum performance, the operating frequency bands with lumped correcting elements are slightly offset to lower frequencies relative to frequency bands without correction (arithmetical symmetry with respect to the quarter-wavelength frequency of the conductors of the coupled line). Instead of LC-elements, open-circuited at the far end, a low-impedance transmission line could be used. In this case, the isolation is superior and a frequency offset is not necessary. A more complicated isolating circuit also provides a further increase of operating bandwidth. For example, the circuit shown in Figure 8 has bandwidth close to 1:20, assuming R_L = $R/2$. This type of correction can also be used for N-way combiners. For simplicity, the common ground plate is not discussed in this article.

The additional beneficial effect of these isolation-correcting circuits is that they decrease the coupling coefficient between line conductors, and this simplifies practical realizations. Compare, for example, Figure 5(b) and Figure 7(c) for equal bandwidth ratios.

For all considered combiners with symmetrical coupled lines, a well-developed 3-dB coupler's technology can be used. At that time, in the most common practical case, when load impedance and impedances at all inputs are equal, considered combiners should have internal impedance transformation that results in significantly narrowed operating bandwidth. The performances can be improved if additional series LC-circuit are connected to the load, as shown in Figure 9(a).

In the case of internal impedance transformation, each two-conductor line is non-symmetrical, and we numerate conductors defining corresponding independent characteristic impedances: $Z_{10} = 1/Y_{10}$, $Z_{12} = 1/Y_{12}$, $Z_{21} = 1/Y_{21}$ ($Z_{12} = Z_{21}$), and $Z_{20} = 1/Y_{20}$. These imped-



▲ **Figure 9. (a) Two-way combiner with equal port impedances and LC correction circuits; (b) values of isolating elements; (c) characteristic impedances and isolation; and (d) in-phase VSWR and load inductance L.**

ances are interconnected in the π-circuit, and in the same manner corresponding transmission lines are interconnected at both ends. It may be any real non-negative values, because it is a property of characteristic admittances Y_{10}, $Y_{12} = Y_{21}$ and Y_{20}.

For symmetrical coupled lines, $Z_{10} = Z_{20} = Z_e$ and

$$Z_{12} = R\sqrt{\frac{1-k^2}{k}}$$

Figure 9(b-d) shows the results of optimization for the case R = 50 ohm, when the electrical length of the coupled line equals 90 degrees at the center frequency f_0 = 100 MHz, and for arithmetical symmetry of the lower and upper bands frequencies relative to f_0 = 100 MHz. Correcting LC-elements (in nH and pF) are related as

$$\text{L1} \times \text{C1} = \text{L} \times \text{C} = 2533 \qquad (5)$$

which corresponds to a resonant frequency of f_0 = 100 MHz. Some effect can be achieved using offset in frequencies, as was illustrated for the circuit shown in Figure 7(a). Alternative combinations of VSWR and isolation also take place for different characteristic impedances: Z_{10}, Z_{12} and Z_{20}.

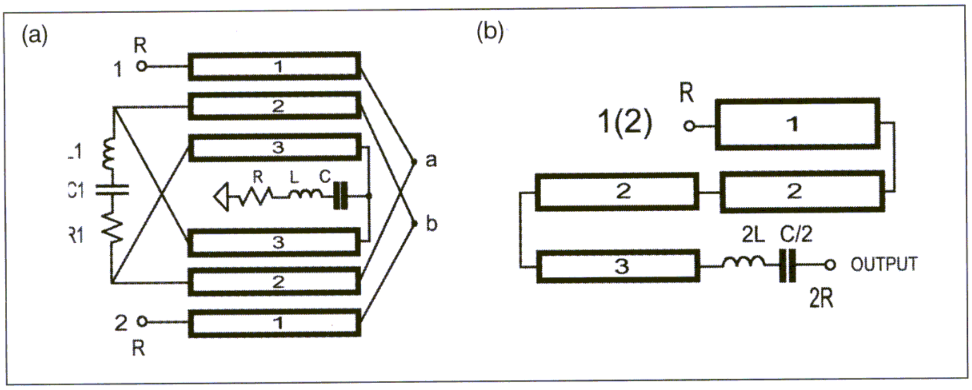
In real designs, there are usually some stray series inductances for connecting to the load and to the isolating resistors. With additional series capacitors, these inductances could play a positive role, if properly adjusted. In any case, there is a significant decrease in bandwidth as a price for an internal impedance transformation.

Besides correction by lumped or distributed elements applied to single section N-way combiners with two-conductor coupled lines, there are other options, such as increasing the number of sections, as is commonly used for Wilkinson combiners or increasing the number of conductors in the coupled lines. In addition, for high bandwidth ratios (as in the case of Figure 8), a broadband transmission-line impedance transformer that is much more compact compared to multiple quarter-wavelength transformer can be used instead of built-in impedance transformation in combiner.

Examples

Compact design can be obtained using three- or multi-conductor coupled transmission lines. Figure 10(a) illustrates a two-way combiner that consists of one quarter-wavelength three-conductor coupled lines with LC-correction and provides equal input and load impedances. An even-mode decomposition circuit is shown in Figure 10(b) for the simplest case in which each three-conductor coupled line has coupling exists only between the adjacent conductors. This circuit defines VSWR at each input (or output VSWR) for in-phase operation. This circuit is a two-step meander-line impedance transformer with additional LC-circuit.

Figure 11(a-c) shows results of optimization for certain values of coupling impedances Z_{12} and Z_{23}, 50-ohm impedances at all ports and central frequency 100 MHz (90 degrees of lines conductors). Inductive elements are defined from (5). Better performance provides additional resistor connected between nodes "a" and "b," as well as offset central frequency, as shown in Figure 7.



▲ **Figure 10. (a) Two-way combiner with 3-conductor coupled lines and (b) its even-mode decomposition circuit.**

Broader bandwidth can be achieved if instead of LC-elements series connected to the load, additional two-way Wilkinson section is used, as shown in Figure 12(a).

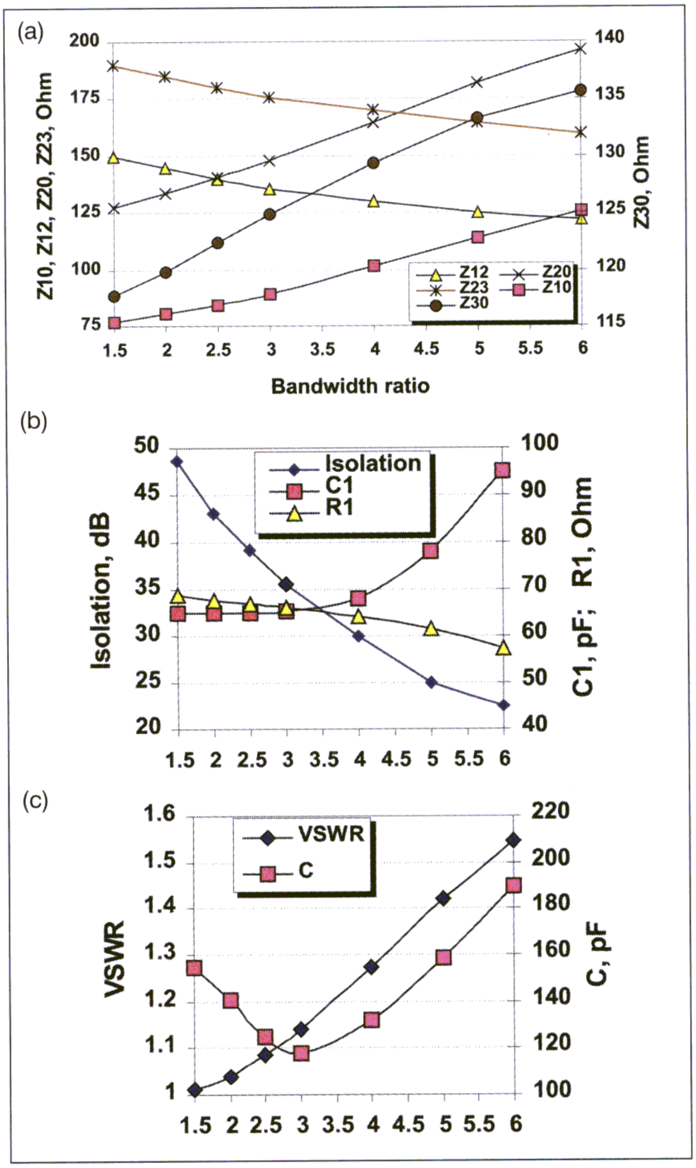
The even-mode decomposition circuit is the same as shown in Figure 10(b), when a single transmission line replaces series LC elements. For a full circuit, as in Figure 12(a), different criteria of optimization could be applied. One result, as a compromise between in-phase VSWR and isolation, is shown in Figure 12(b-d). For this particular case, R = 50 ohms, Z_{30} = 100 ohms, R1 = 150 ohms and center frequency equals 100 MHz. Values of C1 are defined by (5). Other solutions also exist.

Similar results could be achieved in two-section combiner with two-conductor coupled lines in each section. Besides, this type of combiner with symmetrical coupled lines, i.e., without internal impedance transformation (and matched) provides, in particular, 20 dB isolation at bandwidth ratio four octaves, 26 dB at three octaves and 42 dB at two octaves. In addition to Figure 3 and Figures 5 through 8, this demonstrates that without internal impedance transformation, multi-octave bandwidth could be achieved in a simple design.

Conclusion

Novel N-way coupled-line power combiners/splitters are proposed and briefly analyzed. They are based on the use of coupled meander-line impedance transformers (or phase shifters) as in-phase operating (even-mode decomposition) circuits. This approach provides broad bandwidth and relatively small size by using two- and multi-conductor coupled transmission lines.

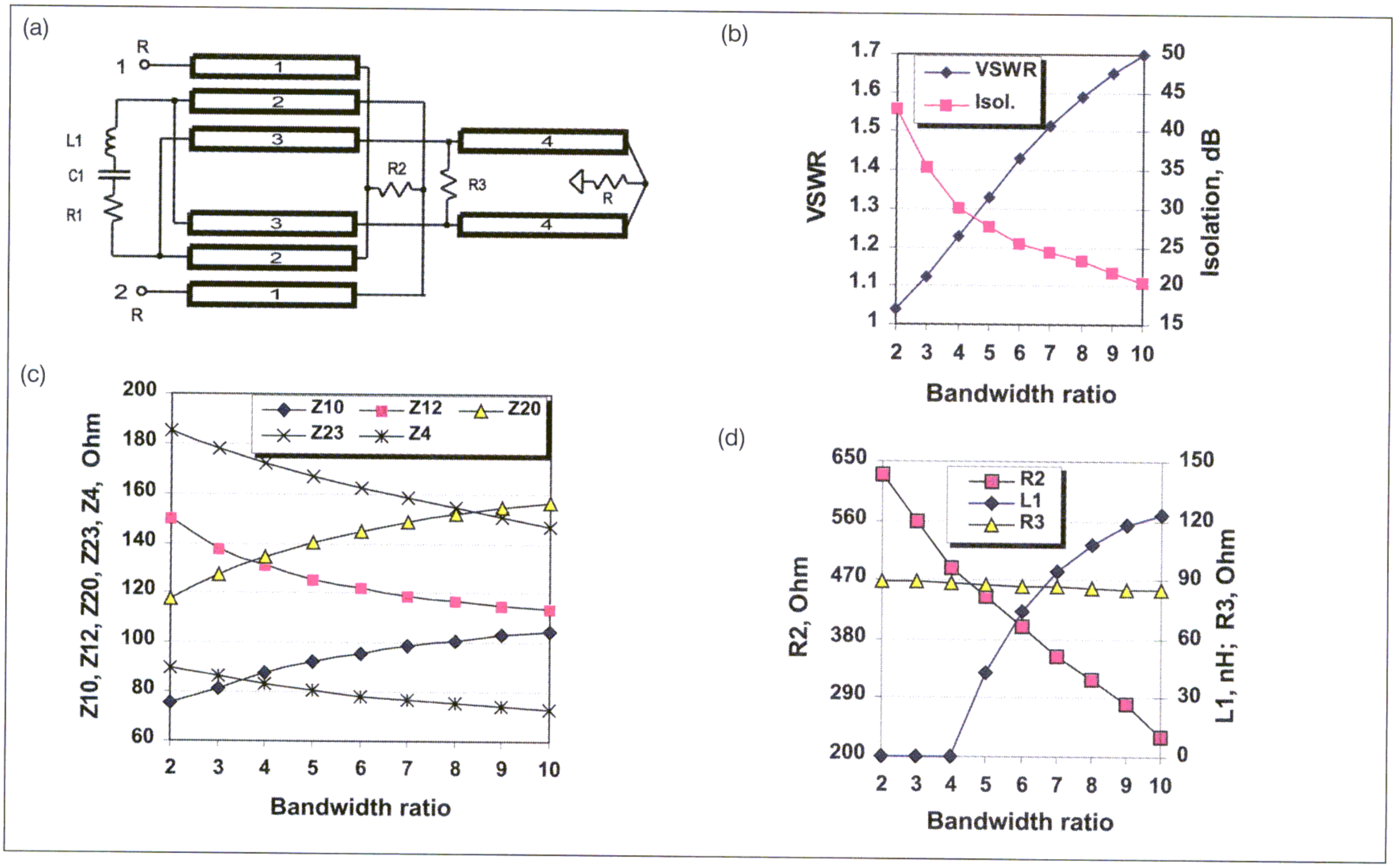
Simple correction is effectively used for increasing bandwidth and for decreasing coupling coefficients between the line conductors. Grouping of combiner without internal impedance transformation and additional broadband transmission-line transformer is one of the effective ways to achieve multi-octave bandwidth and reasonable size. ■



▲ **Figure 11. Characteristics of a two-way three-conductor line combiner with LC-correction: (a) line impedances; (b) isolation and isolating elements; (c) in-phase VSWR and capacitor values.**

Acknowledgement

The author acknowledges the helpful technical and



▲ **Figure 12. (a) Two-section coupled-line power combiner and (b-d) its characteristics.**

editorial comments of Dr. Leon Susman and Dave MacEnany, his colleagues at APTI.

References

1. Harlan Howe, Jr., *Stripline Circuit Design*, Norwood: Artech House, Inc., 1974: Chapter 3.

2. G.L. Matthaei, L. Young and E.M.T. Jones, *Microwave Filters, Impedance Matching Networks, and Coupling Structures*, Norwood: Artech House, 1980.

3. Chi-Yang Chang, and Chu-Chen Yang, "A novel broad-band Chebyshev-Response rat-race ring coupler," *IEEE Trans. Microwave Theory Tech.*, Vol. MTT-47, April 1999: 455-462.

4. Simon Y. London, "Broadband coupled-line power combiner/divider," US Patent No. 6,121,853, Int. Cl. H01P5/12, 2000.

5. H.J. Carlin and A.B. Giordano, *Network Theory*, Englewood Cliffs: Prentice-Hill, 1964: Chapter 3.

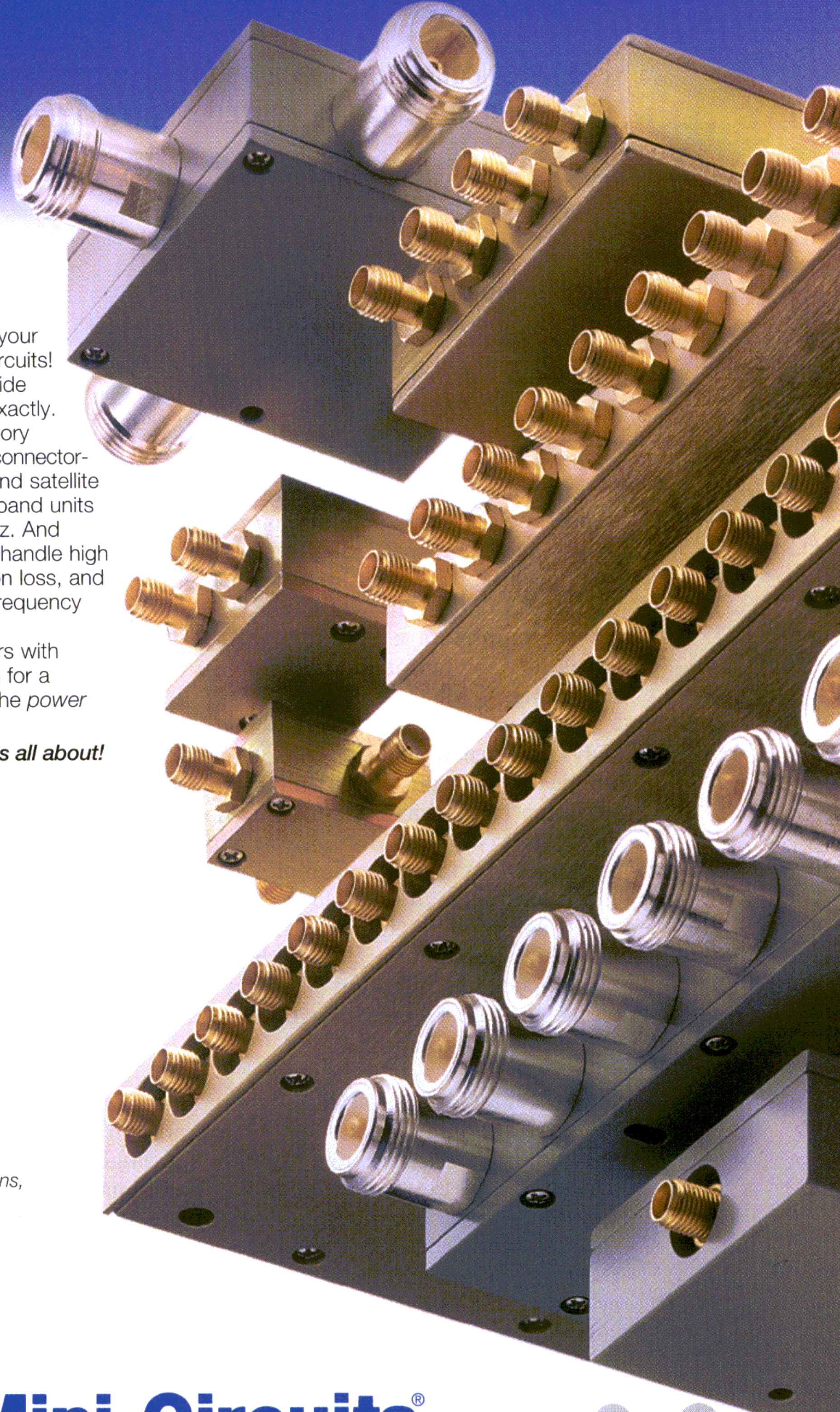
6. Edward E. Cristal, "Meander-line and hybrid meander-line transformers," *IEEE Trans. Microwave Theory Tech.*, Vol. MTT-21, February 1973: 455-462.

7. Simon Y. London, patent pending.

Author information

Simon Y. London is a Senior RF Engineer with Advanced Power Technologies, Inc., in Washington, DC. He is currently involved in the design of high power broadband systems. He received a Ph.D. in 1990 from the Electrotechnical Institute in St. Petersburg, Russia. His main interests are broadband high power amplifiers and passive devices: multiport combiners/splitters, impedance transformers, matching units and filters. He may be contacted by telephone at 202-223-8808 or by e-mail at simon@apti.com.

POWER DIVIDERS
0.47 to 10GHz



2 to 32 Way from $49.95 (1-9)

Looking for a "perfect fit" power divider for your 50 or 75 ohm design...*fast?* Just call Mini-Circuits! Our quick response and wide variety can provide on-target performance to match your needs exactly. That's because we've developed a vast inventory of low cost/high value SMA, BNC, and Type-N connectorized units covering cellular, GSM, ISM, PCS, and satellite bands. Select from 2 to 32way models, wide band units and microstrip designs going down to 470MHz. And Mini-Circuits power dividers are built tough to handle high matched power with good VSWR, low insertion loss, and high isolation between ports. For even lower frequency applications, check out our family of torroidal transmission line power splitters and combiners with frequencies as low as 500Hz. If you're looking for a better blend of usability and affordability, put the *power* of Mini-Circuits to work for you today!

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

Model	No. Of Models	Freq. Range (GHz)
2WAY-0°	151	0.50-10.0
2WAY-90°	4	1.00-4.20
2WAY-180°	2	1.00-2.49
3WAY	41	0.50-4.20
4WAY	83	0.47-8.40
5WAY	6	0.80-1.98
6WAY	25	0.80-5.00
7WAY	4	1.00-1.99
8WAY	62	0.50-8.40
9WAY	3	0.80-4.80
10WAY	11	0.75-2.40
12WAY	9	0.50-4.20
14WAY	1	0.90-0.99
16WAY	28	0.47-4.80
32WAY	1	0.95-1.75

For detailed model numbers, specifications, and prices, consult our web site, RF/IF Designer's Guide, or call Mini-Circuits.

See us at MTT-S — Booth #333

Mini-Circuits®

US 106 INT'L 116
CIRCLE READER SERVICE CARD

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

YONI™ ***The Design Engineers Search Engine*** *Provides ACTUAL Data Instantly From MINI-CIRCUITS At:* ***www.minicircuits.com***

ISO 9001 *CERTIFIED*

F 177 Rev D

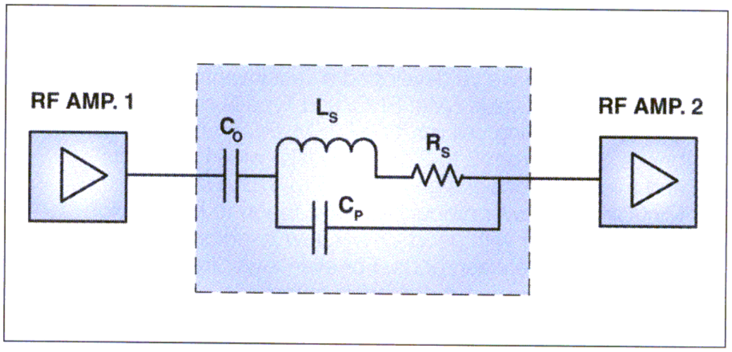
Capacitors in Broadband Applications

Proper selection of capacitors for RF broadband applications requires careful evaluation of frequency dependent parameters and circuit design requirements

By Richard Fiore
American Technical Ceramics

In today's rapidly expanding RF and microwave markets, numerous designs must operate over multiple octaves of frequency spectrum. Some of the more common of these include broadband bias networks such as transistor emitter and FET source bypassing, transistor collector and FET drain feed structures, as well as interstage RF coupling, DC blocking and wideband impedance matching.

This article will explore various ways to accommodate broadband application designs with the proper selection of capacitive elements. The first part of this discussion will address the implementation of a single capacitor solution followed by a multiple capacitor approach. Pertinent electrical design parameters, such as the magnitude of the impedance, insertion loss and the capacitor's parasitic elements, will be examined in detail for each method.



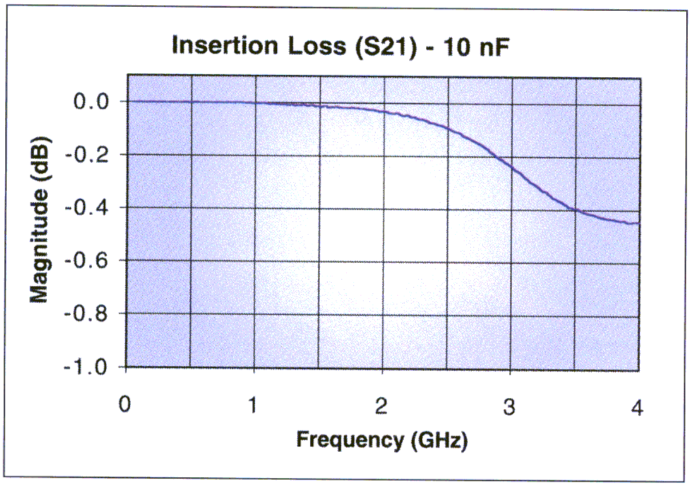
▲ **Figure 1. Interstage coupling, 50 MHz to 3.6 GHz.**

Note: The coupling capacitor C_0 is represented with its equivalent series resistance (ESR), denoted as R_S, equivalent series inductance (ESL), denoted as L_S, and parasitic parallel capacitance C_P, associated with the parallel resonant frequency (F_{PR}).

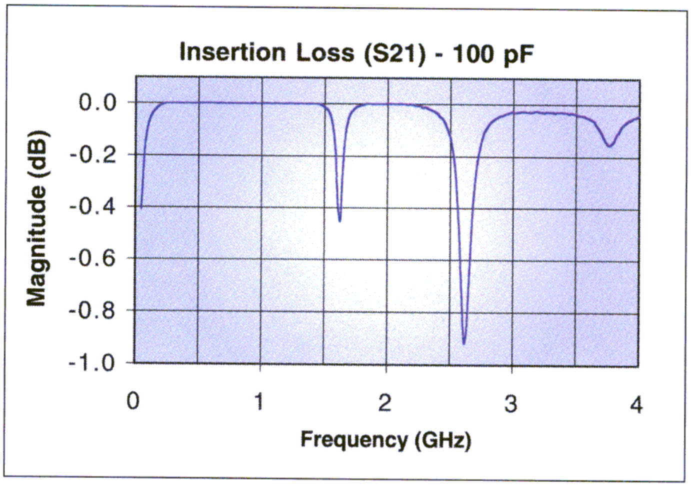
Single capacitor approach

There are many broadband applications with specific design requirements in which a single capacitor will provide an excellent functional solution. Given that the impedance of a capacitor, its equivalent series resistance (ESR), net reactance and quality factor (Q) are all frequency dependent, the designer must carefully consider these parameters before designing capacitive elements into a broadband application. Another critical parameter to take into account is the capacitor's insertion loss characteristic, i.e. the magnitude of S_{21}. By evaluating the insertion loss over the frequency band of interest, the designer can readily determine whether or not the subject capacitor is suitable for broadband DC blocking and coupling applications. This will also serve as a good starting point for selecting a broadband bypass capacitor. In contrast to DC blocking and coupling, a bypass capacitor also requires careful evaluation of its complex impedance over the entire frequency range of interest with emphasis on the inductive reactance resulting from the capacitor's parasitic inductance. The magnitude of both the real and reactive parts of the capacitor's impedance over frequency can easily be seen on a Smith chart presentation. Assessment of the net parasitic inductance will be discussed in greater detail later in this article.

In the following example, two RF amplifier stages operating in a 50-ohm network require



▲ **Figure 2. Insertion loss versus frequency for the 10 nF ceramic chip capacitor.**



▲ **Figure 3. Insertion loss versus frequency for the 100 pF ceramic chip capacitor.**

broadband interstage coupling, as illustrated in Figure 1. Assume that the application requires DC blocking and coupling over the frequency range of 50 MHz to 3.6 GHz. In order to achieve a solution using a "one capacitor" approach, several design considerations must be judiciously evaluated beforehand. An ATC200A103 (10 nF) capacitor has been selected as a starting point for this application since its large capacitance value will provide a low impedance, i.e. 0.22 ohms at 50 MHz, the lowest operating frequency in this example. Another fundamental consideration for all capacitor applications is the insertion loss over the desired frequency band. It is especially important to carefully examine the magnitude of S_{21} of a given capacitor for the presence of one or more parallel resonances falling within the desired passband. These resonances will generally show up as distinct attenuation notches at their frequencies of occurrence. Examination of a capacitor's S_{21} data will define these losses over the frequency range of interest. An insertion loss of several tenths of a dB is generally an acceptable criterion for virtually all applications.

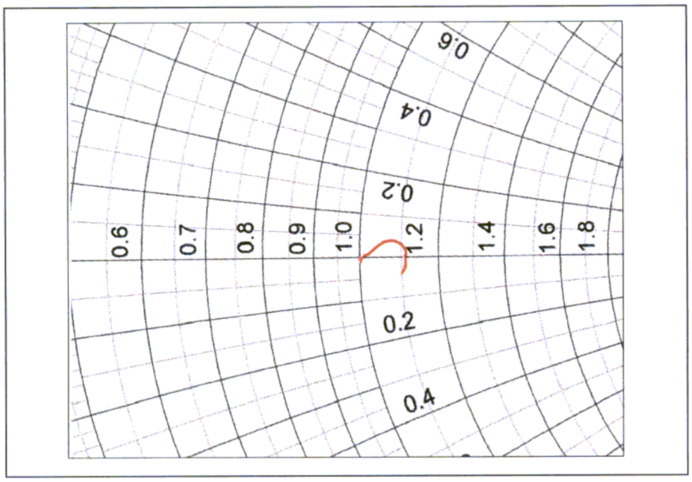
The 10 nF capacitor used in the above example is an X7R type, which provides an excellent solution for this requirement. This is based on its large capacitance value and low insertion loss characteristic across the entire passband. Accordingly, an X7R capacitor may provide a better solution than an NPO for many multi-octave applications due to its inherently higher volumetric efficiency, i.e. the availability of more capacitance per unit volume. The higher capacitance values provided by X7R capacitors are frequently needed in order to satisfy the lower frequency requirement imposed by most broadband applications, such as the one illustrated in Figure 1.

A capacitor's series resonant frequency (F_{SR}), also referred to as self-resonance, occurs at the frequency where the capacitor's net reactance is zero and is readily seen on an S_{11} Smith chart. At this frequency, the impedance of the device will be equal to a small ESR value, generally in the order of 100 milliohms at 1 GHz for high Q ceramic chip capacitors. Therefore, a capacitor will provide its lowest impedance path required for optimal coupling and bypass functionality at its series resonant frequency. In contrast, the impedance of a capacitor at its parallel resonant frequency (F_{PR}) can be precipitously high, especially for high Q devices.

By examining the magnitude of S_{21} versus frequency of a given capacitor, excessive losses associated with F_{PR} within the frequency band of interest can be readily observed. In many broadband designs, the capacitor's series resonant frequency may be exceeded without negative consequence, with the exception of matching and bypassing applications. Exceeding F_{SR} will result in a net impedance that is inductive. This will usually not pose a problem in DC blocking and coupling applications, however, bypass and matching applications require careful scrutiny of the net impedance and the level of parasitic inductance.

In bypass applications, it is desirable to operate at the capacitor's F_{SR} where the impedance is essentially equal to the ESR and zero net reactance. For the best practical solution, the author suggests selecting the lowest standard EIA capacitor value that exhibits an F_{SR} that is slightly higher than the application bypass frequency. This will ensure that the impedance will be low with a net reactance that is capacitive. These performance characteristics are defined by S-parameter data files supplied by the manufacturer. The S-parameter files are typically derived from measurements of standard EIA capacitor values within a given product series.

For non-standard values, the magnitude and phase attributes can be estimated by interpolating the S-parameter data associated with the adjacent standard EIA capacitor values. These approximations are valid when the S-parameter data used in the interpolation



▲ **Figure 4. Smith chart plot for the 10 nF capacitor in series through configuration.**

has been derived from capacitors having the same basic internal design and dielectric type. Exceptions to this rule occur when there are significant deviations in the capacitor's internal design structure, such as electrode pattern geometry, electrode count and spacing, electrode end and side margins, as well as variations in the dielectric constant and loss tangent characteristics over frequency.

Insertion loss

As previously stated, a large value capacitor is generally selected in order to satisfy the low frequency region of a broadband design requirement. These applications can expose a capacitor to operating frequencies that far exceed its self-resonant frequency where the occurrence of parallel resonances within the desired passband are imminent. Therefore, the designer must balance between the capacitance value needed to satisfy the low frequency requirement and the inevitability of in-band parallel resonances brought about by large value capacitors. If a parallel resonance does fall within the operating passband, it will be necessary to evaluate the depth of the associated attenuation notch in order to determine whether or not this loss is acceptable for a particular design requirement. In many instances, the magnitude of S_{21} for a given capacitor may be excessive, thereby making the device unusable for a given application.

Frequency (MHz)	Real (Ω)	Reactive (Ω)	Impedance Magnitude (Ω)
50	50	$-j2.5$	50.06
150	50	$-j0.15$	50
450	50.2	$-j0.15$	50.2
900	50.8	$+j0.25$	50.8
1800	51.5	$+j0.5$	51.5
2400	52.2	$+j2$	52.3
3600	52	$j0$	52
4000	55	$-j2$	55.04

▲ **Table 1. Complex impedance summary for the 10 nF capacitor in series through configuration.**

Frequently, however, the capacitor's series resistive losses at F_{PR} are great enough to damp the resulting attenuation notch. In these instances, the notches are present yet very shallow in magnitude and are frequently obscured. This operating condition is valid for many broadband designs using one capacitor. The S_{21} plots in Figures 2 and 3 show a comparison in the relationship between frequency and the magnitude of S_{21} over more than six frequency octaves (50 MHz to 4 GHz). Figure 2 illustrates the S_{21} insertion loss characteristic for an ATC200A103 (10 nF) capacitor, while Figure 3 illustrates the same parameter for an ATC100A101 (100 pF) capacitor. Both devices were measured in a series through configuration with the capacitor's electrodes parallel to the substrate, i.e. flat mount orientation.

From Figure 2, it can be seen that the insertion loss of the selected 10 nF capacitor is less than 0.5 dB throughout the plotted frequency range, making it suitable for virtually all wireless frequency broadband applications, such as the coupling application referenced in Figure 1. In contrast, the 100 pF capacitor illustrated in Figure 3 exhibits notable in-band insertion losses, which makes it a less likely candidate for the above mentioned application. Losses that exceed several tenths of a dB within the passband could easily compromise the end performance of a circuit design. Therefore, the decision is ultimately left up to the discretion of the designer to determine whether or not these losses are acceptable for a particular design requirement.

Figure 4 is an S_{11} Smith chart representing the 10 nF capacitor sample used to generate the S_{21} data in Figure 2. Since this measurement was performed in a series through configuration, the resulting Smith chart illustration is especially useful for evaluating a capacitor's complex impedance in coupling and DC blocking applications. The Smith chart clearly shows that both the real and reactive parts of the impedance of this device are very close to the center of the chart, i.e. normalized impedance throughout the entire frequency range.

Table 1 was constructed from the Smith chart data in Figure 4 and summarizes the real and reactive parts of the impedance referenced to a 50-ohm system at eight different frequencies. The table also shows the magnitude of the impedance as calculated from the vector sum of the real and reactive parts. It becomes clear from this data that the subject 10 nF capacitor will serve as an excellent coupling and DC blocking capacitor throughout the entire frequency range.

Effects of ESR and *Q*

A capacitor's quality factor (Q) is numerically equal to the ratio of its net reactance $|X_C - X_L|$ to its equivalent series resistance (ESR), or

$$Q = \frac{|X_C - X_L|}{ESR}$$

From this expression, it can be seen that the capacitor's Q varies inversely proportional to its ESR and proportionally to the net reactance at a given frequency. The capacitor's ESR should always be taken into account over the entire frequency band of interest, as it becomes a major consideration when designing a single capacitor into a multi-octave application. This parameter is especially useful in the region where parallel resonances are present. As previously mentioned, an attenuation notch will occur at the capacitor's parallel resonant frequency (F_{PR}), the depth of which is inversely proportional to the ESR. Therefore, the capacitor's ESR will largely determine the depth of the attenuation notch at the parallel resonant frequency.

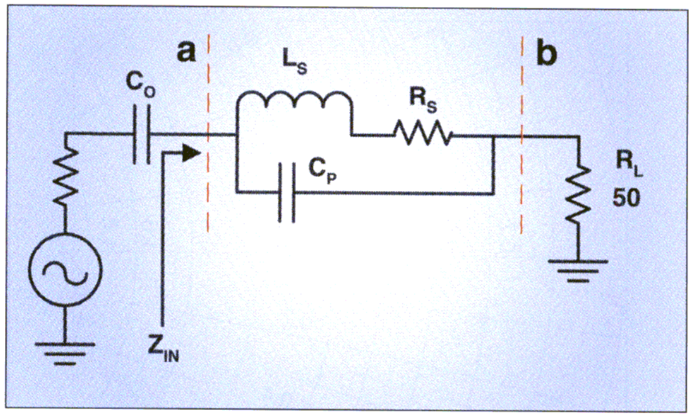
A practical design approach is to select a capacitor large enough in value to cover the lowest operating frequency requirement, while making sure that additional losses brought about by the occurrence of in-band parallel resonances are within acceptable limits. The effects of ESR at the parallel resonant frequency are best evaluated by examining the real part of the capacitor's impedance at F_{PR}. Evaluating this impedance will give the designer a clear indication of the capacitor's usability at this frequency. If the ESR is high at the parallel resonant frequency, the resultant insertion loss will be correspondingly low. Accordingly, the associated notch depth will be shallow and generally not be discernible in the magnitude of S_{21}. This will provide for a low loss "one capacitor" broadband DC blocking and coupling solution over the frequency band of interest. The same considerations hold true for broadband bypassing applications, how-ever, in addition to the magnitude of the impedance, an evaluation of the S_{11} Smith chart must also be taken into account.

As seen in Figure 5, the parasitic elements associated with capacitor C_0 consist of L_S, R_S and C_P. The real part of the impedance looking into the parasitic branch at parallel resonance is:

$$Z_{IN\,(REAL)} = \frac{L_S}{R_S C_P} \quad (\text{at } F_{PR})$$

where C_P is a small parasitic capacitance associated with C_0's parallel resonant frequency and R_S and L_S are the capacitor's ESR and ESL, respectively.

From the relationship between $Z_{IN\,(REAL)}$, L_S, R_S and C_P, it can be seen that at F_{PR}, a low R_S will yield a high impedance, thereby giving rise to a deep attenuation notch. The converse is also true, in that a high R_S will yield a low impedance, thereby resulting in a more shallow-attenuation notch. The impedance of this network increases with decreasing values of R_S. Since this impedance is in series with the nominal capacitor C_0, the net impedance from terminal (a) to terminal (b) will increase for decreasing values of R_S and vice versa.



▲ **Figure 5. Nominal capacitor C_0 with parasitic elements.**

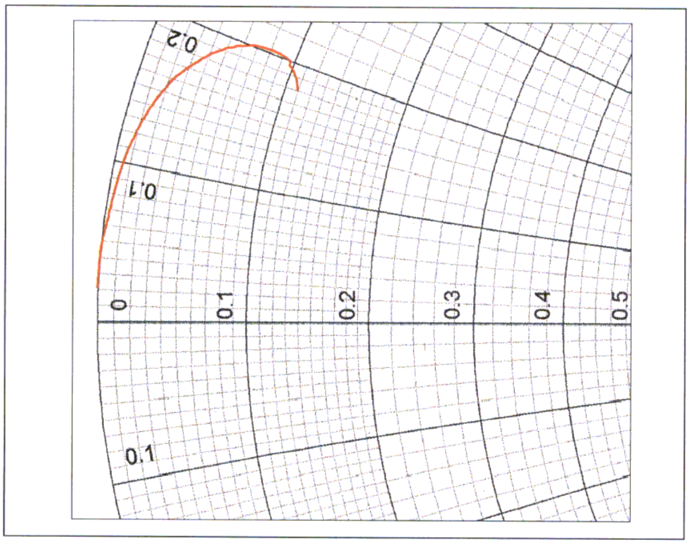
It is generally desirable to have very low impedance looking into the parasitic branch of the network shown in Figure 5, however, in many broadband applications, a capacitor may be required to operate substantially above its series resonant frequency and at or near its parallel resonant frequency. In these applications, it may be more advantageous to select a capacitor that exhibits high loss at its F_{PR}, since the resultant notch depth at the parallel resonant frequency will be very shallow. Under these conditions, it likely that the attenuation notch will be low enough, i.e. less than 0.1 dB, making it non-discernible in the magnitude of S_{21}.

This concept can be used to provide the basis for an excellent low loss broadband "one capacitor" DC block and coupling solution over a wide range of frequencies. The same considerations hold true for broadband bypassing and matching, however, the sign ($+j$ or $-j$) and magnitude of the impedance of the subject capacitor must also be considered, as inductive properties may adversely affect these applications.

Another consideration worthy of mentioning applies to phase sensitive applications. There are rapid insertion phase transitions around zero degrees at and in proximity to the capacitors parallel resonant frequency. This condition may cause excessive group delay, which is generally not well tolerated in phase sensitive applications. Group delay can be calculated by taking the first derivative of S_{21} insertion phase. It is especially important in these applications to know whether this resonance is present within the design passband and is generally best to avoid them if possible.

Effects of net inductance

When designing capacitors into a broadband bypassing circuit application, one of the first parameters to consider is the capacitors parasitic inductance and its



▲ **Figure 6. Smith chart for the 10 nF capacitor in shunt configuration.**

associated inductive reactance. The effects of the parasitic series inductance (ESL) and inductive reactance become more prominent at high frequencies, particularly in the region above the capacitor's series resonant frequency (F_{SR}). The net impedance decreases with increasing frequencies up to the series resonant frequency, however, as the frequency is increased above F_{SR}, the net impedance becomes inductive and gradually increases. It is acceptable to use a capacitor above its F_{SR}, as long as the inductive reactance does not become too large. A Smith chart analysis is essential for assessing the complex impedance of a device intended for these applications. Figure 6 shows a Smith chart presentation derived from a shunt to ground configuration measurement of an ATC 200A series 10 nF capacitor in the flat mount orientation, i.e. electrodes parallel to the substrate. A shunt to ground configuration was intentionally chosen, as it is best suited for evaluating the complex impedance of a capacitor intended to be used in a bypass application.

The results of a shunt measurement for the 10 nF capacitor are illustrated in the Smith chart plot in Figure 6. Table 2 summarizes the impedance data from the Smith chart illustrated in Figure 6 and tabulates the real and reactive parts of the impedance referenced to a 50-ohm system at eight different frequencies. The table also shows the magnitude of the impedance as calculated from the vector sum of the real and reactive parts.

Frequency (MHz)	Real (Ω)	Reactive (Ω)	Impedance Magnitude (Ω)
50	0	+0	0
150	0	+*j*0.4	0.4
450	0	+*j*1.2	1.2
900	0	+*j*2.4	2.4
1800	0.2	+*j*5.2	5.20
2400	0.9	+*j*7.6	7.65
3600	5	+*j*9.6	10.82
4000	5.6	+*j*8.8	10.43

▲ **Table 2. Complex impedance summary for the 10 nF shunt to ground configuration.**

In order to achieve good bypass performance, the designer will opt for a low impedance and low inductive reactance. The ideal placement on the Smith chart for this configuration is at the outer rim along the real axis, i.e. zero resistance and zero reactance. This is achieved by selecting a capacitor that exhibits both low impedance and a low inductive reactance at the frequencies of interest. The 10 nF capacitor referenced above will serve as an excellent choice for bypass applications up to about 900 MHz.

As seen in Table 2, the impedance and inductive reactance look reasonably low for bypassing applications up to about 1800 MHz. However, at frequencies above 2600 MHz, the impedance and the level of inductive reactance are significant. The requirements of the design will determine whether this impedance is too high for use in bypass applications at these frequencies. An impedance magnitude of 10.82 ohms at 3.6 GHz for the subject device represents more than 20 percent of the network impedance and would not be a good candidate for bypassing or any other application at this frequency.

The elements that make up a capacitors parasitic inductance depend greatly on its physical design. A capacitor's form factor, i.e. ratio of length to width, plays a major role in the magnitudes of both ESR and ESL. Low parasitic resistance and inductance are achieved with form factors in which the width of the device approaches or exceeds its length dimension. For example, an ATC 180R series capacitor has a nominal length of 70 mils and a width of 105 mils, resulting in very low ESR and ESL. Other factors that influence a capacitor's parasitic elements include electrode composition, electrode pattern geometry, electrode count and spacing, case thickness and the dielectric's relative permittivity and loss tangent characteristics over frequency. Each one of these properties plays a part in the capacitors overall performance.

Likewise, the network environment that surrounds the device will prominently influence the net parasitic inductance. Details such as the mechanical and electrical properties of the substrate on which the capacitor is mounted, as well as the placement and dimensional matching between the width of the capacitor's terminations and the board traces, are factors that will all influence the net inductance. Other factors left up to the discretion of the circuit designer involve the placement and orientation of the capacitor relative to the ground plane. There are additional contributions of inductance from the interaction between the capacitor's closest electrode

and its proximity to the ground plane. It is desirable to mount the device as close as possible to the ground plane by using thin boards wherever possible. The use of boards having a thickness in the order of 25 mils or less is preferable for minimizing the net inductance. Also, mounting orientation is yet another factor to be taken into account regarding its effect on the net parasitic inductance. Edge mounting a capacitor, i.e. electrodes normal to the ground plane, is typically taken as the optimal orientation, as it yields the benefit of greatly suppressing odd order parallel resonances.

In bypass applications the flat mount scenario with electrodes parallel to the ground plane may prove to be more advantageous because the net inductance resulting from this mounting orientation is lower. This also equates to a somewhat higher series resonant frequency. The designer must judiciously balance be-tween the magnitude of net inductance and the depth of the in-band attenuation notches brought about by the presence of parallel resonances in order to determine the best mounting orientation for a given application. Evaluating the scattering parameters for the subject capacitor will always be helpful in determining this trade-off.

It is also advantageous to keep board traces as short as practical, especially between vias and neighboring devices. Inductance per unit length L_L is based on the relationship between the characteristic impedance of the substrate and the phase velocity and is stated as:

$$L_L = \frac{Z_0}{V_P} = \frac{Z_0\sqrt{\varepsilon_{EFF}}}{c} = \text{H per meter}$$

where

- L_L = inductance per unit length
- Z_0 = characteristic impedance in ohms
- V_P = phase velocity on microstrip = $c / \sqrt{\varepsilon_{EFF}}$
- c = speed of light in a vacuum (inches per second)
- ε_{EFF} = effective permittivity
- H = inductance in Henrys (H)

Examples

The following examples show calculations for determining the inductance per unit length for both Rogers RO4350 soft board and alumina. Both examples refer to a 50-ohm microstrip with typical trace width dimensions.

For convenience, c is converted from miles per seconds to inches per second by multiplying by 1.1785×10^{10}. Therefore, inductance per unit length is expressed in H per inch:

$$L_L = \frac{(1.1785 \times 10^{10})Z_0}{V_P} = \frac{(1.1785 \times 10^{10})Z_0\sqrt{\varepsilon_{EFF}}}{c}$$

Example 1:

Substrate = RO4350
ε = 3.48
ε_{EFF} = 2.83

For Z_0 = 50 ohms on microstrip
Substrate thickness = 20 mils
Trace width = 45 mils
Calculate inductance L_L in nH per inch for RO4350

Solution:

$$L_L = \frac{Z_0}{V_P} = \frac{Z_0\sqrt{\varepsilon_{EFF}}}{c}$$

$$= \frac{50 \times \sqrt{2.83}}{1.1785 \times 10^{10}} \quad \text{(multiply by } 10^9 \text{ for nH)}$$

$$= 7.14 \text{ nH per inch}$$

L_L = 0.714 nH per 100 mils of trace.

Example 2:

Substrate = Alumina
ε = 9.9
ε_{EFF} = 6.47

For Z_0 = 50 ohms on microstrip
Substrate thickness = 25 mils
Trace width = 24.5 mils

Calculate inductance L_L in nH per inch for Alumina

Solution:

$$L_L = \frac{Z_0}{V_P} = \frac{Z_0\sqrt{\varepsilon_{EFF}}}{c}$$

$$= \frac{50 \times \sqrt{6.47}}{1.1785 \times 10^{10}} \quad \text{(multiply by } 10^9 \text{ for nH)}$$

$$= 10.8 \text{ nH per inch}$$

L_L = 1.08 nH per 100 mils of trace.

As seen in these examples, the board traces will contribute significant amounts of additional inductance. In the example using Rogers soft-board, an increase of

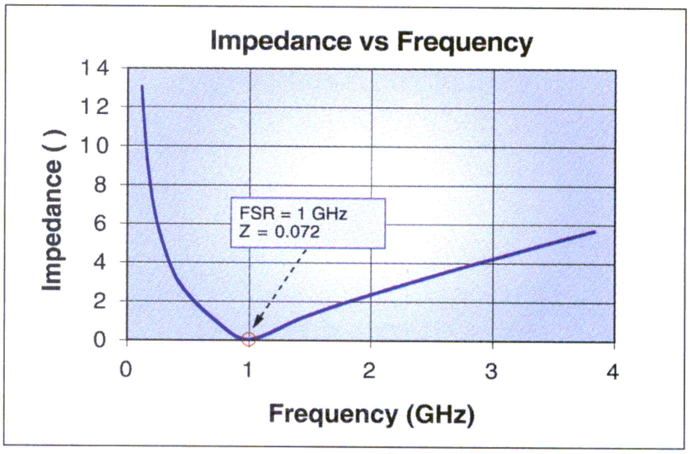
more than 0.7 nH per 100 mils of trace is contributed. Therefore, a capacitor exhibiting 0.6 nH of inductance mounted on this board with 100 mils of trace on either side will result in a net inductance of approximately 2 nH referenced at the far end of the traces. This represents an increase of more than twice that of the capacitor by itself. Likewise, the same capacitor mounted on an alumina substrate with 100 mils of trace on either side will result in a net inductance of 2.76 nH, an increase of more than three times that of the capacitor. Smaller trace widths should be avoided where possible, as they will contribute even higher levels of inductance. Another factor concerning the board layout is the diameter of vias, as they also contribute to the net inductance. The use of larger diameter via holes is preferable in order to minimize the associated inductance. All of the aforementioned factors will contribute to the net inductance and, therefore, must be carefully managed in the early stages of the design.

Effects of net impedance

The magnitude of a capacitor's impedance is equal to $\sqrt{(ESR)^2 + (X_L - X_C)^2}$. As seen by this relationship, a capacitor's impedance is significantly influenced by its net reactance ($X_C - X_L$). This will serve as a good guideline for usability across the frequency band of interest. Knowing the magnitude of the impedance, especially at the lowest and highest frequency, is an important factor for all broadband applications. Ideally, the designer will be looking to achieve reasonably low impedance at both band edges.

The design philosophy suggested here is to simply select a large enough value of capacitance such that the corresponding impedance is low enough to provide a good through path at the lowest operating frequency. For example, a capacitor that exhibits a maximum impedance of 1 ohm at the lowest frequency represents 2 percent of the total impedance referenced to a 50-ohm network, which should provide an acceptable impedance criterion for most applications. If low impedance cannot be achieved across the desired frequency range using one capacitor, then it will be necessary to use multiple capacitors by selecting staggered capacitance values in order to meet the low impedance requirements throughout the entire passband. The impedance of each capacitor will have to be low enough to provide for a good RF path over successive frequency segments. For a given capacitor, the impedance will become progressively lower as the frequency is increased reaching its lowest value at F_{SR} and will start to gradually increase at frequencies above F_{SR}, as seen in Figure 7.

A high capacitance value will generally exhibit a suitably low impedance required for low frequency coverage as stated above, however, the capacitor's ESR should also be known at all frequencies within the passband, especially for frequencies above the capacitor's series resonant frequency. At the frequency where the electrode thickness is equal to or greater than one skin depth, the ESR will increase as the square root of f. Accordingly, the ESR will rapidly increase with increasing frequencies and will become a dominant factor in the net impedance.

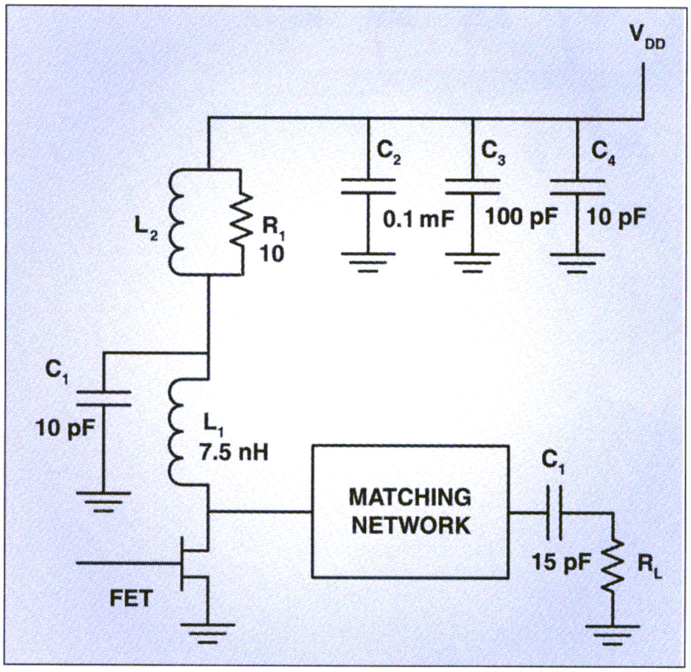


▲ **Figure 7. Impedance versus frequency for an ATC100A101 (100 pF).**

Note that the net impedance below F_{SR} is capacitive and is dominated by $1 / \omega C$, therefore yielding a hyperbolic curve for frequencies less than F_{SR}. Conversely, the net impedance above F_{SR} is inductive and is dominated by ωL, therefore yielding a linear line segment for frequencies greater than F_{SR}. As illustrated by the impedance chart in Figure 7, the 100 pF capacitor would be suitable for most coupling applications from about 450 MHz through 1.8 GHz. For bypass and matching applications, the usability over frequency based on the impedance would be from about 450 MHz to 1 GHz. Frequencies in excess of 1 GHz are inductive and require S-parameter data to further assess the usable frequency range above F_{SR}.

Multiple capacitor approach

All of the guidelines outlined above for the single capacitor approach remain valid for the multiple capacitor scenario, however, the implementation of two or more capacitors will usually provide a more efficient solution while allowing for operation over a wider frequency spectrum. Small value resistors and inductors, as well as lossy ferrite beads, are sometimes used in conjunction with multiple capacitors that are connected in parallel, as they serve to electrically separate the capacitors as well as damping in-band resonances. At microwave frequencies, the inductance of a section of microstrip trace, typically in the order of 1 nH per 100 milli-inches, may be used to isolate the capacitors in this configuration. In many instances, the capacitor's inherent parasitic elements will represent a significant contribution to the overall circuit and should always be included.



▲ **Figure 8. Diagram of a 1.9 GHz cellular FET amplifier with emphasis on the broadband drain bias network.**

Broadband bypassing is a critical design matter that requires serious attention. Figure 8 shows a 1.9 GHz cellular FET amplifier with emphasis on the drain bias network. The circuit elements depicted in this figure will serve to suppress RF energy from getting onto the V_{DD} supply line, while providing high impedance at the drain in order to maintain optimum in-band RF gain. It also functions to keep noise generated by the power supply from appearing on the drain of the FET. High-speed switching environments created by switch mode power supplies (SMPS) will generate noise on V_{DD} supply lines. The instantaneous current generated with fast rising and falling switch pulse edges can easily cause the V_{DD} supply line to ring. Since the losses within an SMPS are inversely proportional to switching frequencies, today's designs have spiraled these frequencies upward for a more efficient operation. RF energy generated from a typical SMPS operating anywhere from frequencies of 100 kHz to hundreds of megahertz must be prevented from appearing on the drain circuit. Spurious emissions generated by the SMPS consist of innumerable spectral components, which are generated by harmonics and intermodulation products of switched pulse edges. The resultant noise can easily include frequencies of up to several hundred MHz. The RF noise generated by SMPS switching is continuous and will generally occur up to frequencies equal to 0.35 / P_E, where P_E = pulse rise or fall time in seconds. For example, a switched pulse with a rise and fall time of 1.5 ns will yield spurious spectral components up to 233 MHz.

Broadband drain bypass bias network

As illustrated in Figure 8, the FET's drain bias network consists of series inductive elements having an impedance of ωL and shunt capacitive elements with an impedance of $1 / \omega C$. Proper selection of these circuit elements in this bias network is essential, as they will serve to de-couple RF energy from the V_{DD} supply line to ground over a wide range of frequencies.

Since the capacitors exhibit a small parasitic inductance, there is an associated series (self) resonant frequency where

$$F_{SR} = \frac{1}{2\pi\sqrt{L_s C_0}}$$

At F_{SR}, the magnitude of the inductive and capacitive reactances are equal, and hence the net impedance ($\sqrt{(ESR)^2 + (X_L - X_C)^2}$) is equal to a small ESR value, typically expressed in milliohms. Accordingly, the designer will ideally select a capacitor that has an F_{SR} at or close to the desired "bypass frequency." This preference is based on establishing a low impedance path with minimal or zero net reactance, thereby making it ideal for bypassing applications.

As previously mentioned, it is essential that the capacitor's ESR and Q be taken into account at or near the parallel resonant frequency (F_{PR}) for all applications. F_{PR} usually occurs at more than twice F_{SR} for edge-mounted multi-layer ceramic capacitors. At this frequency, the capacitor's impedance is likely to be high and inductive ($R + jX_L$) and may not provide an adequate RF path to ground. To alleviate this, the multiple capacitor approach uses two or more capacitors connected in parallel. They are selected such that their self-resonant frequencies are staggered in order to cover a wide range of frequencies with reasonably low loss. The number of required capacitive elements depends on the loss and impedance characteristics of each element over the intended frequency band segments.

From Figure 8, it can be seen that the inductors are in series with the drain and are not directly connected to reference RF ground. Accordingly, they rely on the bypass capacitors C_1 through C_4 to obtain a low impedance path to ground. As a rule, inductor L_1 will have a reactance of at least 10 times higher than that of the transistor's drain impedance, whereas L_2 will be as large as possible. One caveat while selecting L_2 is to ensure that it is capable of handling the DC drain current with minimal IR drop. The combination of L_1 and C_1 will greatly suppress the in-band 1.9 GHz carrier frequency energy from appearing on the V_{DD} supply line. Inductor L_1 will act as a block at this frequency, while capacitor C_1 will serve to further suppress in-band RF energy by bypassing it to ground. L_2, C_2, C_3 and C_4 will suppress RF energy at frequencies below the 1.9 GHz carrier frequency, where the gain of the amplifier may be much higher. C_1's capacitance value is selected such that its F_{SR} is close to the amplifiers operating frequency.

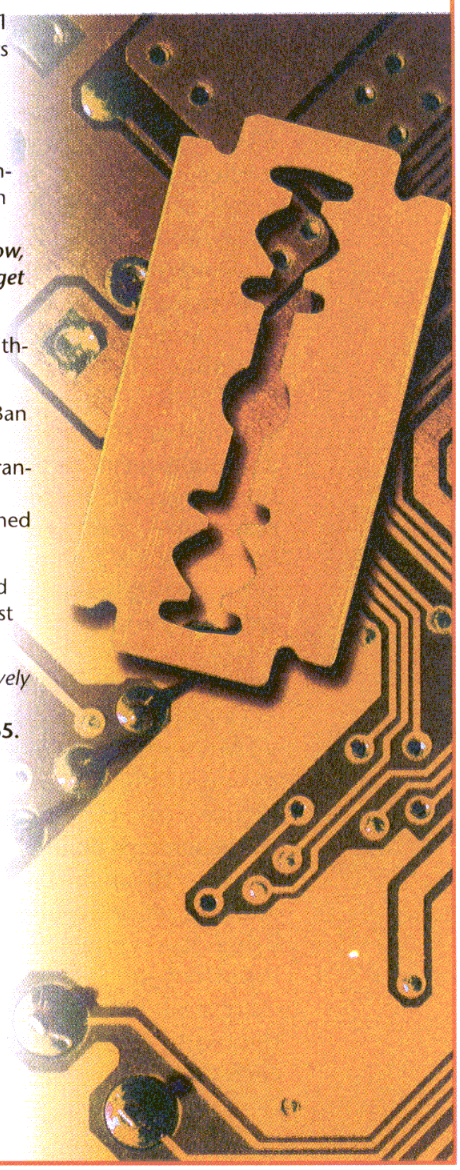
Since C_1 is a shunt element, and the impedance is low at its F_{SR}, the RF energy at the operating frequency will be bypassed to ground. Capacitor elements C_2, C_3 and C_4 are staggered in value and are selected so that the impedance and inductive reactance of each will be low at successive frequency segments in order to offer continuous bypassing of frequencies below the amplifier's operating band. The use of ferrite beads may also be used in between the capacitive elements. Their inherently low Q offer good rejection of power supply noise over a wide range of frequencies, and they will also tend to isolate the effects of individual capacitive element.

Conclusion

This article has illustrated the various considerations for selecting capacitors for broadband applications. It has highlighted the frequency dependent properties of capacitors in relation to the parasitic elements and their implications to the various functional applications. Most important, it has been strongly suggested that capacitive elements be selected only after carefully and thoroughly evaluating both the circuit design requirement and the electrical and mechanical characteristics of the capacitor under consideration. ■

Author information

Richard Fiore has 25 years of experience in RF engineering. His professional experience includes design and implementation of RF automated test systems for the defense electronics industry, filter design for both military and commercial markets, EMC design and testing, and the design, prototype and evaluation of RF components, modules and systems. He is presently working as a senior RF Applications Engineer at American Technical Ceramics, 1 Norden Lane, Huntington Station, NY 11746, and has been with the company since 1994. He can be reached by e-mail at rfiore@atceramics.com.

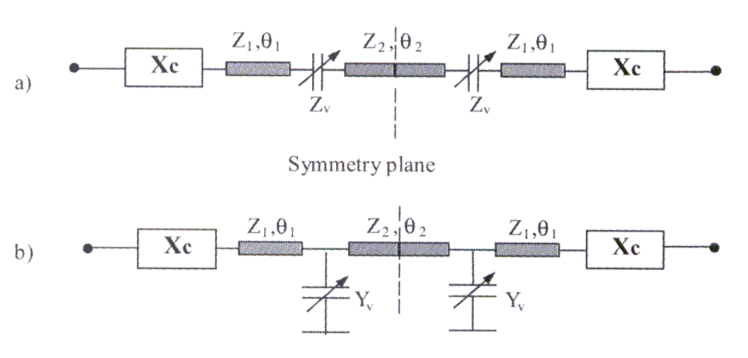


Modeling Varactor Tunable Microstrip Resonators for Wireless Applications

By Boris Kapilevich and Roman Lukjanets
Siberia State University of Telecommunications & Informatics

In a previous article [1], we described single terminated varactor tunable microstrip resonators. Configurations with series and parallel varactor circuits in the center of resonator were considered. The advantages of those configurations are a simplicity and minimum number of varactors. Their major drawbacks are rather limited tuning range and harmonic suppression.

Another configuration of tunable resonator is considered here — Double-terminated Varactor Tunable Microstrip Resonator (D-VTMR). This configuration demonstrates some advantages as compared to its single terminated counterpart, due to additional degrees of freedom. The general form of resonance conditions, tuning facilities and higher harmonics suppression of this configuration are investigated in this paper on the basis of the appropriate circuit model.



▲ **Figure 1. Configurations of double terminated varactor tunable microstrip resonator (D-VTMR) (a) in series; (b) in parallel.**

Resonance conditions

Consider the two basic configurations of D-VTMR with different varactor circuits: in series, shown in Figure 1(a), and in parallel, shown in Figure 1(b). Using the result described in [1], the resonance conditions of both circuits can be written through transmission matrixes. The analysis of a resonator can be simplified by using its symmetry property with respect to input/output ports. Hence, a transmission matrix of left and right parts of a resonator related to a symmetry plane are dependent on each other:

$$[A]_{left} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \text{ and } [A]_{right} = \begin{bmatrix} D & B \\ C & A \end{bmatrix} \tag{1}$$

So the only matrix in Equation (1) must be determined that simplifies an analysis. Finally, a resultant transmission matrix of the resonator considered can be written as follows using Equation (1).

$$[R_s] = \begin{bmatrix} A\times D + B\times C & 2\times A\times B \\ 2\times C\times D & A\times D + B\times C \end{bmatrix} \tag{2}$$

The above expressions have been used to estimate resonance conditions $|S_{11}| = 0$, which correspond to the following equalities:

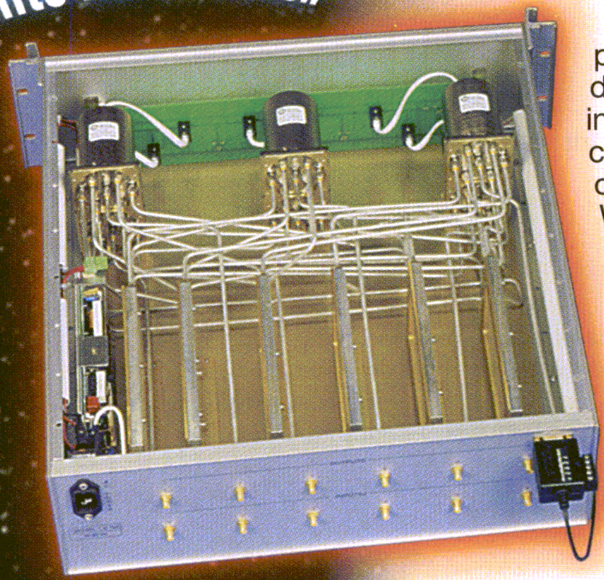
$$A_sB_s - Z_0^2C_sD_s = 0 \tag{3}$$

for the series configuration, and

Need Help With Signal Capture and Redirection?

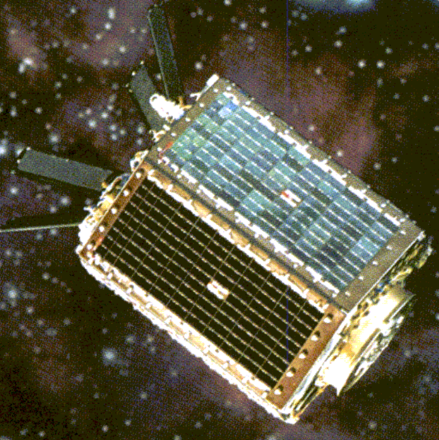
Manage Your Broadband Signal Environment With A Dow-Key Microwave Switch Matrix

Dow-Key Microwave's ***Coaxial Switch Matrices*** make it easy for you to meet the demand for high speed, multi-source information switching. Our ***Non-Blocking Switch Matrix*** product line will enable you to capture and redirect signals with minimum distortion and maximum ease.



Dow-Key engineers focus on providing optimized routing designs and use our own low insertion loss switches to deliver the cleanest signal from input to output over the DC to 26.5 GHz range. Whether your system requires the highest level of reliability or must meet the price demands of the commercial market, Dow-Key will design a customized ***Switch Matrix*** to meet your needs with a control interface to match your system whether it be a CANbus, RS-232, RS-422, or GPIB.

Our expertise and experience in supplying matrices to secure networks, SatCom, direction finding, eavesdropping, broadcast, and ATE provides you with a broad line of products and optimized designs. We offer remote control interface options and premium components all carefully assembled in a rugged, rack mount chassis.



For uniquely and superbly engineered designs that meet and exceed market demands, for unprecedented customer service and on-time delivery, for the highest quality product with unsurpassed reliability at the right price, ***Dow-Key Microwave*** *is your solution.*

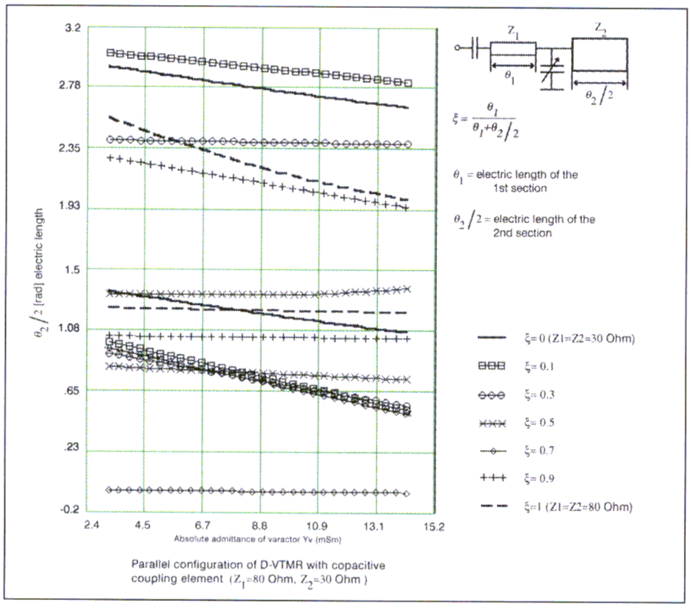
Dow-Key® Microwave
CORPORATION
4822 McGrath Street, Ventura, CA 93003
Tel: (805) 650-0260 • Fax: (805) 650-1734
Visit at www.dowkey.com.

ISO 9001 CERTIFIED

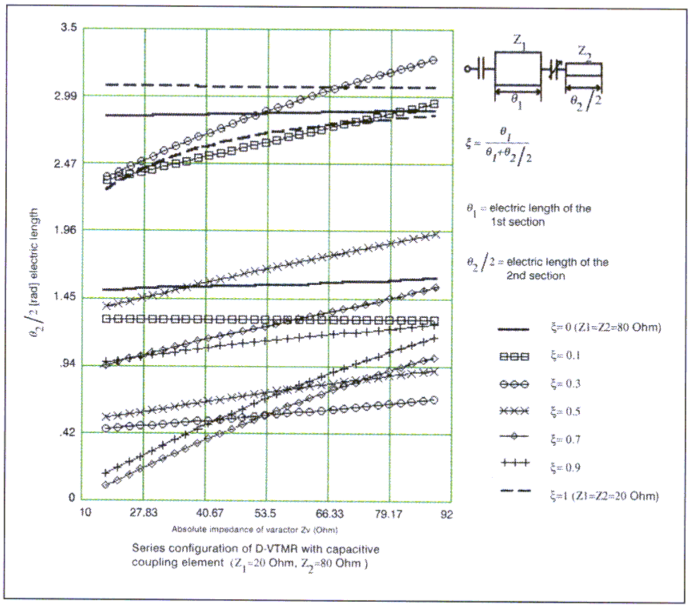
A DOVER COMPANY

Circle 37

See us at MTT-S — Booth #1140



▲ **Figure 2. Behaviour of the calculated electric length $\theta_2/2$ for PDC of D-VTMR.**



▲ **Figure 3. Behaviour of the calculated electric length $\theta_2/2$ for SIC of D-VTMR**

$$A_pB_p - Z_0{}^2C_pD_p = 0 \tag{4}$$

for the parallel configuration, where indices s and p correspond to series or parallel configurations, respectively, and Z_0 is the system impedance.

Substituting the elements of matrixes into (3) and (4), the general resonance condition determining resonance lengths θ_{1res} and $\theta_{2res}/2$ of the D-VTMR can be written in polynomial form:

$$P_4T^4 - P_3T^3 + P_2T^2 - P_1T + P_0 = 0 \tag{5}$$

where

$$T = \cos^2\left(\frac{t_2}{2}\right);\ t_1 = \frac{\theta_1 - \theta_2}{2};\text{and } t_2 = \frac{\theta_1 + \theta_2}{2}$$

P_0, P_1, P_2, P_3 and P_4 are polynomial coefficients, depending on the varactor's parameters and impedance of the coupling element, calculated as follows:

$$P_0 = \frac{R_2^2}{4} - R_2K_1 + R_2K_3 + K_1^2 - 2K_1K_3 + K_3^2$$
$$P_1 = 4K_2^2 + 4R_5^2 - 10K_1R_2 + 4R_2^2 + 4K_1^2 + 8R_2K_3 - 4K_1K_3 - 8R_5K_2$$
$$P_2 = 8R_2K_3 - 24R_5K_2 + 20R_2^2 + 4K_1^2 - 24R_2K_1 + 20R_5^2 + 4K_2^2$$
$$P_3 = 32R_5^2 - 16R_2K_1 + 32R_2^2 - 16R_5K_2$$
$$P_4 = 16R_2^2 + 16R_5^2$$

For a simplicity of consideration capacitive or inductive coupling elements are discussed here. Each of them provides a specified value of θ_{1res} and $\theta_{2res}/2$ through the parameters K_1, K_2, K_3, R_1, R_2, ..., R_9. General expressions determining resonance conditions of the D-VTMR configurations are written as:

$$\begin{aligned} K_1 &= R_6\cos(t_1) + R_9\sin(t_1) \\ K_2 &= R_7\sin(t_1) + R_8\cos(t_1) \\ K_3 &= R_1\cos^2(t_1) + \frac{R_4}{2}\sin(2t_1) + R_3 + \frac{R_2}{2} \end{aligned} \tag{7}$$

Detailed specifications of R-parameters are given in the Appendix for series and parallel configurations.

Calculating polynomial roots from Equation (5), we can determine the resonance frequencies and estimate the available tuning range of D-VTMR. As an illustration, we assume that the absolute impedance of the coupling elements is 220 ohms at a design frequency of 1.8 GHz. The impedances Z_1 and Z_1 are varied within 20 ohms = Z_1 = 80 ohms and 20 ohms = Z_1 = 80 ohms. The junction capacitive of the idealized varactor is assumed to be 0.5 pF = C_v = 2.5 pF.

Since θ_1 and $\theta_2/2$ are the independent polynomial parameters, families of curves for different relative varactor position ξ were calculated, where

$$\xi = \frac{\theta_1}{\theta_1 + \dfrac{\theta_2}{2}} \tag{8}$$

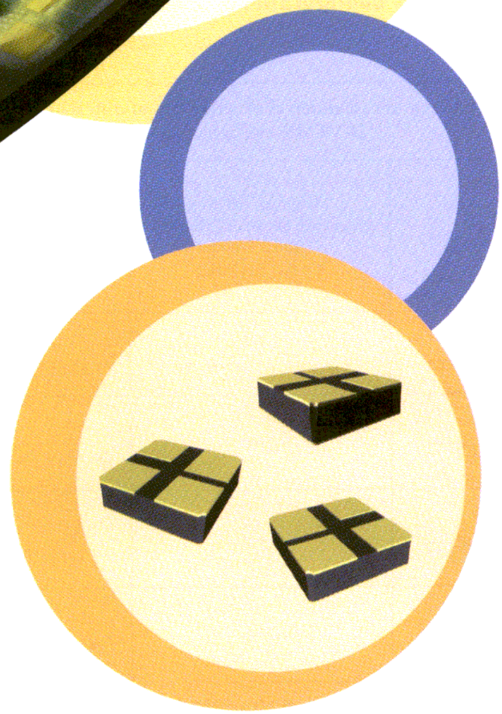
The total electric lengths $\theta_1 + \theta_2/2$ for series and par-

BUILD YOUR FUTURE WITH SAWTEK!

Sawtek delivers a full line of RF SAW filters for all your design needs.

Our expanded capacity and product portfolio make Sawtek your total SAW solution. These products – plus a complete line of SAW filters for worldwide wireless architectures – are setting a new standard for performance and dependability.

Sawtek... Your Total SAW Solution!



Sawtek's RF Filter Family

Frequency (MHz)	Bandwidth (MHz)	Band	Application	Part Number
836.5	25	Tx	U.S. Cellular	855779
836.5	25	Tx	U.S. Cellular	855729
836.5	25	Tx	U.S. Cellular	855821
881.5	25	Rx	U.S. Cellular	855728
881.5	25	Rx	U.S. Cellular	855782
942.5	35	Rx	EGSM	855810
942.5	35	Rx	EGSM	855820
1842.5	75	Rx	DCS	855860
1880.0	60	Tx	U.S. PCS	855849
1880.0	60	Tx	U.S. PCS	855833
1960.0	60	Rx	U.S. PCS	855817
1960.0	60	Rx	U.S. PCS	855850

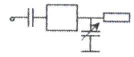
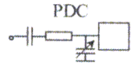
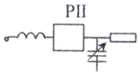
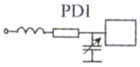
SAWTEK INCORPORATED

Call us or visit our website.

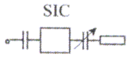
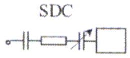
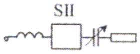
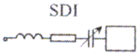
www.sawtek.com

Phone: (407) 886-8860
Fax: (407) 886-7061

Visit Sawtek at booth #2117 at MTT-S in Phoenix.

Comparison of calculated characteristics of different parallel D-VTMR configurations		
Type of Configuration	Maximum Relative Frequency Separating Between 1st and 2nd modes $s = f_{02} / f_{01}$ [MHz]	Maximum Absolute and Relative Frequency Tuning Range $\Delta f_j = f_0^{0.5}$ $f_0^{2.5}$ [MHz] $\Delta = 2(f_0^{0.5}$ $f_0^{2.5})/(f_0^{0.5} + f_0^{2.5})$ [%]
PIC 	2.175	752 38.43 ($\xi = 0.1$, $Z_1=30$, $Z_2=40$)
PDC 	2.082	831 40.81 ($\xi = 0.1$, $Z_1=80$, $Z_2=30$)
PII 	2.047	1071 56.14 ($\xi = 0.1$, $Z_1=70$, $Z_2=80$)
PDI 	2.473	1070 46.76 ($\xi = 0.1$, $Z_1=80$, $Z_2=40$)

▲ **Table 1. Comparison of calculated characteristics of different parallel D-VTMR configurations.**

Comparison of calculated characteristics of different series D-VTMR configurations		
Type of Configuration	Maximum Relative Frequency Separating Between 1st and 2nd modes $s = f_{02} / f_{01}$ [MHz]	Maximum Absolute and Relative Frequency Tuning Range Δ$f_j = f_0^{0.5}$ $f_0^{2.5}$ [MHz] $\Delta = 2(f_0^{0.5}$ $f_0^{2.5})/(f_0^{0.5} + f_0^{2.5})$ [%]
SIC 	1.548	1000 51.52 ($\xi = 0.65$, $Z_1=20$, $Z_2=80$)
SDC 	1.172	847 38.64 ($\xi = 0.7$, $Z_1=60$, $Z_2=50$)
SII 	1.578	979 49.73 ($\xi = 0.65$, $Z_1=20$, $Z_2=80$)
SDI 	1.079	987 35.16 ($\xi = 0.7$, $Z_1=30$, $Z_2=20$)

▲ **Table 2. Comparison of calculated characteristics of different series D-VTMR configurations.**

allel configurations were chosen to be 2.1 and 0.87 , respectively, in order to provide an existence of lowest resonance within frequency band 1.5 to 2.5 GHz. In any case, total electric length $\theta_1 + \theta_2/2$ is the constant value regardless of ξ.

The eight different configurations of D-VTMR were investigated:

1. *Series* configuration with *Increasing* impedance and *Capacitive* coupling element (SIC);
2. *Series* configuration with *Decreasing* impedance and *Capacitive* coupling element (SDC);
3. *Series* configuration with *Increasing* impedance and *Inductive* coupling element (SII);
4. *Series* configuration with *Decreasing* impedance and *Inductive* coupling element (SDI);
5. *Parallel* configuration with *Increasing* impedance and *Capacitive* coupling element (PIC);
6. *Parallel* configuration with *Decreasing* impedance and *Capacitive* coupling element (PDC);
7. *Parallel* configuration with *Increasing* impedance and *Inductive* coupling element (PII);
8. *Parallel* configuration with *Decreasing* impedance and *Inductive* coupling element (PDI).

It should be pointed out that the variety of resonator configurations depends on combining a type of coupling element (capacitive or inductive), a type of varactor circuit (parallel or series) and the behaviour of the transmission line impedance (increasing or decreasing) from the ends of a resonator toward the center of a resonator.

Figure 2 demonstrates the behavior of the calculated electric length $\theta_2/2$ as a function of the absolute admittance of varactor $Y_v(mSm)$ for different relative position ξ corresponding to the PDC configuration of D-VTMR. Figure 3 demonstrates the similar characteristics as a function of the absolute impedance of varactor Z_v(ohm) for different relative position ξ corresponding to the SIC configuration of D-VTMR. Sometimes the negative electric length can be obtained during analysis of resonance conditions. In this case, it is necessary to add a transmission line section with electric length π.

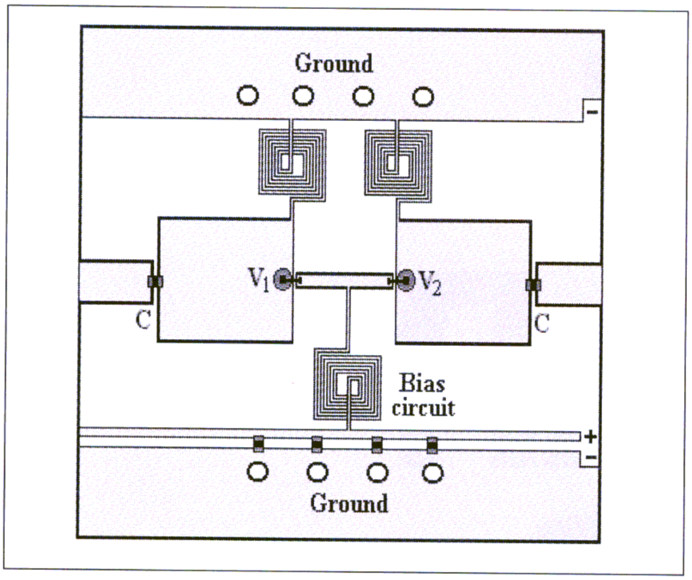
Comparisons of the calculated characteristics of different D-VTMR configurations are shown in Tables 1 and 2 and discussed in more detail in the following sections.

Analysis and discussion

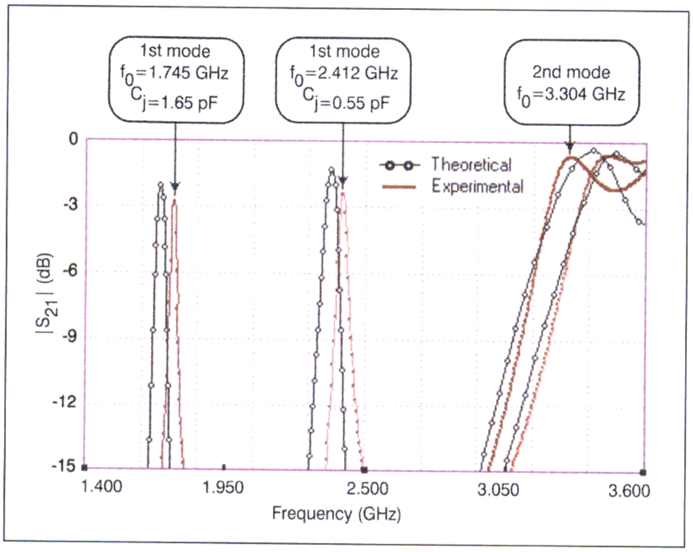
The two key criteria — maximum relative frequency tuning range and frequency separating between 1st and 2nd modes — were used to find out the better configurations of D-VTMR. Typical values of transmission line impedances ratio and relative positions of varactor were used in the analysis.

a) Parallel configuration:

When the relative position of a varactor ξ is varied from 0 to 0.2, both resonances move along the frequency axis almost synchronously. Maximum relative frequency tuning range corresponds to $\xi \approx 0.15$. It is necessary to note that the parallel configurations with inductive coupling elements give wider tuning range compared to PIC and PDC. The frequency separation



▲ **Figure 4. Experimental D-VTMR with series configuration and simple capacitive coupling element.**



▲ **Figure 5. Characteristics of S_{21} for the theoretical model and experimental performance of the D-VTMR series configuration.**

between 1st and 2nd modes is approximately the same. Preference should be given to configurations with capacitive coupling elements that are simpler to be used in practice.

b) series configuration:

When the relative position of a varactor ξ is fixed near 0.6 to 0.7, the maximum relative frequency tuning range of all possible configurations with different ratios of transmission line impedances and coupling elements is achieved. However, only SIC and SII configurations provide the maximum frequency separation between 1st and 2nd modes. SDC and SDI configurations demonstrate an unfavorable effect of modes converging.

Based on the results considered, some recommendations and limitations concerning the choice of the D-VTMR configurations may be formulated.

1. All parallel configurations give better relative frequency separating between 1st and 2nd modes.
2. SDC and SDI configurations are not recommended because of existing effect of modes converging.
3. SIC and SII configurations give better tuning facilities.

It should be pointed out that we have neglected losses in transmission lines and varactor in the above described results. This approach allows the designer to gather general information concerning the resonators studied and choose a configuration for further experiments. However, the suggested circuit model can also be used when losses in transmission lines and varactors are not equal zero. In this case, the varactor must be described by the real equivalent circuit [2]. The latter has been applied in estimating real world characteristics of D-VTMR and comparison with experimental results below.

Experimental results

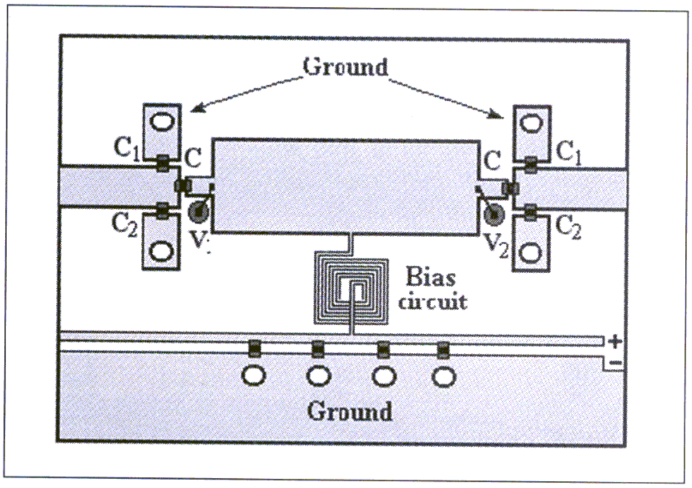
This section describes the design and performance of experimental D-VTMRs with parallel and series configurations, comparison their calculated and measured characteristics.

The designed resonator frequency was 1.8 GHz. A substrate of a dielectric constant ε_r = 2.6 and thickness 1.5 mm has been used for fabrication. A GaAs D-610C packaged varactor diode V with a capacitor ratio of 3:1 from 0 V to 30 V having $C_j(0)$ = 1.65 pF and $C_j(b)$ = 0.55 pF was used in the experiments. The unloaded quality factor of resonators was 200.

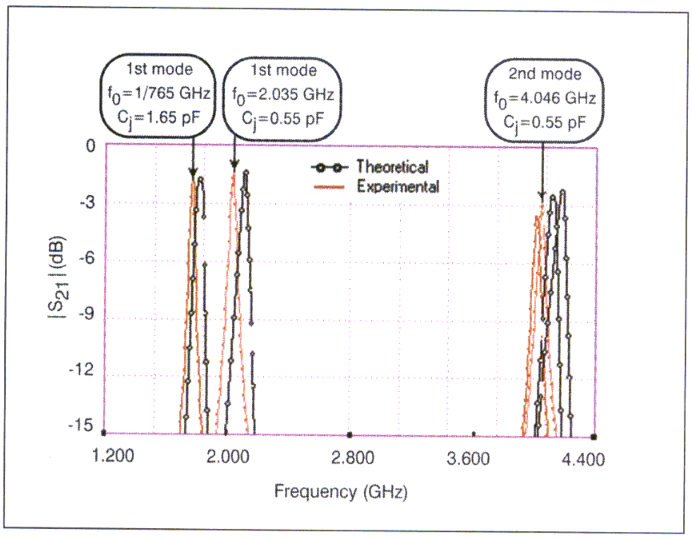
The first experimental D-VTMR was realized as the SIC configuration providing the maximum absolute frequency tuning range. The relative position of varactor ξ was chosen to be 0.7 as the optimal. The impedances Z_1 and Z_2 were chosen to be 20 and 80 ohms, respectively. The layout of D-VTMR is shown in Figure 4.

In Figure 5, the dotted line illustrates the theoretical results of $|S_{21}|$ and the solid one corresponds to measured characteristics of $|S_{21}|$. Capacitive coupling elements with C = 0.6 pF were used. In this case, the 3-dB bandwidths of $|S_{21}|$ were 38 MHz and 22 MHz for $C_j(b)$ = 0.55 pF and $C_j(0)$ = 1.65 pF, respectively. Insertion losses of the experimental D-VTMR with series configuration were varied near 2.8 dB at a whole tuning range, compared with 2.5 dB predicted by theoretical model.

The second experimental D-VTMR was realized as the PDC configuration providing the maximum frequency separating between 1st and 2nd modes. Relative position of varactor ξ was chosen to be 0.1 as the optimal one. The impedances Z_1 and Z_2 were chosen to be 70 and



▲ **Figure 6. Experimental D-VTMR with parallel configuration and capacitive coupling elements.**



▲ **Figure 7. Characteristics of S_{21} for the theoretical model and experimental performance of D-VTMR parallel configuration.**

30 ohms, accordingly. The layout of the D-VTMR is shown in Figure 6.

In Figure 7, the dotted line illustrates the theoretical results of $|S_{21}|$ and the solid one corresponds to the measured characteristics of $|S_{21}|$. L-type of capacitive coupling element having C_1 = 3.6 pF, C = 1.2 pF and C_2 = 3.6 pF was implemented to achieve the minimum bandwidth change with frequency tuning. In this case, the 3 dB bandwidths of S_{21} were 36 MHz and 26 MHz for $C_j(b)$ = 0.55 pF and $C_j(0)$ = 1.65 pF, respectively. The second mode was near 4 GHz. A good agreement of resonance frequencies for both calculated and measured characteristics was achieved with resonator tuning. Insertion losses of the experimental D-VTMR with parallel configuration were varied near 2.0 dB at a whole tuning range compared with 1.6 dB predicted by the theoretical model. An active device can be implemented for a loss compensation. One of the possible realizations of such an approach has been reported in [3].

Conclusion

An analysis of double terminated varactor tunable microstrip resonators has been presented in this paper using a proper circuit model. The resonance conditions have been obtained and applied to find out a better configuration of D-VTMR. The two experimental D-VTMRs with series and parallel varactor circuits have been fabricated. A good agreement has been demonstrated between the calculated and experimental results.

On the basis of the analysis carried out, some recommendations have been formulated for better choice of resonator's configuration. Finally, it is necessary to notice existing a natural limitation concerning D-VTMRs; namely, there is no universal D-VTMR configuration that satisfies both above mentioned criteria simultaneously. The designer will need to make a proper choice of D-VTMRs, taking into account specified system requirements. ■

Acknowledgement

This work was supported by INTAS Project no. 96-0851. The authors would like to thank the project coordinators, Dr. B. Jarry (IRCOM, France) and Dr. M. Guglielmy (ESA ESTEC, The Netherlands), for current discussions and supporting the topics considered. The authors would like also to thank Vladimir Smirnov for his useful advice and valuable assistance in the process of the experiments.

References

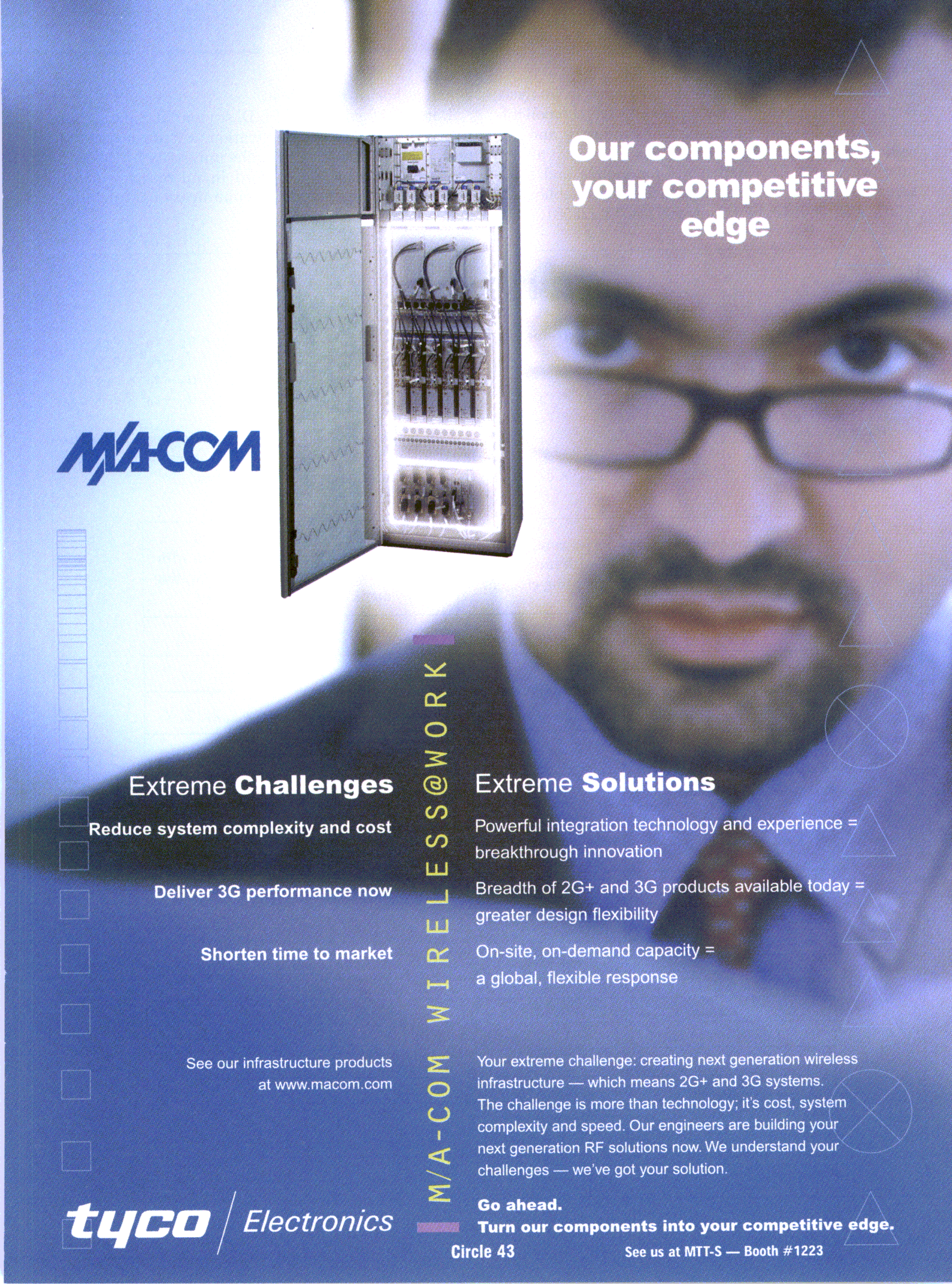
1. B.Yu. Kapilevich and R.L. Lukjanets, "Modeling Varactor Tunable Microstrip Resonators for Wireless Applications," *Applied Microwave & Wireless*, Vol. 10, No. 7 (September 1998): 32-44.

2. K.C. Gupta, Garg Ramesh and Chadha Rakesh, *Computer Aided Design of Microwave Circuits*, New York: Artech House, 1981.

3. B.Yu. Kapilevich and R.L. Lukjanets, "Tunable Active Bandpass Filter with Fixed Bandwidth," *Fourth International Wireless and Telecommunications Symposium* (IWTS-2000), Malaysia, May 15-19, 2000: 36-40.

Author information

Boris Kapilevich is a professor of microwave and RF and head of the Applied Electromagnetics Department at Siberia State University of Telecommunication & Informatics, Novosibirsk, Russia. He received an MS degree from Tomsk State University in 1965, a Ph.D. in 1969 from Novosibirsk State Technical University and a Dr.Sc. in 1986 from Moscow Power Energy University.



Our components, your competitive edge
M/A-COM
M/A-COM WIRELESS@WORK
Extreme Challenges
Reduce system complexity and cost
Deliver 3G performance now
Shorten time to market
See our infrastructure products at www.macom.com
Extreme Solutions
Powerful integration technology and experience = breakthrough innovation
Breadth of 2G+ and 3G products available today = greater design flexibility
On-site, on-demand capacity = a global, flexible response
Your extreme challenge: creating next generation wireless infrastructure — which means 2G+ and 3G systems. The challenge is more than technology; it's cost, system complexity and speed. Our engineers are building your next generation RF solutions now. We understand your challenges — we've got your solution.
Go ahead.
Turn our components into your competitive edge.
tyco Electronics
Circle 43
See us at MTT-S — Booth #1223

He has more than 30 years of experience in analysis, design and implementation of microwave components and devices for the communications industry and is a senior member of the IEEE. His interests are in microwave and RF components for mobile and space communications. He may be reached by telephone at +007 3832 660943; by fax at +007 3832 222581; or by e-mail at boris@neic.nsk.su.

Roman Lukjanets is a Ph.D. student at Siberia State University of Telecommunication & Informatics. He received his MS degree from the university in 1996. His research interests are focused in microwave and RF components for mobile communications, including microwave active filters.

Appendix

The general expressions for $R_1, R_2 \ldots R_9$ parameters are written as:

$$R_1 = a_1 \times b_1 - a_3 \times b_3 - z_0^2 \times c_1 \times d_1 + z_0^2 \times c_3 \times d_3$$
$$R_2 = a_2 \times b_2 - a_4 \times b_4 - z_0^2 \times c_2 \times d_2 + z_0^2 \times c_4 \times d_4;$$
$$R_3 = a_3 \times b_3 + a_4 \times b_4 - z_0^2 \times c_3 \times d_3 - z_0^2 \times c_4 \times d_4;$$
$$R_4 = a_1 \times b_3 + a_3 \times b_1 - z_0^2 \times c_1 \times d_3 - z_0^2 \times c_3 \times d_1;$$
$$R_5 = a_2 \times b_4 + a_4 \times b_2 - z_0^2 \times c_2 \times d_4 - z_0^2 \times c_4 \times d_2;$$
$$R_6 = a_1 \times b_2 + a_2 \times b_1 - z_0^2 \times c_1 \times d_2 - z_0^2 \times c_2 \times d_1;$$
$$R_7 = a_4 \times b_3 + a_3 \times b_4 - z_0^2 \times c_3 \times d_4 - z_0^2 \times c_4 \times d_3;$$
$$R_8 = a_4 \times b_1 + a_1 \times b_4 - z_0^2 \times c_1 \times d_4 - z_0^2 \times c_4 \times d_1;$$
$$R_9 = a_2 \times b_3 + a_3 \times b_2 - z_0^2 \times c_2 \times d_3 - z_0^2 \times c_3 \times d_2.$$

Using Table 3, $R_1, R_2 \ldots R_9$ parameters can be calculated for series or parallel configurations with capacitive and inductive coupling elements.

	Series configuration with capacitve coupling element	Series configuration with inductive coupling element	Parallel configuration with capacitive coupling element	Parallel configuration with inductive coupling element
a_1	$1 \quad Z_1/Z_2 + X_c Z_v/Z_1 Z_2$	$1 \quad Z_1/Z_2 \quad X_c Z_v/Z_1 Z_2$	$1 + X_c Y_v \quad Z_1/Z_2$	$1 \quad X_c Y_v \quad Z_1/Z_2$
a_2	$1 + Z_1/Z_2 \quad X_c Z_v/Z_1 Z_2$	$1 + Z_1/Z_2 + X_c Z_v/Z_1 Z_2$	$1 + X_c Y_v + Z_1/Z_2$	$1 \quad X_c Y_v + Z_1/Z_2$
a_3	$X_c/Z_1 \quad X_c/Z_2 \quad Z_v/Z_2$	$X_c/Z_1 + X_c/Z_2 \quad Z_v/Z_2$	$X_c/Z_1 \quad X_c/Z_2 \quad Z_1 Y_v$	$X_c/Z_1 + X_c/Z_2 \quad Z_1 Y_v$
a_4	$X_c/Z_1 + X_c/Z_2 + Z_v/Z_2$	$X_c/Z_1 \quad X_c/Z_2 + Z_v/Z_2$	$X_c/Z_1 + X_c/Z_2 \quad Z_1 Y_v$	$X_c/Z_1 \quad X_c/Z_2 \quad Z_1 Y_v$
b_1	$X_c Z_2/Z_1 \quad Z_v \quad X_c$	$X_c \quad Z_v \quad X_c Z_2/Z_1$	$X_c (Z_2/Z_1 \quad 1)$ $Y_v Z_1 Z_2$	$X_c (1 \quad Z_2/Z_1)$
b_2	$X_c Z_2/Z_1 \quad Z_v \quad X_c$	$X_c \quad Z_v \quad Z_v Z_1/Z_2$ $X_c Z_2/Z_1$	$X_c (Z_2/Z_1 + 1) +$ $Y_v Z_1 Z_2$	$X_c (1 + Z_2/Z_1)$
b_3	$Z_1 \quad Z_2 \quad X_c Z_v/Z_1$	$Z_1 \quad Z_2 + X_c Z_v/Z_1$	$Z_1 \quad Z_2 \quad X_c Y_v Z_2$	$Z_1 \quad Z_2 + Y_v X_c Z_2$
b_4	$Z_1 + Z_2 \quad X_c Z_v/Z_1$	$Z_1 + Z_2 + X_c Z_v/Z_1$	$Z_1 + Z_2 + X_c Y_v Z_2$	$Z_1 + Z_2 \quad Y_v X_c Z_2$
c_1	$Z_v/Z_1 Z_2$	$Z_v/Z_1 Z_2$	Y_v	Y_v
c_2	$-Z_v/Z_1 Z_2$	$-Z_v/Z_1 Z_2$	Y_v	Y_v
c_3	$1/Z_1 \quad 1/Z_2$	$1/Z_1 \quad 1/Z_2$	$1/Z_1 \quad 1/Z_2$	$1/Z_1 \quad 1/Z_2$
c_4	$1/Z_1 + 1/Z_2$	$1/Z_1 + 1/Z_2$	$1/Z_1 + 1/Z_2$	$1/Z_1 + 1/Z_2$
d_1	$1 \quad Z_2/Z_1$	$1 \quad Z_2/Z_1$	$1 \quad Z_2/Z_1$	$1 \quad Z_2/Z_1$
d_2	$1 + Z_2/Z_1$	$1 + Z_2/Z_1$	$1 + Z_2/Z_1$	$1 + Z_2/Z_1$
d_3	Z_v/Z_1	Z_v/Z_1	$Y_v Z_2$	$Y_v Z_2$
d_4	$-Z_v/Z_1$	Z_v/Z_1	$-Y_v Z_2$	$-Y_v Z_2$

▲ **Table 3. Series and parallel configurations.**

Fundamentals of RFIC Package Characterization

RF and microwave packages are a necessary part of the total circuit and must have their effects included in design

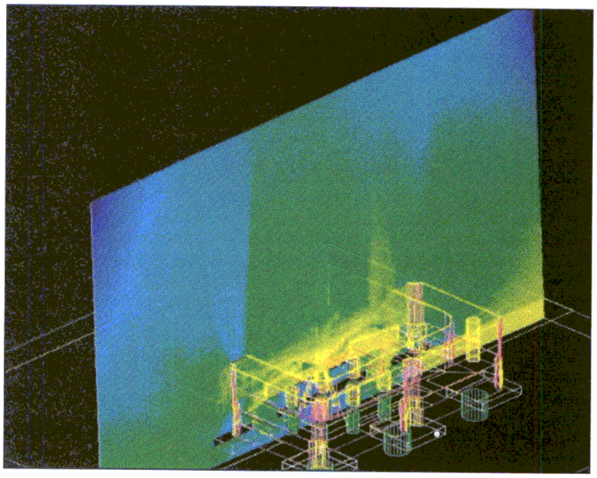
By Scott A. Wartenberg
Agilent Technologies

Most RFIC designers concentrate their characterization effort on the die. Overlooked in the design process is the package. This article gives a sampling of the basic issues involved in package characterization and discusses fundamental characterization concepts.

The design cycle of an RFIC is well-known. Built from a database of elements, the RFIC or MMIC seeks a response that will meet the customer's needs. To understand how the design will hold up over IC process variances, stability and sensitivity analyses are performed until a satisfactory circuit is obtained. Next, the components in the schematic are laid out. An optimal layout achieves the circuit in the smallest area. Wafer die are then fabricated to the layout. Following several weeks of fab processing, sample die are measured in the lab. Correlation is established between simulated and measured. If problems arise, the die is redesigned. After a number of iterations, a die with acceptable RF performance is achieved. Throughout this cycle, the RFIC designer directs maximum effort to the die design.

The second step is the package. Ideally, the package should be transparent to the die, "invisible" at RF. At high frequencies, nothing physical is invisible over a significant bandwidth. The package frequently adds another iteration to the design cycle. More troublesome is that the package is not predefined; each is custom-designed to the die layout. For superior performance, packages cannot be simply pulled off the shelf.

All the customer cares about is the performance of the final component. Yet the component is composed of pieces, like a puzzle. Try to understand how the pieces behave separately and together. With the right tools and procedures, the puzzle can be solved. Five concepts guide RFIC package characterization.

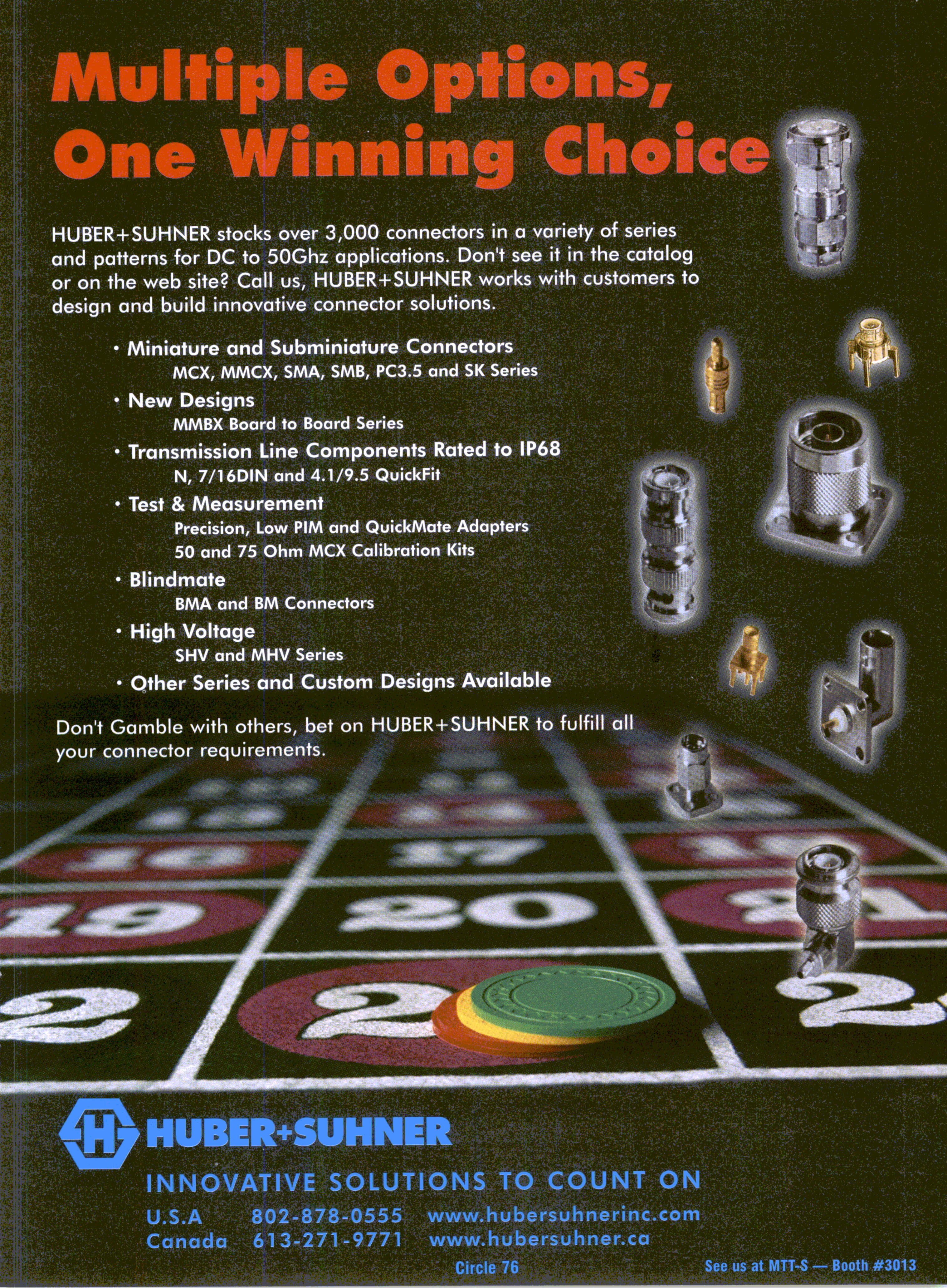


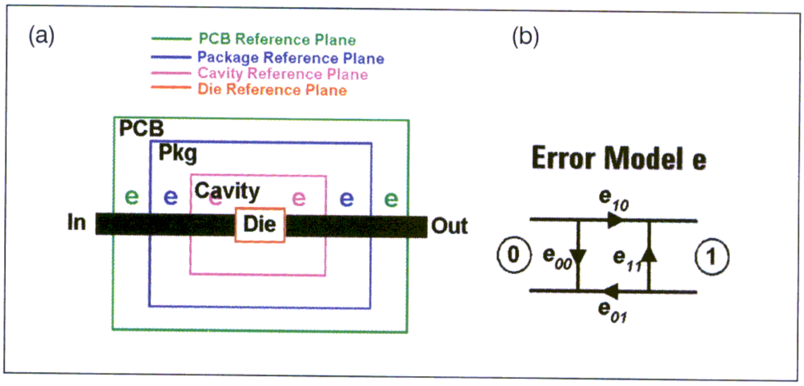
▲ **Figure 1. E-field plot of a component soldered to a PCB.**

Using electromagnetic field simulators

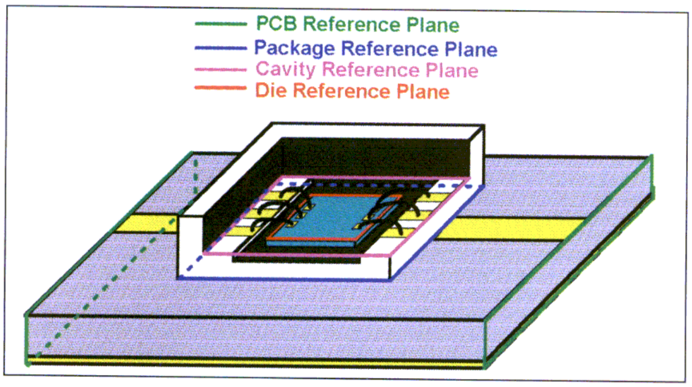
Understanding electromagnetic interactions is at the heart of package characterization. Conductor layers couple to nearby conductors. Coupled electric fields induce current. The induced current leads to more E-fields elsewhere. Dielectric interfaces reflect some energy but allow a portion to pass. Inadequate grounding allows energy to propagate in the ground plane [1]. These electromagnetic effects, while difficult to quantify, impact the package RF behavior.

Electromagnetic field simulators provide insight into dynamic field action within the package. This supports the equivalent-circuit modeling effort. Shown in Figure 1 is an E-field


Multiple Options, One Winning Choice
HUBER+SUHNER stocks over 3,000 connectors in a variety of series and patterns for DC to 50Ghz applications. Don't see it in the catalog or on the web site? Call us, HUBER+SUHNER works with customers to design and build innovative connector solutions.
• Miniature and Subminiature Connectors
MCX, MMCX, SMA, SMB, PC3.5 and SK Series
• New Designs
MMBX Board to Board Series
• Transmission Line Components Rated to IP68
N, 7/16DIN and 4.1/9.5 QuickFit
• Test & Measurement
Precision, Low PIM and QuickMate Adapters
50 and 75 Ohm MCX Calibration Kits
• Blindmate
BMA and BM Connectors
• High Voltage
SHV and MHV Series
• Other Series and Custom Designs Available
Don't Gamble with others, bet on HUBER+SUHNER to fulfill all your connector requirements.
19
20
2
HUBER+SUHNER
INNOVATIVE SOLUTIONS TO COUNT ON
U.S.A 802-878-0555 www.hubersuhnerinc.com
Canada 613-271-9771 www.hubersuhner.ca
Circle 76
See us at MTT-S — Booth #3013

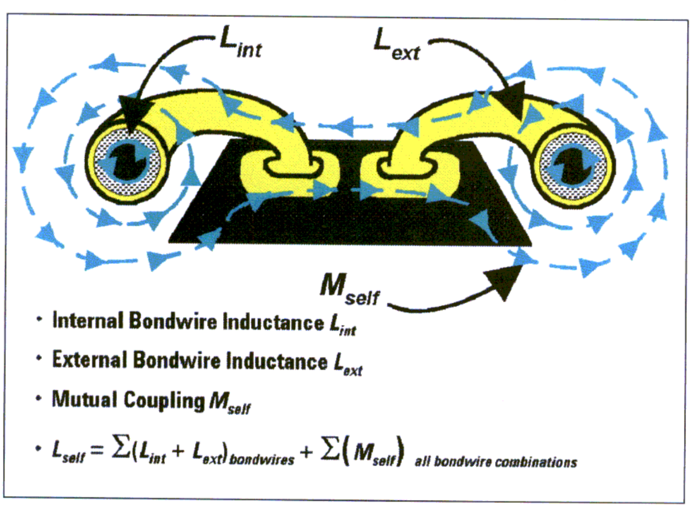


▲ **Figure 2. (a) Division of the component into calibration planes; (b) Error adapter for a segment between planes.**



▲ **Figure 3. The component divided into physical calibration planes.**

plot of a component soldered to a PCB. The plane cuts through the middle of the PCB, microstrip and package. The package is a LCC (Leadless Chip Carrier). Solderpads, shown in white, mount the package to the PCB. Filled vias in the PCB, shown in green, ground the unused pins. Epoxied inside the package is a die. The current on its surface creates intense E-fields, shown in



▲ **Figure 4. Inductances associated with bond wires.**

yellow. The package is unlidded, so electric fields radiate out the top. One-mil diameter bond wires connect the package and die pads inside. Each connection is double-bonded.

Layering the RFIC design

Calibration planes section the component, as shown in Figure 2. Mathematical error models represent each portion. Measurements are then referred to the bounds of the reference planes. Typically, inside the boundaries is what is being measured and outside is the test system. This is the concept of a reference plane. Sectioning the component into reference planes can become complicated, as shown in Figure 3. For example, the area between the package and die pads contains bond wires. Coupling occurs from the bond wires to adjacent metal in the package and on the die. This makes the bond wire cavity the most difficult to characterize. Arbitrarily allotting coupling effects to one reference plane or the other is valid. However, such decisions should be clearly described.

Reference planes consist of two types, physical and electrical. Upon calibration, the electrical reference plane and the calibration plane align along the same line. Unlike physical reference planes, electrical reference planes can overlap. In packages, coupling overlaps the electrical calibration planes.

Package behavior affecting RF characterization

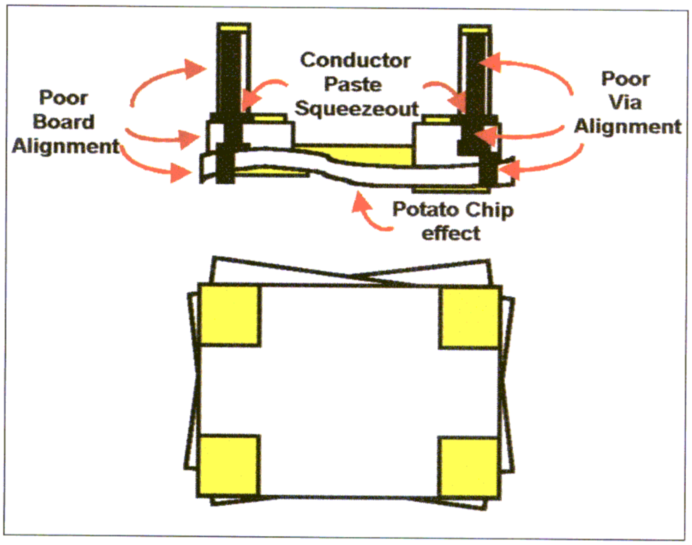
Inductance L is the proportion of magnetic flux ψ to the current flow I that created it. In a bond wire, inductance exists internally and externally (see Figure 4). Internally, I flows uniformly through the bond wire at DC. As the frequency f increases, I flows closer to the surface. This property is known as the skin depth. The wire's internal inductance L_{int} decreases as the square root of f, or –10 dB per decade. As f increases, the current moves toward the surface. Dynamic I creates ψ, so ψ exists nearer the surface, too. As I crowds, less of it flows. This makes for less ψ.

Externally, flux lines run just beyond the wire's diameter. This leads to external inductance L_{ext}. If two or more bondwires connect to the same pad, then current will flow in both. Since I flows in the same direction, external ψ lines will constructively couple. The net self-inductance L_{self} is the sum of the individual bondwire inductances ($L_{int} + L_{ext}$), plus the mutual coupling M_{self} between them. When bondwires are orthogonal, no coupling occurs.

The package design can point to problems with the die design, such as on-die mutual coupling between elements.

Selecting the style of package

Out of a multitude of packages on the market today, three common ones are discussed here.



▲ **Figure 5. Mechanical issues associated with multi-layer ceramic boards.**

1. *Small-outline transistor* (SOT) packages are the most common. The black plastic acts as a dielectric covering ($\varepsilon_r \approx 5$), which affects the fields coming off the die surface. It loads the conductors differently than air ($\varepsilon_r = 1$). The die will be encased in plastic. RF on-wafer testing occurs with air above the die. This is an important detail. The S-parameters of the die are often imported into Agilent's ADS CAE package for simulation. To emulate the final product, they should be accompanied by EM-field simulations of the encapsulated die. The SOT legs add loss and parasitic effects limiting the high-frequency performance.

2. *Single-layer ceramic* does away with package legs. Alumina provides a durable mounting surface and a uniform dielectric. A thin-film etch process offers better tolerances on the conductor line widths. This package is a compromise between the SOT and multi-layer ceramics.

3. *Multi-layer ceramics* permit vertical circuit integration. When the boards are fired at low temperatures, passive components can be incorporated into the body of the package [2]. This shrinks the size of the circuit. Although offering the most benefits, multi-layer ceramics require an intense design effort. Good electrical performance hinges on detailed electromagnetic field analysis. Mechanically, various problems can occur in the layer stack (see Figure 5).

Sketch a design flow

Most RFIC designs adhere to a common flow. First, review the design specs. Understanding the spec flow-down process, the IC fabrication process and the package process, as well as knowing the limits of manufacturing, comprise a huge amount of information. Engineering teams are often dedicated to each. Second, divide the component into layers. Due to ground plane leakage and die radiation, the layers are never fully separate. Consider merging layers.

Third, design the component from the inside out. Calibrated RF on-wafer testing makes the die the best-defined layer. Adjust input/output ports on the die and package pads to meet the RF performance. When optimizing, determine the degree of fit needed. Characterize and model each layer, selecting the best hardware and software to use. Understand the limits of each characterization method. The primary difficulty is translating mechanical package tolerances to electrical performance.

Conclusion

Most RFIC designers limit their understanding of the package to a simple RF lumped-element equivalent-circuit model. The major RF variations in the package usually depend on less than 20 percent of the circuit elements. Finding which are the critical ones is the challenge. A detailed characterization effort gives a better understanding of the package's contribution.

Some RF applications are more forgiving of packaging mistakes than others. In linear amplifiers and power amplifiers, simply increasing the gain a few tenths of a dB overcomes package losses. When package parasitics lead to oscillation, the solution is not so simple. Some applications are especially sensitive to package parasitics. Examples are low-noise amplifiers and filters. These can require more than 50 dB of sensitivity. Such sensitivity is affected by package reactances less than 100 pH or 100 fF. The application often determines the degree of package modeling required. ■

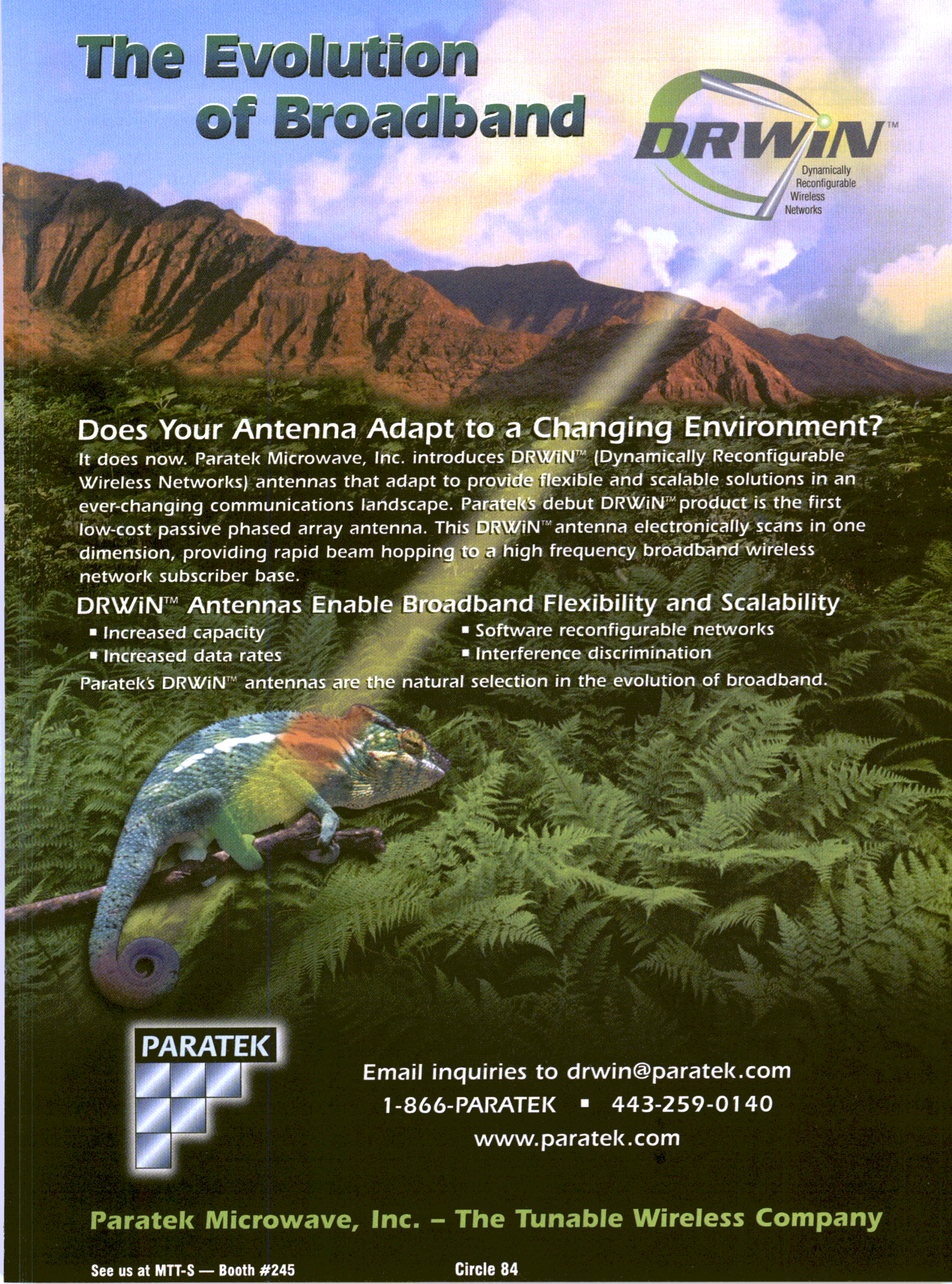
References

1. Y. Liu and T. Itoh, "Leakage Phenomena in Multilayered Conductor-Backed Coplanar Waveguides," *IEEE Microwave and Guided Wave Letters*, Vol. 3, No. 11 (November 1993): 426-427.

2. M. Tredinnick and D. Malanga, "Extending Gold Thick-Film Technology Through Materials and Process Development," *Microwave Journal*, Vol. 43, No. 11 (November 2000): 64-74.

Author information

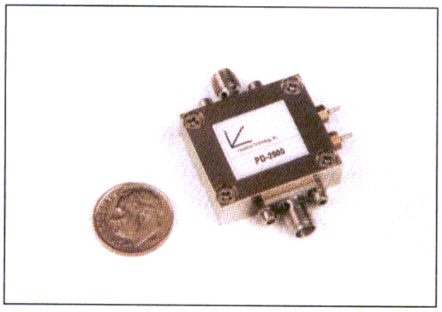
Scott Wartenberg is a test engineer with Agilent Technologies' Wireless Semiconductor Division in Newark, CA. He received a Ph.D. in Electrical Engineering from the Johns Hopkins University in Baltimore, MD. He has designed RF, microwave and millimeter-wave packages for commercial and defense applications and has published several articles on RF and microwave package and module design. He may be reached by telephone at 510-505-5585 or by e-mail at scott_wartenberg@agilent.com.


The Evolution
of Broadband
DRWiN™
Dynamically
Reconfigurable
Wireless
Networks
Does Your Antenna Adapt to a Changing Environment?
It does now. Paratek Microwave, Inc. introduces DRWiN™ (Dynamically Reconfigurable Wireless Networks) antennas that adapt to provide flexible and scalable solutions in an ever-changing communications landscape. Paratek's debut DRWiN™ product is the first low-cost passive phased array antenna. This DRWiN™ antenna electronically scans in one dimension, providing rapid beam hopping to a high frequency broadband wireless network subscriber base.
DRWiN™ Antennas Enable Broadband Flexibility and Scalability
▪ Increased capacity
▪ Increased data rates
▪ Software reconfigurable networks
▪ Interference discrimination
Paratek's DRWiN™ antennas are the natural selection in the evolution of broadband.
PARATEK
Email inquiries to drwin@paratek.com
1-866-PARATEK ▪ 443-259-0140
www.paratek.com
Paratek Microwave, Inc. – The Tunable Wireless Company
See us at MTT-S — Booth #245
Circle 84

AMPLIFIERS

Linearizer modules

Linearizer Technology has announced its new PS-2000 linearizer modules, which can be integrated with solid state power amplifiers. The new linearizers are designed to achieve optimal results

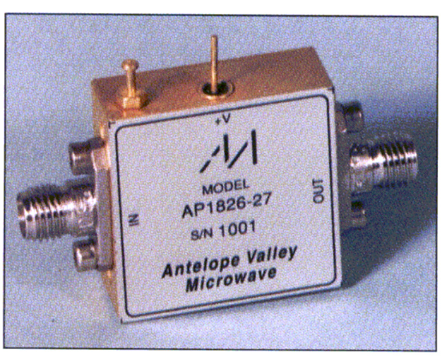


when paired with power amplifiers required to produce 10 watts or greater linear power. Since SSPAs operating on the same frequency band and using similar devices can have different amplifier characteristics and linearization requirements, Linearizer Technology has developed a customized program to determine and manufacture a predistorter module for a desired solid state amplifier design.

Linearizer Technology, Inc.
Circle #134

High-power amplifiers

Antelope Valley Microwave has introduced a new line of high-power millimeter-wave amplifiers covering the 15 to 40 GHz frequency range. The amplifiers feature 1 dB compressed power output of

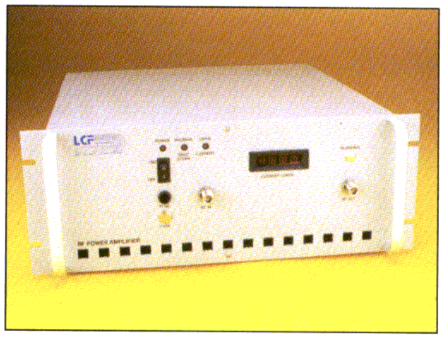


greater than +27 dBm (0.5 watt) from 18 to 26 GHz for Model AP1826-27 and from 26 to 32 GHz for Model AP2632-27, with other models providing +30 dBm (1 watt) at frequencies up to 40 GHz. These mm-wave amplifiers have a typical input and output VSWR of 2.5:1 with SMA, 2.92 mm connectors or standard waveguides.

Antelope Valley Microwave
Circle #135

RF power amplifier

LCF Enterprises has developed a high performance 100-watt RF power amplifier that covers the frequency range from 0.3 to 30 MHz with 45 dB of gain. Features include automatic current limiting, forced air cooling, current meter, over-current and thermal protection. Performance specifications for



the AC Full Amplifier System include 100 watts CW (typical) output power, 0.3 to 30 MHz frequency range, 45 dB typical gain, AB linear classification and 120/220 VAC AC power. The amplifier measures 19 × 18 × 7 inches, weighs 35 pounds and includes N female connectors. The amplifier is also available as a DC module in a small, high-efficiency package.

LCF Enterprises
Circle #136

SEMICONDUCTORS

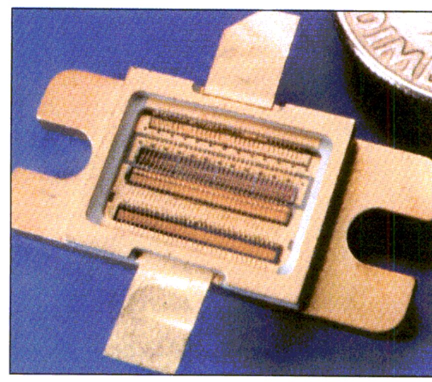
DSL processors

Texas Instruments has announced a complete family of digital subsriber line (DSL) communications processing solutions for the router and voice over DSL (VoDSL) gateway market segments. The processors enable consumers to network multiple PCs and other Internet appliances with high-speed data and voice. Comprised of the voice processing capabilities of TI's programmable TM320C54x DSP and a 125 MHz MIPS microprocessor, the TNETD5310 and TNETD5320 DSL communications processors enable toll-quality digital voice, lifeline telephony, packet routing and advanced network-powered services.

Texas Instruments Incorporated
Circle #137

Bipolar RF transistors

Northrop Grumman introduces the WPTB32A0912Ax application-specific transistor, using the 3217 L-Band die, which was developed for pulse radar systems. Optimal internal matching delivers high performance for applications such as the MIDS and JTIDS communication systems. Low thermal resistance and high-efficiency couple to



provide nearly imperceptible droop across the entire TDMA burst waveform at power levels of more than 200 watts. Features include refractory/gold metalization, metal/ceramic hermetic package, typical power out of 180 watts, two stage internal matching and single transistor die implementation.

Northrop Grumman
Circle #138

IC and system software solutions for 3G

QUALCOMM has announced the MSM6500™ and MSM6600™ mobile station modem integrated circuit and system software solu-

tions to support third-generation (3G) wireless technology. The MSM6500 supports 3G technologies including cdma2000 1x; cdma2000 1x Evolution (1xEV) for high-speed data, supporting data rates of up to 2.4 Mbps; Global System for Mobile Communications (GSM); and General Packet Radio Services (GPRS). The MSM6600 supports cdma2000 1x, Wideband CDMA (WCDMA) and GSM/GPRS, enabling true second-generation (2G) and 3G global roaming.

QUALCOMM Incorporated
Circle #139

SIGNAL PROCESSING

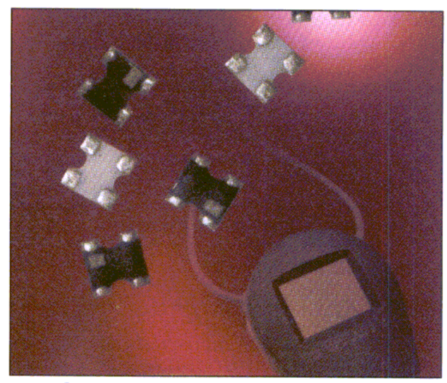
Bandpass filter

Microwave Filter Company introduces the Model 14042 bandpass filter. This filter is used to prevent PCS interference at the ENG receive site. It passes the entire ENG band (channels 1 through 10, 1990-2500 MHz). The unit provides stopband rejection of 25 dB (minimum) at 1910 MHz and 2580 MHz, with a passband insertion loss of 1.0 dB (maximum). The impedance is 50 ohms, with standard type-N (female) connectors. The filter is designed for indoor use but can be provided as a temperature compensated unit. The filter's package size is 6 × 2 × 2 inches.

Microwave Filter Company
Circle #140

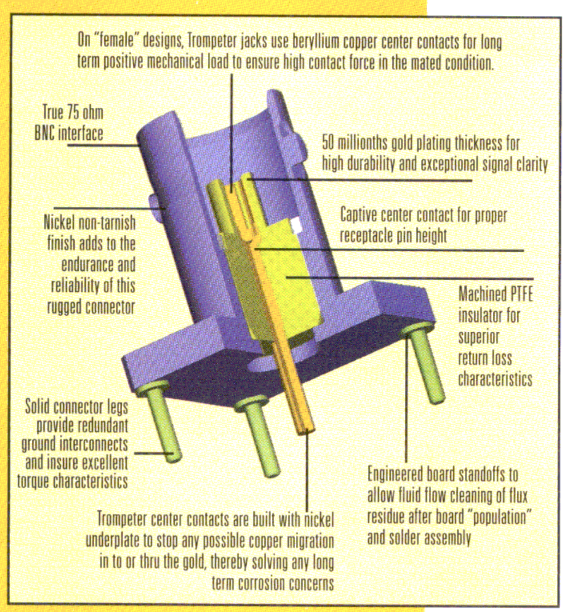
Surface-mount chip attenuators

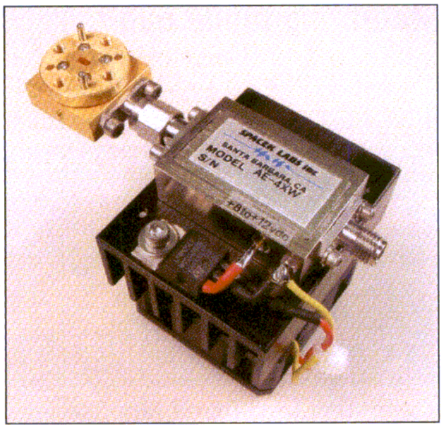
Vishay Intertechnology has introduced a new series of surface-mount thick film chip attenuators. The Dale CZA chip attenuators will provide improved attenuation in a single device, as compared to three or more discrete resistors. Additional benefits include lower overall component cost, board space and



weight savings for the manufacture of communications, automotive and consumer electronic products. The CZA series is designed for signal attenuation in the RF section in cell phones and wireless information appliances. The range of impedance options are 50, 75, 300 and 600 ohms, with an attenuation range from 0.5 to 20 dB. The attenuators are available in both 40 mW (CZA04S) and 75 mW (CZA06S) maximum input power options.

Vishay Intertechnology, Inc.
Circle #141





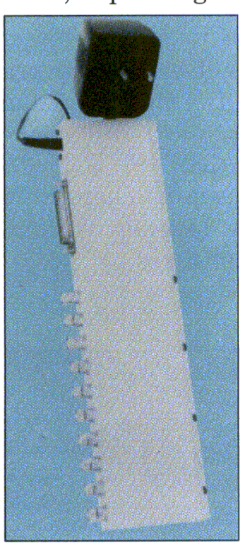
× 4 multiplier

Spacek Labs introduces its model AE-4XW, an active × 4 multiplier covering all of E-band (60 to 90 GHz). Input power is +10 to +15 dBm at 15 to 22.5 GHz. The typical output power is +4 dBm, with a minimum output power of +2 dBm. Narrow band units can achieve +10 dBm output power.

Spacek Labs
Circle #142

Coaxial relay module

Matrix Systems has introduced a coaxial relay module that maintains switching continuity over a wide range of critical and severe environmental conditions. Model 7000 features 2 to 24 throws; DC up to 800 MHz, depending on the number of throws; continuous shield continuity; switchpoints individually field replaceable; signal circuits isolated from control circuitry; low EMI and VSWR; built-in amplifiers available for video and RF applications; and matrix and hybrid systems that can be easily constructed using 9000 series push-on cross straps, which then mate with BNC connectors on the switch mode. Typical applications include RF and IF signal switching, base band video and pulse switching; applications requiring high degree of shielding integrity, low contact and induced noise; switching DS-1, DS-3, T-1, 1553B and ECL signals; and switching balanced audio.

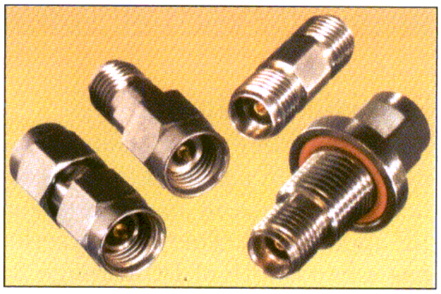


Matrix Systems
Circle #143

CABLES & CONNECTORS

Precision adapters

RF Connectors has added four new precision adapters to its product line for use in microwave and RF applications. This 3.5 mm series has a bandwidth of DC through 34 GHz and inter-mate with 2.9 mm and SMA connectors and adapters.



Female contacts feature a four-slot configuration, ensuring that pressure is distributed evenly during the engagement of the male pin, a design which, when combined with a shortened male pin, eliminates misalignment during engagement. All bodies are stainless steel with a captivated dielectric bead and gold-plated BeCu contacts. Adapters available include male to male, female to female, male to female, and female to female bulkhead with o-ring seal.

RF Connectors
Circle #144

Upgraded installer tool kit

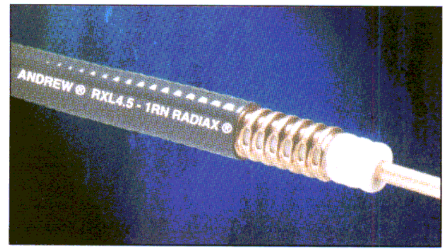
Trompeter Electronics has announced the introduction of an improved version of their BNC installation tool kit. The upgraded features include a rapid charger for the battery-powered coax wire

stripping tool, an ergonomically improved crimp sleeve tool frame and a newly modified BNC tester. Custom kits can be ordered, offering a mix of tools for specific applications needs.

Trompeter Electronics
Circle #145

Radiating mode cable

Andrew Corporation has launched its new RADIAX® RXL4.5-1, a 5/8-inch coupling mode



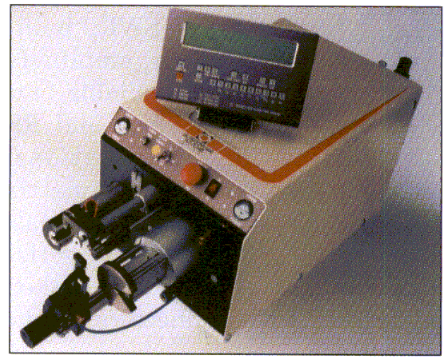
cable for broadband applications. RXL4.5-1 cable is suited for installation in buildings and in tunnels where speed of installation and high performance is required. The new cable's coupling mode ensures that signal power is radiated uniformly around the cable and along its length providing a more efficient platform for multiple frequencies.

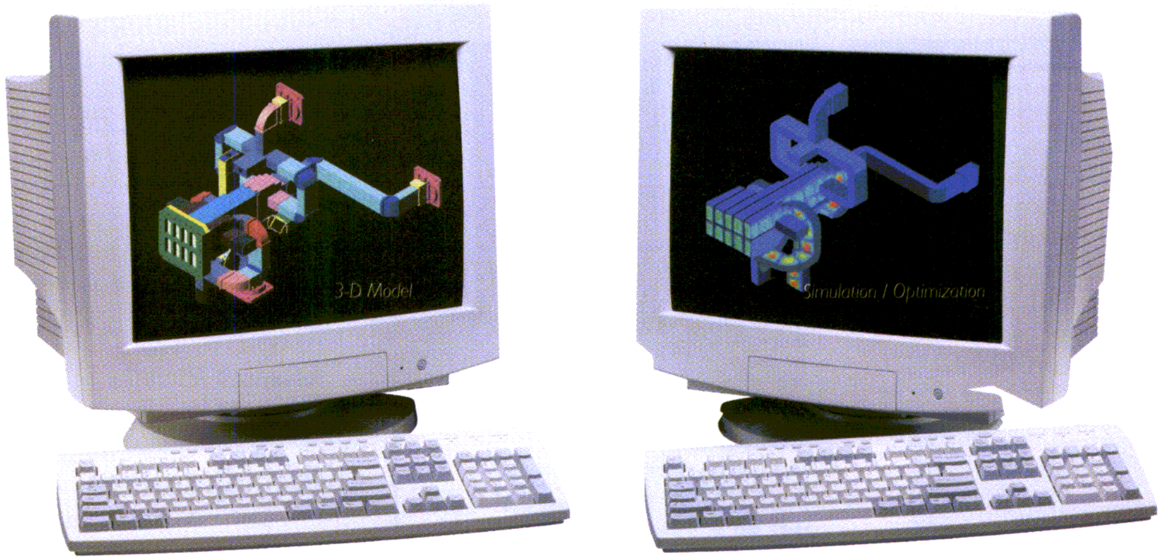
Andrew Corporation
Circle #146

Cable stripping machine

Schleuniger's FO 7045, which is specifically designed for fiber optic cable, incorporates four stripping functions that can be programmed to allow for a variety of stripping combinations. The system processes many different cable types and thicknesses up to a length of 70 mm and an outer diameter of up to 4.5 mm. The FO 7045 strips the outer jacket, Kevlar, and buffer and primary coating on the most commonly used single and multi-mode cables in less than 14 seconds. Cable programs can be changed in less than three seconds without tooling or blade changes.

Schleuniger
Circle #147

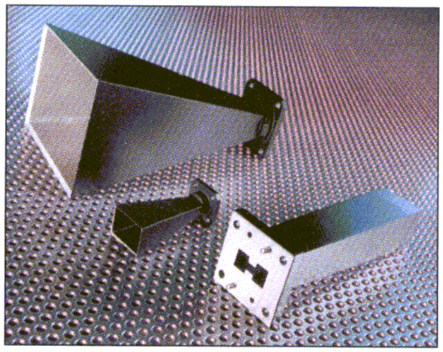



3-D Model
Simulation / Optimization

Products

ANTENNAS

Horn antennas

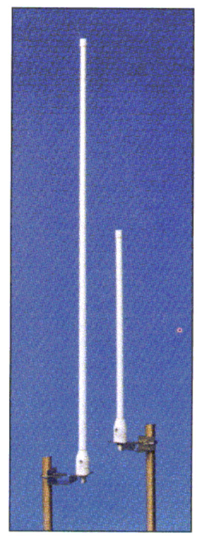


Advanced Microtek has introduced its new range of standard-gain horn antennas that can be specified with a choice of double-ridge or rectangular waveguide inputs. Covering the frequency range from about 1 to 40 GHz, the new antennas are suited for use as gain references and in applications such as antenna gain test measurements, EMC field probing and line-of-sight communications. The range of standard products includes rectangular waveguide sizes from WR650 to WR28 and double-ridge waveguide sizes from WRD350D24 to WRD180D24.

Advanced Microtek
Circle #148

Omnidirectional antennas

Pacific Wireless has announced two new omnidirectional antennas operating from 2400 to 2484 MHz for wireless base station applications including transmit and receive operations for industrial, scientific and medical (ISM), point-to-point communication and wireless broadband communications. Model PAWOD24-9 features 9 dBi antenna gain and 14 degrees of vertical beam width. It is 5/8 inch in diameter and 20 inches in length and weighs 2.2 pounds. Model PAWOD24-12 features 12 dBi of antenna gain, 7 degrees of vertical beam width. It is 5/8 inch in diameter and 40 inches in length and weighs 4.4 pounds. Both antennas are constructed of UV-stable fiberglass and include 50-ohm passive feeds that come with industry-standard type N female connectors.



Pacific Wireless
Circle #149

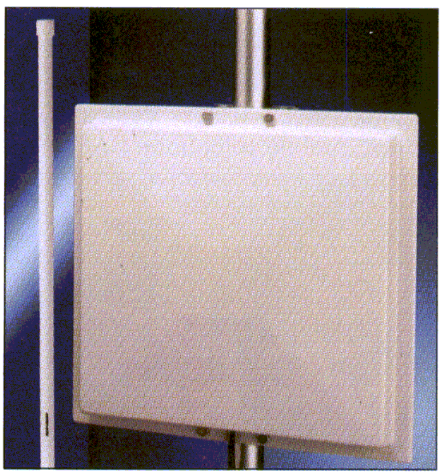
Antennas for Bluetooth

Centurion Wireless Technologies introduces two new antennas for Bluetooth applications. The BlueChip™ is an internal antenna that offers high-gain performance (>2.0 dBi) with a wide bandwidth, in a small, lightweight PCB surface mount package. It can be delivered in tape and reel packaging. The MicroBlue antenna features a .03 inch thick footprint and provides 3 dBi gain. It is customizable for high-volume embedded applications in either board- or cable-mount configurations.

Centurion Wireless Technologies, Inc.
Circle #150

MMDS antenna solutions for wireless Internet

MAXRAD announces two new high-performance MMDS antenna solutions for wireless Internet and other wireless applications. The MP25017PT directional panel covers frequencies from 2500 to 2700 MHz and provides 17 dBi gain with a VSWR of less than 1.5:1. Front to



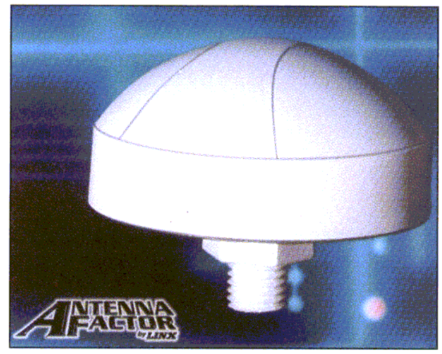
back ratio is greater than 25 dB with power handling of 100 watts. It provides 3 dB vertical and horizontal beamwidths of 18 degrees. The antenna can be mast- or wall-mounted and includes a 12-inch pigtail that can be fitted with any type of connector.

MAXRAD
Circle #151

Dual-band antenna

Antenna Factor has introduced its new CELNSAT 01 dual-band low-profile antenna, which combines a wideband omnidirectional disk covering the ISM and cellular bands with a high-efficiency amplified ceramic GPS antenna. Housed in a weather-tight, tamper-resistant dome, the antenna is suited for mounting on devices such as vehicles, vending machines or equipment housings. It is priced at $42 in production quantities and is available with labeling, color and terminations of a customer's choosing.

Antenna Factor
Circle #152

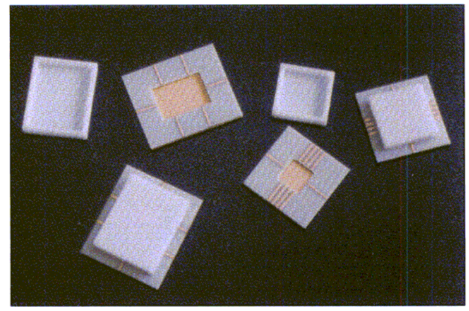


Products

MATERIALS & MANUFACTURING

Ceramic packages for microwave

StratEdge's SE50 line of standard off-the-shelf designs handle packages operating from DC to more than 50 GHz. These commercial packages can withstand the heavy electrical and thermal demands required to protect the broadband and power MMIC amplifiers needed for LMDS, point-to-point and point-to-multipoint technologies.

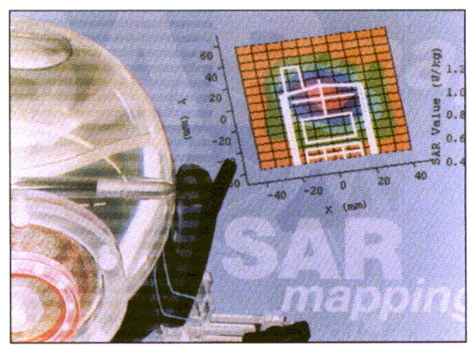


StratEdge
Circle #153

TEST EQUIPMENT

SAR measurement system

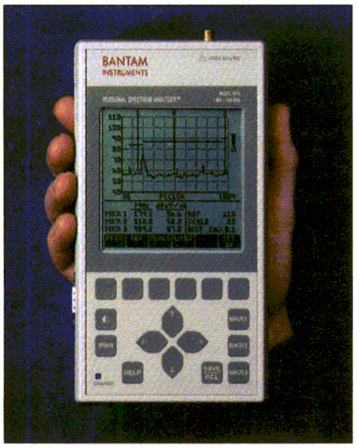
IndexSAR has introduced a new bench-top measurement system to measure SAR (specific absorption rate) of mobile telephones and other wireless devices. The system allows a standard, mobile telephone SAR measurement in less than three minutes using a two-dimensional scanning technique. The system is suited for development applications, antenna characterizations and comparative phone assessments. A flexible test device positioner gives a range of phone angles from the starting touch position to +15 degrees, or any position within a range of 30 degrees, as required by CENELEC Pr EN 50361. A graduated scale allows for easy setting. For accessory testing, an optional mount is available to accommodate most standard earpieces.



IndexSAR
Circle #154

Spectrum analyzer

Bantam Instruments has unveiled its new handheld battery operated spectrum analyzer. The Model 401A Personal Spectrum Analyzer™ covers 1 to 1024 MHz and is intended for both bench top and field use. It is suited for the measurement of harmonic and spurious emissions, identification of unknown or unwanted signals, signal monitoring, field strength measurements and EMC pre-compliance testing. Included with the spectrum analyzer is the Model P101A Active E-Field Probe for troubleshooting EMC measurements. The probe's internal amplifier is powered through the input connector of the spectrum analyzer and calibrated in dBμv/m. The probe functions as a miniature focused antenna, allowing circuits to be non-invasively measured and trouble spots identified quickly.

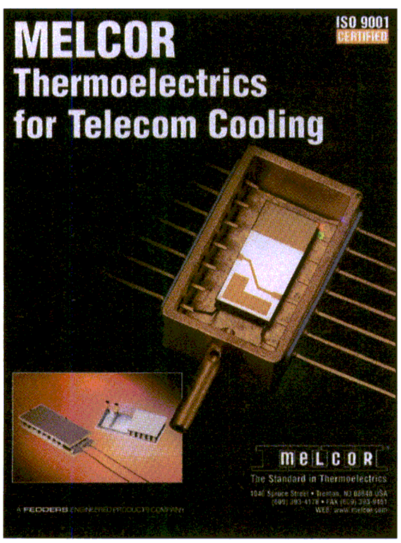


Bantam Instruments
Circle #155

LITERATURE

Thermoelectrics brochure

Melcor introduces its new brochure for cooling and temperature control of telecom components. The publication contains a listing of the standard thermoelectrics that Melcor provides for the telecom thermoelectrics market, including thermoelectrics constructed with solders of either 138, 232 or 271 degrees Celsius, giving the customer the ability to choose a cooler based on specific processing or operational requirements. Melcor also introduces three new standard thermoelectrics with aluminum nitride ceramics in this brochure.



Melcor Corporation
Circle #156

Ultra broadband capacitor brochure

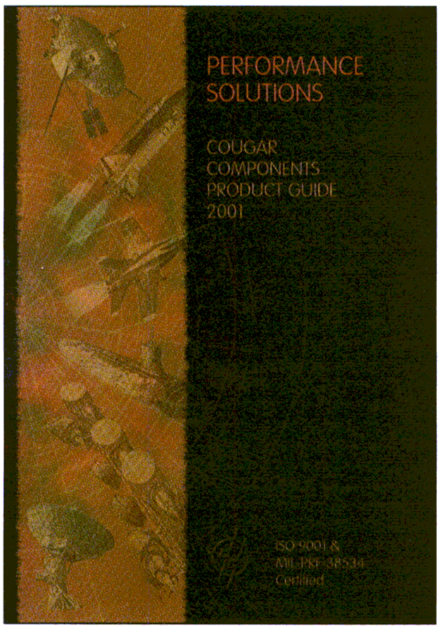
Dielectric Laboratories has published its new Ultra Broadband DC Blocking Capacitor brochure. The brochure features Opti-Cap™ and Milli-Cap® broadband solutions, as well as 0603 and 0805 size broadband DC blocks. The Opti-Cap™ takes advantage of Milli-Cap characteristics, such as 0502 footprint, high Q and low series inductance, and combines them with high-value capacitance for coverage from DC to Light (12 kHz to

40+ GHz). Although the DC blocking capabilities are the key feature, the overall size of 0.0552 inches with an 0502 footprint combined with single step assembly makes this package suitable for fiber optic applications such as OC-192 and OC-768.

Dielectric Laboratories, Inc.
Circle #157

Product guide

Cougar Components has released its 2001 product guide. The guide includes a company pro-



file; technology review board; product design and development; sales, marketing and service; manufacturing operations; and product overviews, which include specifications, intermodulation performance, absolute maximum ratings, typical performance and typical automatic test data.

Cougar Components Corporation
Circle #158

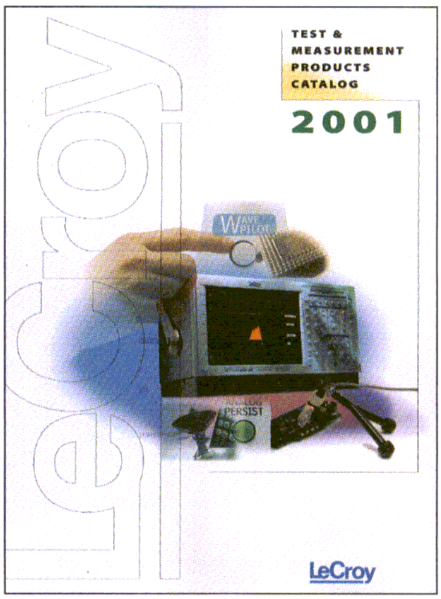
Frequency-control product guide on CD-ROM

Rakon is now offering a free frequency-control product guide on CD-ROM. This interactive CD-ROM covers all of Rakon's new and existing product lines, including TCXO, VCTCXOs, microprocessor and communication crystals, precision products and clock oscillators. All featured products have temperature stability and no frequency perturbations. A quick product reference guide, a company profile, crystal and oscillator terminology and direct links to the Rakon Web site are also included.

Rakon Ltd.
Circle #159

Test and measurement product catalog

LeCroy has released its 2001 Test and Measurement Products Catalog. Products featured include



digital oscilloscopes, digitizing systems, analog oscilloscopes, probes and accessories, jitter and timing, general-purpose DSO options and power measure systems. The catalog also includes disk drive analysis, communications analyzers and telecom test solutions.

LeCroy
Circle #160

Superconductor brochure

Supercon is offering a new brochure describing the company's range of low-temperature superconductor wire with different constructions and copper-to-superconductor ratios. The Supercon Low-Temperature Superconductor Materials Brochure features off-the-shelf NbTi-based superconducting wire with Cu:SC ratios ranging from 0.9 to 11:1. Included are descriptions of a new 56 filament wire, as well as multifilament, monofilament and CuNi resistive matrix wire with their critical currents and dimensions. The six-page brochure also has a section describing the comparative properties of insulations. Both round and shaped conductors and a description of their custom manufacturing and quality control capabilities are included along with cross-section drawings of wire samples.

Supercon, Inc.
Circle #161

Fiber optics brochure

Trompeter Electronics has released a 12-page brochure featuring the company's new fiber optic cable assembly operation. The brochure offers a photographic tour

of Trompeter's facility, including state-of-the-art clean room production lines, along with information on the standards involved in the manufacturing process.

Trompeter Electronics
Circle #162

Send your company's new product information to the address on page 8.

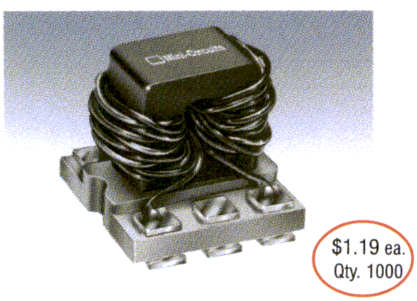
NEW PRODUCTS

NO. 81

RF/IF MICROWAVE COMPONENTS

10dB SMA ATTENUATORS ARE LOW COST DC TO 18GHz SOLUTION

Mini-Circuits BW-S10W5 precision fixed attenuators provide 10dB nominal attenuation with ±0.60dB accuracy (add 0.5dB typ above 12.4GHz) in the broad DC to 18GHz frequency band. Built tough to handle 5W average with 125W maximum peak power, these small 1.20" units exhibit excellent VSWR with high temperature stability and high repeatability. Equipped with stainless steel SMA-Male/Female connectors and available off-the-shelf.



18dB "DO-IT-YOURSELF" COUPLER DELIVERS COST SAVINGS

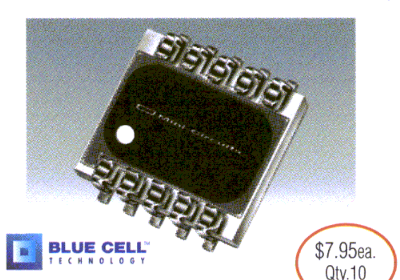
Designed to lower costs through automated manufacturing, the TCD-18-4 from Mini-Circuits needs only a commercially available 50 ohm external chip resistor, and a complete 5 to 1000MHz directional coupler is realized. Electrically, this patented 50 ohm coupler provides 17.9dB±0.5dB nominal coupling with ±0.6dB (max.) flatness. Midband, typical mainline loss is 0.7dB and directivity is 20dB (typ). The 50/75 ohm "do-it-yourself" TCD family contains 9 units with 9 to 20dB coupling for 5 to 1000MHz.

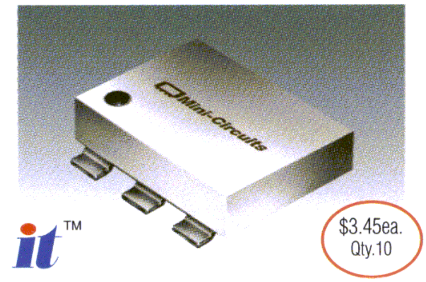
1700 TO 2100MHz 2WAY SPLITTERS DELIVER LOW HEIGHT AND LOW COST

Leading characteristics of Mini-Circuits 2way-0° SBB-2-21W Blue Cell™ power splitters include superb temperature stability within the 1700 to 2100MHz band, low 0.070" height, high repeatability, and low cost. Electrically, these 50 ohm units display excellent 0.6dB insertion loss and 22dB isolation typical. The item is part of Mini-Circuits patented family of 10W (max. power input) "SBB" model 2way power splitters for the 800 to 2300MHz band.

1400 TO 2400MHz MIXERS HAVE LOW PROFILE AND HIGH IP3

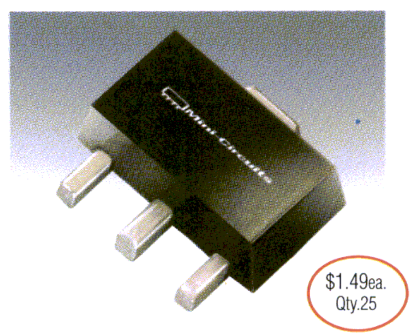
Mini-Circuits MBA-15MH Blue Cell™ mixers are a low 0.070" profile solution for today's compact 1400 to 2400MHz wireless products. This patented mixer offers high 18dBm IP3 (typ, center band) to help suppress intermodulation products, plus low 5.5dB typical midband conversion loss with superb temperature stability and low cost. High repeatability is achieved through state-of-the-art automated manufacturing.





0.5 TO 1700MHz TRANSFORMERS PROVIDE 1.5:1 IMPEDANCE

Mini-Circuits patented ADT1.5-17 surface mount RF transformers are ideal for 50 to 75 ohm impedance matching and provide 1.5:1 impedance ratio in the broad 0.5MHz to 1700MHz band. Referenced to midband loss of 0.3dB typical, insertion loss is 1dB in the 2 to 1100MHz frequency band, 2dB from 1 to 1500MHz, and 3dB band wide. The low profile package stands only 0.112" high, and operating temperature range is -20°C to +85°C (max.). Available off-the-shelf.



DC TO 4GHz MMIC AMPLIFIER HAS HIGH RELIABILTY

Mini-Circuits has unveiled the GAL-51, a newly developed surface mount MMIC amplifier for the DC to 4GHz band. When operated at 1GHz/25°C, the unit delivers high 17.5dB gain (±1.0dB flat DC-2GHz, typ), maximum output power of 18dBm typical (at 1dB comp.), and high 35dBm (typ) IP3. These 50 ohm amplifiers are housed in an SOT-89 package with exposed metal bottom for excellent heat dissipation, and displays low 78°C/W (typ, θjc) thermal resistance. Value priced.

See us at MTT-S — Booth #333

Mini-Circuits®

US 107 INT'L 117
CIRCLE READER SERVICE CARD

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

YONI™ *The Design Engineers Search Engine Provides ACTUAL Data Instantly From MINI-CIRCUITS At: www.minicircuits.com*

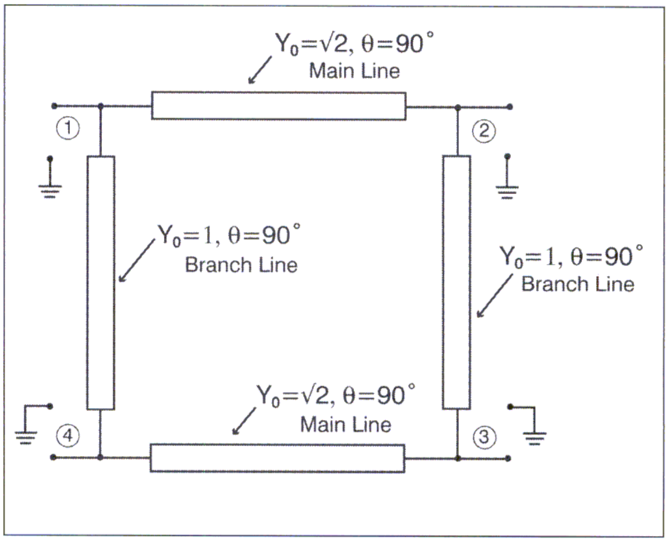
ISO 9001 CERTIFIED

F 350 Rev. Org.

Lumped Element Quadrature Hybrid Provides Supplementary Low Pass Filtering

By Richard M. Kurzrok, PE
RMK Consultants

A quadrature hybrid, also called a branch line directional coupler, uses quarter-wave transmission lines for both the main lines and branch lines, as shown in Figure 1. Upon replacing each quarter-wave transmission line with its π equivalent, the hybrid is implemented using artificial lines, as shown in Figure 2. This technique has also been used for the one and a half wavelength hybrid ring [1]. The replacement of transmission lines by lumped circuit elements results in substantial size reduction. This enhances inclusion of the hybrid in integrated circuits, which could include active devices.



▲ **Figure 1. Diagram of a quadrature hybrid with transmission lines.**

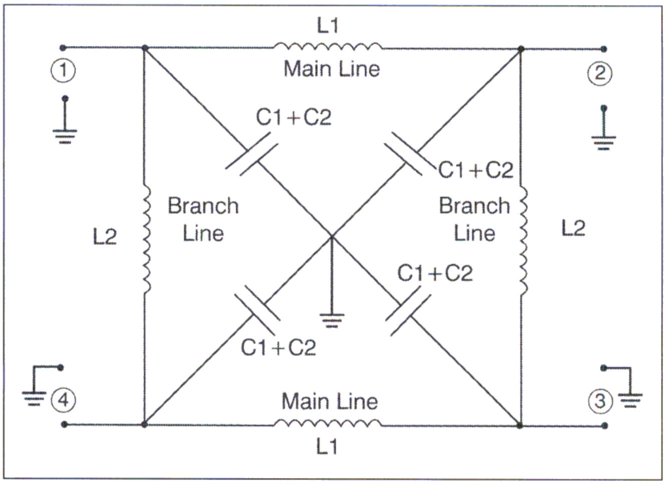
Design equations and circuit elements

Design equations for the hybrid are shown in Equation (1). As an illustrative example, a hybrid has been designed for a center frequency of 60 MHz and a characteristic impedance of 50 ohms. Circuit element values are summarized in Table 1.

$$L = \frac{Z_0 \times 10^3}{2\pi f} \text{ nH}$$
$$C = \frac{10^6}{2\pi f Z_0} \text{ pF} \qquad (1)$$

where

- Z_0 = source and load impedances in ohms;
- f = hybrid center frequency in MHz;
- L = series inductance; and
- C = shunt capacitance.



▲ **Figure 2. Diagram of a quadrature hybrid with artificial lines.**

Parameter	Main Lines	Branch Lines
Y_0 – siemens	0.02828	0.02
Z_0 – ohms	35.36	50
L–nH	L1 = 93.8	L2 = 132.63
C – pF	C1 = 75.02	C2 = 53.05
Total Shunt Capacitance = 75.02 + 53.5 = 128.07 pF		

▲ **Table 1. Circuit element valves for quadrature hybrid (Z_0 = 50 ohms and F = 60 MHz).**

x	*f*	P2 (dB)	P3 (dB)	P4 (dB)
0.1	6	6.2	6.1	6.2
0.3	18	7.7	6.7	7.2
0.5	30	9.3	6.5	8.2
0.7	42	9.2	4.9	8.5
0.90	54	4.1	3.1	13.0
0.92	55.2	3.7	3.1	14.7
0.94	56.4	3.4	3.1	17.0
0.96	57.6	3.2	3.0	20.5
0.98	58.8	3.1	3.0	26.6
1.0	60	3.0	3.0	52.2
1.02	61.2	3.1	3.0	25.9
1.04	62.4	3.2	3.1	20.1
1.06	63.6	3.4	3.1	16.8
1.08	64.8	3.6	3.1	14.6
1.10	66	3.9	3.2	12.9
1.3	78	5.1	5.3	7.2
1.5	90	7.1	11.1	9.1
1.7	102	12.5	19.9	14.9
1.9	114	17.3	27.5	19.9
2.1	126	21.2	33.6	24.0
2.3	138	24.4	38.8	27.3
2.5	150	27.2	43.4	30.1
2.7	162	29.7	47.4	32.6
2.9	174	31.9	51.1	34.9
3.1	186	34.0	54.4	36.9
x = normalized frequency variable, *f* = frequency in MHz				

▲ **Table 2. Transmission responses from Port 1 to Ports 2, 3 and 4 for the quadrature hybrid where Z_0 = 50 ohms, *f* = 60 MHz and unloaded *Q* = 150.**

Transmission responses

Predicted transmission responses between a port 1 input and ports 2, 3 and 4 outputs are shown in Table 2. These computations utilize the classic method of analysis for symmetrical four port networks (2). The hybrid is bisected and reduced to a two port network, which is analyzed via even and odd mode excitations. Unloaded *Q*s of 150 have been assumed for all inductors.

Conclusion

The quadrature hybrid, using only two branch lines, is limited in useful bandwidth to about five percent. Wider bandwidths can be obtained using more than two branch lines [2, 3]. At frequencies above 150 MHz, appreciable supplementary low pass filtering is achieved for the nominal 60 MHz hybrid. Lumped element hybrids [4] have become useful in monolithic microwave integrated circuits (MMICS). ■

References

1. R.M. Kurzrok, "Design Technique for Lumped-Circuit Hybrid Rings," *Electronics*, May 18, 1962.
2. J. Reed and G. Wheeler, "A Method of Analysis of Symmetrical Four-Port Networks," *IRE Trans. MTT*, Vol. MTT-4, October 1956: 246-252.
3. G. Matthaei, L. Young and E.M.T. Jones, *Microwave Filters, Impedance Matching Networks, and Coupling Structures*, New York: McGraw-Hill, 1962: 809-835.
4. S. J. Parisi, "A Lumped Element Rat Race Coupler," *Applied Microwave*, August/September 1989: 130-135.

Author information

Richard M. Kurzrok, PE, is an independent consultant specializing in filters and equalizers from baseband through microwave frequencies. He may be reached at RMK Consultants, 82-34 210th Street, Queens Village, NY, 11427-1310; by telephone at 718-776-6343; by fax at 718-776-6087; or by e-mail at rmkconsulting@aol.com.


MITEQ
FROM COMPONENTS TO SYSTEMS
MITEQ INC
AMPLIFIERS TO 60 GHz
• Octave to ultra-broadband
• Noise figures from 0.35 dB
• Power to 10 watts
• Temperature compensated
• Cryogenic
MIXERS TO 60 GHz
• Single-, double-, and triple-balanced
• Image rejection and I/Q
• Single-sideband, BPSK and QPSK modulators
• High dynamic range
• Active and passive frequency multipliers
INTEGRATED SUBASSEMBLIES TO 60 GHz
• Integrated up/downconverters
• Monopulse receiver front ends
• PIN diode switches
• Ultra-miniature switch matrices
• Missile receiver front ends
• Switched amplifier/filter assemblies
FREQUENCY SOURCES TO 40 GHz
• Free-running VCOs/DROs
• Phase-locked cavity oscillators
• Phase-locked coaxial resonators
• Synthesizers for SATCOM
• Fast-tuning communication synthesizers
IF AND VIDEO SIGNAL PROCESSING
• Logarithmic amplifiers
• Constant phase-limiting amplifiers
• Frequency discriminators
• AGC/VGC amplifiers
• I/Q processors
• Digital DLVAs
SATCOM EARTH STATION EQUIPMENT TO Ka-BAND
• Synthesized up/downconverters
• Test translators
• LNA systems
• 1:N redundancy units
• INMARSAT products
• FM modems
MITEQ
TEL: (631) 436-7400
FAX: (631) 436-7430
100 Davids Drive, Hauppauge, NY 11788
www.miteq.com
Circle 14
See us at MTT-S — Booth #1232

Frequency Downscaling of an ISM Band Superhet Receiver IC

A low-cost, effective approach to extend the operating frequency range of an existing double-conversion superhet receiver IC down to lower RF bands

By Andreas Laute, Jeff Peter and Matthias Lange
Melexis GmbH Haarbergstrasse

Today, users of wireless systems can take advantage of a broad range of worldwide license-exempt industrial/scientific/medical (ISM) and short-range-device (SRD) bands. Many applications cover the frequency range of a few kilohertz to 930 MHz, including telemetry, telecommand, alarms, model control, immobilizers, animal identification, wireless voice, personal identification and general data transmission. Even new technologies, such as Bluetooth and HomeRF, will not easily compete with most of these well-established, very low cost approaches.

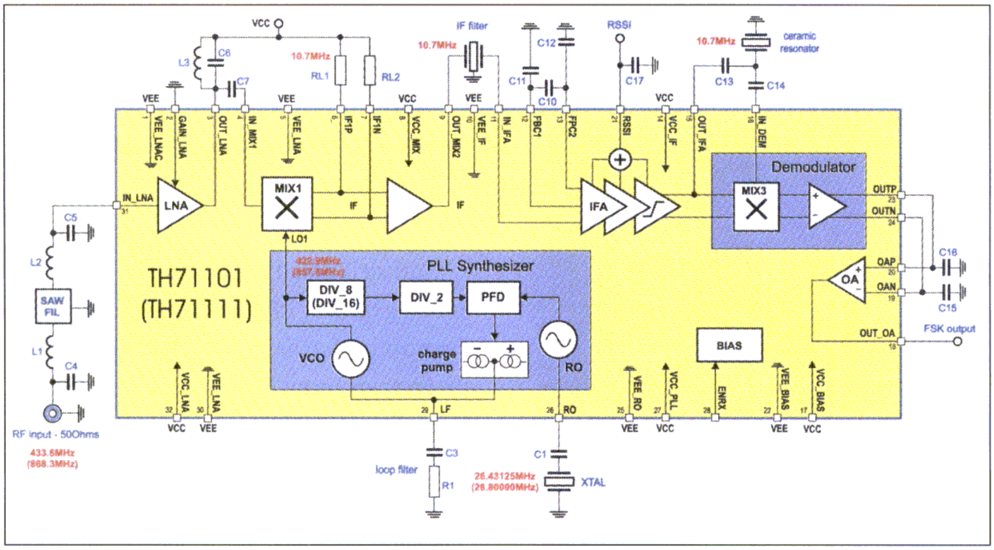
Naturally, it is the goal of a manufacturer of radio frequency integrated circuits (RFICs) to offer a product spectrum that covers as much as possible of the available frequency allocation for such ISM and SRD applications. The current RFIC standard product line of Melexis contains six different receiver versions. These receiver chips have been originally designed to deal with the frequency range of 310 to 950 MHz [1, 2, 3]. A variety of frequency-compatible RF transmitter ICs is also available from Melexis [3, 4]. One member of the receiver family is the TH71102, a fully integrated double-conversion superhet receiver designed in an advanced RF-dedicated 0.6 μm BiCMOS process.

This article shows how the TH71102 may be used to extend its operating frequency range from 310 to 480 MHz down to the lower ISM and SRD bands located between 26.9 and 47 MHz. The range extension can be easily achieved without adding any external circuitry. A brief description of the RFIC's original receiver architecture, which is double-conversion superhet, is also provided, and the functionality of some building blocks of the TH71102 FSK/FM/ASK receiver chip is explained. A theoretical approach to modify the existing double-conversion receiver in order to derive a single-conversion system is outlined. By doing so, a downward operating frequency extension by more than one decade is possible. The basic idea behind this concept is to bypass the first mixer of the superhet receiver IC. Then, the LNA directly drives the second mixer and the second mixer is actually the only mixer in the receiver. The first mixer input has to be terminated in order to prevent undesired signal pick-up. Applying a capacitor to ground can do this very easily. Finally, measured results are presented. System performance measures as for example input sensitivity, image suppression or spurious responses are reported.

The TH711xx family of superhet receivers

Table 1 shows some of the system parameters of the 32-pin low-cost variants of the Melexis TH711xx receiver family. Some functional blocks, common to all of these receiver ICs, are the LNA with selectable gain (in order to assure a high dynamic range), as well the first and second down-conversion mixers in case of double conversion reception, or just one mixer in case of the single superhet. A high-gain limiting IF amplifier (IFA) with RSSI signal generation and a phase-coincidence demodulator (DEMOD) create the IF gain strip and demodulator part. A PLL synthesizer (PLL SYNTH) featuring a fully on-chip RF VCO (VCO) and some additional circuits are implemented for frequency generation, data slicing, filtering and biasing.

Figure 1 shows the block diagram of the single-conversion superhet receivers TH71101 and TH71111, respectively. The user has the choice



▲ **Figure 1. Single-conversion FSK superhet block diagram with external components.**

to configure an ASK, FM or FSK receiver by arranging the external components appropriately. An RF front-end filter should be used to achieve both a high degree of image rejection and good blocking immunity. For high frequencies (greater than 100 MHz), the best trade-off with respect to cost, performance and repeatability usually comes with a surface acoustic wave filter (SAWFIL). After pre-amplification by the LNA, the mixer (MIX1) downconverts the RF signal to the IF range, where a ceramic filter sets the desired receiver bandwidth and, hence, defines its selectivity. A phase-coincidence demodulator, formed by an internal mixer (MIX3) and an external ceramic resonator with two capacitors, performs both FSK and FM modulation.

The operational amplifier (OA) acts as a comparator that delivers a rail-to-rail output signal. In case of ASK reception, where the external FSK/FM components are not needed, the RSSI signal can be directly taken to feed the OA, in this case constituting an adaptive threshold data slicer, in order to set up an ASK demodulator.

The single-conversion superhet allows a reasonably high degree of image suppression by selecting a high IF, in addition to good front-end filtering [5]. A typically used IF is 10.7 MHz. In this case, the RF front-end filter's attenuation at 21.4 MHz off the center frequency determines the image suppression, which is about 50 dB (measured value derived with TH71101 and TH71111).

The double-conversion approach can be treated as the next step in the evolution of the superhet receiver. It should be used if higher values of image rejection are needed. Of course, other receiver concepts can be employed toward the same goal; some of them are direct-conversion and low-IF receivers. Direct-conversion receivers have an inherently high degree of image rejection (theoretically up to infinity), but they suffer from other problems, such as DC offsets and LO signal spurious emission [6]. Low-IF receivers do image rejection electronically, but practical values are poor (around 30 dB) [7]. With the Melexis receiver chips, the system designer has the choice to do a simple upgrade from the single to the double superhet, just by replacing either TH71101 with TH71102 (310 to 480 MHz) or TH71111 with TH71112 (800 to 950 MHz). A corresponding double superhet application diagram is depicted in Figure 2.

Here, a second mixer (MIX2) is needed to convert the first IF (IF1) to the second (IF2). Additionally, the PLL synthesizer has been modified slightly to

Receiver IC	TH71101	TH71102	TH71111	TH71112
Frequency Range	310 to 480 MHz	310 to 480 MHz	800 to 950 MHz	800 to 950 MHz
Supply Range	2.5 to 5.5V, FSK 2.2 to 5.5V, ASK	2.5 to 5.5V, FSK 2.2 to 5.5V, ASK	2.5 to 5.5V, FSK 2.2 to 5.5V, ASK	2.5 to 5.5V, FSK 2.2 to 5.5V, ASK
Supply Current	6.5 to 7.8 mA	6.5 to 7.8 mA	7.6 to 9.2 mA	7.6 to 9.2 mA
Standby Current	< 50 nA	< 50 nA	< 50 nA	< 50 nA
Demodulation	FSK, FM, ASK	FSK, FM, ASK	FSK, FM, ASK	FSK, FM, ASK
Frequency Conversion	single superhet	double superhet	single superhet	double superhet
Input Sensitivity, narrow band (including RF front-end filter loss)	–111 dBm, FSK –109 dBm, ASK @ 40 kHz IFBW	–111 dBm, FSK –109 dBm, ASK @ 40 kHz IFBW	–109 dBm, FSK –108 dBm, ASK @ 40 kHz IFBW	–109 dBm, FSK –108 dBm, ASK @ 40 kHz IFBW
Input Sensitivity, wide band (including RF front-end filter loss)	–104 dBm, FSK –106 dBm, ASK @ 150 kHz IFBW	–104 dBm, FSK –106 dBm, ASK @ 150 kHz IFBW	–102 dBm, FSK –104 dBm, ASK @ 150 kHz IFBW	–102 dBm, FSK –104 dBm, ASK @ 150 kHz IFBW
Maximum Input Signal	–10 dBm, FSK –20 dBm, ASK	–10 dBm, FSK –20 dBm, ASK	–10 dBm, FSK –20 dBm, ASK	–10 dBm, FSK –20 dBm, ASK
Image Rejection (including RF front-end filter loss)	> 50 dB	> 65 dB	> 50 dB	> 65 dB
Spurious Emission	< –65 dBm	< –65 dBm	< –65 dBm	< –65 dBm
Package	LQFP32	LQFP32	LQFP32	LQFP32

▲ **Table 1. Parameters of the Melexis 32-pin TH711xx receiver family.**

2W & 5W
DC to 18GHz ATTENUATORS

from $29.95 ea. (1-49)

Rugged Stainless Steel Construction, High Repeatability, Miniature Size, Low Cost, and Off-The-Shelf Availability are some of the features that make Mini-Circuits "BW" family of precision fixed attenuators stand above the crowd! This extremely broad band DC to 18GHz series is available in 5 watt Type-N and 2&5 watt SMA coaxial designs, each containing 15 models with nominal attenuation values from 1 to 40dB. Built tough to handle 125 watts maximum peak power, these high performance attenuators exhibit excellent temperature stability, 1.15:1 VSWR typical, and cover a wealth of applications including impedance matching, reducing power levels when testing higher power amplifiers, wide band matching during intermodulation measurements, and providing a 2W or 5W termination load for power amplifiers. Call Mini-Circuits today and capture this next generation of performance and value!

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

MODELS (Add Prefix BW-)

2W SMA	5W SMA	5W Type-N	Attenuation (dB) Nominal	Attenuation (dB) Accuracy•
$29.95	$44.95	$54.95		
S1W2	S1W5	N1W5	1	±0.40
S2W2	S2W5	N2W5	2	±0.40
S3W2	S3W5	N3W5	3	±0.40
S4W2	S4W5	N4W5	4	±0.40
S5W2	S5W5	N5W5	5	±0.40
S6W2	S6W5	N6W5	6	±0.40
S7W2	S7W5	N7W5	7	±0.60
S8W2	S8W5	N8W5	8	±0.60
S9W2	S9W5	N9W5	9	±0.60
S10W2	S10W5	N10W5	10	±0.60
S12W2	S12W5	N12W5	12	±0.60
S15W2	S15W5	N15W5	15	±0.60
S20W2	S20W5	N20W5	20	±0.60
S30W2	S30W5	N30W5	30	±0.85
S40W2	S40W5	N40W5	40	±0.85

•At 25°C includes power and frequency variations up to 12.4GHz. Above 12.4GHz add 0.5dB typ. to accuracy.

ALL MODELS IN STOCK

See us at MTT-S — Booth #333

Mini-Circuits®

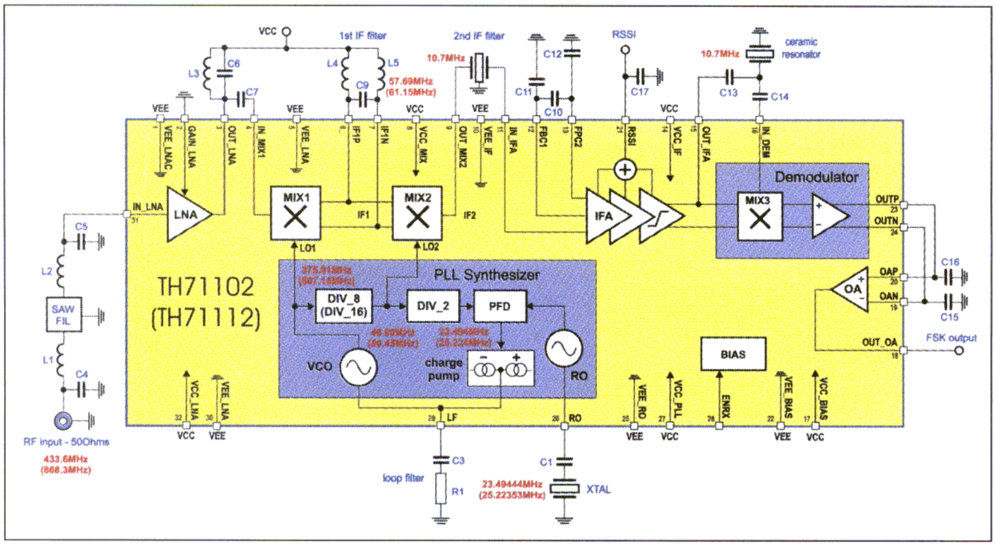
US 108 INT'L 118
CIRCLE READER SERVICE CARD

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

YONI™ ***The Design Engineers Search Engine*** *Provides ACTUAL Data Instantly From MINI-CIRCUITS At:* ***www.minicircuits.com***

ISO 9001 *CERTIFIED*

F 331 Rev Orig.



▲ **Figure 2. Double-conversion FSK superhet block diagram with external components.**

deliver two LO signals (LO1 and LO2) that drive the mixers. A simple external LC network between MIX1 and MIX2 acts as a band-pass filter for the IF1 signal. Considering the same frequency of 10.7 MHz, as for the single-conversion case, now as IF2, the values for the first IF may be in the order of 60 MHz (depending on the exact RF needed). This leads to a substantially higher degree of image rejection (65 dB measured) because the attenuation of the SAW front-end filter, taken approximately 120 MHz away from its pass-band frequency, is now much higher than at 21.4 MHz.

Transformation to a low-RF SCSH receiver

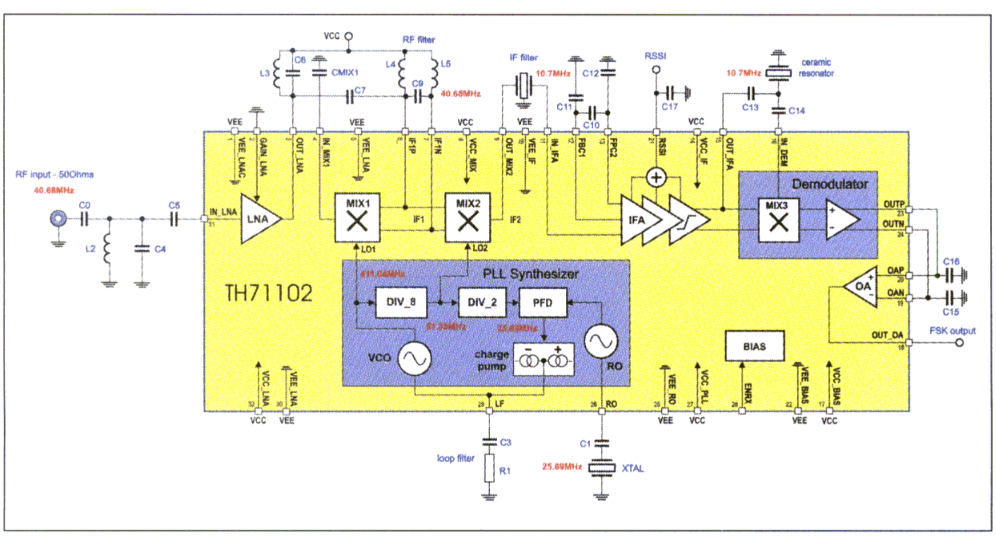
Receiver ICs with fully integrated VCOs are very welcome to the system designer because there is no need for external VCO components, such as varactor diodes or inductors. On the other hand, a fully integrated VCO typically has a limited LO frequency range that restricts the receiver's operating frequency range. The frequency translation scheme of a standard double-conversion superhet (DCSH) receiver follows the rule that the highest frequency of operation (high-RF) is down-converted by the first mixer to a lower frequency of operation (low-RF) that constitutes the first IF. A second mixer handles the next step of downconversion to derive the second IF. It follows logically that the operating frequency range of a DCSH should be down-scalable, if the first mixer could be bypassed to make the second mixer's input to be the terminal of the desired signal frequency (now the low-RF). Then, the DCSH is transformed to a single-conversion superhet (SCSH) receiver.

The TH71102 block diagram, shown in Figure 2, reveals that MIX1 ports IN_MIX1 and IF1 are fully accessible. This gives the chance to connect the LNA output not to the input of MIX1 but to the input of MIX2. In this situation, MIX2 is the one and only mixer in the system, able to receive low-RF signals. Figure 3 outlines how the transformation from DCSH to SCSH can be realized by using the TH71102. As can be seen from this application circuit, port LO1 of MIX1 cannot be disconnected because it is internal to the IC. Furthermore, the internal signal path from MIX1 to MIX2 is fixed. This affects two issues:

1. The input of MIX1 must be AC-grounded to prevent from picking up unwanted high-RF signals that could be down-converted and interfere with the desired low-RF,
2. The output of MIX2 must be matched to the desired low-RF signal to keep parasitic LO1 feed-through as low as possible.

Both demands can be easily met — the first by applying a capacitor to pin IN_MIX1 that is well connected to ground, and the second because the LC tank at pins IF1P and IF1N is trimmed to the desired low-RF.

The specified LO1 frequency range of the TH71102 is 300 to 450 MHz [8]. This translates to an LO2 range of 37.5 to 56.25, which is the new LO frequency range of the receiver that has



▲ **Figure 3. Low-RF FSK superhet derived by DCSH-to-SCSH transformation.**

been derived by DCSH-to-SCSH transformation. Table 2 summarizes the new operating frequency range of the SCSH. According to CEPT/ERC recommendation 70-03 [9], the low-frequency services shown in Table 3 can be covered by the modified TH71102 application circuit.

	LO high-side injection	LO low-side injection
possible RFs	LO – IF	LO + IF
range of RFs	(37.5 to 56.25)MHz – RF	(37.5 to 56.25)MHz + IF
range of RFs at IF = 10.7 MHz	26.8 to 45.55 MHz	48.2 to 66.95 MHz

▲ **Table 2. Summary of the new operating frequency range of the SCSH.**

Experimental data of the low-RF SCSH receiver

A test board has been fabricated to validate the theoretical approach of the DCSH-to-SCSH transformation. The board's circuit schematic corresponds to Figure 3, with a receiving frequency of 40.68 MHz, the center frequency of one of the non-specific SRD bands. The receiver's front-end RF filter characteristic is constituted by three separated LC band-pass filters (L2 and C4; L3 and C6; L4, L5 and C9).

A frequency sweep measurement can be performed to check the system's RF response without disturbing the LC filters' impedances — a common RF test problem caused by the coupling effect of the measurement system.

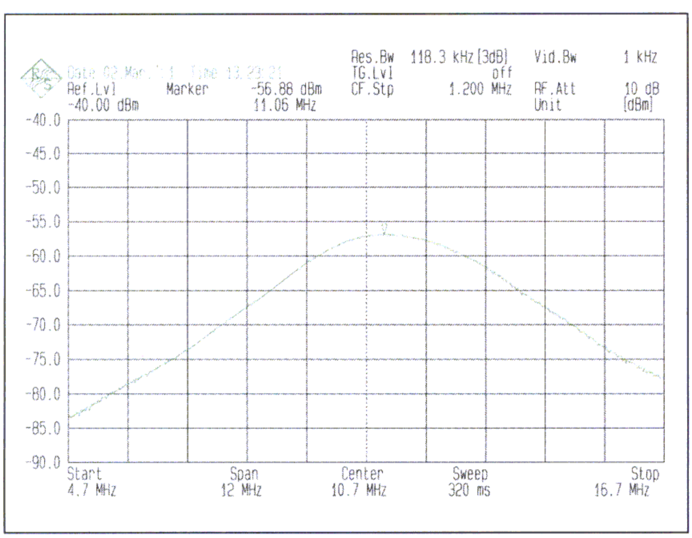
The test configuration consists of a swept frequency signal generator to input the RF signal over the desired measurement frequency range, and a spectrum analyzer operating in max hold mode to display the output signal at the IF port. In this case, the superhet receiver's re-sponse is taken indirectly through its RF-to-IF conversion. Figure 4 shows the corresponding front-end filter characteristic, measured at pin OUT_MIX2, down-converted to the IF of 10.7 MHz.

While Figure 4 gives some insight in front-end selectivity, blocking and image rejection capability of the receiver, the same measurement should be made with the spectrum analy-zer picking up the signal behind the IF filter, in order to visualize the channel selectivity. The result is depicted in Figure 5, showing the ceramic IF filter response with a 3 dB bandwidth of 150 kHz.

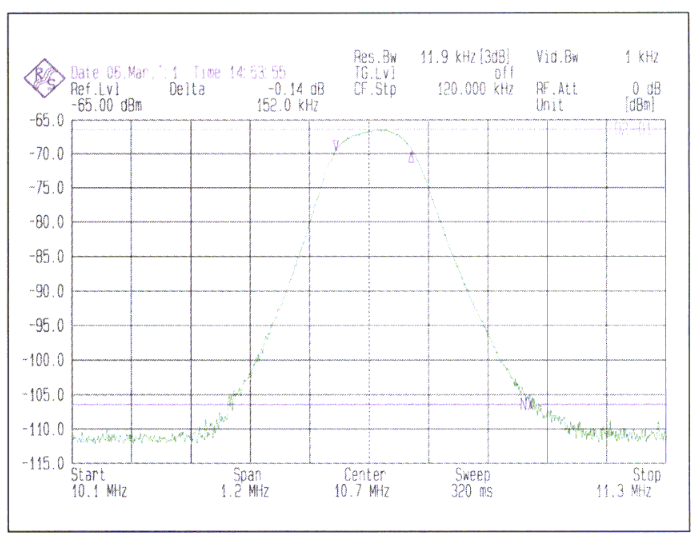
Table 4 summarizes the most important parameters in order to quantify the receiver's performance.

Service	Frequency Range	Channel Spacing	Typical Applications
Non-specific SRDs	26.957 to 27.238 MHz 40.660 to 40.700 Mhz	No channels specified	Telemetry, telecommand alarms, data in general and other similar applications
Model Control	26.995 to 27.195 MHz 34.995 to 35.223 MHz 40.665 to 40.695 MHz	10 kHz	Controlling the movement of a model
Inductive Applications	26.957 to 27.283 MHz	No channels specified	Car immobilizers, animal identification, alarm systems personal identification, proximity sensors, anti-theft systems, automatic article identification
Narrow-band audio	29.7 to 47.0 MHz	50 kHz	Audio signal transmission

▲ **Table 3. Low-frequency services covered by the modified TH71102 application circuit.**



▲ **Figure 4. Receiver RF front-end response, downcoverted to IF.**



▲ **Figure 5. Receiver IF response behind the 150-kHz-wide ceramic filter.**

Parameter	Condition	Value	Unit
Stand-by current	ENRX at 0 V	<1	nA
Current consumption at LNA high gain	GAIN_LNA at 0 V	7.7	mA
Current consumption at LNA low gain	GAIN_LNA open	6.3	mA
FSK input sensitivity at LNA high gain	GAIN_LNA at 0 V	–108	dBm
FSK input sensitivity at LNA low gain	GAIN_LNA open	–70	dBm
FSK maximum input signal at LNA high gain	GAIN_LNA at 0 V	–10	dBm
FSK maximum input signal at LNA low gain	GAIN_LNA open	0	dBm
ASK input sensitivity at LNA high gain	GAIN_LNA at 0 V	–110	dBm
ASK input sensitivity at LNA low gain	GAIN_LNA open	–72	dBm
ASK maximum input signal at LNA high gain	GAIN_LNA at 0 V	–24	dBm
ASK maximum input signal at LNA low gain	GAIN_LNA open	–5	dBm
Image rejection	GAIN_LNA at 0 V	36	dB
Rejection of undesired double-conversion RF at 451.72 MHz	GAIN_LNA at 0 V	77	dB
Rejection of undesired double-confersion RF at 370.36 MHz	GAIN_LNA at 0 V	65	dB
Spurious emission	GAIN_LNA at 0 V	< –104	dBm

▲ **Table 4. Summary of important parameters quantifying the receiver's performance.**

Conclusion

This article has described how a frequency range extension of a commercially available integrated receiver IC can be realized. A very effective frequency downscaling can be arranged by applying the DCSH-to-SCSH transformation to the double-conversion receiver chip TH71102. This leads to a shift in frequency from the 310 to 480 MHz range to approximately 27 to 67 MHz, without the need for any extra components.

A reasonable amount of image suppression can be achieved even without a SAW front-end filter. A cascade of three simple LC band-pass filters yields a value of 36 dB. This is good news for the system designer because the cost of expensive SAW filters can be saved. All other system parameters, such as input sensitivity or spurious emission, are in very good shape. ■

References

1. A. Laute and J. Peter, "A Fully Integrated 900 MHz Double Superhet Receiver Chip," *Microwave Engineering Europe*, August/September 2000: 41-48.

2. "RF Receivers Support Many Appli-cations," *Electronic Products*, December 2000: 87.

3. Jack Brown, "Transmitter and Receiver ICs Run on ISM and SRD Bands," *Microwaves & RF*, December 2000: 196-198.

4. A. Laute and J. Peter, "A Fully Silicon Monolithic Integrated 868/915 MHz FSK/FM/ASK Transmitter Chip," *Proceedings of the IEEE MTT-S Workshop on Silicon Monolithic Integrated Circuits in RF Systems*, Garmisch-Partenkirchen, Germany, April 26-28, 2000.

5. U. Rohde, J. Whitaker and T.T.N. Bucher, *Communications Receivers, Second Edition*, New York: McGraw-Hill, 1997.

6. C.D. Hull, J.L. Tham and R.R. Chu, "A Direct-Conversion Receiver for 900 MHz (ISM Band) Spread-Spectrum Digital Cordless Telephone," *IEEE Journal on SSC*, 12/1996: 1955-1963.

7. J. Crols and M.S.J. Steyaert, "Low-IF Topologies for High-Performance Analog Front Ends of Fully Integrated Receivers," *IEEE Trans. on Circuits and Systems — II*, 3/1998: 269-282.

8. http://www.melexis com/home_products.htm

9. CEPT/ERC/REC 70-03 relating to the use of short range devices (SRD), March 1, 1999.

Author information

Dr. Andreas Laute joined German IC manufacturer Thesys in 1994, where he worked as the manager of the application laboratory dealing with RF device test and characterization, parameter extraction, system design and application support. Melexis, a Belgium microelectronics company, acquired Thesys in 1999. Since that time, Laute has been manager of the business unit BiCMOS. He holds four patents in the fields of RF receiver and demodulator circuits, and his research interests include bipolar transistor modeling, wireless transmitter, receiver, transceiver and VCO circuit design, as well as RF system architectures. He may be reached by e-mail at andreas.laute@melexis.com.

Jeff Peter received a Dipl.-Ing. degree in electrical engineering from the Technical University of Dresden, Germany, in 1996. He joined Thesys that year and began working in the area of BiCMOS and bipolar technologies. From 1998 to 1999, he was with Austria Mikro Systeme in Unterpremstaetten, Austria, where he has been involved in the design of frequency synthesizers. He is now working at Melexis as a project engineer in the BiCMOS business unit, where he designs RF transmitter and receiver chips for ISM bands. His research interests include high-performance analog integrated circuits for telecommunications.

Matthias Lange received a Dipl.-Ing. degree in electrical engineering from the Technical University of Dresden, Germany, in 1996. In the same year, he joined the Institute of Microelectronic and Mechatronic Systems (IMMS) in Erfurt, where has been engaged in the development of integrated wireless RF systems for ISM/SRD applications. He joined Melexis in 2000 and is now focused on receiver and transmitter designs in the business unit BiCMOS. His research interests include analog integrated circuit design for RF applications.

MEMS Switch Technology Approaches the "Ideal Switch"

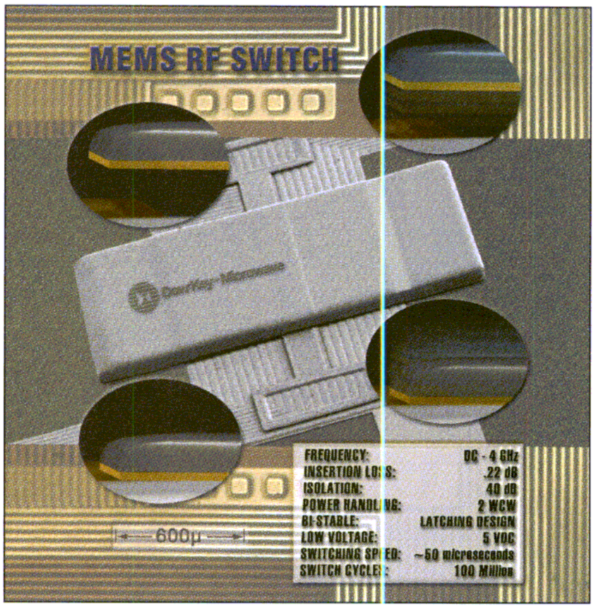
This month's cover features a commercial product development effort using MEMS RF switch technology to achieve low loss and fast switching times

By Tom Campbell
Dow-Key Microwave Corp.

Low insertion loss, reduced power consumption, small size, long life, and high speed are the goals driving MEMS (Micro-Electromechanical Machine System) RF switch development. Typically built upon silicon, gallium arsenide (GaAs) or glass wafers, switches are just some of the structures being designed with MEMS techniques. Other 3-D MEMS structures are magnets, nozzles, mirrors, diaphragms, coils, springs, gears, tweezers, filters, couplers, inductors and power dividers. Of the many MEMS devices that move, switches have the added challenge of maintaining contact closure forces over multi-million life cycles with little or no contact degradation. When ready to deliver all of these benefits, MMR (Micro-Mechanical Relay) use is predicted to grow beyond 100 million units by 2003 to 2004.

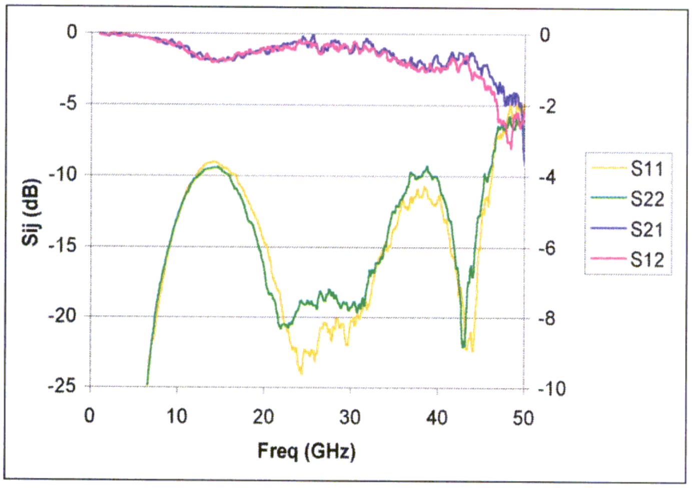
Dow-Key recognizes MEMS technology benefits for RF switching and has established a formal development program. First, we identified focus applications and clients, then analyzed how MEMS switches could expand our product line. Working with existing clients, we determined target device characteristics and especially cost goals. With this market study, we approached a number of MEMS device designers to understand the technology trade-offs in order to produce switch devices capable of meeting the RF market needs.

Figure 1 (next page) shows the results from one promising switch technology that Dow-Key evaluated. This data incorporates all of the losses in the switch, the wire bonds, the chip carrier, reflow soldering and solder joints to the test motherboard. Even with a non-optimized carrier, we see excellent potential for realizing a true broadband device.



Where will MEMS switches gain a foothold?

MMRs will compete with three main existing product channels: small signal mechanical relays, low power solid state switches, and low power, high frequency mechanical switches (2 to 70 GHz). Penetration into the relay and solid state switch markets will be limited by cost. Necessary protective structures that keep particles and liquids away from moving components will add cost factors over those of typical semiconductor devices. As MEMS technology advances and techniques for micro-cover application at the wafer level are developed, MMRs will begin to compete in the lower price tier markets. Integrating multiple switches, such as 1×4 and 1×10, at the wafer level will also reduce per switch prices. So why consider MEMS switches now?



▲ **Figure 1. Performance measurements of one MEMS switch technology evaluated by Dow-Key.**

Many applications demand the lowest attainable insertion losses. For example, consider transmitter design trade-offs. Strict linearity (ACPR) requirements in digital mode transmission conflict with the need for a high power-added efficiency (PAE) in the power amplifier. Insertion loss from switches increases the required power from the amplifier and negatively impacts the noise figure for the system. A MEMS transmit/receive switch can be used instead of a duplexer in TDMA half-duplex mode, yielding smaller after-PA insertion losses and significant PCB space savings. Table 1 compares MMR performance with solid state switches and electromechanical relays.

Multiple transmitters and receivers in the same mobile-phone package also present challenges for RF designers. Global Positioning System (GPS), Bluetooth, HomeRF and wireless-LAN systems are just a few of the RF-module candidates awaiting integration into mobile phones. Cell phone vendors are putting two or more simultaneously operating radio transceivers into smaller and smaller mechanical assemblies. Ensuring that these systems work properly together requires careful RF-system analysis, tighter filtering, better shielding and higher linearity. These complex RF circuits must not impact overall cellular system performance.

The optimum solution lies with MEMS switches. Activating a bandpass filter only when the GPS is on and switching back to a lowpass filter during the other times is an example. This switching arrangement minimizes losses in the GPS "off" mode and reduces overall current consumption.

Automatic test equipment is another demanding niche for MEMS switches. With the proliferation of higher frequency chips such as those for Bluetooth applications, equipment manufacturers need switching performance to 2.5 GHz and beyond, plus multi-million switch cycle durability.

Currently, there are more than 30 companies, government laboratories and universities around the world developing both relay switches and RF switch technology. Among these, there are only three companies currently ready to accept orders for packaged products. As more of these efforts reach the pre-production stage, leading circuit designers will migrate to the technology for a combination of benefits of high switch life, faster switching times, size reduction, lower insertion loss, higher isolation and, in many applications, lower cost in use.

The smallest electromechanical switch is a MEMS

Built using semiconductor processing techniques, the MEMS switch performs a "make and break" operation, typically with metal to metal contacts. RF properties can be optimized with smart device layout coupled to the SMT chip carrier design effort. Once processes are optimized, a number of MEMS foundries such as Standard MEMS, Intellisense, Analog Devices, OnStream, MOSIS, Cronos, MicroFAB Bremen and PHS MEMS are ready to ramp up wafer production. Some design examples are shown in Figure 2.

Characteristic	MMR	GaAs FET	Pin Diode	EMR PCB	EMR SMA
Size	Small	Very Small	Small	Medium	Large
Resistance	0.5 ohm	1-5 ohms	1-5 ohms	0.1 ohm	0.5 ohm
Switching Power	2 W CW	0.5 W CW	5 W CW	10 W CW	35 W CW
Breakdown Voltage	Low	Low	Varies	High	High
Speed	0.5-200 μs	10-100 ns	10-100 ns	0.8-10 ms	1-40 ms
Life Cycle	100 million+	Billion	Billion	0.5-5.0 million	0.1-2.0 million
Frequency Performance	Up to 70 GHz	Up to 4 GHz	Up to 20 GHz	Up to 5 GHz	Up to 40 GHz
Insertion Loss (dB max)	0.25	0.5	0.5	0.4	0.1
Isolation (dB min)	40	30	30	40	80
3rd Order Harmonics	Very Good	Poor	Poor	Good	Very Good
Power Consumption	Very low	Low	Low	Medium	High
Drive Voltage	5V, 28V, 48V	3V, 5 V	3V, 5 V	5 V, 12 V	12 V, 28 V
Integration Capability	Very Good	Very Good	Very Good	Average	Difficult
Cost - SPDT Type	$8.00-$20.00	$0.50-$4.50	$0.90-$8.00	$0.85-$12.00	$38 - $90

▲ **Table 1. Comparisons of existing technologies with MEMS micromechanical relays (MMRs).**

Dow-Key Microwave's evaluation spanned all of the MEMS actuation methods (Table 2). With each of these actuation systems, moving structures can be incorporated to execute micro-motion. The most typical structure for MEMS switches is a springy cantilever beam composed of silicon nitride, silicon dioxide or polysilicon. The next most popular is a suspended (both ends attached) beam, plate or membrane (capacitive switch). A third structure is a rocker or "see-saw" beam. This design permits a separate driving force on each end of the beam to overcome potential stiction problems. The last type of contact is a moving liquid. Controlled deposition of mercury permits a conductive, flowable contact system. Unfortunately, mercury is a poor RF conductor, but it does overcome potential contact wear and signal bounce issues.

Funding and technical development issues

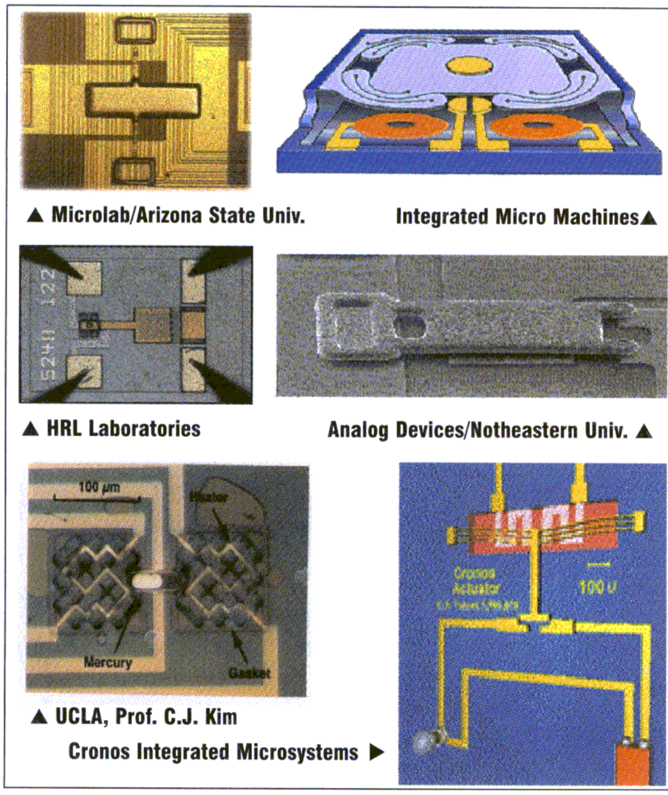
One of the largest benefactors to MEMS switch development is the US government through SBIR grants and DARPA awards from William Tang, MEMS Program Manager in the agency's Microsystems Technology Office. The balance of the efforts typically use internal R&D funds and venture capital. As the technology matures, there will be more specific contracts let by client companies to obtain unique variations on standard products. The most interested clients are in the ATE, radar, smart antenna and wireless product fields.

MEMS modeling tools — Most MEMS houses and Universities have access to a wide range of CAD modeling tools: MEM CAD™, MEMS CAP™, Intellisense™ and Catapult™ to name a few. To develop a truly functional RF switch, however, these tools have to interface with the existing RF design tools currently in use such as ANSYS, Cadence, Agilent EESof and Ansoft HFSS.

Protection of the MEMS structure with silicon, glass or plastic "caps" — One of the greatest challenges with MEMS RF switches is to provide a cap over the switch element at the wafer level. Prior to production readiness of this technology, we are forced to use a cavity package or a cavity lid that can be placed on a planar substrate. The selected "lid" material must not deteriorate RF signals passing through the switch. Ideally, the cavity will be back filled with nitrogen or some other protective gas to maintain optimum switch contact interfaces.

Some switch designs which rely on a two-piece construction may prove successful in the long run. For now, there are sealing problems and height tolerance management issues with the two piece systems. These height tolerances determine the final gap between the two switching contact surfaces. Gaps typically are only 10 microns, so there is very little working tolerance with two-piece designs.

Packaging the MEMS switch — Laminate based packages offer lower costs than ceramic based chip carriers, as well as lower dielectric constants. With little heat typically generated in the switches, Dow-Key Microwave expects the low dielectric constant laminate carriers to be the most desirable option. For high reliability clients, ceramic hermetic cavity packages will still be required to deploy MEMS switches. With the initial ceramic carrier,



▲ Microlab/Arizona State Univ.

Integrated Micro Machines▲

▲ HRL Laboratories

Analog Devices/Notheastern Univ. ▲

▲ UCLA, Prof. C.J. Kim

Cronos Integrated Microsystems ▶

▲ **Figure 2. MEMS switch designs.**

Electrostatic with Capacitive or Metallic Contacts

Electric charge applied to a base plate creates an attraction for another plate suspended above it. High voltage is typically necessary to create sufficient attractive forces. [Highest voltage: 28-48 VDC (typ.); fast: 1-200 microsec; low power consumption; stiction problems exhibited]

Electromagnetic

Coil structures create a magnetic field when energized. A central plate or beam is attracted downward. Opening of the switch relies on a memory response of the structure or a second magnetic field that is energized. [Low voltage: 5 VDC; low contact resistance; large by comparison; special permalloy materials required; non-latching design draws current: 100-300 mW]

Thermal: Bulk Material Expansion or Bi-Metal Construction

Heating expands a fluid or a solid structure which, in turn, applies a pressure force between two contact elements. Some issues exist with sensitivity to external temperature, i.e. freezing in the case of liquids used as the thermal expansion media. [slowest: 10s of msec; heater elements interfere with clean RF pathways; low voltage: 5 VDC; highest power consumption: 200 mW]

Piezoelectric with Metal or Ceramic Film(s)

Piezoelectric materials develop strain in the presence of an electric field, allowing mechanical expansion and contraction of the material to be controlled by an applied voltage. [Fastest speed: 100 ns to 1 μs; requires unique materials; closing force between the metal-to-metal contacts can be improved with increased bias voltage across the piezoelectric material]

▲ **Table 2. MEMS switch actuation methods.**

the metal lid, inert gas backfilling and low temperature brazing processes, ceramic carriers naturally represent higher costs.

Lidding for the dielectric carriers typically involves plastic cavity covers bonded over the carrier with low outgassing adhesives. If the MEMS switch technology includes a protective cover at the wafer level, the device can be potted or it can be mounted on a lead frame and overmolded like most integrated circuits.

MEMS implementation at Dow-Key Microwave

In less than two years, standards will become accepted within the MEMS relay and RF switch community. Dow-Key Microwave plans to be very active in helping to formalize this technology for ease of system integration. In fact, Dow-Key plans to immediately integrate MEMS switches into its existing Switch Matrix product line.

The unique and difficult challenges in qualifying MEMS switch technology are very similar to the everyday challenges Dow-Key has with PCB mount and coaxial RF switches. Control of the actuator mechanism tolerances, as well as surface finishes, required for long life and low insertion loss are the characteristics that we monitor everyday. Controlling the contact interface is the number one task with electromechanical switches and, so too, with MEMS switches.

Dow-Key has been working with Microlab, Inc. to refine their promising magnetic latching technology into SPST and SPDT switch products. In addition to low contact resistance and a hinge design that is less sensitive

Latching operation	Bi-stable; no power consumtion in quiescent state
Low voltage	<5 volts DC
Fast switching speed	50 microseconds
Low power	<40 microjoules consumed to throw switch
Low current	~60 milliamperes
Low contact resistance	<50 milliohms
Life test to date	No contact resistance change after 5 million cycles
Expected life	100 million cycles
Temperature range	–25° to +85 ° C
Shock	In test
Vibration	In test
Current size of SPST die	2 × 3 mm
Future size of SPST die	1 × 1 mm
Future size of SPDT die	1 × 2 mm

▲ **Table 3. Dow-Key Microwave/Microlab, Inc./ASU MEMS switch parameters.**

Characteristic:	DC - 1 GHz	1 - 2 GHz	2 - 4 GHz	4 - 8 GHz	8 - 12 GHz
Insertion loss	0.05 dB	0.1 dB	0.2 dB	0.3 dB	0.4 dB
Isolation	40 dB	40 dB	40 dB	30 dB	25 dB
VSWR	1.1:1	1.2:1	1.25:1	1.3:1	1.35:1
RF power	3 watts	2.5 watts	2 watts	1.5 watts	1 watt
Passive IMD	–90 dBc	–85 dBc	–80 dBc	–75 dBc	–70 dBc

▲ **Table 4. Dow-Key Microwave/Microlab Inc. expected MEMS switch RF parameters.**

to variation in stress of the deposited materials, Microlab has designed a latching configuration.

In addition to the obvious advantage of no power consumption except during activation, a compelling reason to pursue a latching design is to avoid a phenomena called "nitride charging," which occurs after extended periods of continuously applied DC current. A charge builds up on the silicon nitride layer(s) typically used as the spring member. This accumulated charge can lead to "stiction" effects. Stiction is the name given to the process where top and bottom electrodes bond together by microscopic surface forces. One way around this problem is to use a 10 kHz AC source to activate the switch instead of DC.

Summary

As the largest electro-mechanical RF switch manufacturer, Dow-Key Microwave recognized the potential for MEMS technology to influence our niche market and to allow us to penetrate the solid state switch markets. By running our controlled evaluation program of thermal, shock and vibration testing, Dow-Key will provide valuable user data upon which design engineers can proceed with confidence. ■

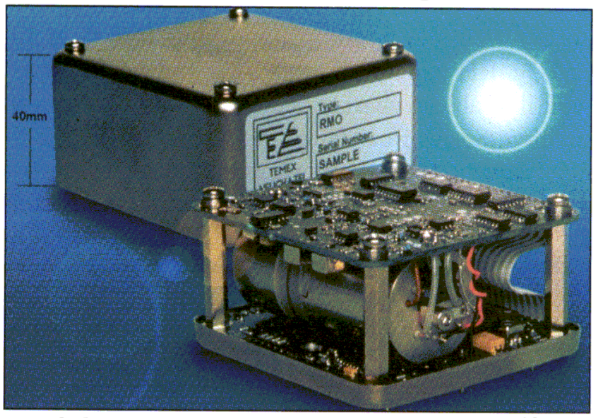
For more information, conatact Tom Campbell, Product Manager, Dow-Key Microwave Corp., 4822 McGrath St., Ventura, CA 93003; tel: 805-650-2322; fax: 805-650-1734; e-mail: tcampbell@dowkey.com. The Dow-Key Web site URL is http://www.dowkey.com

New Products on Display at the MTT–S IMS2001

Here are some of the new products that will be introduced by companies exhibiting at the IEEE Microwave Theory & Techniques Society's International Microwave Symposium in Phoenix, AZ, May 20–25, 2001.

Clock oscillator

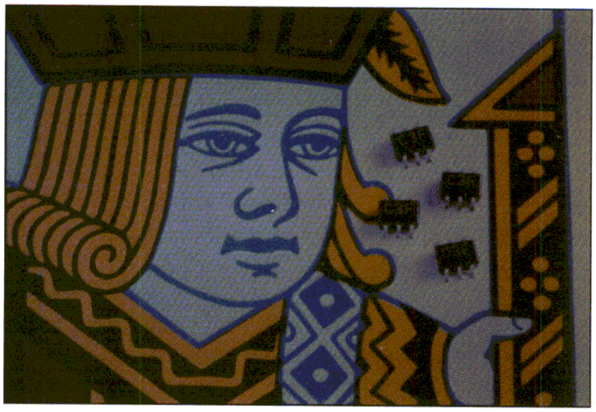
Temex Components announces the availability of the new miniature RMO (Rubidium Master Oscillator) series that takes up just 200 cc of space and is only 40 mm tall. Long-term stability of this product is specified as $<1 \times 10^{-10}$ per month, with $<5 \times 10^{-11}$ per month typical. The RMO can be used to upgrade existing (OCXO) designs or in new synchronization applications. Standard frequencies are 5, 10 and 20 MHz; others include 8.192 and 4.096 MHz for ISDN systems, 13 MHz for GSM base stations and 10.23 MHz for GPS. The RMO is PCB mountable and has a wide input voltage range of 11.2 to 15.5 volts for the 12-volt version and 18 to 32 volts for the 24-volt version. A two-pin RS232 port is provided for digital frequency adjustment and monitoring. The RMO exhibits a typical frequency stability change of $\pm 5 \times 10^{-11}$ over the temperature range of –5 degrees Celsius to +55 degrees Celsius. Cost for 1,000 pieces is $1,180.



Temex Components
Circle #163

Driver amplifier for mobile communications

California Eastern Laboratories has added a new medium power amplifier to its line of NEC Silicon RFICs. The new UPC8182TB has an upper operating frequency of 2.9 GHz at 3 dB bandwidth, making it suitable for a variety of mobile communications applications. Designed to drive two-stage PAs, the amplifier also offers 30 dB isolation to minimize loading effects. Performance specifications include typical output power of +9.5 dBm and typical power gain of 21.5 dBm at 0.9 GHz; typical output power of +9.0 dBm and typical power gain of 20.5 dBm at 1.9 GHz; and typical output power of +8.0 dBm and typical power gain of 20.5 dBm at 2.4 GHz. Supply voltage and circuit current are the same at all levels, with supply voltage ranging from 2.7 to 3.3 volts and typical circuit current 30 mA at 3.0 volts. The UPC8182TB is housed in a

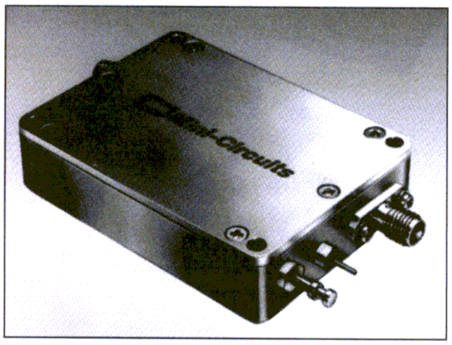


miniature 6-pin SOT-363 package and is available on tape and reel for high-volume automated assembly. It is priced at $0.91 in quantities of 12,000 pieces.

California Eastern Laboratories
Circle #164

Low-noise amplifier

Mini-Circuits offers a new ZQL-1900LN low-noise coaxial amplifier for engineers working in the 1850 to 1910 MHz PCS band. Typically, these medium power amplifiers operate with 21 dBm maximum power output at 1 dB compression, ultra-low 0.9 dB noise figure, and

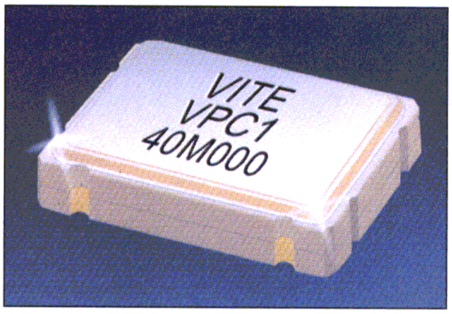


high +37 dBm IP3 to help suppress noisy intermodulation products. Gain is 16.5 dB typical with ±0.2 dB (typical) flatness. The ZQL-1900LN is equipped with 50-ohm SMA-Female connectors. It is priced at $249 each in quantities of 1 to 9.

Mini-Circuits
Circle #165

Programmable oscillators

VITE (Vectron International Technology Express) has introduced a series of SMD programmable clock oscillators for use in telecommunication and networking applications. The model VPC1 programmable crystal-controlled oscillators are housed in an industry-standard 5 × 7 mm ceramic surface-mount package and have a frequency range of up to 160 MHz. With a proprietary design and an exclusive programming method, the oscillators are programmed to a specific frequency prior to shipment using an EPROM (Electronically Programmable Read Only Memory) integrated circuit. The units are HCMOS or TTL compatible and available with a supply voltage of either 5.0 VDC ±10 per-



cent or 3.0 VDC ±10 percent. Operating temperatures are 0 to +70 degrees Celsius or –40 to +85 degrees Celsius. Other options include ±25, ±50 or ±100 ppm frequency stabilities and a tri-state or power-down function. Jitter performance as low as 7 ps rms is available in some packages. Standard pricing for the metal can and plastic package units starts at $2.05 each in 1,000-piece quantities, depending on specifications.

VITE
Circle #166

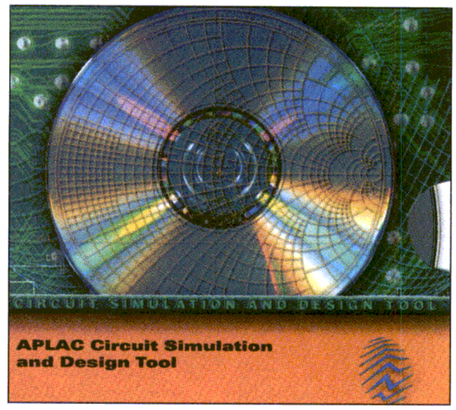
Voltage-controlled oscillator

Sawtek offers two voltage-controlled SAW oscillator (VCSO) products for broadband access applications. The single-ended sine wave oscillator is maximized for SONET, LMDS/MMDS point-to-point/multipoint microwave and software radio designs. Specifications include frequencies from 300 MHz to 2.5 GHz with 622.08 MHz, 666.51 MHz and 2.488 GHz being standard frequencies. Surface Transverse Wave (STW) resonator technology offers low phase noise and extremely low noise floors to ensure high frequency jitter performance (<5 fs RMS). Low g-sensitivity versions are available up to 5×10^{-10}/g. These narrowband VCSOs are designed for use in phase-locked loop applications. The differential output emitter coupled logic (ECL) clock is suited for the low jitter requirements of SONET, Ethernet and network servers. Specifications include frequencies from 600 MHz to just over 1 GHz, with standard frequencies at 622.08 MHz and 666.51 MHz. STW resonator technology offers low jitter performance at high fundamental frequencies (<.3 ps RMS). These narrow-band oscillators are designed for use in phase locked loop applications.

Sawtek
Circle #168

Design software

APLAC Solutions has introduced the APLAC 7.6 (student version) circuit simulation and design tool, equipped with the latest enhancements. This version can run on any supported operating system, such as Windows 95, 98, 2000 and NT, as well as Linux, HPUX and Sun



Solaris for Unix users. The CD-ROM also includes the time-limited but full-featured APLAC 7.6 evaluation version, which can be run to sample the simulations described in the RFIC mixer paper included with the CD-ROM.

APLAC Solutions Inc.
Circle #167

HBT gain block amplifiers

Alpha Industries has introduced a family of four new broadband HBT amplifiers for the broadband and wireless access markets. The amplifiers exhibit low noise and high linearity performance characteristics over a wide frequency range and are suitable for applications in cellular and PCS basestations, cable systems, direct to home satellite systems and wireless LAN, including Bluetooth, 802.11b, HomeRF, WI-FI, HiperLAN2 and 802.11a systems. The amplifiers are designed as cascadable 50-ohm gain blocks and are available in industry-standard tape and reel packages. The GBH112 provides 13 dB of small signal gain with 8.0 GHz of bandwidth. It has a P_{1dB} of 12.5 dBm at 2.0 GHz and IP_3 of 25 dBm. The GBH114 operates from DC to 6.0 GHz with 15 dB of gain and a 3 dB bandwidth of 6.0 GHz. It provides P_{1dB} of 16 dBm at 2.00 GHz and IP_3 of 31 dBm. The GBH120 is designed for DC to 4.0 GHz operation with 18 dB small signal gain. It provides P_{1dB} of 18 dBm at 2.0 GHz and 33 dBm of IP_3. The GBH121 is designed for DC to 3.0 GHz operation with 22 dB small signal gain. It provides 12 dBm of P_{1dB} and 25 dBm IP_3 at 2.0 GHz. All four amplifiers are available in plastic Micro-X and the smaller SC-88 package. Pricing ranges from $0.95 to $2.40 each in quantities of 100,000 or more.

Alpha Industries
Circle #169

Dual band, tri-mode receiver

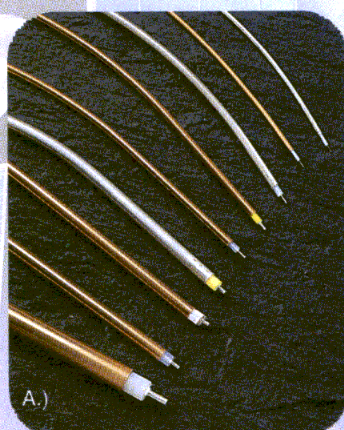
RF Micro Devices has announced the availability of the RF2489 LNA/mixer, a complete dual band, tri-mode receiver for the CDMA handset market. The RF2489 features 30 dB of stepped LNA/mixer gain control, as well as adjustable LNA IIP_3 versus bias current. Typical LNA performance for the RF2489 for cellular LNA is 15 dB gain, 1.1 dB noise figure and +12.0 dBm IIP_3; for PCS LNA is 16 dB gain, 1.3 dB noise figure and +10 dBm IIP_3; and for GPS LNA is 18 dB gain, 1.2 dB noise figure and –4 dBm IIP_3. The RF2489 is manufactured using a SiGe HBT process technology and is offered in a 5× 5 mm, leadless plastic package. The unit is priced at $2.31 in quantities of 100,000 or more. Samples and fully assembled evaluation boards are available now from RFMD, with production quantities available in the third quarter of 2001.

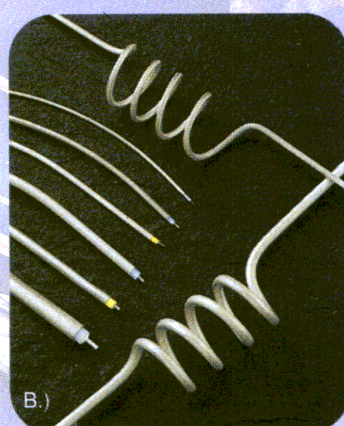
RF Micro Devices, Inc.
Circle #170

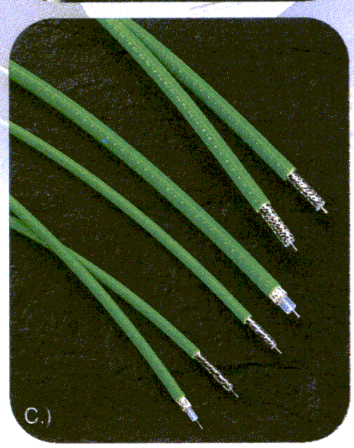
In-band transceiver

REMEC Broadband Wireless has announced the first in-band transceiver product roadmap to provide high-speed transmission capability that can triple the amount of transmission bandwidth currently available to subscribers. This transceiver contains signal filters, a signal amplifier and a converter to change the signal frequency to interface with the modem. The modem is located at the subscriber's home or office and connects via coaxial cable to the REMEC Broadband Wireless transceiver located on the rooftop. Data and voice signals are then transmitted via an antenna to a nearby hub station where the information is processed.

REMEC, Inc.
Circle #171

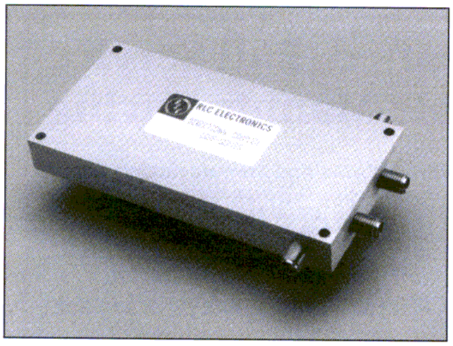






Low frequency directional couplers

RLC Electronics' low frequency high-power directional couplers offer accurate coupling, low insertion loss and high directivity in a compact package. Standard units are optimized for octave bandwidths and are available with a choice of coupling values. These units are ideal for sampling power with a negligible effect on the transmission line and



very low intermodulation products. Specifications for model LCHP-0205 include 250 to 500 MHz frequency range, minimum 25 dB directivity, maximum 1.15 primary VSWR, maximum 1.15 secondary VSWR and maximum 0.15 dB insertion loss. The LCHP-0510 model specifications include 500 to 1000 MHz frequency range, minimum 25 dB directivity, maximum 1.15 primary VSWR, maximum 1.15 secondary VSWR and maximum 0.20 dB insertion loss. Additional specifications include 50 ohms impedance; 500 watts average; 5 kW peak power; 20 or 30 dB coupling (NOM); ±1.25 dB accuracy (includes frequency variation); better than –130 dB intermodulation; and SMA female connectors.

RLC Electronics
Circle #172

Dual-band amplifier

M/A-COM, a brand of Tyco Electronics, has announced a new dual-band, low-cost integrated circuit power amplifier (PA) for use in high volume cellular GSM and DCS wireless handsets. The MAAPSS0011 RF power amplifier provides two independent transmit paths in a compact 4 × 4 mm plastic micro leadframe (FQFP-N) package, the industry's smallest package to date. The amplifier features a power-down mode to conserve battery power when the handset is not transmitting. Both three-stage PA paths run on a single 3 to 3.5 volt supply. The GSM path provides an output power of 35.5 dBm at 55 percent efficiency, and the DCS path provides 34 dBm at 50 percent efficiency. The amplifier is priced for high volume applications at less than $2.99 in quantities of 100,000. Availability of samples and production quantities is from stock.

M/A-COM, Inc.
Circle #173

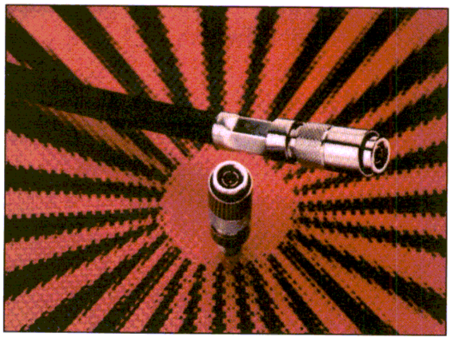
High-power VHF

The new Aethercomm P/N SSPA 0.118–0.137–100 is a high-power, solid state RF amplifier for use in commercial or military avionics systems. This unit has been optimized for analog voice, DSB AM, analog MSK and 8 PSK modulation formats. It offers a minimum gain of 55 dB and operates from –40 to +85 degrees Celsius in harsh environments with minimum degradation to gain and power. The amplifier is capable of delivering well over 100 watts of RF power to the antenna. Input VSWR is less than 2.0:1, and the output VSWR is typically 1.25:1. Typical gain flatness is <±1.5 dB. Applied voltage is 28 VDC, with a quiescent current of 3.0 amps typical. Output short and open circuit protection is standard. The unit comes packaged in a 6 × 8 × 2 inch housing with an input SMA female connector and a female type N output connector.

Aethercomm
Circle #174

Male crimp connectors

Times Microwave Systems has announced the availability of a 1.0/2.3 DIN male connector for LMR-240 flexible low loss coaxial cable. The TC–240–1.0/2.3 M connector enables fast, push-pull coupling and positive locking. It is suited for applications where space is limited and the goal is to minimize panel size. It can be densely packed, allowing for many more cables per unit area than with an SMA connector. It is suitable for use at frequencies up to 5.9 GHz. The connector



design also eliminates the need to achieve the proper torque and the potential of cross threading. The pin is gold-plated brass, and the body is nickel-plated brass.

Times Microwave Systems
Circle #175

Digital converters

Analog Devices has announced the new VersaCOMM product family of re-configurable digital converters that perform digital filtering and frequency conversion for high-speed signal processing applications. VersaCOMM digital converters are ideal for macro-, micro- and pico-cellular base station designs and are field-reconfigurable for multi-standard signals including 2G and 3G cellular standards. Other suitable applications include cellular E911 location services, wireless local loop, phased array antennas, digital video, communications test equipment and ultrasound applications.

Analog Devices, Inc.
Circle #176

RF switches

Peregrine Semiconductor has introduced the PE4210/4220/4230, the first low insertion loss CMOS RF switches, targeted to wireless applications up to 2.5 GHz. The PE4210/4220/4230 Ultra-Thin-Silicon (UTSi) MOSFET RF switches are true single supply, single pole double throw (SPDT) RF switches with performance comparable to

Gallium Arsenide (GaAs) RF switches. The switches' single-pin control voltage levels are CMOS compatible, allowing them to interface with other CMOS control signals used in wireless systems. The switches are available in small 8-lead MSOP packages and operate over a wide frequency range of 50 MHz to 2500 MHz. They are integrated with on-chip CMOS control logic providing a simple control interface to other CMOS devices and offer true single supply operation enabled by an integrated charge pump for –3 volt bias generation. The CMOS switches have ultra-low power consumption. Pricing for the PE4210/4220/4230 starts at $0.65 per unit in quantities of 10,000 or more.

Peregrine Semiconductor
Circle #177

Non-blind-slot transceiver IC

Atmel Corporation has announced the first non-blind-slot transceiver IC. The T2801 is a solution for a wide range of DECT data and voice applications, including residential cordless phones, WPBX1, WLL2 and WLAN3. The T2801 includes image rejection mixer, IF amplifier, FM demodulator, baseband filter, RSSI, transmitter amplifier, power ramping generator for the power amplifier, integrated synthesizer and voltage-controlled oscillator. The on-chip transmitter filter, with a modulation compensation circuit for advanced closed loop modulation, and a fast phase-locked loop setting time enable non-blind-slot operation. The universal transceiver-to-baseband interface can be used along with any major DECT baseband IC since the transceiver is suitable for both 13.824 MHz and 10.368 MHz clock reference frequency. Along with Atmel's low-noise amplifier/power amplifier U7006B, the T2801 transceiver forms a complete DECT system solution that is easy to use. Samples of the T2801 in MLP48 pin package are available now. Samples of the U7006B in SS016 (head slug) packages are also available. Pricing starts at $9.30 each for the T2801 and $4.93 each for the U7006B in quantities of 10,000 or more.

Atmel Corporation
Circle #178

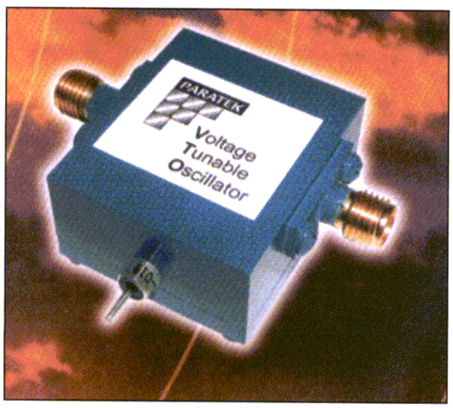
SMA connector series

Compel Electronics has introduced a SMA connector series. Operating from DC to 18 GHz, the new line offers typical insertion loss of <0.06 dB and VSWR of <1.15:1, with 50-ohm impedance. RF leakage runs typically measures <90 dB. Brass or stainless steel housings are available with gold, passivate or ternary alloy plating options. To facilitate numerous applications, designs are available for flexible, conformable and semi-rigid cable, PCB mount and panel or bulkhead mounting. All styles are available in straight, angled and swept right angle configurations. The family also includes in-series and between series adapters, dust caps and terminations. Custom cable assemblies are available upon request. Hermetically sealed connectors are available for use in harsh environmental applications.

Compel Electronics, Inc.
Circle #179

Voltage tunable oscillator

Paratek Microwave has introduced a voltage tunable oscillator (VTO) for microwave radios. The VTO features 600 MHz tunability, fast tuning, low power consumption and software control. Benefits include low phase noise, fundamental frequency operation, no spurious responses and no sub-harmonics. Specifications include a tuning

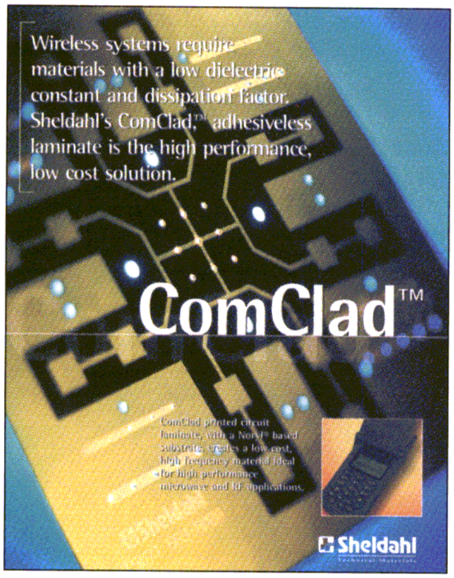


range of 10.55 to 11.15 GHz, output power of 0 dBm, harmonics of <–26 dBc, no spurious, phase noise of <–106 dBc/Hz at 100 kHz and SMA RF interface.

Paratek Microwave Inc.
Circle #180

High frequency circuit material

Sheldahl has introduced its ComClad™ HF high frequency circuit material, which consists of Noryl® plastic material as the base dielectric and has electrical performance for use in microwave and RF applications. ComClad™ HF has a combination of a dielectric constant of 2.6 and a dissipation factor of 0.0025. Because it uses a common

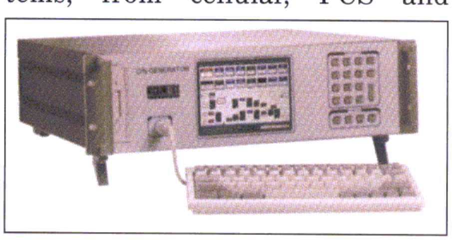


plastic as the base dielectric, designers and fabricators can form, mold, bend and even insert-mold it in a plastic injectionprocess. ComClad™ HF is available in standard circuit board panel sizes of 12 × 18 inches and 18 × 24 inches, with a variety of standard dielectric thicknesses and copper cladding. It is rated at continuous operating temperatures of –40 to +85 degrees Celsius and can be SMT or through hole soldered with shielding fixtures to prevent direct heat contact to the material. Applications for ComClad™ HF include cellular and PCS base stations, direct broadcast antennas, wireless LANs, antennas for various applications, automotive collision avoidance radar and three-dimensional circuit boards.

Sheldahl Inc.
Circle #181

Test equipment

Micronetics Test Equipment has introduced a family of precision C/N Generators for noise testing. The CNG series evaluates the performance of digital communication systems, from cellular, PCS and



W–CDMA to satellite modem and earth station testing. The CNG helps speed up the bit-error-rate test sequence now required in the manufacturing of digital communication systems. It allows the operator to accurately and automatically set C/N or Eb/No ratios to pinpoint a system's bit-error-rate under a variety of different noise levels. The CNG Series provides accuracy up to 0.15 dB RSS. It offers an internal calibrator for on-the-fly calibration, eliminating any drift from the factory. It offers three modes of operation: full keyboard, keypad and IEEE-488.2 GPIB bus. Operators can also choose from a variety of different mode settings for carrier-to-noise ratios, including E_b/N_0, C/N, C/N_0, C/I and noise only.

Micronetics Test Equipment
Circle #182

Radio modem

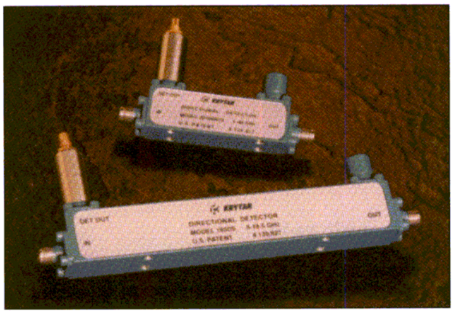
RF Neulink's RF9600 is now available on the new MURS frequencies. These five VHF channels are

available for use by almost anyone and no license is required. The MURS radio modem is capable of 9600 baud, has error correction, reliability and comes pre-programmed with all five frequencies. Each station may have its own ID code to ensure that it responds to commands. Units will work well with many commercial weather stations, as well as the home variety. Other Neulink radio modems are available on VHF, UHF and 2.4 GHz frequencies.

RF Neulink
Circle #184

Directional detectors

Krytar has designed a complete line of broadband directional detectors beginning at 0.5 GHz. The new line uses the company's directional couplers and microwave zero bias schottky detectors. Model 201040013 (13 dB nominal coupling) covers the



entire frequency band of 1 to 40 GHz. Frequency sensitivity (with respect to output) is ±1.7 dB minimum. Directivity is 14 dB minumum at 1 to 20 GHz and 10 dB minimum from 20 to 40 GHz. Maximum VSWR is 1.5 at 1 to 20 GHz and 1.7 at 20 to 40 GHz. Maximum insertion loss (includes coupling) is 1.1 dB at 1 to 20 GHz and 1.8 dB at 20 to 40 GHz. Low level sensitivity is 20 μV/μW minimum. The model is available with input correctors of 2.4 mm or K female. Other narrower frequency bands are available.

Krytar
Circle #185

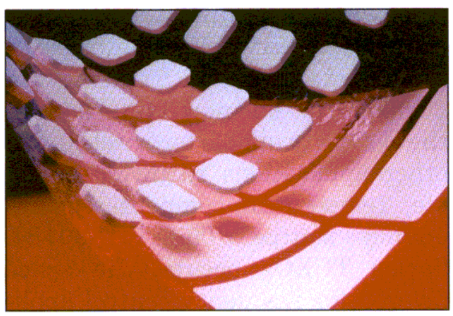
Ultra-compact RF ICs

Toshiba American Electronic Components has extended its family of ultra-compact RF integrated circuit (IC) packages, called Cell Packs. These new Cell Packs offer designers a way to implement a variety of functions required for both mobile communications and Bluetooth™-enabled devices. Each RF Cell Pack eliminates the need for multiple discrete devices required to perform specific functions, such as wide band amplifier, mixer, attenuator and single-pole double-throw (SPDT) switch. The extended family now includes three-wideband amplifier Cell Packs for low voltage operation, Cell Packs for crystal oscillator functions and Cell Packs for SPDT switch functions. As a result, RF designers can reduce total system component count, save board space and shorten the design cycle. Toshiba's wideband amplifier Cell Packs, designated TA4011FU/AFE, TA4012FU/AFE and TA4016FE, are housed in compact surface mount device (SMD) packaging and are suited for PDA, cellular phone, portable computer, set-top box and tablet PC applications.

Toshiba American Electronic Components, Inc.
Circle #183

Thermal interface material

W. L. Gore and Associates has introduced its POLARCHIP™ thermal interface material. This compressible, thermally conductive material is suited for filling the air gaps between heat generating devices on printed circuit boards (PCBs) and the heat sinks, heat spreaders and metal chassis that are used to dissipate the heat. POLARCHIP™ thermal interface material is a fluoropolymer composite that consists of an expanded polytetrafluoroethylene (ePTFE) matrix filled with boron nitride (BN) parti-

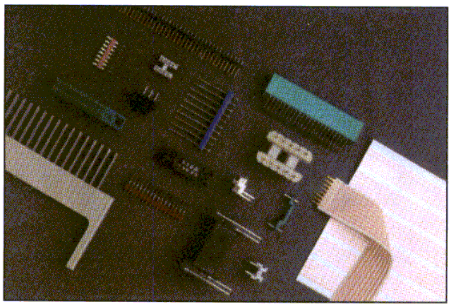


cles. The low elastic modulus of the ePTFE matrix imparts softness, conformability and compressibility to the composite, while the thermal conductivity of the BN particles gives the composite its thermal transport characteristics. The reinforcing nature of the ePTFE matrix results in a composite that is robust, easy to handle and does not require additional reinforcements. The POLARCHIP CP7003 thermal interface material is recommended for applications that require between 10 to 40 percent compression, and POLARCHIP CP8000 thermal interface material is recommended for applications that require greater than 40 percent compression. Both materials can be supplied in sheet form or precision die-cuts.

W. L. Gore and Associates, Inc.
Circle #186

Copper alloys

AMETEK Specialty Metals offers Pfinodal® and AM388™ high-performance Spinodal copper alloys as an alternative to beryllium copper, which is in tight supply due to the strong demand from cellular phones

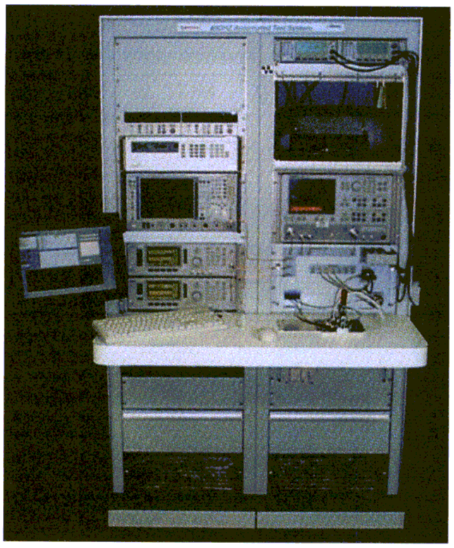


and other electronic devices that use the copper. AMETEK's Pfinodal and AM388 alloys are made using a proprietary wrought powder metallurgy technology. They offer strength and formability and, like beryllium copper, are available in mill-hardened and age-hardenable tempers. They provide conductivity, corrosion-resistance, plateability and solderability. AMETEK's Pfinodal and AM388 alloys are also available. Lead times are normally four to six weeks.

AMETEK Specialty Metals
Circle #187

Automatic test system

In-Phase Technologies has introduced its Model 1011 for the LMDS market. The Model 1011 was developed to address the production test requirements of transceiver related components found in LMDS system designs. The use of ATE test methodology is mandatory to ensure correlation of test results and to achieve the stringent production throughput goals that exist in most LMDS component/system supplier

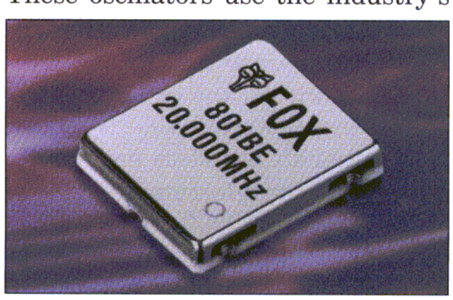


organizations. The basic system operates over the frequency range of 2 to 40 GHz and consists of a spectrum analyzer, vector network analyzer, microwave power meter and associated synthesized signal sources, power supplies, RF switch assemblies and UUT test fixtures. Systems that operate up to 60 GHz are also available.

In-Phase Technologies
Circle #188

Crystal oscillators

Fox Electronics has expanded its series of low-profile, temperature-compensated crystal oscillators with a new standard of frequency of 20.000 MHz. The new TCXO adds to the choices available for wireless and other applications requiring a stable, temperature-compensated frequency source. The FOX801BE Series TCXOs occupy the space favored for frequency control applications. The SMD device is 9.6 × 11.4 mm with a profile only 2.0 mm high, making it well-suited where headroom is a critical consideration. These oscillators use the industry's

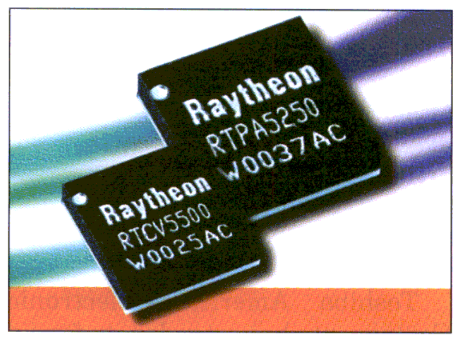


standard pinout configuration. The TCXOs display frequency stability of ±2.5 PPM over a frequency range of 10.000 MHz to 22.000 MHz. Operating temperature range is –30 to +75 degrees Celsius, with a voltage choice of 3.0 or 5 volts. An optional trimmer allows frequency adjustments of ±3.0 PPM. OEM pricing for a FOX801A TCXO is less than $5 each in quantities of 10,000 or more.

Fox Electronics
Circle #189

Radio chipsets

Raytheon Company's Components Division (RRFC) has introduced a line of fully integrated radio chipsets for point-to-point, point-to-multipoint and LMDS applications at 23, 26 and 38 GHz. These chipsets are designed to be used in wireless radios serving as alternatives to optical fiber installations for high speed data transmission networks. All chipset components are fully integrated within a common design



framework using Raytheon's 0.25 μm PHEMT process. As a result, they allow designers to eliminate the problems associated with multi-manufacturer sourcing, such as inconsistent power levels, operating frequencies and bias requirements. Each chipset has its own specially designed components including a power amplifier, low noise amplifiers, low noise/IF amplifiers, mixers, drivers, multipliers and buffer amplifiers. Component selection is governed by the specification of the power amplifier.

Raytheon Company
Circle #190

SAW-based oscillators

Micro Networks has developed a series of voltage controlled SAW oscillators (VCSOs) suited for high-performance telecommunication applications. The M600 series of VCSOs use Micro Networks' capability in the design of high-performance oscillators featuring low phase noise and jitter over a frequency range of 300 to 900 MHz. These devices are suited for phase-locked loop applications, as well as clock and data recovery and clock smoothing circuits used in OC-12, OC-48 and OC-192 SONET/SDH systems. The M600 series is available in a 28-pin surface mount package and offers an output disable feature that forces the output into a static condition, enabling an external clock to control the output frequency. Opera-ting from a single +5 volt supply, the M600's differential outputs are 10K/100K PECL logic compatible.

Micro Networks
Circle #191

Series capacitor

Murata Electronics North America has announced the introduction of its GRM 615 Series capacitors, featuring a capacitance range of 0.1 to 20 pF, offered in standard E24 steps. The component's benefits include higher Q, less power consumption and decreased size (0402). With these advancements, the higher *Q* and resulting lower loss translates into greater battery life for mobile and hand held devices. The capacitor utilizes copper inner electrode technology. The resistivity is approximately 10 percent lower than that of common silver and palladium electrodes. The GRM 615 Series is priced at $0.05 per capacitor.
Murata Electronics North America
Circle #192

Wave oscillators

Gilland Electronics introduces its ELVA-1's CIDO-series cavity-stabilized millimeter wave oscillators, producing fine-spectrum resolution and low phase noise with high output power and frequency stability. The CIDO solid-state, IMPATT-based design combines the extended frequency range and output power of IMPATT technology with the stability and phase noise characteristics associated with cavity-stabilized Gunn sources. These CIDOs are available in waveguide bands from 26 to 150 GHz. Standard CIDO models are supplied mounted on a finned heatsink and can maintain their operating frequency within a few megahertz over their operating temperature range of –50 to +80 degrees Celsius, with no temperature controller or heater. An optional built-in temperature-controlled heater can maintain the CIDO's internal temperature within a narrow specified range, resulting in a precise frequency output. Custom configurations and specifications can be negotiated. Maximum CIDO mid-band output power ranges from 150 mW at Ka band to 40 mW at D band, with typical frequency stability (per degree Celsius) of 10^{-5} to 5×10^{-6}, and amplitude stability (dB per degree Celsius) of 0.01 to 0.02. Several performance-enhancement and control options are offered. Applications for CIDOs include stable, fixed-frequency LO, communications systems, instruments and test equipment, space-based or HI-REL systems.
Gilland Electronics, Inc.
Circle #193

Power meter

TEGAM has announced its Model 7100 Portable RF Power Meter, offering a lightweight, compact instrument for average-power RF measurements. A frequency range of 10 to 2000 MHz and power input range up to 500 mW continuous make the Model 7100 suitable for numerous low-power test and troubleshooting applications in telecom, product development, repair, field service and manufacturing. The 31/2-digit liquid crystal display (LCD) eliminates confusion and potential errors from "reading between the lines" and locating decimal points that can result with conventional analog readouts. Four ranges provide sensitive readings up to 1.999 mW, 19.99 mW, 199.9 mW and 1999 mW (500 mW max.) full-scale. Basic accuracy of the unit is ±10 percent of full scale from 10 MHz to 1 GHz and ±15 percent of full scale from 1 to 2 GHz. The power meter is priced at $300 in the United States and $439 for export.

TEGAM, Inc.
Circle #194

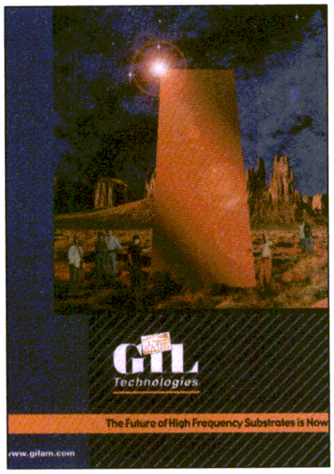
Coaxial TEM resonators

Integrated Microwave has introduced its line of coaxial resonators. Made with high-performance ceramic dielectric materials for use, these resonators have compact frequency standards, filter elements and distributed inductive or capacitive circuit elements. Coaxial TEM Resonators feature thermally stable ceramics in seven resonator sizes (3, 4, 5, 6, 8, 10, and 12mm) and four dielectric constants (8, 20, 36 and 98). Applications include dielectric resonating oscillators (DRO), voltage-controlled oscillators (VCO), pagers, global positioning systems (GPS), cellular and wireless communications, bandpass/bandstop filters, narrow-band/delay filters and EMI filtering.

Integrated Microwave
Circle #195

Laminates brochure

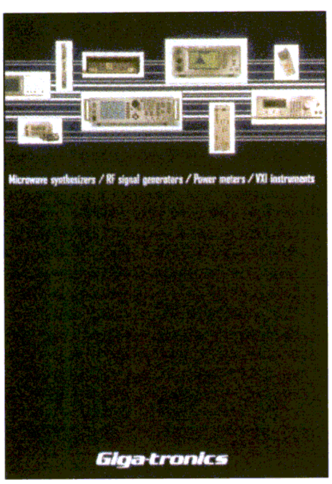
GIL Technologies has released a new four-page brochure highlighting the company's product line, materials and manufacturing capabilities. GIL Technologies creates laminates for commercial microwave and RF circuit board applications. The company's substrates are used for flat panel antennas, transceivers, low noise blockdown converters, low noise amplifiers and power amplifiers. End-use systems that benefit from GIL substrates include cellular and personal communications systems, GPS locators, wireless local area networks, satellite TV dishes, residential security sensors and in-home wireless networks.



GIL Technologies
Circle #196

Short form catalog

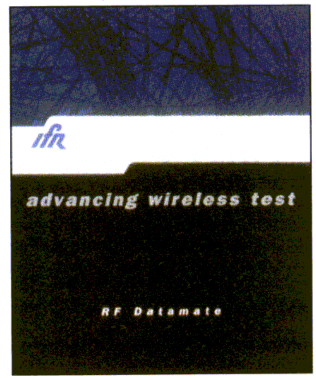
Giga-tronics has issued a new short form catalog featuring its high performance products, including microwave synthesizers, power meters, RF signal generators and VXI instruments. The catalog provides a quick guide to Giga-tronics' key product features, statistics and applications. A sensor selection chart is included to help customers match products to measurement requirements.



Giga-tronics, Inc.
Circle #197

Radio frequency data handbook

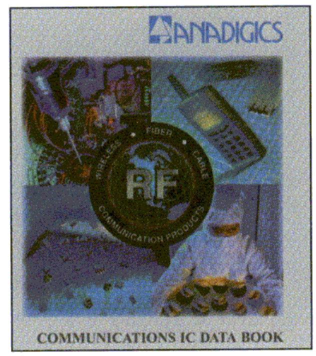
A new handbook of RF data is now available from IFR Systems. The RF Datamate is a 72-page reference guide to commonly used RF data. Among the topics covered are modulation, methods of measuring phase noise, intermodulation, receiver measurements, RF mixers, splitters and combiners, transmission lines, measurement uncertainties, substrates and RF level conversion. The guide also includes an overview chart of the U.S. spectrum allocation. The RF Datamate complements IFR Systems' Microwave Datamate. Both are available at no charge.



IFR Systems, Inc.
Circle #198

Data book on CD-ROM

Anadigics introduces its new Communications IC Data Book, available on CD-ROM. The publication includes the company's communication products for wireless, fiber and cable applications.



Anadigics, Inc.
Circle #199

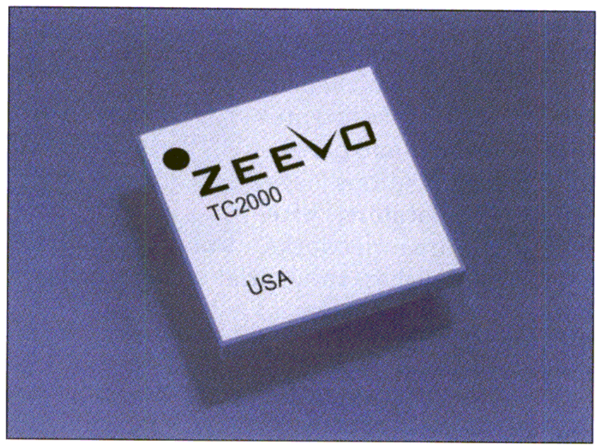
A One-Chip Design Solution for Bluetooth™ Wireless Applications

Zeevo has announced the availability of a highly integrated single-chip Bluetooth™ solution, the TC2000™. Using 0.18-micron CMOS technology, the TC2000 combines a low cost, low power consumption semiconductor process with the latest packaging technology. The result is a 10 × 12 mm device that operates from a 3.3 VDC supply and is fully compliant with the current Bluetooth 1.1 specification.

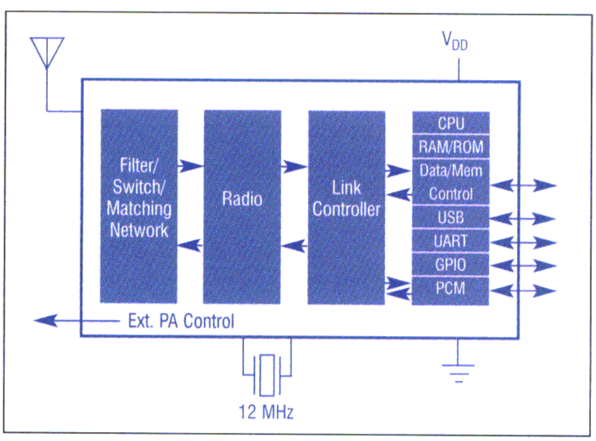
The TC2000 integrates all RF functions into a single device, including balun, switch, shield, impedance matching and RF filters. It provides 4 dBm transmit power and features –80 dBm receiver sensitivity.

The CPU section is based on an ARM7TDMI and is supported with 64 kilobytes of on-chip RAM. Versions of the ship are available with either 4 megabytes of Flash memory or with an external memory bus interface. The user interface includes a USB version 1.1, high speed UART and 8 General Purpose I/O (GPIO).

The TC2000 is fully supported with a standard Bluetooth HCI interface for USB and UART. A Bluetooth Protocol Stack (for L2CAP, RFCOMM, SDP, OBEX and TCS), Bluetooth test tool and all current Bluetooth Profiles are available.



▲ **The Zeevo TC2000 is a true single-chip solution for Bluetooth applications.**

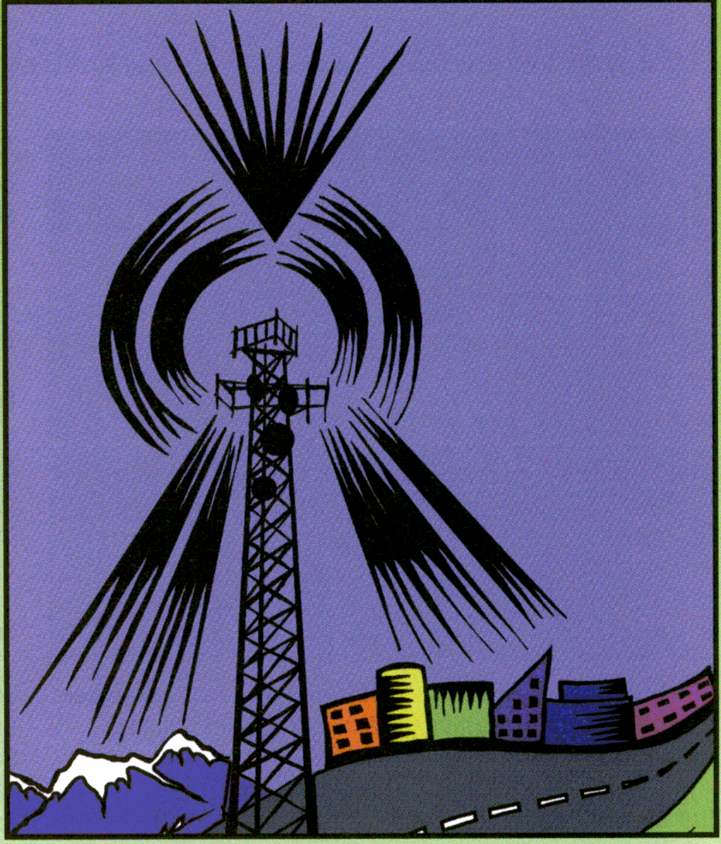


▲ **Basic block diagram of the TC2000.**

The device support point-to-point and point-to-multipoint operating modes, with up to 7 slaves per piconet and up to 4 piconets for scatternet operation. Zeevo also provides a proprietary feature called "Turbo Mode" that can increase the effective data transmission rates by 2 to 4 times between two Zeevo enabled devices.

Ease of implementation is the goal of Bluetooth-enabled product developers. The TC2000 requires only a crystal, antenna, decoupling capacitors, a reference resistor and a printed circuit board. Digital designers can implement this device nearly the same as a digital IC. With an external antenna, the process is simplest, although antennas designed as part of the circuit board require specialized expertise.

Base Station Repeater Radio OEM's



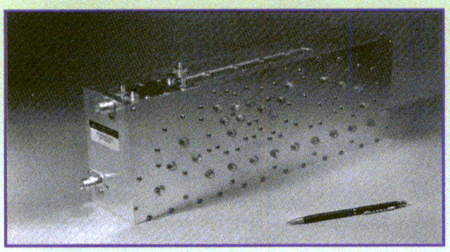
Improve your system performance with ClearComm Technologies' line of "off the shelf" and custom designed, application specific Filter and Duplexer products. With ClearComm's state of the art design technology and technical support, OEM's are realizing the highest performance possible with the most cost effective solutions available.

ClearComm Technologies offers a variety of filter products targeted at the wireless/telecommunications market.

Applications include:

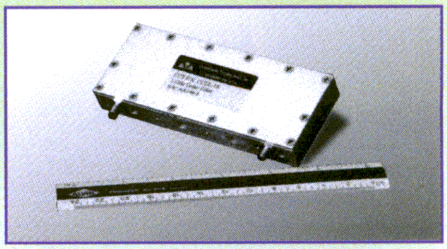
- Standard base station filters/duplexers
- Custom performance enhancing base station assemblies
- Delay filters for feed-forward amplifiers
- Cosite interference solutions
- Diplexers for 2.4-5.8GHz radios
- Custom products up to 40GHz

PCS/Cellular Duplexers

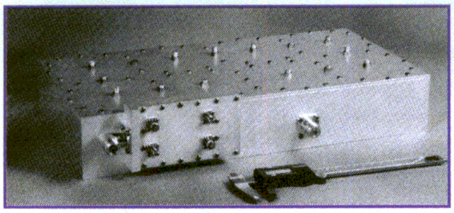


Transmit Receive Filters

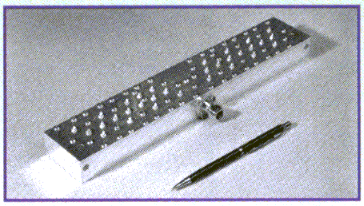
Delay Filter



Integrated Assemblies



2.4/5.8 Duplexers



Waveguide/Duplexers

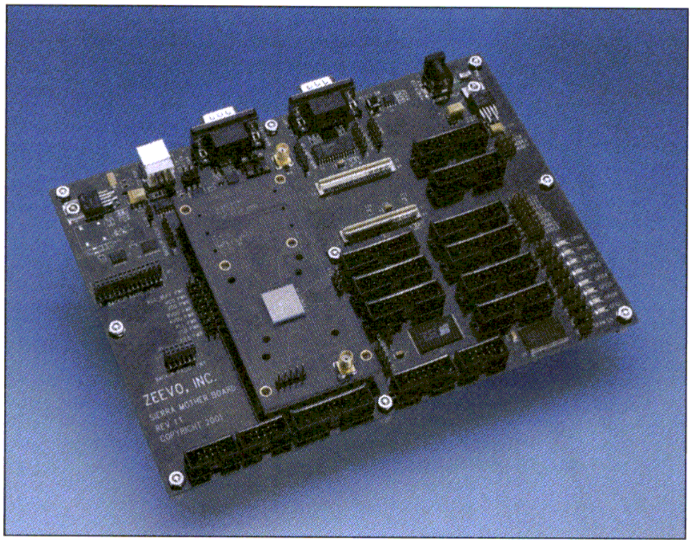
ClearComm technologies, LLC

Tel: 410-860-0500
Fax: 410-860-9005
E-mail: sales@clearcommtech.com

600 Beam Street
Salisbury, Maryland 21801
Web: clearcommtech.com

Circle 62

See us at MTT-S — Booth #3323



▲ **The Blue Shark developer's kit from Zeevo helps designers bring Bluetooth-enabled products to market quickly.**

Blue Shark™ developer's kit

To help designers implement the TC2000 quickly and efficiently, Zeevo offers the Blue Shark developer's kit. Everything is included to establish a working Bluetooth link that serves as a platform for development. Both the BlueOS RTOS and Nucleus Plus are supported, although Nucleus Plus is optional and requires a separate license. Test tools speed the application development process.

The interface between the host and development kit are USB or UART. Host utility software and a Flash loader provide additional development support.

Pricing and availability

The TC2000 Development Kit is available now for $8,000. Samples of the TC2000 are also available. Full production quantities will be available in the 3rd quarter of 2001. Pricing for the TC2000P-4 is $17 in OEM quantifies of 1 million or more.

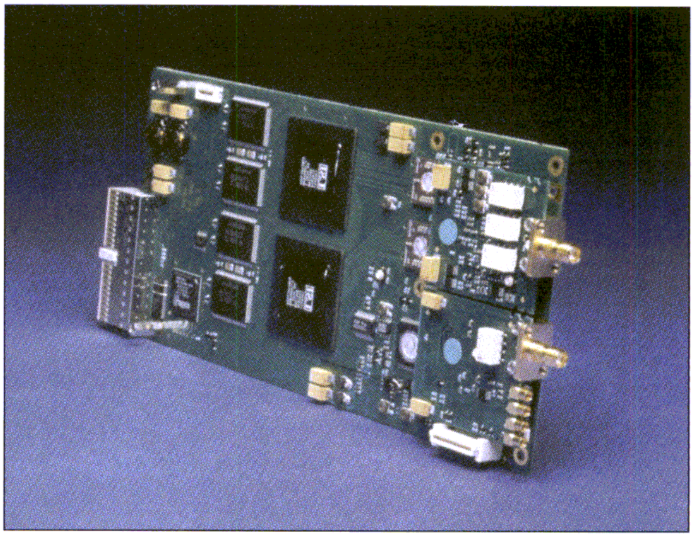
For more information, contact:

Zeevo, Inc.
2500 Condensa Street
Santa Clara, CA 95051
Tel: 408-982-8000
Fax: 408-982-8008
E-mail: sales@zeevo.com
Internet: http://www.zeevo.com

or circle Reader Service #201

High Speed Digitizer Captures Complex Signals and Events

High-speed capture of signals and sensor data is required for precision measurements of high frequency, high speed or short duration events. The new DBS 908 from Analogic provides 8-bit waveform digitization at speeds from 100 samples/second (S/s) to 2 GS/s in a DC to 500 MHz –3 dB analog bandwidth.



▲ **Analogic's DBS 908 Waveform Digitizer for VXI-based applications can capture data up to 2 GigaSamples/second for signal or event recording and analysis.**

The DBS 908 is a plug-in module for the VXI-compliant DBS 9905 carrier module. The compact mezzanine board concept allows a single VXI chassis slot to provide multiple functions. Two DBS 908s can be installed in a single DBS 9905 carrier module.

Flexible trigger and clock selections can be defined through software. Pre- or post-triggering delays are adjustable from 0 to 100 percent of the acquisition frame. Waveforms can be captured using a single trigger event, or memory can be segmented and data stored based on a series of successive triggers. A 5 ps resolution Trigger Timer Interpolator can be used to precisely measure the time between trigger occurrences. On-board memory of 4 MegaSample is standard, with 16 M optional.

High performance applications

Applications of the DBS 908 digitizer include telecommunications equipment, magnetic media storage, systems, automotive systems, time-of-flight measurements, mass spectroscopy, particle physics, explosive weapons and ballistics testing and other applications where the capture of high-speed data is required for measurement and analysis.

The unit comes with VXI-compliant Plug & Play drivers for Windows® versions 9x, NT or 2000. Support is also provided for C, Visual C++®, Visual BASIC®, LabView™ and LabWindows™/CVI. ■

For more information, contact:

Analogic Corporation
8 Centennial Drive
Peabody, MA 01960
Tel: 800-446-8936 or 978-977-3000
E-mail: T&M_info@analogic.com
Internet: http://www.analogic.com

or circle Reader Service #202

Product Spotlight

Advertising works!

To get your company's ad into *Applied Microwave & Wireless*, call your advertising sales representative today!

Scott Spencer
Eastern region
Tel: 603-472-8261
E-mail: slspencer@csi.com

Tim Burkhard
Western region
Tel: 707-544-9977
E-mail: TPBurk@aol.com

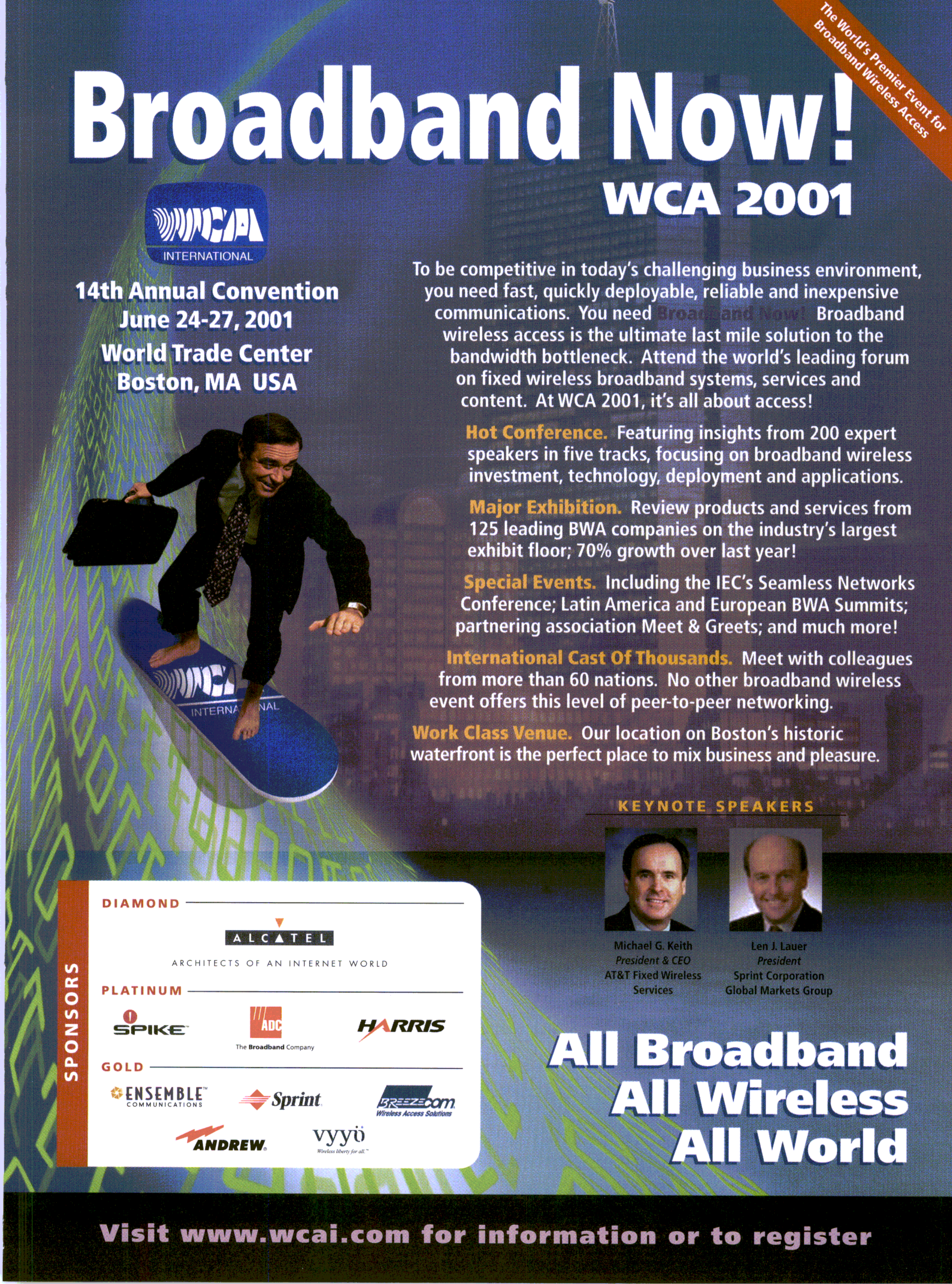
Aileen Kronke
Product Spotlight and Classifieds
Tel: 770-449-6774
E-mail: aileen@noblepub.com

How to place Product Spotlight and Classified ads in Applied MICROWAVE & WIRELESS

Our Product Spotlight section allows you to show off your company's products or services in an economical 1/9 page color ad. Ads may be sent camera ready, or we'll make up an ad for you! All you'll need to provide is a product photo, company logo and a description of the product or service you want to advertise.

Our Classifieds section is the place to advertise career opportunities, consulting services, used test equipment and just about anything else. Special Classifieds rates are available and are agency-commissionable if material is supplied. Or, if you prefer, our staff can make up the ad for you. Classified display ads are available in color or black and white in standard ad sizes, or in black and white by the column inch.

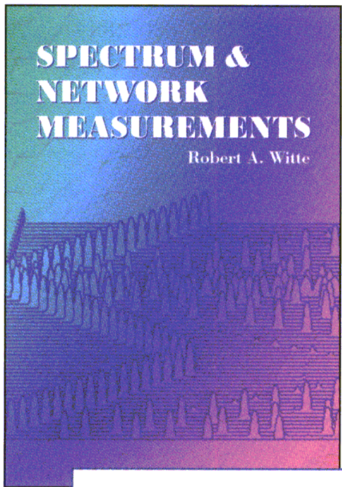
For more information on advertising in these two sections, please contact Aileen Kronke, Tel: 770-449-6774; Fax: 770-448-2839; E-mail: aileen@noblepub.com.


The World's Premier Event for Broadband Wireless Access
Broadband Now!
WCA 2001
WCA INTERNATIONAL
14th Annual Convention
June 24-27, 2001
World Trade Center
Boston, MA USA
To be competitive in today's challenging business environment, you need fast, quickly deployable, reliable and inexpensive communications. You need Broadband Now! Broadband wireless access is the ultimate last mile solution to the bandwidth bottleneck. Attend the world's leading forum on fixed wireless broadband systems, services and content. At WCA 2001, it's all about access!
Hot Conference. Featuring insights from 200 expert speakers in five tracks, focusing on broadband wireless investment, technology, deployment and applications.
Major Exhibition. Review products and services from 125 leading BWA companies on the industry's largest exhibit floor; 70% growth over last year!
Special Events. Including the IEC's Seamless Networks Conference; Latin America and European BWA Summits; partnering association Meet & Greets; and much more!
International Cast Of Thousands. Meet with colleagues from more than 60 nations. No other broadband wireless event offers this level of peer-to-peer networking.
Work Class Venue. Our location on Boston's historic waterfront is the perfect place to mix business and pleasure.
KEYNOTE SPEAKERS
Michael G. Keith
President & CEO
AT&T Fixed Wireless Services
Len J. Lauer
President
Sprint Corporation
Global Markets Group
SPONSORS
DIAMOND
ALCATEL
ARCHITECTS OF AN INTERNET WORLD
PLATINUM
SPIKE
ADC
The Broadband Company
HARRIS
GOLD
ENSEMBLE COMMUNICATIONS
Sprint
BREEZECOM
Wireless Access Solutions
ANDREW
vyyo
Wireless liberty for all.
All Broadband
All Wireless
All World
Visit www.wcai.com for information or to register

Upcoming Editorial Calendar

Issue	Ad Closing	Materials Due	Editorial Emphasis	Special Coverage & Bonus Distribution*
July	June 1	June 8	Digital Broadcasting Transistors Filter Design	
August	July 2	July 9	Wireless Consumer Electronics Oscillators Diode Circuits & Tehcnology	RAWCON 2001
September	August 1	August 8	Satellite & Space Systems Spectrum & Network Analysis Using CAD/CAE in Design	PCIA European Microwave
October	September 3	September 10	Microcells & Picocells Capacitors & Inductors Digital Modulation	
November	October 1	October 8	Industrial RF & Microwaves Attenuators & Terminations Baseband Circuits	

NEW RELEASES CLASSIC TOPICS



"Bob's book is an easy read that takes the mystery out of frequency domain, Fourier transforms, aliasing and more."
—Marsh Faber, *Agilent*

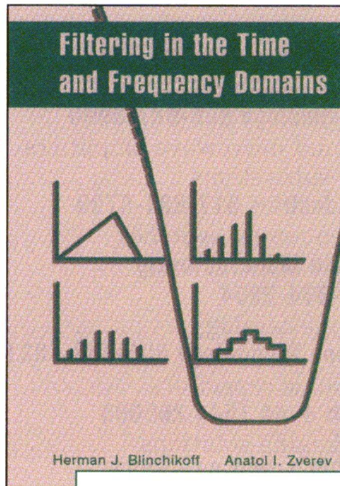
Spectrum & Network Measurements

Robert A. Witte

This book covers the theory and practice of spectrum and network measurements in electronic systems. Intended for readers who have a background in electrical engineering and use spectrum or network analyzers to characterize electronic signals or systems, this classic volume successfully consolidates the pertinent theory into one comprehensive treatment of frequency domain measurements. Covered are these critical concepts:

- Fourier analysis
- Transmission lines
- Intermodulation distortion
- Signal-to-noise ratio
- S-parameters

2001 (reprint of 1993 edition)
320 pages, ISBN 1-884932-16-9
NP-38 . . . . $59.00



"This book is one of the most suitable texts for an undergraduate course in network synthesis or filter design."
—*Proceedings of the IEEE*

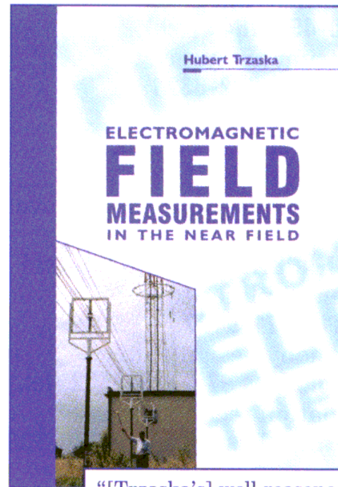
Filtering in the Time and Frequency Domains

Anatol I. Zverev   Herman J. Blinchikoff

Long regarded as a classic of filter theory and design, this book stands as the most comprehensive treatment of filtering techniques, devices and concepts as well as pertinent mathematical relationships. Topics discussed include:

- Derivation of filtering functions
- Fourier, Laplace, Hilbert and *z* transforms
- Lowpass responses
- Transformation of lowpass to other filter types
- The all-pass function
- Effect of losses on theoretical responses
- Matched filtering
- Methods of time-domain synthesis
- Digital filtering

2001 (reprint of 1987 edition)
520 pages, ISBN 1-884932-17-7
NP-39 . . . . $69.00



"[Trzaska's] well-reasoned commentary adds valuable insight into the practical aspects of EMF measuring equipment, its accuracy and its proper use."
—Gary Breed, *Preface*

Electromagnetic Field Measurements in the Near Field

Hubert Trzaska

In this book, internationally respected EMF measurement expert Hubert Trzaska discusses the specific problems of EMF measurements in the near field and the main factors limiting measurement accuracy. In light of the growing concern over the intensity of these fields and their potential health risks, Trzaska describes methods that provide accurate data to aid in the development of new, improved standards. Measuring methods are examined for electromagnetic fields (EMF), electric fields and magnetic fields; measurement discussions include power density and photonic EMF measurements.

2001, 232 pages
ISBN 1-884932-10-X
NP-37 . . . . $69.00

For more information, or to place your order online, point your browser to www.noblepub.com

For information or to order contact:
Noble Publishing Corporation
630 Pinnacle Court
Norcross, GA 30071
Tel: 770-449-6774 • Fax: 770-448-2839
Internet: www.noblepub.com

European Customers:
Please order through
American Technical Publishers
Tel: +44 (0) 1462 437933
Fax: +44 (0) 1462 433678
www.ameritech.co.uk

NOBLE PUBLISHING

Circle 39

See us at MTT-S — Booth #115

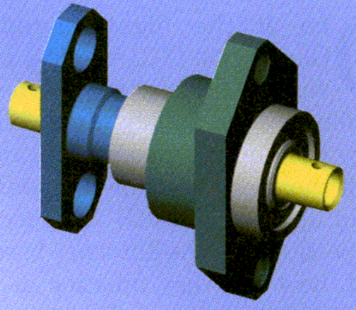
Advertiser Index

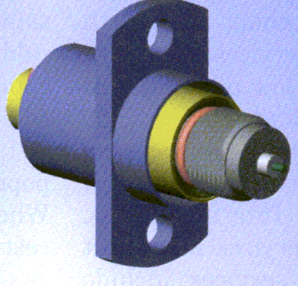
Tell them you saw it in
Applied Microwave & Wireless!

Applied Microwave & Wireless (USPS 011-596) (ISSN 1075-0207), printed in the U.S.A., is published monthly by Noble Publishing Corporation, 630 Pinnacle Court, Norcross, GA 30071. May 2001. Twelve issues are mailed in the United States for $30, outside the U.S. for $60, or provided free, with a completed and signed subscription form, to qualified professionals engaged in electronics engineering at 1 MHz to lightwave frequencies. Single issues, when available, are $7 in the U.S. and $12 outside the U.S. The material contained in this magazine is believed to be true and correct; however, the responsibility for the contents of articles and advertisements rests with the respective authors and advertisers. Periodical Rate postage paid at Norcross, GA 30071 and additional mailing offices.

Postmaster: Send address corrections to *Applied Microwave & Wireless*, 630 Pinnacle Court, Norcross, GA 30071.

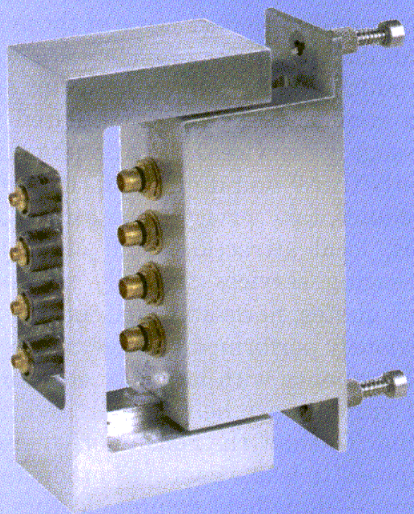
BLINDMATE
BMA, BMZ, BZ
Connectors & Components

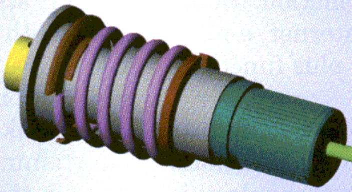




Features

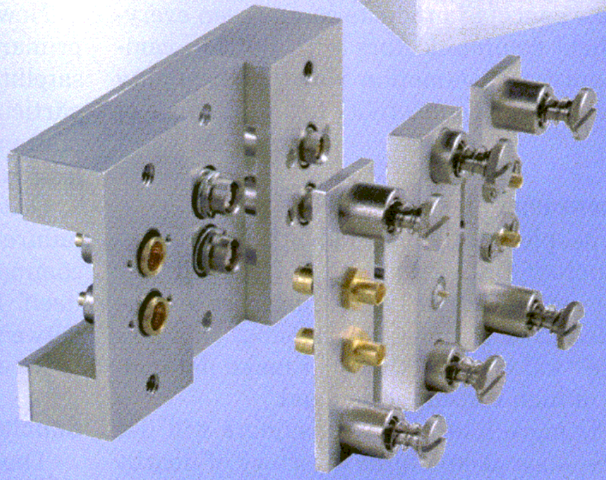
- Offers the advantage of slide-on mating while providing superior microwave performance
- Unique spring-loading mechanism allows for axial and radial misalignment
- Increased package densities
- Quick connect/disconnect
- Lower applied cost
- First QPL source for Mil PRF-31031





Configurations

- Semi-rigid and flexible cable connectors
- Hermetic versions and adapters
- Fixed and floating versions
- Low profile
- High power
- Stripline and microstrip launchers
- Adapter
- Terminations



Typical Applications

- Radars and sensors
- Integrated avionics
- Missile systems
- Navigation systems
- Automated test equipment
- Satellite communication
- Wireless/broadcast

SV MICROWAVE™

RF Connectors & Components

3301 Electronics Way, West Palm Beach, Florida 33407
Phone: 561-840-1800 • FAX: 561-842-6277 • E-Mail: sales@svmicro.com
Website: www.svmicrowave.com

Circle 27

See us at MTT-S — Booth #614

Wireless Internet Access — How Much, How Soon?

One of the highly-touted features of Third Generation (3G) wireless is access to digital services, including the Internet, with sufficient data transfer speed to satisfy nearly all users. Current technology (2G) only supports data transmission at a fraction of the speed of a dial-up modem. The next wireless system upgrade (2-1/2G) will reach perhaps one-fourth the speed of 3G. As Internet-based services are introduced, how will they function at the low data rates of the present wireless infrastructure, and what will be consumers' perceived value of those limited services?

All major wireless providers are now in the process of introducing data services, including Internet access. The emphasis is on location-based services and short messaging services. Location-based services include mostly travel and dining information, including airline schedules, taxi services, nearest restaurants, hotel locations, local attractions and other information. Short messaging services typically include Internet e-mail, stock quotes, news and weather services, plus functions previously performed by pagers.

Telephones with larger screens to accommodate text and graphics are being advertised heavily in the mass media. To show the consumer where this technology is supposed to lead, "concept" products can be seen everywhere — handheld communicators with built-in cameras, voice recognition, live-motion video, high quality digital audio and wireless connectivity to a wide range of accessories.

Satisfying the consumer

How many people really care about minute-by-minute stock quotes? Do we want to be "beeped" for every significant news headline? Although these are the services being featured in most advertising, they are probably not the "killer apps" that will make data-on-the-go a matter of high consumer demand.

In reality, it is more likely that consumers will use practical services, such as an online directory of nearby services or local maps to help navigate around an unfamiliar part of town. Weather forecasts, traffic reports, road construction activity and other dynamically changing information are also ideal for a mobile user.

Like the wired Internet, the value of the information service is in the content, not the delivery method. Also like the wired Internet, speed enables a wider range of content. Video and MP3 audio are two services that will need the speed of 3G to be viable for mobile delivery.

Food for thought

A few issues that are not widely discussed but are pertinent to mobile data services include:

User distraction by visual data — There is currently an intense debate over the use of wireless phones in vehicles. At issue is the ability of the driver to travel safely while distracted by purely verbal communication. Adding visual data to the mobile communication environment will certainly raise additional concern over the safety of performing multiple tasks while driving.

It should also be noted that, despite the immense popularity of television, it is rarely found in vehicles. When TV is present in a vehicle, it is nearly always restricted to use by passengers. This could be construed as evidence that it simply is not practical to add much visual information to the driving tasks.

Diminishing information via broadcast radio — Radio is still the dominant form of mobile communications. With the exception of National Public Radio and a few AM stations around the country, the amount of information included in radio programming is minimal. Music, talk and sports are the dominant forms of radio entertainment, and many stations include no news coverage in their programming.

Newspapers, television and the Internet are now the primary delivery methods for information. Developing satellite broadcast services might restore some of radio's participation in news delivery, but even then local information may be missing. Mobile data services via wireless "phones" have an opportunity to fill the void.

Overblown expectations for Internet commerce — The failure of e-commerce companies must be a lesson. E-commerce (or mobile Internet access) is not an end in itself. It is simply one more avenue of communication between an information provider and its audience or between a product provider and its customers.

Conclusions

These issues together define the task of the designers of mobile information services — find a way to deliver information that is safely usable in a mobile wireless environment, yet substantial enough to satisfy the high expectations for Internet-based content. They must be defined by their value to the user rather than the technology of their delivery. With limited access speed and the nature of the mobile environment, the applications must be tailored to the delivery medium, and targeted to the mobile user's specific needs. ■