Vol. 50 • No. 11

November 2007

Microwave Journal

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Passive and Control Components

Technological Advances in Solid-state Switches

Method to Reduce Dimensions of Planar Passive Circuits

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MIXER ASSEMBLIES
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MIXERS

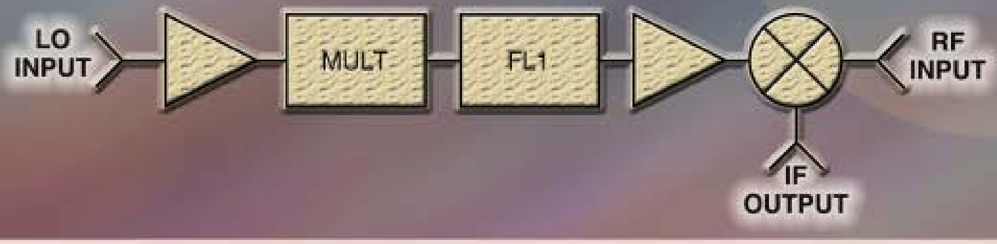
Model Number	Frequency (GHz) RF	LO	IF	LO Power (dBm)	Conversion Loss (dB Typ.)	LO-RF Isolation (dB, Typ.)
TB0440LW1	4–40	4–42	.5–20	10–15	10	20
DB0440LW1	4–40	4–40	DC–2	10–15	9	25
SBE0440LW1	4–40	2–20**	DC–1.5	10–15	10	20
IR2640L17*	26–40	26–40	Note 1	15	10	15
M2640W1	26–40	26–40	DC–12	10–12	10	20
TB2640LW1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

* Image Rejection typically 15 dB. ** Sub Harmonic
Note 1: IF Option A: 20–40 MHz, B: 40–80 MHz, C: 100–200 MHz, Q: DC–1000 MHz

MULTIPLIERS

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

MIXER/MULTIPLIER ASSEMBLIES



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

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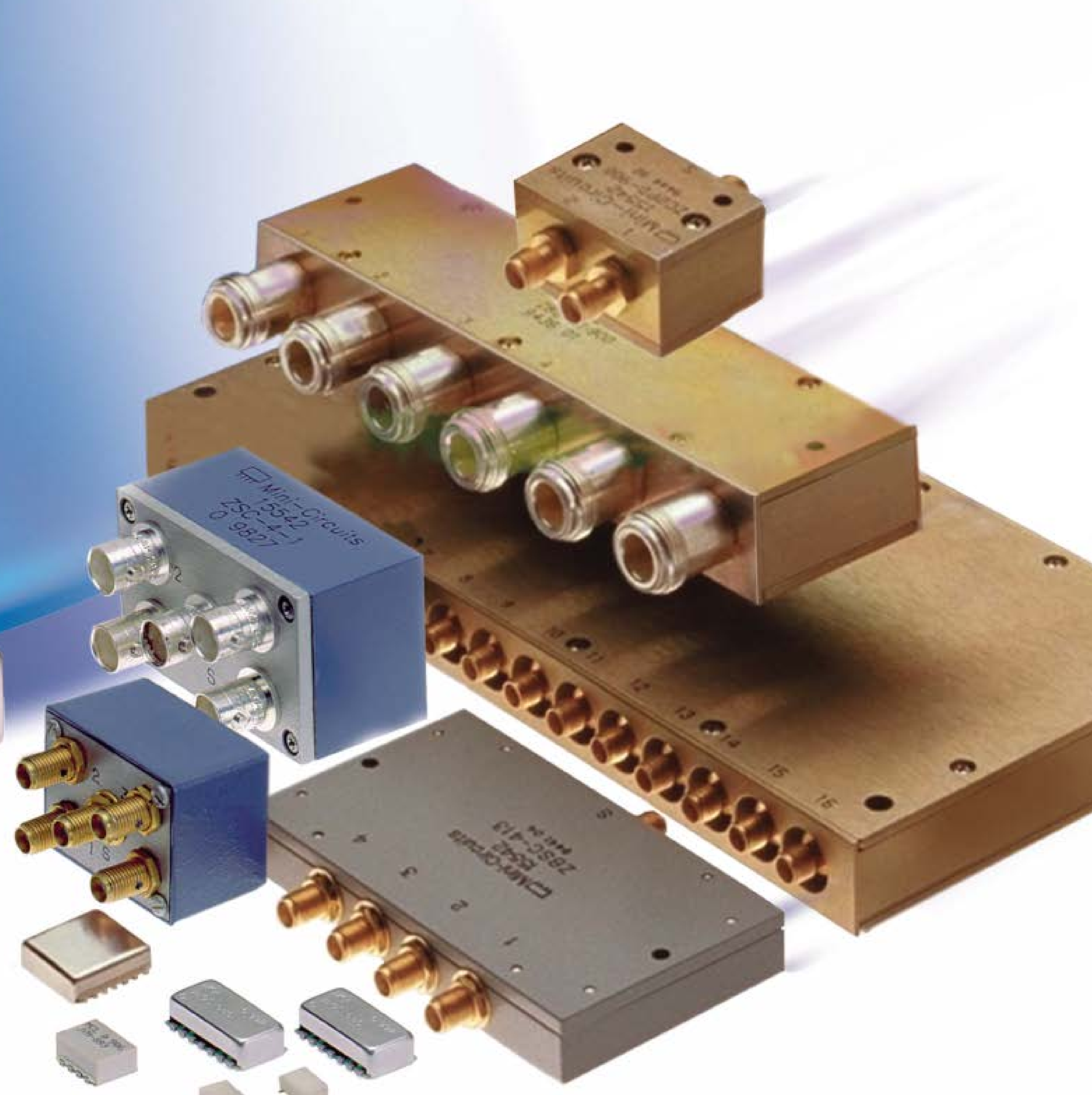
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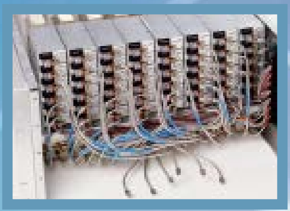
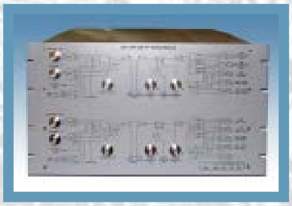


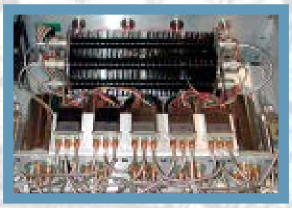
Attenuation Matrices & Multi-Channel Subsystems

RF Distribution Networks

Switch Matrices



RF/Microwave Frequency Translators



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Microwave Journal

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FEATURES

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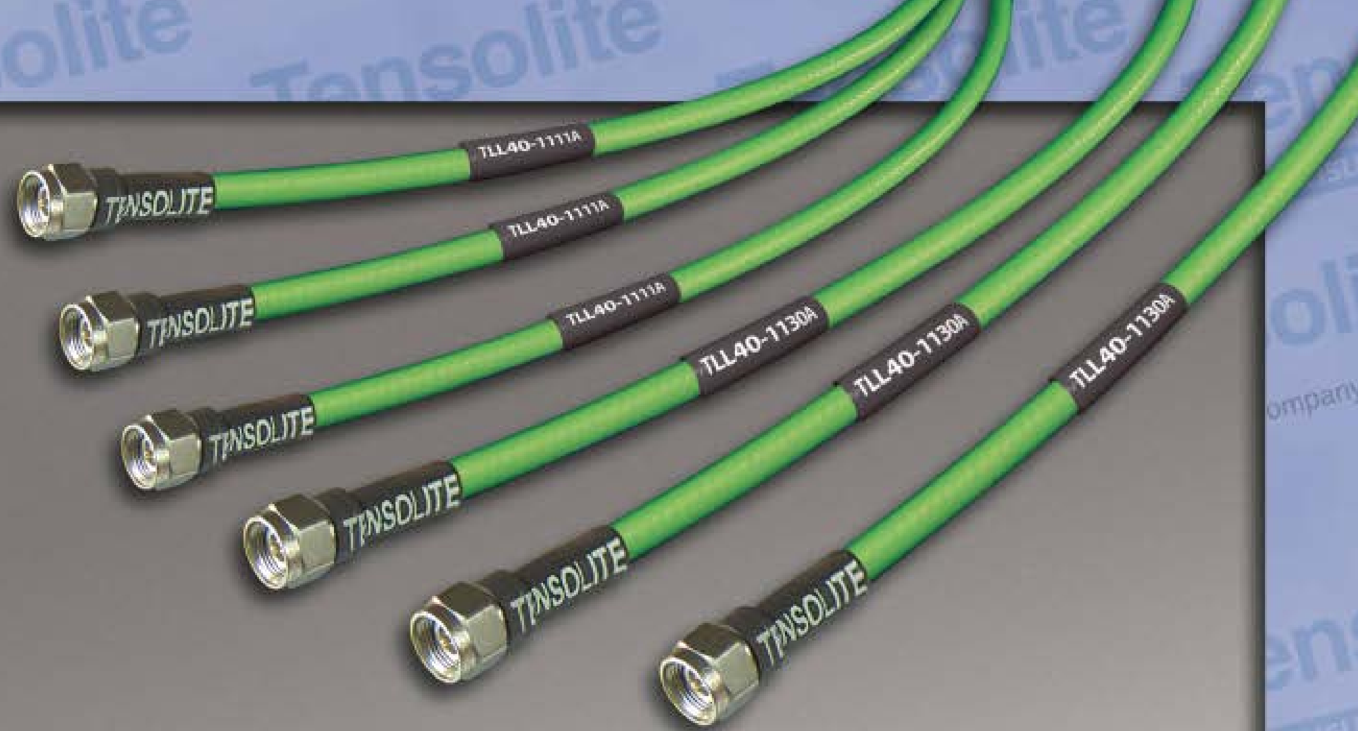

INTRODUCING

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Microwave Journal

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

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

Semiconductor Devices for RF/µW Design-Device Materials/ Fabrication and Impact on Performance – *This Webinar provides design engineers with an overview of the structure and operation of HBTs and HFETs and how these affect performance issues such as frequency range, noise figure and phase noise.*

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Live webcast: 11/20/2007, 11:00 AM (EST)

Events

AMTA 2007, Nov. 4–9, 2007
MWJ online provides a wrap-up of the Antenna Measurement Techniques Association (AMTA) 2007 Symposium. This conference promotes advances in electromagnetic technologies applicable to antenna and radar cross-section measurements and includes more than 500 AMTA global members from industry, government and educational institutions. *MWJ*'s exclusive coverage will include the proceedings and news from exhibitors.

Online Technical Papers

"WiMAX Power Amplifiers and Front-end Modules: A Primer in Design Considerations"
Darcy Poulin, SiGe Semiconductor

"Pad Geometry Scaling and Removal in Advanced Capacitor Models"
Larry Dunleavey, Modelithics

"Balanced Amplifiers in RF Design"
Bruce Marks, Mini-Circuits

Executive Interview

Reducing the operational cost of existing 3G and future 4G base stations requires more efficient power amplifier technology such as digital pre-distortion and advanced circuit topologies. In this month's executive interview, we talk with Brian P. Balut, Vice President, Networks Business Units, **TriQuint Semiconductor**, about their product portfolio, the challenges of WiMAX, various semiconductor technologies, and the current state-of-the-art in power amplifier efficiency.

Expert Advice

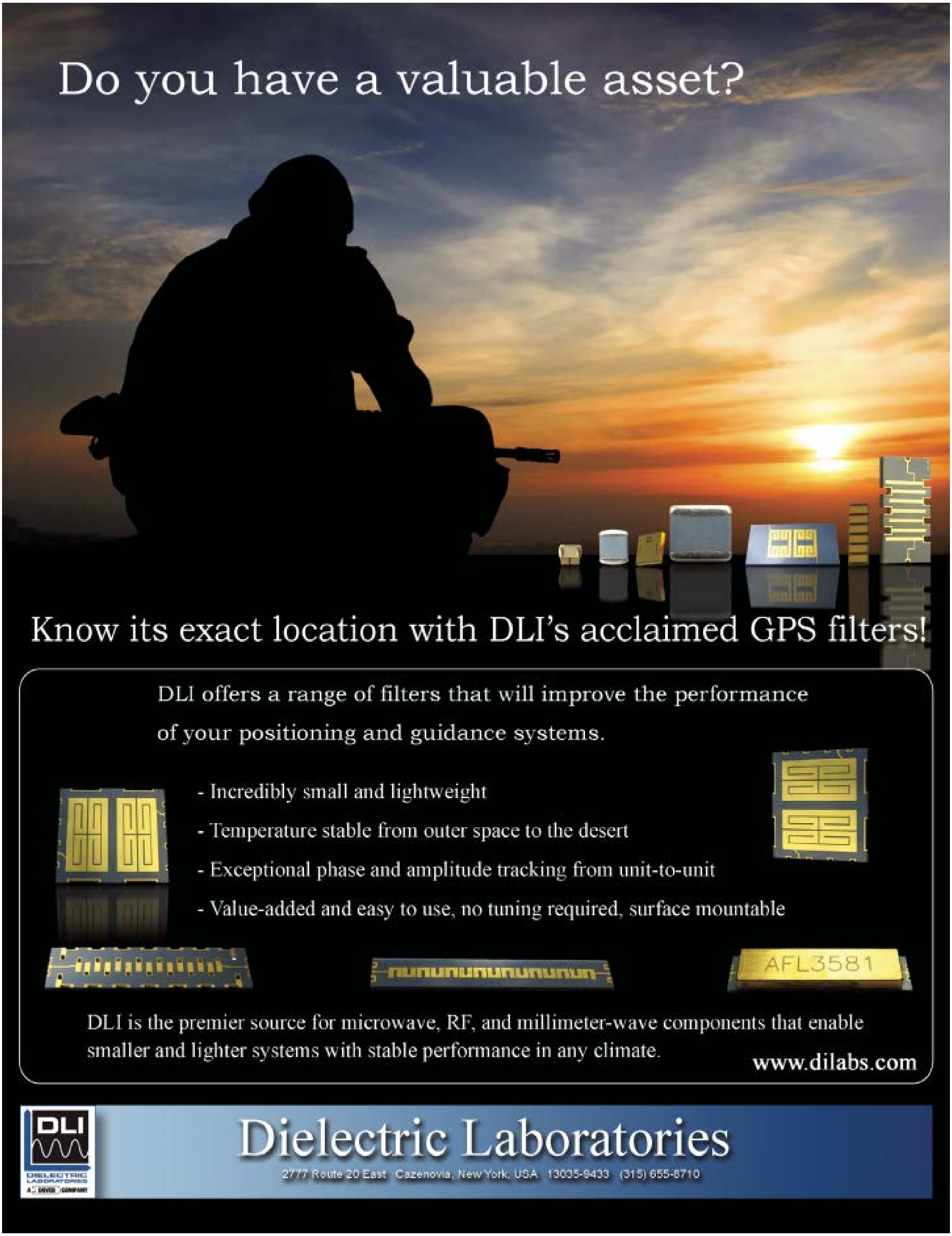
featuring Ask Harlan

Industry expert Harlan Howe has worked in the global microwave industry for over 50 years. To help build an online community dedicated to peer-to-peer communication and the exchange of technical information, Harlan monitors the responses and chooses the best answer to the online featured microwave-related question of the month. All of the responses to the featured question will be posted on our web now exclusively online.

This Month's Question:

Alexander Dmiterko asks–

I want to use a defected ground structure technique for improving a PA's linearity...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MORE OPPORTUNITIES FOR MICROWAVE ENGINEERS

DAVID VYE, *Microwave Journal* Editor

With the *Microwave Journal* (MWJ) November supplement "WiMAX and Emerging Technologies" hitting the streets and the WiMAX World and European Microwave Week (EuMW) conferences still fresh in the minds of those who attended, now seems like a great time to consider the impact these utopian "wireless everywhere" systems will have on the health of our industry and related job security. Certainly the hype over WiMAX as well as Long Term Evolution (LTE) and Ultra Mobile Broadband (UMB) is keeping the business and marketing departments employed and busy. Is this technology a panacea for the near and long-term engineering job market as well?

At WiMAX World, Sprint Nextel CTO, Barry West, stated, "all the emerging wireless technologies would be differentiated by the width of available spectrum channels and bound by physics." The wider spectrum of course will provide the speed and capacity necessary for the services (mainly the mobile Internet) to win over customers. The major service providers seem committed to the vision and are acknowledging the hardware challenges; chief among these are bandwidth, linearity, efficiency, size and cost. So what's the industry response?

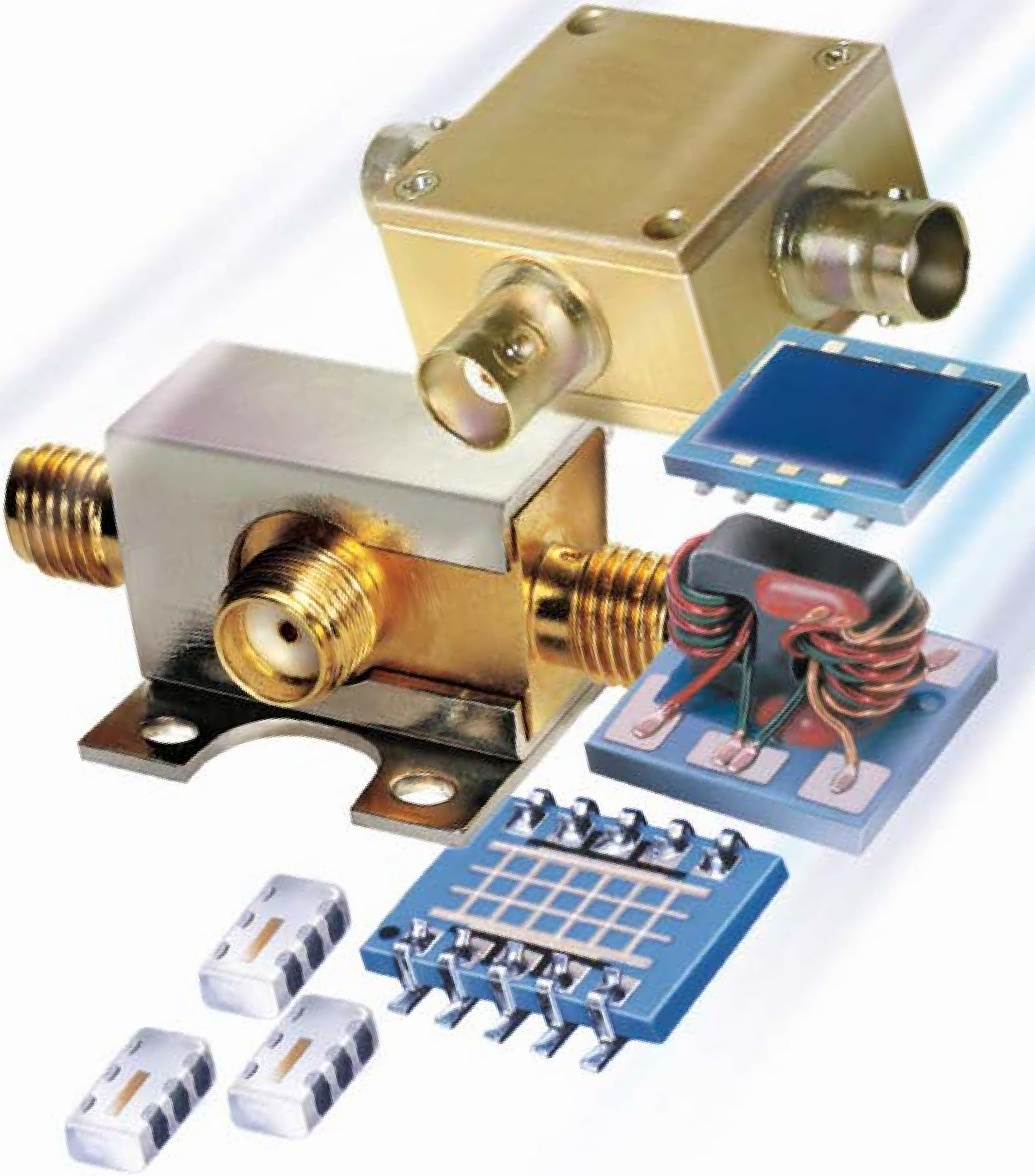
Judging from various press releases at both shows, the current wave of activity is coming mostly from the test and measurement equipment providers and the active device manufacturers (power transistors and MMICs/RFICs). This is no big surprise, as advancements in transistor technology from GaN, LDMOS and High-Voltage HBTs will be needed to address the demanding efficiency and linearity system requirements. And of course, testing is required to verify the performance of these devices.

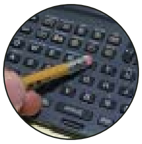
News items in these areas were reported in the MWJ online coverage of both the WiMAX World and EuMW conferences. New test solutions addressing Wave 2 system profile, modulation quality and interoperability testing, fast-switching signal generators for rapid R&D and production test, handheld test solutions for field engineers as well as configurable 4 × 4 multiple-input, multiple-output (MIMO) test systems were announced from Agilent, Aeroflex, Anritsu, Rohde & Schwarz and Keithley to name a few.

Articles in our WiMAX supplement this month further discuss the latest in test and measurements with features on "Design and Test Challenges of 3GPP LTE," "Mobile Fading Simulation," and "Generating UWB Waveforms." From the integrated device manufacturer's perspective we have the supplement cover story "Making Sense of WiMAX" from Triquint in which the author relates the history of the WiMAX Forum™—the industry consortium, the various IEEE standards, terms such as "profiles, releases and waves" and how these factor into hardware specifications. Additionally, Freescale presents the latest advances in its LDMOS RFIC technology, targeting the simplification of WiMAX Base Station Design. And this month, in one of our spotlight web exclusive articles on the MWJ home page, a senior system engineer from SiGe Semiconductor presents the challenges of WiMAX for handset and RF front-end module design.

Of course the engineering work extends beyond transistors and test systems. Device makers such as Nitronex were on hand at WiMAX World to promote its new GaN-on-Si broadband Doherty Power Amplifier reference design for the engineers who will be developing mobile WiMAX infrastructure. Other members of the RF food chain from balun, switch and filter manufacturers to antenna and connector companies are also staking their claims in this emerging technology landscape as many report on new products specifically for the various 802.16 standards. Clearly the sheer number of product-related news items speaks volumes for the amount of engineering effort that is being applied to the emerging technologies that will be critical to the success and proliferation of mobile-based (Internet plus) services. I share the big service providers' belief that consumers will want this level of connectivity. Like high-definition television that may seem frivolous until you've seen the side-by-side comparison to a standard picture, mobile connectivity will be a must have service in the near future.

Looking back at last year's IMS technical program, one can see how the presented papers reflect the industry's dedication to both basic microwave R&D and specific applications such as WiMAX. Perhaps that is why we have enjoyed such a long and healthy existence—advancing the state-of-the-art, adapting to changes and benefiting from opportunities. So lets work together to expand what Sprint's Barry West called the "bounds of physics" and change the way the world is connected. Next month the *Journal* looks at how microwaves have affected our lives through medical, scientific and industrial (including automotive) applications. There's lots of work to be done and personally I love it when we're busy. ■





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IEEE MTT-S International Microwave Symposium 2008
by December 7, 2007
IEEE Radio Frequency Integrated Circuits Symposium
by January 3, 2008
IEEE EMC Symposium
by January 15, 2008

NOVEMBER

70TH ARFTG MICROWAVE MEASUREMENT SYMPOSIUM
November 27–30, 2007 • Tempe, AZ
www.arftg.org

DECEMBER

INTERNATIONAL RADAR SYMPOSIUM INDIA (IRSI 2007)
December 10–13, 2007 • Bangalore, India
www.radarindia.com

ASIA-PACIFIC MICROWAVE CONFERENCE (APMC 2007)
December 11–14, 2007 • Bangkok, Thailand
www.apmc2007.org

JANUARY

IEEE MEMS 2008 CONFERENCE
January 13–17, 2008 • Tucson, AZ
www.mems2008.org

IEEE TOPICAL SYMPOSIUM ON POWER AMPLIFIERS FOR WIRELESS COMMUNICATIONS
January 21–22, 2008 • Orlando, FL
http://pasymposium.ucsd.edu

IEEE RADIO AND WIRELESS SYMPOSIUM (INCORPORATING WAMICON)
January 22–24, 2008 • Orlando, FL
www.radiowireless.org

WCA INTERNATIONAL SYMPOSIUM AND BUSINESS EXPO
January 29–February 1, 2008 • San Jose, CA
www.wcai.com

FEBRUARY

INTERNATIONAL SOLID-STATE CIRCUITS CONFERENCE (ISSCC 2008)
February 3–7, 2008 • San Francisco, CA
www.isscc.org

NATIONAL ASSOCIATION OF TOWER ERECTORS (NATE 2008)
February 11–14, 2008 • Orlando, FL
www.natehome.com

SATELLITE 2008 CONFERENCE AND EXHIBITION
February 25–28, 2008 • Washington, DC
www.satellite2008.com

INTERNATIONAL WIRELESS COMMUNICATIONS EXPO (IWCE 2008)
February 27–29, 2008 • Las Vegas, NV
www.iwceexpo.com

JUNE

IEEE RADIO FREQUENCY INTEGRATED CIRCUITS SYMPOSIUM (RFIC 2008)
June 15–17, 2008 • Atlanta, GA
www.rfic2008.org

IEEE MTT-S INTERNATIONAL MICROWAVE SYMPOSIUM AND EXHIBITION (IMS 2008)
June 15–20, 2008 • Atlanta, GA
www.ims2008.org

AUGUST

IEEE EMC SYMPOSIUM
August 18–22, 2008 • Detroit, MI
www.emc2008.org

Workshops & Courses

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■ **Site:** Darmstadt, Germany
■ **Date:** November 29, 2007
■ **Contact:** For more information, contact info@cst.com or call +49-6151-7303-0.

Antenna Engineering

■ **Topics:** This course provides an overview of the theory and practice of antenna engineering, including a range of antenna types, applications and electromagnetic properties from basic to state-of-the-art. Explore a wide spectrum of frequency from 550 kHz to 550 GHz, with primary emphasis in the VHF, UHF and microwave regions. Examine communications and radar, commercial and military applications.
■ **Site:** Las Vegas, NV
■ **Dates:** December 3–7, 2007
■ **Contact:** Georgia Institute of Technology, Professional Education, PO Box 93686, Atlanta, GA 30377 (404) 385-3500.

Market Success of 3G and Wireless Mobile Services

■ **Topics:** This intensive two-day course looks at the business, services and launch marketing for advanced wireless services on all major related technologies, such as 2.5G, 3G, 3.5G and 4G, as well as WiFi and WiMAX. The course is non-technical in nature and provides an impartial overview of the wealth of opportunities for mobile data, presents the latest findings, research and theories, and looks at models for rapid and profitable launch of new mobile services.
■ **Site:** Oxford, UK
■ **Dates:** December 11–12, 2007
■ **Contact:** University of Oxford Continuing Education, +44 (0)1865 270360, or visit www.conted.ox.ac.uk.

2007 Power Seminars

■ **Topics:** Fairchild will provide the latest in design techniques for optimizing system power with analog, discrete and optoelectronic solutions at these one-day events. The technical sessions include: low cost, isolated current source for LED strings, design considerations of LLC resonant converters and application review and comparative evaluation of low side MOSFET drivers. For more information, visit www.fairchildsemi.com/powerseminar07/.
■ **Site:** For location information, please visit url.
■ **Dates:** For date information, please visit url.
■ **Contact:** Fairchild Semiconductor Corp., 82 Running Hill Road, South Portland, ME 04106 (207) 775-8100, www.fairchildsemi.com.

The Entrepreneurial Engineer

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

PCB Design Techniques for EMC and Signal Integrity

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

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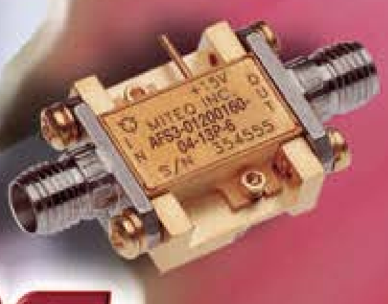

AMPLIFIERS

Model Number	Frequency Range (GHz)	Gain (Min./Max.) (dB)	Gain Flatness (±dB, Max.)	Noise Figure (dB, Max.)	VSWR Input (Max.)	VSWR Output (Max.)	Output Power @ 1 dB Comp. (dBm, Min.)	Nom. DC Power (+15 V, mA)
TEMPERATURE COMPENSATED AMPLIFIERS								
AFS3-01000200-15-TC-6	1–2	36–40	1.00	1.5	2.0:1	2.0:1	+5	125
AFS2-02000400-15-TC-6	2–4	22–26	1.00	1.5	2.0:1	2.0:1	+5	125
AFS3-02000400-15-TC-6	2–4	26–30	1.00	1.5	2.0:1	2.0:1	+5	125
AFS2-04000800-15-TC-2	4–8	17–22	1.00	1.5	2.0:1	2.0:1	+5	100
AFS3-04000800-12-TC-4	4–8	25–30	1.00	1.2	2.0:1	2.0:1	+8	100
AFS2-02000800-30-TC-2	2–8	14–19	1.50	3.0	2.0:1	2.0:1	+5	100
AFS3-02000800-30-TC-4	2–8	22–27	1.50	3.0	2.0:1	2.2:1	+8	150
AFS2-08001200-30-TC-2	8–12	12–16	1.00	3.0	2.0:1	2.0:1	+5	100
AFS3-08001200-22-TC-4	8–12	24–28	1.00	2.2	2.0:1	2.0:1	+8	100
AFS4-12001800-30-TC-6	12–18	22–26	1.00	3.0	2.0:1	2.0:1	+8	150
AFS4-06001800-35-TC-6	6–18	22–26	1.00	3.5	2.0:1	2.0:1	+8	150
AFS6-06001800-35-TC-6	6–18	30–34	1.00	3.5	2.0:1	2.0:1	+8	200
AFS4-02001800-45-TC-6	2–18	18–24	1.50	4.5	2.2:1	2.2:1	+8	120

Note: All specifications guaranteed -54 to +85°C.
Many other frequencies, noise figures and gain windows are available.

Model Number	Frequency Range (GHz)	Gain (Min./Max.) (dB)	Gain Flatness (±dB, Max.)	Noise Figure (dB, Max.)	VSWR Input (Max.)	VSWR Output (Max.)	Output Power @ 1 dB Comp. (dBm, Min.)	Nom. DC Power (+15 V, mA)
HIGHER POWER AMPLIFIERS								
AFS3-00050100-15-27P-6	0.05–1	36	1.50	1.5*	2.0:1	2.5:1	+27	300
AFS3-00100100-15-27P-6	0.1–1	33	2.00	1.5	2.0:1	2.5:1	+27	300
AFS3-00100200-20-27P-6	0.1–2	34	1.50	2.0	2.0:1	2.0:1	+27**	300
AFS3-00100300-20-23P-6	0.1–3	28	1.50	2.0	2.0:1	2.0:1	+23	275
AFS3-00100400-25-20P-4	0.1–4	24	1.50	2.5	2.0:1	2.0:1	+20	250
AFS4-00100600-24-20P-4	0.1–6	30	1.50	2.4	2.0:1	2.0:1	+20	300
AFS4-00100800-26-20P-4	0.1–8	30	1.50	2.6	2.0:1	2.0:1	+20	300
AFS4-00101200-35-20P-4	0.1–12	27	2.00	3.5	2.0:1	2.0:1	+20	300
AFS4-00501800-40-20P-6	0.5–18***	25	2.75	4.0	2.5:1	2.2:1	+20	350
AFS3-01000200-18-27P-6	1–2	32	1.50	1.8	2.0:1	2.0:1	+27	350
AFS4-02000400-20-25P-6	2–4	36	1.50	2.0	2.0:1	2.0:1	+25	275

* Noise figure degrades below 100 MHz. Please consult MITEQ for details.
** P1 dB spec below 0.2 GHz : +25 dBm.
*** Usable to 0.1 GHz.

Note: Noise figure increases below 500 MHz in bands wider than .1-10 GHz.

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MODERATE BAND AMPLIFIERS								
AFS2-00700080-06-10P-6	0.7–0.8	28	0.50	0.60	1.5:1	1.5:1	+10	90
AFS2-00800100-05-10P-6	0.8–1	30	0.50	0.50	1.5:1	1.5:1	+10	90
AFS3-01200160-05-13P-6	1.2–1.6	40	0.50	0.50	1.5:1	1.5:1	+13	150
AFS3-01400170-06-13P-6	1.4–1.7	40	0.50	0.60	1.5:1	1.5:1	+13	150
AFS3-01500180-06-13P-6	1.5–1.8	40	0.50	0.60	1.5:1	1.5:1	+13	150
AFS3-01500250-06-13P-6	1.5–2.5	38	1.00	0.60	1.8:1	1.8:1	+13	150
AFS3-01700190-06-13P-6	1.7–1.9	38	0.50	0.60	1.5:1	1.5:1	+13	150
AFS3-01800220-06-13P-6	1.8–2.2	38	0.50	0.60	1.5:1	1.5:1	+13	150
AFS3-02200230-06-13P-4	2.2–2.3	38	0.50	0.60	1.5:1	1.5:1	+13	150
AFS3-02300270-06-13P-6	2.3–2.7	36	0.50	0.60	1.5:1	1.5:1	+13	150
AFS3-02700290-06-13P-6	2.7–2.9	32	0.50	0.60	1.5:1	1.5:1	+13	150
AFS3-02900310-06-13P-6	2.9–3.1	32	0.50	0.60	1.5:1	1.5:1	+13	150
AFS3-03100350-06-10P-4	3.1–3.5	29	0.50	0.60	1.5:1	1.5:1	+10	150
AFS4-03400420-10-13P-6	3.4–4.2	40	0.50	1.00	1.5:1	1.5:1	+13	200
AFS3-04400510-07-S-4	4.4–5.1	30	0.50	0.70	1.5:1	1.5:1	+10	100
AFS3-04500480-07-S-4	4.5–4.8	30	0.50	0.70	1.5:1	1.5:1	+10	100
AFS3-05200600-07-10P-4	5.2–6	30	0.50	0.70	1.5:1	1.5:1	+10	100
AFS3-05400590-07-S-4	5.4–5.9	30	0.50	0.70	1.5:1	1.5:1	+10	100
AFS3-05800670-07-S-4	5.8–6.7	30	0.50	0.70	1.5:1	1.5:1	+10	100
AFS3-07250775-06-10P-4	7.25–7.75	30	0.50	0.60	1.5:1	1.5:1	+10	100
AFS3-07900840-07-S-4	7.9–8.4	30	0.50	0.70	1.5:1	1.5:1	+10	100
AFS4-08500960-08-S-4	8.5–9.6	32	0.75	0.80	1.5:1	1.5:1	+10	125
AFS3-09001100-09-S-4	9–11	26	0.50	0.90	1.5:1	1.5:1	+10	100
AFS4-09001100-09-S-4	9–11	32	0.75	0.90	1.5:1	1.5:1	+10	125
AFS4-10951175-09-S-4	10.95–11.75	32	0.75	0.90	1.5:1	1.5:1	+10	125
AFS4-11701220-09-5P-4	11.7–12.2	32	0.75	0.90	1.5:1	1.5:1	+10	125
AFS2-12201280-14-5P-2	12.2–12.8	14	0.75	1.40	1.4:1	1.5:1	+5	80
AFS4-12201280-13-12P-4	12.2–12.8	25	1.50	1.30	2.0:1	2.0:1	+12	200
AFS4-12701330-15-10P-4	12.7–13.3	30	0.75	1.50	1.5:1	1.5:1	+10	175
AFS4-13201400-16-10P-4	13.2–14	30	0.75	1.60	1.5:1	1.5:1	+10	175
AFS4-14001450-15-10P-4	14–14.5	30	0.75	1.50	1.5:1	1.5:1	+10	175
AFS4-20202120-25-8P-4	20.2–21.2	24	1.00	2.50	1.5:1	1.5:1	+8	175
AFS4-21202400-28-10P-4	21.2–24	23	1.00	2.80	2.0:1	2.0:1	+10	100
OCTAVE BAND AMPLIFIERS								
AFS3-00120025-09-10P-4	0.12–.25	38	0.50	0.9	2.0:1	2.0:1	+10	125
AFS3-00250050-08-10P-4	0.25–0.5	38	0.50	0.8	2.0:1	2.0:1	+10	125
AFS3-00500100-06-10P-6	0.5–1	38	0.75	0.6	2.0:1	1.5:1	+10	150
AFS3-01000200-05-10P-6	1–2	38	1.00	0.5	2.0:1	2.0:1	+10	150
AFS3-01200240-06-10P-6	1.2–2.4	34	1.00	0.6	2.0:1	2.0:1	+10	150
AFS3-02000400-06-10P-4	2–4	32	1.00	0.6	2.0:1	2.0:1	+10	125
AFS3-02600520-10-10P-4	2.6–5.2	28	1.00	1.0	2.0:1	2.0:1	+10	125
AFS3-04000800-07-10P-4	4–8	28	1.00	0.7	2.0:1	2.0:1	+10	125
AFS3-08001200-09-10P-4	8–12	26	1.00	0.9	2.0:1	2.0:1	+10	125
AFS3-08001600-15-8P-4	8–16	28	1.00	1.5	2.0:1	2.0:1	+8	100
AFS4-12001800-18-10P-4	12–18	28	1.50	1.8	2.0:1	2.0:1	+10	125
AFS4-12002400-30-10P-4	12–24	24	2.00	3.0	2.0:1	2.0:1	+10	85
AFS3-18002650-30-8P-4	18–26.5	18	1.75	3.0	2.2:1	2.2:1	+8	125
MULTIOCTAVE BAND AMPLIFIERS								
AFS3-00300140-09-10P-4	0.3–1.4	38	1.00	0.9	2.0:1	2.0:1	+10	125
AFS2-00400350-12-10P-4	0.4–3.5	22	1.50	1.2	2.0:1	2.0:1	+10	80
AFS3-00500200-08-15P-4	0.5–2	38	1.00	0.8	2.0:1	2.0:1	+15	125
AFS3-01000400-10-10P-4	1–4	30	1.50	1.0	2.0:1	2.0:1	+10	125
AFS3-02000800-09-10P-4	2–8	26	1.00	1.0	2.0:1	2.0:1	+10	125
AFS4-02001800-23-10P-4	2–18	25	2.00	2.3	2.0:1	2.0:1	+10	175
AFS4-06001800-22-10P-4	6–18	25	2.00	2.2	2.0:1	2.0:1	+10	125
AFS4-08001800-22-10P-4	8–18	28	2.00	2.2	2.0:1	2.0:1	+10	125
ULTRA WIDEBAND AMPLIFIERS								
AFS3-00100100-09-10P-4	0.1–1	38	1.00	0.9	2.0:1	2.0:1	+10	125
AFS3-00100200-10-15P-4	0.1–2	38	1.00	1.0	2.0:1	2.0:1	+15	150
AFS1-00040200-12-10P-4	0.04–2	15	1.50	1.2	2.0:1	2.0:1	+10	50
AFS3-00100300-12-10P-4	0.1–3	32	1.00	1.2	2.0:1	2.0:1	+10	125
AFS3-00100400-13-10P-4	0.1–4	28	1.00	1.3	2.0:1	2.0:1	+10	125
AFS3-00100600-13-10P-4	0.1–6	28	1.25	1.3	2.0:1	2.0:1	+10	125
AFS3-00100800-14-10P-4	0.1–8	28	1.50	1.4	2.0:1	2.0:1	+10	125
AFS4-00101200-22-10P-4	0.1–12	30	1.50	2.2	2.0:1	2.0:1	+10	150
AFS4-00101400-23-10P-4	0.1–14	24	2.00	2.3	2.5:1	2.5:1	+10	200
AFS4-00101800-25-S-4	0.1–18	25	2.00	2.5	2.5:1	2.5:1	+10	175
AFS4-00102000-30-10P-4	0.1–20	20	2.50	3.0	2.5:1	2.5:1	+10	125
AFS4-00102650-42-8P-4	0.1–26.5	22	2.50	4.2	2.5:1	2.5:1	+8	135

Note: Noise figure increases below 500 MHz in bands greater than 0.1-10 GHz.

COVER FEATURE
INVITED PAPER

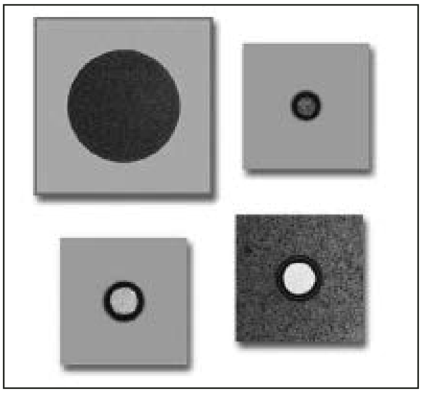
A REVIEW OF TECHNOLOGICAL ADVANCES IN SOLID-STATE SWITCHES

In the 28 years that I have been both a user and designer of solid-state switches, I have witnessed some major technological advances as RF switches have developed from discrete PIN diodes and evolved through recent developments such as HMIC, GaAs MMICs and RF CMOS. Significantly, too, new technologies on the horizon have the potential to impact on the long-term development of RF switches and take them to a new level.

DISCRETE PIN DIODE SWITCHES

How have solid-state switches evolved? My first professional involvement with them came in the mid-1980s when, as a young engineer, I was tasked with designing one of Filtronic's first subsystem products. The design required 2 to 18 GHz high-speed switches and attenuators, and as I had no experience in the design of switches at that time, I selected a well-established supplier who also had a PIN diode fabrication facility. The prototype parts arrived, were tested and a number of issues identified. Consequently, I visited the supplier to review the design and identify corrective actions. During the review it was suggested that in order to obtain the required performance, the suppliers could select a different diode 'lot' and I found myself in a room reminiscent of a Victorian apothecary containing wafers of diodes of almost every possible variety. Not quite Victorian, but a product of the 1950s, the basic PIN diode is a standard PN junction diode with a thin layer of intrinsic material, with a very low level of doping, introduced between the P and N regions. This has the effect of isolating the active regions under low reverse bias conditions as the I-region is fully depleted. When the diode is forward biased, charges are injected into the intrinsic region allowing current to flow across the layer. The electrical characteristics of the diode such as junction capacitance, breakdown voltage and minority carrier lifetime can be altered by changing the process parameters, such as I-thickness, doping levels and electrode dimensions. In addition, exotic ingredients like gold can be added to achieve 'special' characteristics. To form a high isolation RF switch, the PIN diodes are arranged in a series/shunt configuration. The chip shunt diodes (see ***Figure 1***) are mounted on the ground plane, which provides both the electrical connection for the cathode and a

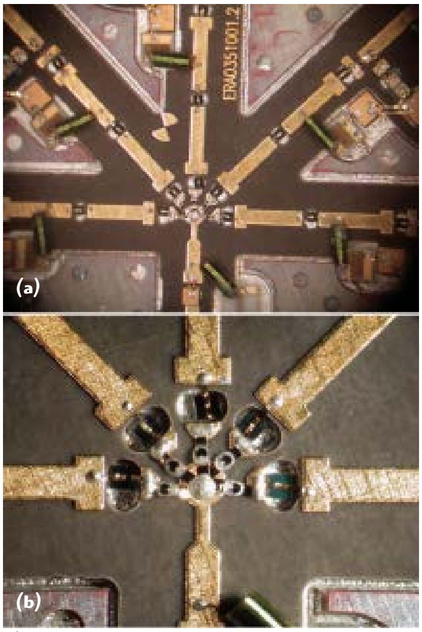
Fig. 1 Chip PIN diodes (courtesy of Aeroflex Metelics).



DAMIAN GOTCH
Filtronic Defence Ltd., UK

thermal path to remove heat generated from the bias current and any RF heating under high power conditions. The shunt diodes are connected using thermo-compression bonding and the gold wire bond inductance can be conveniently designed to match the junction capacitance to form a low pass structure. The series diodes are more of a problem as lead inductance and junction capacitance severely limit the achievable isolation, so a 'beam-lead' diode is used. This is a silicon die encapsulated in glass to which thin gold 'beams' are attached and connected to the active regions (see ***Figure 2***). The beam-lead diode gives a dramatically improved performance and together with the shunt chip has been the mainstay of broadband RF switches for decades.

▲ *Fig. 2 A beam-lead PIN diode (courtesy of Aeroflex Metelics).*

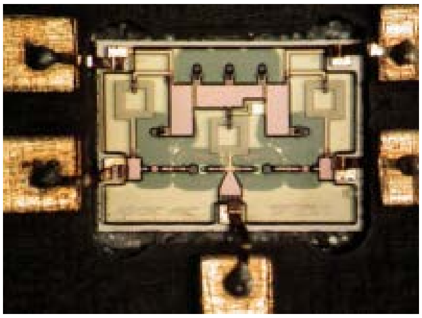


▲ *Fig. 3 SP5T high isolation switch (a) and close-up of the common junction (b) (courtesy of Filtronic Defence).*

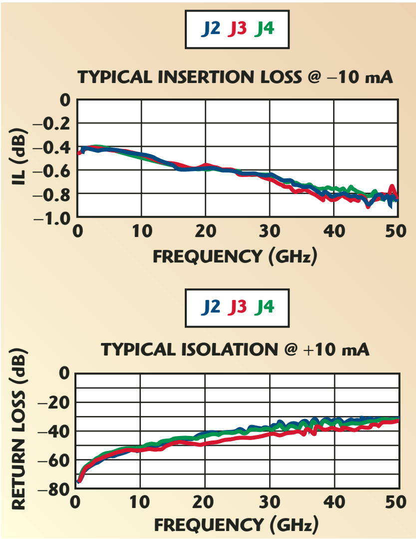
Although the discrete PIN diodes perform well, the manufacturing costs are high and they are prone to assembly variations resulting in degradations of the VSWR and loss. ***Figure 3*** shows a typical 2 to 18 GHz high isolation PIN switch, with a close up of the common junction highlighting the intricate connections of the series and shunt diodes.

MONOLITHIC PIN DIODE SWITCHES

Monolithic technology made significant inroads in the 70s and 80s, but had little impact on the design of microwave switches as the silicon substrate used for PIN diodes is highly conductive and is unsuitable for fabricating the interconnects and series diodes required. However, in the late 1980s, the M/A-COM corporate R&D team pioneered the use of the Glass Microwave Integrated Circuit (GMIC). This was an alternative to the conventional GaAs MMIC and fused an active GaAs wafer with a glass substrate, which allowed active devices to be re-



▲ *Fig. 4 HMIC switch with integrated bias (courtesy of M/A-COM).*



▲ *Fig. 5 AlGaAs PIN switch performance (courtesy of M/A-COM).*

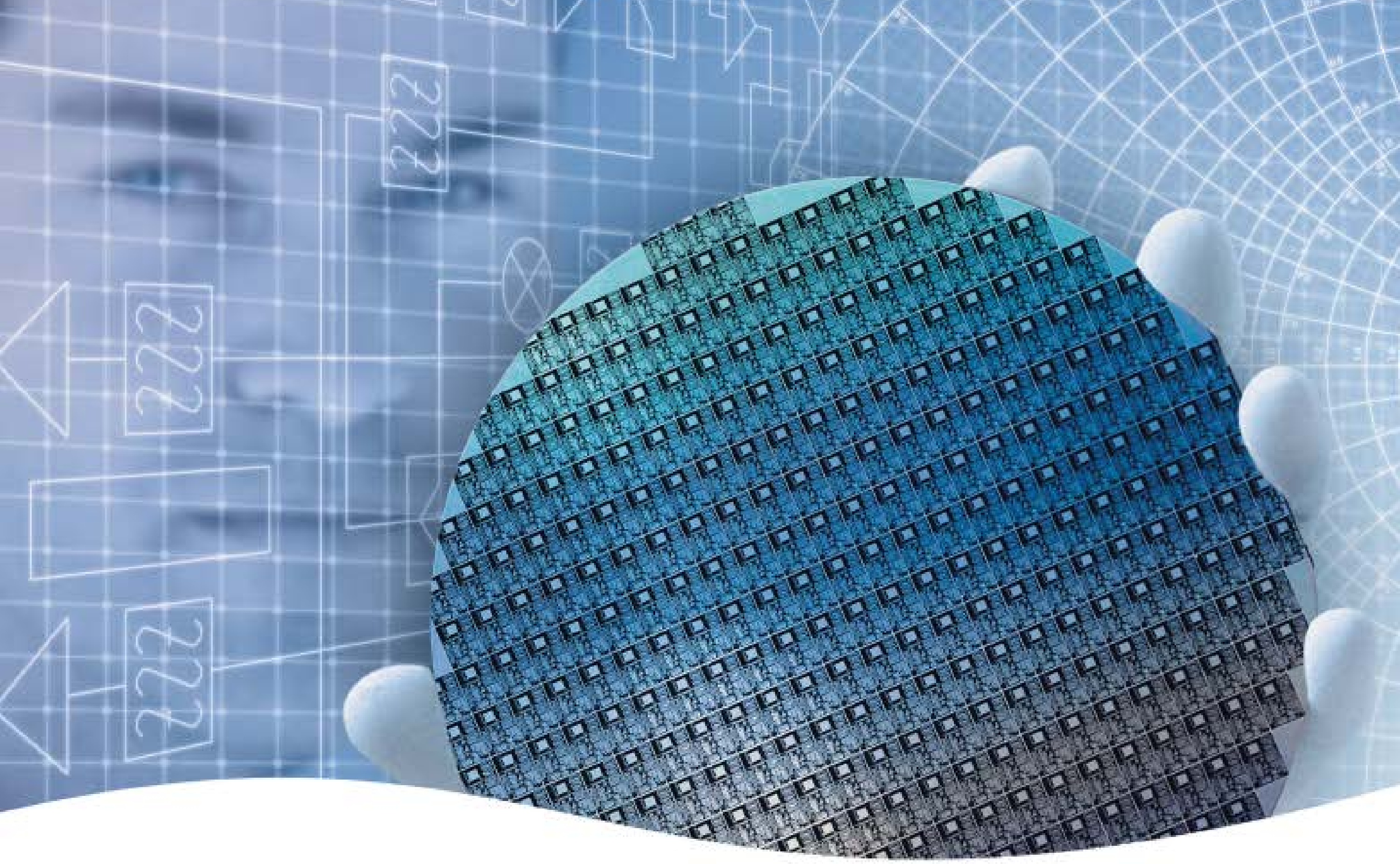
alised together with very low loss passive elements and with vias introduced through the glass substrate to provide electrical grounding. A variant of this technology continues today as M/A-COM's patented Heterolithic Microwave Integrated Circuit (HMIC) technology. Here, a glass substrate is fused to a silicon wafer, and the silicon wafer is etched to create silicon pedestals. A glass layer is deposited on and around the silicon pedestals and polished to expose the mesas. Conductors and air bridges are added and backside vias are etched though the glass substrate and plated to connect to the underside of the silicon.

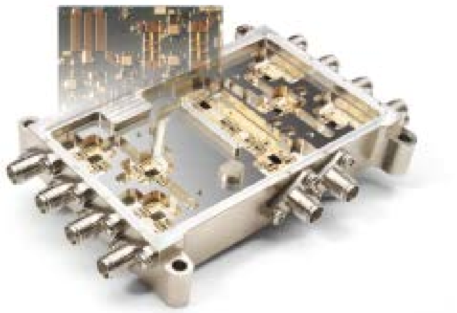
HMIC technology has enabled complete multipole series shunt switches to be manufactured and eliminated the very difficult connection of the beam-lead diodes and the first shunt diode that had long plagued designers. Some designs, such as MA4SW210B-1, also include the bias circuitry, significantly simplifying the manufacturing process and the reproducibility, as shown in ***Figure 4***. However, it may still be necessary to use a more distributed approach if more than 50 dB isolation is required, with additional shunt-only HMIC parts separated by lengths of transmission lines.

GaAs PIN SWITCHES

A further enhancement of the PIN technology saw the introduction of PIN diodes on GaAs substrates. TriQuint Semiconductor offers a vertical PIN (VPIN) foundry process, which achieves lower capacitance than silicon devices and allows operation beyond 50 GHz. The VPIN process allows MMIC switch integration, but cannot be mixed with active devices. M/A-COM recently combined a patent-pending anode-enhanced AlGaAs PIN diode with the HMIC process to produce a range of high performance multi-throw switches such as the SP3T MA4AGSW3, which provides 0.8 dB loss with greater than 30 dB isolation at 50 GHz (see ***Figure 5***).

The range of HMIC switches can be used to replace the majority of legacy discrete PIN diode designs and offers reduced manufacturing cost and significantly enhanced reliability. These parts are very easy to use and offer the designer a very fast and reliable approach to switch design that I could only have dreamed about 10 years ago. Further-

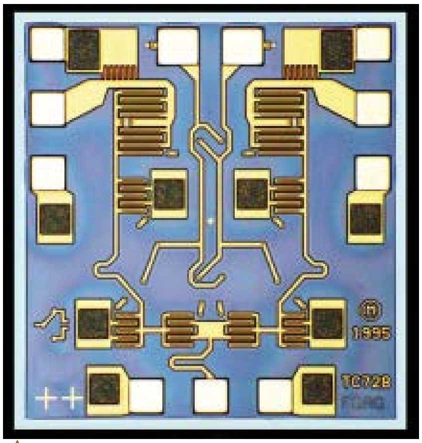




more, the bespoken discrete PIN design has been replaced by a process-based, off-the-shelf part, in a similar way to the evolution from transistors to ICs. The only limitation is that there is only a restricted range of processes, and hence of diode parameters available, so there is still a place for hand-crafted designs, which can in some cases offer better performance for very specific applications. Limiters are a prime example.

GaAs FET SWITCHES

Although PIN diode switches have advanced enormously, they still require a DC bias current to achieve the low loss state and a high reverse voltage to achieve isolation. Biasing PIN diodes is notoriously difficult, as the bias must be applied to the RF signal path. This can result in reduced bandwidth and increased losses. In addition, high-speed switches generate large video transients that can adversely affect the circuitry to which they are connected. Also, high-speed PIN drivers are generally realised as thin film hybrids, which tend to be large and expensive. An alternative switch element has long been available in the form of the field effect transistor (FET), where a voltage applied to the gate can alter the depletion region between source and drain to control the current flow. FETs have the advantage that the control voltage is essentially isolated from the main signal path and very low current is required (in the order of microamps). FET switches are widely used in various forms for low and high current switching at both video and RF frequencies. At microwave frequencies, the GaAs MESFET and more recently GaAs PHEMT devices have been used to replace PIN diode switches, particularly where very high switching speeds are required. GaAs FETs have inherently low charge storage and the channel itself can be switched in picoseconds. Complete switches can be readily realised as MMICs and the bias control is very straightforward, without the need for bias chokes. When Filtronic set up a six-inch GaAs PHEMT foundry in 2000, I was a member of the Global Technology Group that had the opportunity to design MMIC components into the foundry in support of the process development team. I experimented with digital switched attenuators, analogue attenuators and distributed amplifiers, and was amazed at the scope that the process offered. By accurate characterisation and modelling, it was practical to get designs working the first time without needing any 'tuning' (something that had been almost impossible with the discrete designs I had been used to). With the advent of

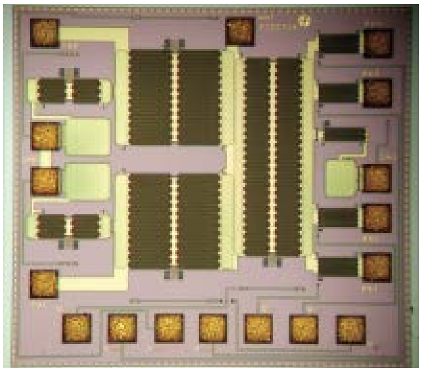


▲ *Fig. 6 DC to 26.5 GHz GaAs MMIC switch (courtesy of Agilent).*

low cost material and such high yield in six-inch foundries, these GaAs switches (see ***Figure 6***) have become more widespread. They are available from a wide range of foundries and fab-less companies, such as Hittite and Mimix Broadband, who offer a range of similar products. An example of a broadband GaAs switch is the Filtronic FMS2030, an SP4T switch that exhibits more than 45 dB isolation and less than 1.5 dB loss at 20 GHz. GaAs switches are ideal for use in complex switched filter assemblies, where the combined bias current of PIN diodes can be a significant issue and the simplicity of the bias networks is a major benefit to manufacturing costs. Level shifters are generally needed to interface to standard positive logic and are readily available as monolithic ICs. In some cases the drivers may be incorporated within the final packaged part. Compression points of +25 dBm are typical for broadband GaAs MMIC switches, which is somewhat lower than a typical PIN diode switch. However, they have the benefit of very low video leakage. GaAs MMIC switches lend themselves well to high levels of integration in the form of switched attenuators and phase shifters and can be easily integrated along with PHEMT amplifiers to produce complete RF modules.

MOBILE WIRELESS APPLICATIONS

Right through to the mid-1990s, PIN diodes remained the preferred option in early single- and dual-band mobile phones, due to their low cost. A circuit configuration was employed that resulted in the PIN diodes, requiring only to be forward biased during transmit, where the bias current was not a serious issue. However, this 'trick' could not be used when triple- and quad-band designs were introduced and GaAs PHEMT switches became the ideal choice. The design of these switches is very demanding; positive only control is required with control voltages less than 2.5 V, transmit powers are in excess of 2 W and harmonic levels must be maintained below –70 dBc. Die size is also critical as the switches are very price sensitive. In 2003, I became involved in the design



▲ *Fig. 7 Dual-mode SP7T antenna switch (courtesy of FCSL).*

▲ *Fig. 8 SP9T CMOS switch (courtesy of Peregrine Semiconductors).*

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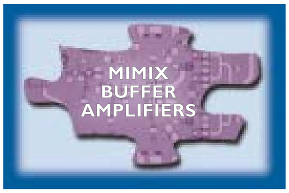

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Self-Bias Architecture and On-Chip Drain Bias Coil/DC Blocking

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Device	Frequency (GHz)	Gain (dB)	Noise Figure (dB)	Output P1dB (dBm)	OIP3 (dBm)	Bias (mA @V)
CMM2000-QT	1.5-6	13	6.0	+14	+24	35 @ 8.0
CMM9000-QT	1.5-6	15	5.5	+15	+25	60 @ 6.0
CMM4000-BD	2-18	8	4.5	+19	+29	115 @ 5.0
XB1007-QT	4-11	23	4.5	+20	+30	100 @ 4.0
CMM0511-QT	5-14	20	-	+11	+22	90 @ 6.0
XB1008-QT	10-21	18	5.5	+20	+30	100 @ 4.0
CMM1118-QT	11-20	20	-	+14	+22	90 @ 5.0
XB1004-BD (Low Noise/Power)	16-30	20 / 21	2.2 / 3.2	+14 / +19	+24 / +29	90 @ 4.0 / 180 @ 6.0
XB1005-BD (Low Noise/Power)	35-45	19 / 23	2.7 / 3.7	+13 / +16	+23 / +26	50 @ 3.5 / 154 @ 4.5

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Mimix Broadband, Inc., 10795 Rockley Rd., Houston, TX 77099 U.S. 281.988.4600 mimixbroadband.com of handset antenna switches and we produced our first SP6T quad-band design. This was an exciting project and the design incorporated a novel topology to reduce the loss.[1] This device is under 1 mm^2 and is in use in a number of high volume phones (see ***Figure 7***). The introduction of 3G handsets now requires antenna switches to operate with a greatly increased level of linearity, with IMD3 levels of less than –110 dBm. This level of linearity requires a very accurate large-signal modelling, low parameter spread and a high yield, all of which have been successfully achieved with the Filtronic 0.5 µm GaAs PHEMT process. GaAs switches have been phenomenally successful and currently account for more than 50 percent of the available market. PIN diode switches are still used in relatively high volumes in the single- and dual-band phones aimed at the Far East market.

CMOS SWITCHES

A recent challenger to GaAs for wireless applications has come in the form of RF CMOS. Historically, CMOS had been restricted to low frequencies due to limitations of the conductive silicon substrate. This has now been overcome by isolating the active devices from the base silicon substrate or using a low loss base substrate. California Eastern Labs (CEL) uses a silicon-on-insulator (SOI) technology and offers an SPDT switch (UPD5710TK), operating to 2.5 GHz. Also, Peregrine Semiconductor has developed Ultra Silicon (UTSi®). This silicon-on-sapphire process was first invented in the early 1960s at Rockwell, but until recently suffered from poor yields and was not exploited. Peregrine has released a wide range of wireless products at frequencies up to approximately 5 GHz. One of its latest is the PE42693, an SP9T for mobile handsets (see ***Figure 8***). The major benefit of RF CMOS technology is the ability to integrate standard CMOS components like charge pumps and decoders. In addition, they can operate from single positive supplies and do not need DC blocking capacitors. CMOS is yet to gain a significant market share over GaAs, which is largely due to the low cost of six-inch GaAs fabrication and the immaturity of the RF CMOS process. This technology is likely to be a strong player in the future, however, although it is not yet clear how CMOS will compete at higher microwave frequencies.

FUTURE SWITCH TECHNOLOGIES

Recent advances have been aimed at low power applications and PIN diodes are still the dominant force at very high powers, but there are a number of emerging technologies that may provide an alternative. Gallium nitride (GaN) on silicon carbide substrates has begun to take a share in the high power amplifier market with its ability to operate at voltages of greater than 100 V and at high temperatures. GaN switches have yet to appear on the market in great numbers but some research[2] has been published, indicating that it can be used to construct very capable switches. Mahamed Kameche[3] gives an excellent review of the technology and concluded that GaN has a bright future for low distortion, high power switches, due to its high break-

down voltage, high saturated velocity and high thermal conductivity. It is currently only available on two- to three-inch wafers and as such is relatively expensive, although this should improve as volumes increase. The aerospace industry has long been looking for a technology that could be used to switch kilowatt levels at tens of amperes and at extremely high temperatures. The missile and radar industry would love to have devices to control kilowatts of power with very low losses and diamond may meet this challenge. As an intrinsic material, diamond demonstrates extreme hardness, chemical inertness, high thermal conductivity, high hole and electron mobility, high dielectric strength and high breakdown strength, and has a wide band gap. These properties are ideal for high power amplifiers and switches. The recent availability of extremely pure single crystal diamond created by chemical vapour deposition has made it possible to contemplate the formation of diamond semiconductors. Diamond FETs are under development in the UK by Diamond Microwave Devices Ltd. (DMD), a subsidiary of Element Six Ltd., in collaboration with Filtronic plc. Diamond bipolar transistors are also under development at University College London under an Engineering and Physical Sciences Research Council (EPSRC) grant. Diamond technology is still in an early R&D phase, but the technology has the potential to make a major impact in the future.

CONCLUSION

RF switches continue to be a key component in all microwave systems. The expansion of the commercial wireless sector has had the effect of driving the costs down and has provided an impetus to develop technologies such as HMIC, GaAs and RF CMOS, together with low cost packaging systems. Coupled with a requirement for higher frequencies for WLAN, WiMAX and automotive radar, this technology has created exciting new products, most of which are readily utilised in the military and security sectors. There are a number of exciting technologies under development, including GaN and diamond that may allow solid-state switches to operate under very adverse conditions, where only mechanical switches have so far been practical. ■

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Damian Gotch *received his BSc degree from Leeds University in 1979. He has worked in the microwave industry for more than 28 years within the Filtronic Group, initially as a designer of RF components and subsystems for the military EW sector, then as part of the company's Global Technology Group designing MMICs for the commercial sector. More recently he became engineering director of Filtronic Defence Ltd.*

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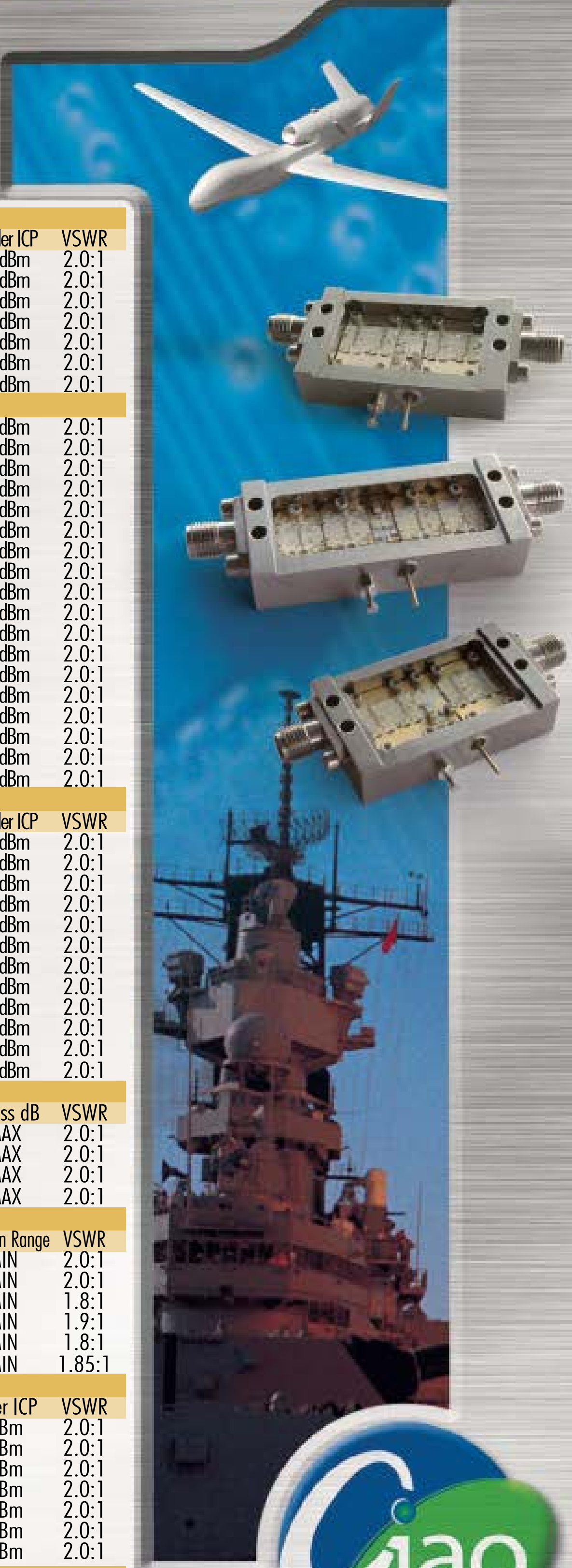

OCTAVE BAND LOW NOISE AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2110	0.5-1.0	28	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2111	0.4 - 0.5	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA01-2113	0.8 - 1.0	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3117	1.2 - 1.6	25	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3111	2.2 - 2.4	30	0.6 MAX, 0.45 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3116	2.7 - 2.9	29	0.7 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA34-2110	3.7 - 4.2	28	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA56-3110	5.4 - 5.9	40	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA78-4110	7.25 - 7.75	32	1.2 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA910-3110	9.0 - 10.6	25	1.4 MAX, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA1315-3110	13.75 - 15.4	25	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3114	1.35 - 1.85	30	4.0 MAX, 3.0 TYP	+33 MIN	+41 dBm	2.0:1
CA34-6116	3.1 - 3.5	40	4.5 MAX, 3.5 TYP	+35 MIN	+43 dBm	2.0:1
CA56-5114	5.9 - 6.4	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6115	8.0 - 12.0	30	4.5 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6116	8.0 - 12.0	30	5.0 MAX, 4.0 TYP	+33 MIN	+41 dBm	2.0:1
CA1213-7110	12.2 - 13.25	28	6.0 MAX, 5.5 TYP	+33 MIN	+42 dBm	2.0:1
CA1415-7110	14.0 - 15.0	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA1722-4110	17.0 - 22.0	25	3.5 MAX, 2.8 TYP	+21 MIN	+31 dBm	2.0:1

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA0102-3111	0.1-2.0	28	1.6 Max, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA0106-3111	0.1-6.0	28	1.9 Max, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-3110	0.1-8.0	26	2.2 Max, 1.8 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-4112	0.1-8.0	32	3.0 MAX, 1.8 TYP	+22 MIN	+32 dBm	2.0:1
CA02-3112	0.5-2.0	36	4.5 MAX, 2.5 TYP	+30 MIN	+40 dBm	2.0:1
CA26-3110	2.0-6.0	26	2.0 MAX, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA26-4114	2.0-6.0	22	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA618-4112	6.0-18.0	25	5.0 MAX, 3.5 TYP	+23 MIN	+33 dBm	2.0:1
CA618-6114	6.0-18.0	35	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA218-4116	2.0-18.0	30	3.5 MAX, 2.8 TYP	+10 MIN	+20 dBm	2.0:1
CA218-4110	2.0-18.0	30	5.0 MAX, 3.5 TYP	+20 MIN	+30 dBm	2.0:1
CA218-4112	2.0-18.0	29	5.0 MAX, 3.5 TYP	+24 MIN	+34 dBm	2.0:1

LIMITING AMPLIFIERS

Model No.	Freq (GHz)	Input Dynamic Range	Output Power Range Psat	Power Flatness dB	VSWR
CLA24-4001	2.0 - 4.0	-28 to +10 dBm	+7 to +11 dBm	+/- 1.5 MAX	2.0:1
CLA26-8001	2.0 - 6.0	-50 to +20 dBm	+14 to +18 dBm	+/- 1.5 MAX	2.0:1
CLA712-5001	7.0 - 12.4	-21 to +10 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1
CLA618-1201	6.0 - 18.0	-50 to +20 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	Gain Attenuation Range	VSWR
CA001-2511A	0.025-0.150	21	5.0 MAX, 3.5 TYP	+12 MIN	30 dB MIN	2.0:1
CA05-3110A	0.5-5.5	23	2.5 MAX, 1.5 TYP	+18 MIN	20 dB MIN	2.0:1
CA56-3110A	5.85-6.425	28	2.5 MAX, 1.5 TYP	+16 MIN	22 dB MIN	1.8:1
CA612-4110A	6.0-12.0	24	2.5 MAX, 1.5 TYP	+12 MIN	15 dB MIN	1.9:1
CA1315-4110A	13.75-15.4	25	2.2 MAX, 1.6 TYP	+16 MIN	20 dB MIN	1.8:1
CA1518-4110A	15.0-18.0	30	3.0 MAX, 2.0 TYP	+18 MIN	20 dB MIN	1.85:1

LOW FREQUENCY AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure dB	Power-out @ P1-dB	3rd Order ICP	VSWR
CA001-2110	0.01-0.10	18	4.0 MAX, 2.2 TYP	+10 MIN	+20 dBm	2.0:1
CA001-2211	0.04-0.15	24	3.5 MAX, 2.2 TYP	+13 MIN	+23 dBm	2.0:1
CA001-2215	0.04-0.15	23	4.0 MAX, 2.2 TYP	+23 MIN	+33 dBm	2.0:1
CA001-3113	0.01-1.0	28	4.0 MAX, 2.8 TYP	+17 MIN	+27 dBm	2.0:1
CA002-3114	0.01-2.0	27	4.0 MAX, 2.8 TYP	+20 MIN	+30 dBm	2.0:1
CA003-3116	0.01-3.0	18	4.0 MAX, 2.8 TYP	+25 MIN	+35 dBm	2.0:1
CA004-3112	0.01-4.0	32	4.0 MAX, 2.8 TYP	+15 MIN	+25 dBm	2.0:1

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Raytheon Key in Successful Ballistic Missile Intercept in Space

Raytheon Co. components built under contract to the Boeing Co., the prime contractor for the Ground-based Midcourse Defense (GMD) system, played key roles in the destruction of a ballistic missile target during GMD's latest successful flight test conducted September 28, by the US Missile Defense Agency. Raytheon-built Exoatmospheric Kill Vehicle (EKV) intercepted the ballistic target in space over the eastern Pacific Ocean. The Raytheon-developed Upgraded Early Warning Radar (UEWR) at Beale Air Force Base, CA, successfully tracked the target system for approximately 15 minutes during its flight down range to the intercept point, several hundred miles west of California. The Raytheon-developed X-band Radar (XBR), the primary payload of the Sea-based X-band Radar (SBX), actively participated in this test by tracking, discriminating and assessing the target. While in flight, the EKV received target updates from the In-flight Interceptor Communication System and performed a star shot to calibrate its own position. The EKV observed the target complex with its advanced multicolor infrared seeker and successfully selected the target from other objects in space. During the end game, as the target grew in the seeker's field of view, the EKV selected the aim point and maneuvered for a direct, lethal hit. As the primary ground-based sensor for this mission, the UEWR successfully acquired, tracked and classified the target system, providing critical targeting data to the system under test. The UEWR achieved all mission objectives as it continues its flawless support to GMD flight tests and path to Air Force operational acceptance. Positioned in the eastern Pacific Ocean, the XBR initiated track on the target complex and collected valuable data, which will be used to hone algorithms for future flight tests. The radar achieved all mission objectives. This test marks the third successful mission that the Sea-based XBR has participated in since September 2006. "This highly successful test of the GMD system once again demonstrates Raytheon's systems performance and reliability," said Louise Francesconi, Raytheon Missile System president. "The test clearly demonstrates the maturity of our technology and our ability to provide this critical capability to the nation." "The XBR and UEWR demonstrated exceptional performance in this critical test of US missile defense capability," said Pete Franklin, vice president, National & Theater Security Programs for Raytheon Integrated Defense Systems (IDS). "This latest exercise confirms the radars' ability to gather information necessary to support an intercept." The test marked the second time an operationally configured ground-based interceptor was launched from an operational GMD site at Vandenberg Air Force Base, CA. The target was launched from Kodiak, Alaska. Designated Flight Test Ground-based Midcourse Defense-03a (FTG-03a), the test included a planned intercept of the target as one of its objectives. Other objectives included the EKV's ability to successfully detect, track, discriminate a target in space and communicate with ground-based sensors, and included participation of the SBX in the test. This test again demonstrated the system's capability to launch a ground-based interceptor and perform separation and delivery of the EKV to the desired point in space and time.

Northrop Grumman Successfully Tests Multi-mission Command and Telemetry

Northrop Grumman Corp., in conjunction with ground system teammate Raytheon, recently completed the System Acceptance Test (SAT) of a Common Command and Telemetry System (CCTS) that will potentially reduce costs between two programs, James Webb Space Telescope (JWST) and the National Polar-orbiting Operational Environmental Satellite System (NPOESS). "The successful completion of this milestone proves our commitment to providing low cost, synergistic enterprise solutions to our customers," said Alexis Livanos, corporate vice president and president of Northrop Grumman's Space Technology Sector. "It also shows that two customers with two separate programs were willing to trust our collaboration and team work to align schedules so that the same system could be used. We have now demonstrated proven efficiencies across different programs that can be utilized to reduce costs and ensure success for future projects." Raytheon's Eclipse® is a commercial off-the-shelf command and telemetry product that was configured to support both satellite flight operations and integration and test (I&T) on the James Webb Space Telescope and NPOESS. Adding the I&T requirements to a traditional flight operations system is an innovative approach, increasing SAT requirements to accommodate different satellite communication protocols and user needs. Software requirements were verified on spacecraft and ground equipment simulators at Northrop Grumman over a four-week period, concluding in August. The test milestone represents the culmination of a four-year Raytheon development effort to bring Northrop Grumman its first true multi-mission command and telemetry system and prove the joint team's ability to engineer a system while balancing combined NPOESS and JWST requirements and schedules. The test verified 1300 requirements through 26 "test-as-you-fly," functional, performance and interface procedures and was the first SAT completed after program-specific requirements were merged into a baseline command and telemetry system. The SAT's objective was to verify command rate and protocol, telemetry decomutation (the ability to transform raw data into engineering values), and to control and monitor the test hardware in an environment unique to Northrop Grumman. The CCTS ECLIPSE has been delivered to science instrument providers at the Goddard Space Flight Center who will use it to develop, test and integrate their instruments for the James Webb Space Telescope. The joint development team includes Northrop Grumman's JWST and NPOESS teams, program customers from NASA's Goddard Space Flight Center, the NPOESS Integrated Program Office (IPO) and Raytheon Mission Command and Control Systems.

Harris Corp. Receives $104 M Order for Falcon HF Radio Systems

Harris Corp., an international communications and information technology company, has received a $104 M order for high-frequency (HF) radio systems. Under the agreement, Harris will provide the US Army with Harris Falcon® II An/PRC-150(C) HF radios and related accessories, as well as installation services and training. The contract is one of several recent orders by the Army of a broad range of Harris radio systems, highlighting the company's technological leadership in tactical communication. "Harris HF radio equipment continues to set the standard for terrestrial, beyond-line-of-sight communications, enabling our forces to stay connected in remote areas and when surrounded by rugged terrain," said George Helm, vice president and general manager, Harris RF Communications. "The unique nature of HF signal propagation makes it ideal for medium- and long-range terrestrial radio communications. We are pleased that the Army is expanding its acquisition of Harris HF radios while at the same time purchasing new Harris products based on our legacy of innovation, reliability and support."

The Falcon II AN/PRC-150(C) is part of the broadest line of tactical radio communication products available today. The Falcon family offers features such as embedded encryption for information security, extended frequency range, adaptability to new waveforms and battlefield networking. The Falcon III AN/PRC-152(C) is the first and only JTRS-approved radio to be certified as fully compliant with version 2.2 of the JTRS Software Communications Architecture. The Falcon family includes radios in all form factors: handheld, manpack, vehicular and personal radio. Harris RF Communications Division is a leading supplier of secure voice and data communications products, systems and networks to military, government and commercial organizations worldwide. ■

ITU Opens Free Online Resource

Following a highly successful trial conducted from January to October 2007, the ITU Standards produced by the Telecommunication Standardization Sector (ITU-T) are now available online free of charge. The aim of the trial was to increase the visibility and easy availability of the output of ITU-T. Offering standards for free is a significant step for the standards community as well as the wider information and communication technologies (ICT) industry. Now, anyone with Internet access will be able to download any of over 3000 ITU-T Recommendations.

These standards are used by equipment manufacturers, telecommunication network operators and service providers throughout the world to drive the information society. The move further demonstrates ITU's commitment to bridging the digital divide by extending the results of its work to the global community. ITU-T Recommendations are developed in a unique contribution-driven and consensus-based environment by representatives of industry and government, with industry providing the most significant technical input. A strong focus of current standards work is laying the foundations for the next-generation network (NGN).

Malcolm Johnson, director of ITU's Telecommunication Standardization Bureau (TSB), presented the results of the trial to the 2007 meeting of ITU's Council. He said that not only had the experiment been a success in raising awareness of ITU-T, it would also attract new members. Most importantly, he noted, it had helped efforts to bridge the 'standardization gap' between countries with resources to pursue standardization issues and those without.

IET and JANET Offer Educational Web Streaming

The Institution of Engineering and Technology (IET) will be collaborating with JANET, the UK's national network for research and education, to enable academic institutions to web stream important research seminars, conferences and lectures, via IET.tv, the institution's web streaming service.

The JANET network, which connects education and research institutions, including schools, further education colleges, universities and large research institutions across the UK, also provides ongoing connectivity to other national education and research networks (NREN) across the globe via the pan-European GÉANT network and the global Internet. The network, with its capacity for real-time data transfer, empowers research projects in a variety of fields and has an infrastructure capable of meeting the explosion of data predicted by research communities.

This IET initiative is a first for the academic community, giving them access to valuable web streaming technology, free of charge, as part of the IET's charitable remit. The research channel initiative provides users with the ability to create live and on-demand video presentations that can be uploaded on to the Internet and distributed to a global audience. Eleven universities are already using the service following the beta trial and now the research seminar channel will be rolled out to all universities.

Milestone in GMES Space Component Programme

The European Space Agency's (ESA) Member States participating in the Global Monitoring for Environment and Security (GMES) Programme approved the transition to Phase-2 of Segment 1 of the GMES Space Component Programme. Oversubscription of the programme by the ESA Council at ministerial level in 2005 was confirmed, with oversubscription to phase 2 of 116 percent, giving a total amount of €500 M. This additional contribution to the programme will allow ESA to confirm the development of the first three Sentinel satellites.

The GMES Space Component Programme is co-funded by the European Commission and ESA is responsible for the management and coordination of the overall GMES Space Component in Europe. As a result of this transition to Phase-2, ESA will be able to make progress on development of the Sentinel satellite series and, in particular, build Sentinel 1, 2 and 3, together with the necessary ground segment.

Prior to launch of the ESA-built Sentinels, which is planned for 2011–12, ESA will coordinate the provision of EO data required by the GMES services currently implemented by the EC. This will help to gradually take GMES from the pre-operational phase to the fully operational stage once the Sentinel satellites are in place.

NEC Corp. Integrates Asia Pacific Subsidiaries

NEC Solutions Asia Pacific Pte. Ltd. and NEC Business Coordination Centre (Singapore), both wholly owned subsidiaries of NEC Corp. in Japan, have integrated to form NEC Asia Pte Ltd.

Previously, NECSAP was the regional sales and service support office for NEC's IT, networking and telecommunications, security, outsourcing and managed services solutions businesses in the Asia Pacific markets, while NEC BCCS was the regional business support function office for purchasing, public relations, finance, human resources and corporate social responsibilities (CSR) for the company's subsidiaries in the same region.

Based in Singapore, NEC Asia remains the regional headquarters for NEC Corp. in the Asia Pacific region, including Singapore, Malaysia, Indonesia, Thailand, the Philippines, Vietnam and India. The company believes that this integration will further boost the customer service support that it currently provides to its customers, and allows it to adapt quickly to customers demands and market changes.

NXP Opens New R&D Facilities in France

NXP Semiconductors, the independent semiconductor company founded by Philips, has opened a new Research and Development centre in Caen, France. The company has invested over €100 M in the last year, from its existing R&D budget, in a new building and around 800 engineers and researchers. This investment aims at enhancing the Caen facility to develop innovations that will see NXP technology improve products.

The teams at the new centre are developing groundbreaking technologies for four of the company's focus areas (mobile and personal, home, multimarket semiconductors and identification). Some of the research and development areas include RF technologies, Silicon tuners, system-in-package process technologies as well as other innovative semiconductor solutions such as Near Field Communications (NFC).

In addition to the NXP activities at the Caen facility, the R&D centre houses a joint research institute with CNRS, known as the Institute for System Testing (ISyTest). The goal of this institute is to develop innovative testing methods and techniques to improve the level of quality of NXP's increasingly complex system solutions.

The opening of the Caen facility follows the recent announcement of a €42 M investment in innovation and manufacturing activities in Vienna, Austria. Frans van Houten, president and chief executive officer, NXP Semiconductors, commented on both initiatives, saying, "It demonstrates the importance of Europe in our annual €1 B R&D program and how we use this investment in innovation to maintain leadership in the high-growth areas where we focus. Our 6000 strong European R&D team consistently delivers the technologies that enable our customers to bring competitive and differentiating products to market." ■

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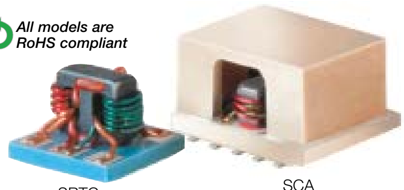

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SBTC-2-15-75+	500-1500	75 Ω	3.49
SBTC-2-10-5075+	50-1000	50/75 Ω	3.49
SBTC-2-10-7550+	5-1000	50/75 Ω	3.49
SCA-4-10+	5-1000	50 Ω	6.95
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RF/IF MICROWAVE COMPONENTS 354 Rev H

New 11 GHz Services as FCC Allows Two-foot Dish

The FCC's recent rule changes in the 11 GHz band will lead to an influx in microwave backhaul services and more efficient use of spectrum, says wireless technology group Radio Frequency Systems (RFS). Inspired by ongoing improvements in microwave antenna technology, changes to Part 101 Category B (Cat B) specifications will now permit use of two-foot antennas in the 11 GHz band, without compromising on interference protection.

According to Asad Zoberi, RFS area program manager, the 11 GHz band has to date been under-utilized, due to the costs associated with installing and operating larger antennas to meet Cat A and Cat B specifications. "RFS welcomes this FCC initiative to permit use of smaller antennas," he said. "The economic advantages will provide an incentive to carriers to make greater use of the 11 GHz band for broadband data and microwave backhaul services. We also predict the introduction of new players into the mix, particularly those providing broadband services."

Previously, Zoberi explained, the gain, beam width and side lobe requirements of Cat B were difficult to achieve with an antenna smaller than three feet. The revised specifications relax the requirement for beam width and gain, along with side lobe specifications close to the main beam, while maintaining stringency of the balance of the radiation pattern. This permits the use of two-foot antennas, leading to lower overall system cost.

"According to the new Cat B ruling, the RFS CompactLine two-foot antenna (SB2-107) easily meets—and even exceeds—the specifications," Zoberi said. "In addition, it offers advantages in gain, weight, tower windloading and overall depth compared with the other two-foot dishes on the market. This is now the best two-foot solution for 11 GHz microwave link networks where Cat B is permitted."

The 11 GHz band (10.7 to 11.7 GHz) is an ideal option for point-to-point communications, with links typically spanning five to 20 miles. Its 40 MHz channels allow high-capacity data transfer (3 DS3s or OC3)—a significant improvement on the capacity-limited 10 GHz band, where data throughput of the 5 MHz channels is restricted to 16 DS1s. Furthermore, the 11 GHz band is less affected by rain attenuation than higher bands such as 18 GHz. RFS expects the CompactLine SB2-107 antenna to play a significant role as carriers exploit the 11 GHz band and offer a host of innovative new services. The antenna exhibits all the features and benefits of the RFS CompactLine range of microwave antennas. This includes a robust mechanical design and lightweight construction from corrosion-resistant materials. With best-in-breed performance and meeting FCC part 101 Category B requirements in the 11 GHz band, it will facilitate zoning and site permit acquisition, making it the ideal solution for backhaul applications.

SOI Industry Consortium Aims to Reduce Costs, Reach New Market

A group of leading companies throughout the electronics industry announced the launching of the SOI Industry Consortium, aimed at accelerating silicon-on-insulator (SOI) innovation into broad markets by promoting the benefits of SOI technology and reducing the barriers to adoption.

Performance and power consumption are now of primary concern throughout the electronics industry. While early adopters have convincingly demonstrated that SOI is a powerful solution in addressing these concerns, they did so largely on their own. The next wave of adopters needs a proven and complete array of readily-accessible SOI design platforms and IP to ensure transparent design platforms and cost-effective manufacturing, The SOI Consortium aims to bridge the gaps—both real and perceived—by reducing adoption costs, making SOI best practices available and facilitating design examples across the value chain.

Covering a spectrum of users, enablers, suppliers and manufacturers, the founding membership roster (listed alphabetically) includes: AMD, ARM, Cadence Design Systems, CEA-Leti, Chartered Semiconductor Manufacturing, Freescale Semiconductor, IBM, Innovative Silicon, KLA-Tencor, Lam Research, NXP, Samsung, Semico, SHE Europe, STMicroelectronics, Synopsis, TSMC and UMC.

"Riding the performance wave, SOI has made significant inroads," notes Andre-Jacques Auberton-Herve, the consortium's newly elected chair. "Now, the focus has expanded to reducing power consumption. SOI can cut power consumption significantly—an enormous advantage—whether you are running a data center or hoping that you have enough battery left to see the end of the match on your mobile phone. By unifying users and enablers, the SOI Industry Consortium can identify and close the gaps in the design chain, making SOI a viable choice for designers over a much broader range of market."

The SOI Industry Consortium will focus on three major goals:

- Ensuring that user needs are heard, understood and addressed;
- Accelerating and facilitating the requisite collaboration in the ecosystem to enable silicon-proven solutions; and
- Promoting SOI benefits, technology innovation and momentum within the greater electronics community.

"SOI benefits are now being recognized by most of the major players in the industry and the technology is on the verge of entering the mainstream," notes Bryan Lewis, semiconductor research VP of Gartner. "Companies from the entire semiconductor food chain are investing time and money to take SOI to the next level and this should clearly accelerate improvements in reduced power consumption and improved performance for a wide range of devices and applications." The Consortium's initial focus is on sharing best practices already established by early adopters and facilitating new design proof points demonstrating SOI's performance, power and area advantages. The Board of Directors was elected in October.

The SOI Industry Consortium is chartered with accelerating silicon-on-insulator innovation into broad markets by promoting the benefits of SOI technology and reducing the barriers to adoption. Membership is open to all companies and institutions throughout the electronics industry. For more information, visit: www.soiconsortium.org.

Intellectual Property and Product Portfolio Expansion Drive Investments

Strategy Analytics has predicted consolidation in the compound semiconductor industry, but industry player strategies have matured beyond simply buying competitors for market share. Companies now look for valuable intellectual properties and opportunities to expand product portfolios into multiple new markets. Detailed analysis of the recent acquisitions and other key events in the compound semiconductor industry can be found in the following regularly scheduled reports from Strategy Analytics covering compound semiconductor industry news, including microelectronics, optoelectronics and material/equipment markets:

- Intellectual Property and Product Portfolio Expansion drive $918 M GaAs Industry Spending Spree.
- Compound Semiconductor Industry June–August 2007: Optoelectronics and Materials.
- Compound Semiconductor Industry June–August 2007 Review: Microelectronics.

Despite the sub-prime lending crunch, acquisitions by Anadigics, Avago Technology, Philips, RFMD, Triquint and others over the summer months approached $2 B, illustrating these trends. "As deals have become more difficult to finance, firms are being forced to scrutinize each deal more closely and use strategic financing to fund deals," noted Asif Anwar. "The industry has learned to look for affordable gems with unique IP suited to products and strategies." ■


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INDUSTRY NEWS

■ **RF Industries Ltd.** announced that it acquired, for cash and equity consideration valued at approximately $700,000, the assets of **RadioMobile Inc.**, a privately held San Diego, California-based supplier and system integrator of custom wireless data and transceiver products. Radio Mobile revenue exceeds $700,000 since January 2007.

■ **ANADIGICS Inc.**, a provider of semiconductor solutions in the rapidly growing broadband wireless and wireline communications markets, has announced that it has acquired from **Fairchild Semiconductor**, for $2.3 M, the RF team, fixed assets, certain leases, software and licenses to intellectual property in connection with Fairchild's exiting of its RF Group business in Tyngsboro, MA. The acquisition, which included the hiring of 23 highly experienced RF design and engineering professionals, will further accelerate the company's design and development of RF active semiconductor devices for the 3G cellular, WiFi and WiMAX markets.

■ **MediaTek Inc.**, a fabless semiconductor company for wireless communications and digital media solutions, announced that it has signed a definitive agreement to acquire the assets related to the **Analog Devices Inc.** (ADI) Othello® radio and SoftFone® baseband chipset product lines, as well as certain cellular handset baseband support operations, for approximately US$350 M in cash. These product lines represented approximately US$230 M in revenue for ADI, based on fiscal year 2006 financial results.

■ **Integrated Barcode Technology** (IBT) has announced that it has been acquired by **Astron Wireless Technologies Inc.**, a northern Virginia-based global manufacturer of antenna, cable and connectivity products for a multitude of wireless communications applications for over 28 years. The acquisition of IBT by Astron Wireless provides an opportunity to diversify Astron's commercial, military and government customer offerings leading to multiple recurring revenue streams from barcode applications.

■ **Keithley Instruments Inc.**, a leader in solutions for emerging measurement needs, announced a new partnership with the **California NanoSystems Institute** (CNSI) at UCLA. The partnership is designed to support research collaboration in the pursuit of nanotechnology and nanoscience solutions for the semiconductor industry's next generation instrumentation and measurement requirements. Keithley and the CNSI will share research information to further the understanding of nanotechnology and nanoelectronic technologies.

■ The **Institute for System Level Integration** (iSLI) has announced an agreement with **Cadence Design Systems Ltd.** to help advance new businesses by giving them easy access to chip design software and methodology services. Providing access to software design tools and methodology services will enable new companies who may not have the finance or resources available to accelerate their product development processes allowing them to become successful in the shortest possible time.

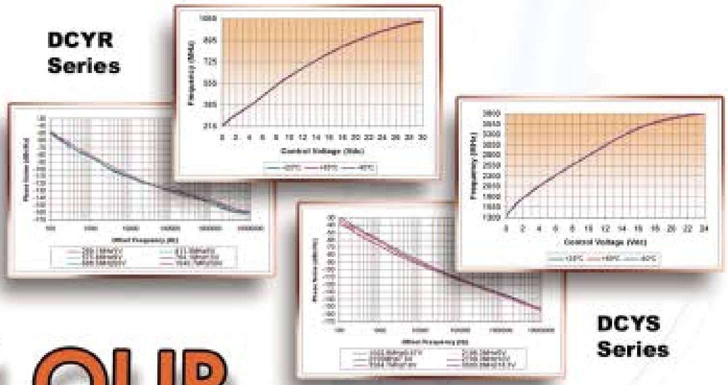
■ **Tyco Electronics** and **OATSystems** announced an alliance to offer a RFID solution targeted for industrial manufacturers to quickly realize the business benefits of RFID by automating asset management processes. Combining Tyco Electronics tag solutions with OATSystems Asset Tracking software will enable businesses to realize an ROI much more quickly. By providing integrated software and hardware solutions, proven at real customers, Tyco Electronics and OATSystems can quickly give industrial manufacturers tangible business benefits such as better control and less loss of reusable assets (shipping containers, for example) and improved supply chain visibility, which allows for better planning and improved customer service. Customers can be up and running in weeks, instead of months, enabling them to respond immediately to mis-shipments and delivery errors, increasing both operational efficiency and customer satisfaction.

■ To better support China's rapidly growing avionics market, **Aeroflex** is partnering with **Ameco Beijing** (Aircraft Maintenance and Engineering Corp.) to provide a local service center for Chinese customers. Located at the Beijing Capital International Airport, Ameco Beijing will provide a convenient site for calibrating and servicing Aeroflex avionics test equipment sold in China for civil end uses. Access to local service and support means customers can reduce their equipment down time, shipping costs, and expensive and time-consuming import/export fees.

■ **Eyelit Inc.**, a manufacturing software provider for visibility, control and coordination of manufacturing operations for the aerospace & defense, electronics, life sciences, semiconductor and solar panel industries, announced that it has purchased and moved into its new corporate office. The new office provides nearly three times more office space than the previously leased building and will provide Eyelit with the necessary office space to meet growing demand for its manufacturing software solutions and services. Eyelit's new address and phone numbers are: Eyelit Inc., 5685 Whittle Road, Mississauga, ON L4Z 3P8 ph: (905) 502-6184 and fax: (905) 502-9117.

■ **Chomerics** Asia Pacific division of Parker Hannifin Corp. announced the opening of a new facility in Sriperumbudur near Chennai, India. Located adjacent to the 260 acre Special Economic Zone, the facility will enable Chomerics to better serve the rapidly growing Indian market for IT, telecom and consumer electronic products. With nearly 1700 square meters of manufacturing and office space, the plant will produce electromagnetic interference (EMI) shielded products to support local customers.

DCYR Series



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* Low Post Thermal Drift
* High Reliability
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* Integrability To MMIC, Chip & Wire
* Standard & Customized Designs
* REL-PRO® - RoHS Compliant
* Patented Technology

0.5" x 0.5"

0.75" x 0.75"

RoHS COMPLIANT

Model	Frequency (MHz)	Tuning Voltage (VDC)	DC Bias VDC @ I (Max)	Typical Phase Noise @ 10 kHz (dBc/Hz)
DCYR2060-5	200 - 600	0.5 - 28	+5 @ 65 mA	-119
DCYR3097-5	300 - 970	0.5 - 28	+5 @ 40 mA	-112
DCYR50125-10	500 - 1250	0.5 - 25	+10 @ 50 mA	-110
DCYR100200-12	1000 - 2000	0.5 - 28	+12 @ 50 mA	-108
DCYS160360-5	1600 - 3600	0.5 - 24	+5 @ 60 mA	-90
DCYS200400-5	2000 - 4000	0.5 - 15	+5 @ 50 mA	-90
DCYS250500-5	2500 - 5000	0.5 - 20	+5 @ 50 mA	-75
DCYS300600-5	3000 - 6000	0 - 25	+5 @ 50 mA	-80
DCYR400800-5*	4000 - 8000	0 - 18	+5 @ 130 mA	-84
DCYR5001000-5*	5000 - 10000	0 - 25	+5 @ 130 mA	-75
DCYR6001200-5*	6000 - 12000	0 - 25	+5 @ 130 mA	-74

* Sub-Harmonic suppression 35 dB typical.

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■ **LS Research**, a leader in the design, development and FCC certification of new products for the wireless market, has announced the opening of a branch facility in Fitchburg, WI. The new office will focus on hardware and software development for ZigBee, Bluetooth, WiFi and low power wireless applications. The new facility's address is: 5520 Nobel Drive, Suite 175, Fitchburg, WI 53711.

■ **Murata Electronics North America**, an innovator in electronics and a global supplier of ceramic passive components, announced that it has selected **Avnet Electronics** to receive the company's Corporate Award for 2006. Avnet was selected out of all Murata's North American distributors based on its continued sales expansion and outstanding contribution to Murata.

■ **State of the Art Inc.** (SOTA), a manufacturer of military and high reliability chip resistors, announced it has been awarded the **Honeywell** Kansas City, MO Supplier Excellence Award for the 2006 fiscal year. Consideration for the award is based on the areas of quality performance, order administration, cost control, technical support, responsiveness and delivery performance along with other factors.

CONTRACTS

■ **Andrew Corp.** has been awarded the third phase of a strategic multiyear contract from a Tier 1 operator in the Middle East for a major geolocation system deployment. The phase three contract award is valued at approximately $9 M, bringing the total contract value to date to more than $30 M. It represents continued expansion of the project in which Andrew is installing its Geometrix® uplink time difference of arrival (U-TDOA) system that, when completed, will cover a network of thousands of cell sites. Work on phase three will begin as the second phase nears completion.

■ **TRAK Microwave** announced the award of a contract valued at over $4 M for a high performance Integrated Microwave Assembly (IMA) from a customer located outside the United States. "This recurring contract award from a most valued US-Allied customer demonstrates that TRAK's investments in factory automation and process controls continues to offer our partners high performance and competitively priced integrated microwave solutions," said Michael Kujawa, VP sales and marketing for TRAK Microwave.

■ **Agilent Technologies Inc.** announced that the US Navy has selected the company's test equipment for the General Purpose Electronic Test Equipment program. The five-year contract, awarded by the Naval Inventory Control Point, is valued at approximately $3.3 M.

■ **Jacket Micro Devices Inc.** (JMD), a worldwide supplier of integrated RF modules for high performance wireless products, has selected Singapore-based **Micro-Circuit Technology (S) Pte. Ltd.** (MCT) for large-scale fabrication of substrates and other products using JMD's proprietary Multi-layer Organic (MLO) technology. MLO technologies use thin low loss organic materials in a system-on-package (SoP) approach to RF modules. This enables the production of substrates for RF front-end modules with higher component aerial density compared to traditional solutions using ceramics.

■ **Tower Semiconductor Ltd.**, a pure-play independent specialty foundry, announced that it has won a multi-million dollar per month manufacturing deal for its Fab2 at the 0.13-micron technology generation from a first-tier, US integrated device manufacturer (IDM). Under this deal, technology will be transferred during the coming several quarters after which Tower expects to manufacture between five and eight thousand wafers-per-month, utilizing the new tools it is purchasing from companies such as AMD and Intel, as was previously announced.

FINANCIAL NEWS

■ **Park Electrochemical Corp.** reports sales of $60.5 M for its 2008 fiscal year second quarter ended August 26, 2007, compared to $66.5 M for the same period in 2007. Net earnings for the quarter were $9.2 M ($0.45/per share), compared to net earnings before special items of $8.5 M ($0.82/per share) for the second quarter of last year.

■ **Ceragon Networks Ltd.** reports sales of $37.3 M for the second quarter ended June 30, 2007, compared to $23.6 M for the same period in 2006. Net income for the quarter was $2.9 M ($0.09/per diluted share), compared to $835,000 ($0.03/per diluted share) for the second quarter of last year.

■ **Merrimac Industries Inc.** reports sales of $6.2 M for the second quarter ended June 30, 2007, compared to $8.3 M for the same period in 2006. Net loss for the quarter was $3.5 M ($1.19/per share), compared to a net income of $529,000 ($0.17/per share) for the second quarter of last year.

■ **Superconductor Technologies Inc.** reports sales of $4.7 M for the second quarter ended June 30, 2007, compared to $5 M for the same period in 2006. Net loss for the second quarter was $2 M ($0.16/per share), compared to a net loss of $22.7 M ($1.82/per share) for the second quarter of last year.

NEW MARKET ENTRIES

■ **Leusin Microwave LLC**, a new supplier of waveguide and coaxial cavity filters and other passive components in the 1 to 40 GHz range, was recently formed. Leusin's team is an experienced combination of talents including engineering, manufacturing and quality assurance. Leusin's headquarters and manufacturing facility is located in Hampstead, NH. For more information, call (603) 329-7270, sales (603) 767-8589, e-mail: sales@leusin.com or visit www.leusin.com.

■ **ClearComm Technologies LLC** has announced its expansion into new facilities in Fruitland, MD. A larger, 35,000 square foot building is being utilized to produce ClearComm's commercial, military and wireless products.

LET THIS BE YOUR GUIDE

TriQuint Semiconductor now offers an extensive product selection guide designed around your RF needs!

Filling your bill of materials just got easier thanks to ***TriQuint's new Product Selection Guide***. We took all the superb designs RF engineers have relied on for years, plus some great new ideas, and put them together in one spot.

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ClearComm is a manufacturer of filters, duplexers, diplexers and RF assemblies covering the frequency range of 10 MHz to 18 GHz. The new address is 28410 Crown Road, Fruitland, MD 21875. The phone number is (410) 860-0500, fax: (410) 860-9005, e-mail: sales@clearcommtech.com or visit: www.clearcommtech.com. In related news, ClearComm announced the appointment of the **Cain-Forlaw Co.** headquartered in Palatine, IL. Cain-Forlaw group will cover the central portion of the US from Illinois to Texas. This group brings a broad experience and complimentary products to ClearComm. To contact Cain-Forlaw's main office, call (847) 202-9898 or visit: www.cain-forlaw.com.

PERSONNEL

■ Inphi® Corp. announced that recognized business and corporate governance expert **Sam Srinivasan** has joined its board of directors. Srinivasan will provide expertise and counsel as Inphi continues to expand by delivering the industry's highest performing integrated circuits with the best signal integrity for processing high speed data. Srinivasan currently serves as a director and chairman of the Audit Committee for Sirf Technology Holdings Inc. and Centillium Communications Inc. In addition, he is a charter member of the Weatherhead School Advisory Council at Case Western Reserve University's school of management in Cleveland, OH.

▲ *Peter L. Gammel*

■ SiGe Semiconductor announced the appointment of **Peter L. Gammel** as chief technology officer (CTO). In his new role, Gammel will be responsible for generating technology and product roadmaps and identifying new application opportunities. He will also work closely with external partners, internal engineering and marketing groups to exploit the company's capabilities in the wireless consumer electronics market segments. Gammel assumes the position of CTO after 20 years experience in new product and funding development, intellectual property investment, and team building and management.

▲ *Don Pearson*

■ Crane Aerospace & Electronics, a segment of Crane Co., announced the appointment of **Don Pearson** as director of operations for microwave systems solutions. In this capacity, Pearson is responsible for manufacturing operations of the Microwave Systems Solutions sites located in Chandler, AZ and Beverly, MA. Prior to joining Crane, Pearson was with UK-based Invensys, a global industrial automation, transportation and controls group. He held a number of increasingly responsible roles at Invensys including vice president of materials and logistics, vice president of operations, corporate vice president of operations services and group vice president of operations.

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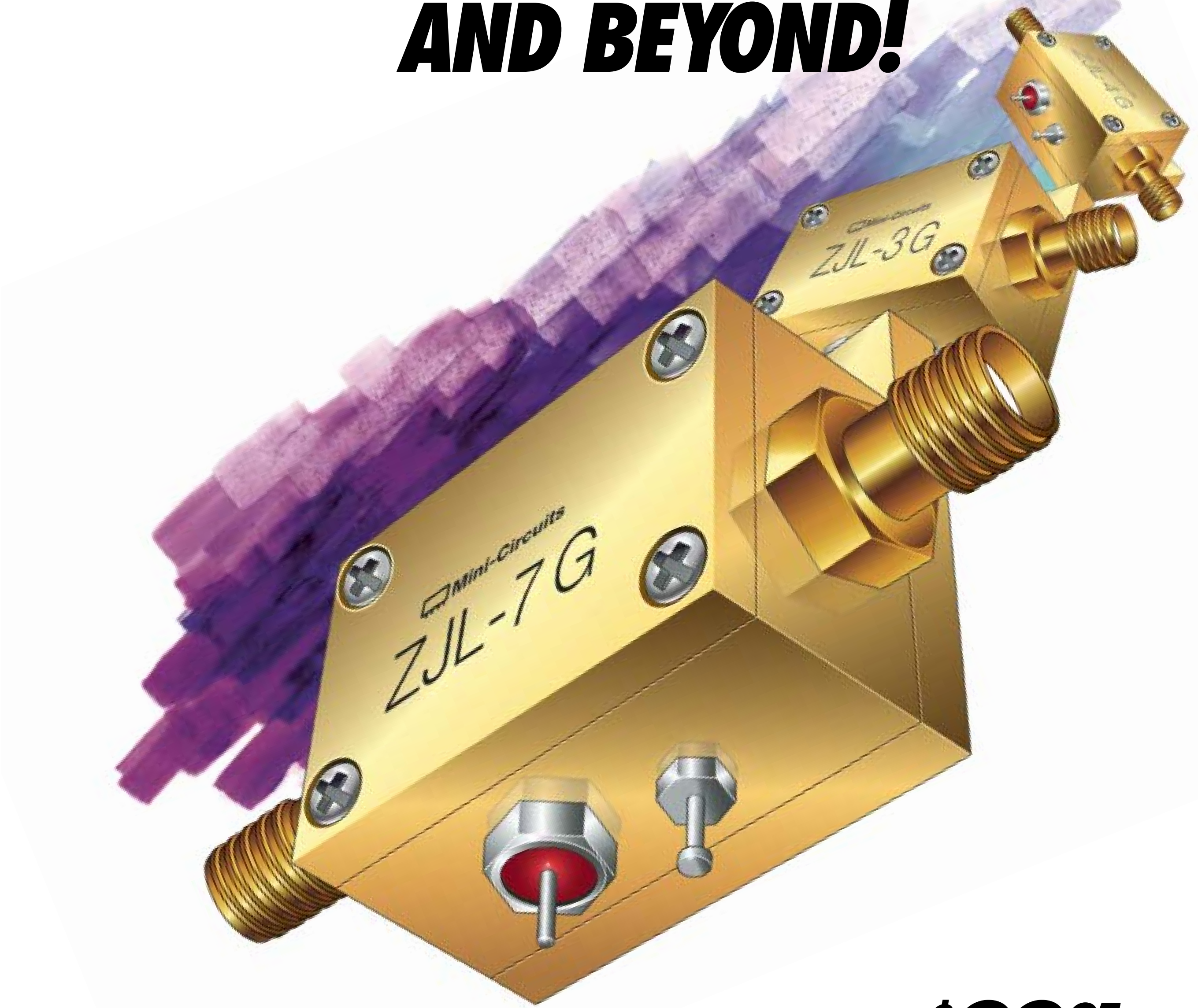

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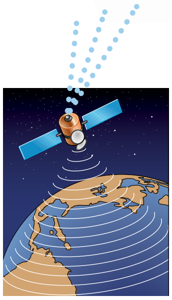

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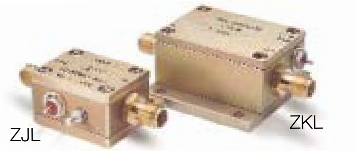
SPECIFICATIONS

Model	Freq (MHz)	Gain (typ) Midband (dB)	Gain (typ) Flat (±dB)	Max. P_{out} 1 (dBm)	Dynamic Range (Typ @2 GHz 2) NF(dB)	Dynamic Range (Typ @2 GHz 2) IP3(dBm)	I(mA) 3	Price $ea. (1-9)
ZJL-5G	20-5000	9.0	±0.55	15.0	8.5	32.0	80	129.95
ZJL-7G	20-7000	10.0	±1.0	8.0	5.0	24.0	50	99.95
ZJL-4G	20-4000	12.4	±0.25	13.5	5.5	30.5	75	129.95
ZJL-6G	20-6000	13.0	±1.6	9.0	4.5	24.0	50	114.95
ZJL-4HG	20-4000	17.0	±1.5	15.0	4.5	30.5	75	129.95
ZJL-3G	20-3000	19.0	±2.2	8.0	3.8	22.0	45	114.95
ZKL-2R7	10-2700	24.0	±0.7	13.0	5.0	30.0	120	149.95
ZKL-2R5	10-2500	30.0	±1.5	15.0	5.0	31.0	120	149.95
ZKL-2	10-2000	33.5	±1.0	15.0	4.0	31.0	120	149.95
ZKL-1R5	10-1500	40.0	±1.2	15.0	3.0	31.0	115	149.95

NOTES:
1. Typical at 1 dB compression.
2. ZKL dynamic range specified at 1 GHz.
3. All units at 12V DC.



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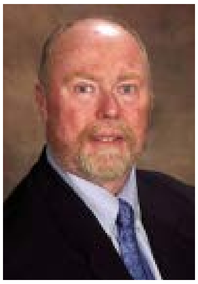


▲ Brad King

■ StratEdge announced the appointment of **Brad King** to the position of senior account manager. Responsibilities include sales and application support for StratEdge's high performance semiconductor packages, filters, and assembly and test services. King has 25 years of experience providing electronic products and services to the industrial, automotive and government marketplace. He has held senior level positions in sales and marketing and business development at companies such as California Amplifier (CalAmp)/Vytek, Indyme Electronics and Dynatech Wireless Technologies.

■ TT electronics BI Technologies Electronic Components Division has hired **Chuck Nelson** as product marketing manager of the company's hybrid microcircuit business unit. Joining BI Technologies' experienced applications engineering staff, Nelson will be responsible for supporting the existing customer base as well as promoting new business growth. Nelson previously worked in ceramic electronic packaging with NTK and Kyocera. He was also employed with BI Technologies earlier in his career in the engineering and production departments.

REP APPOINTMENTS

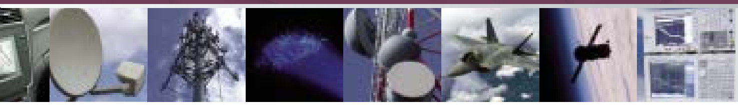
■ **Nitronex**, an innovative developer and manufacturer of high performance GaN on Si RF power transistors for the commercial and broadband wireless infrastructure markets, has expanded its partnership with Richardson Electronics to include distribution in the Americas and all of Asia. The agreement will increase Nitronex's sales and customer support services for its customers throughout these regions.

■ **Aeroflex/Inmet** and **RFMW Ltd.** announced a worldwide distribution agreement. Aeroflex/Inmet is a leading manufacturer of high performance coaxial components for communications and test applications. RFMW Ltd. is a specialized distributor that provides customers and suppliers with focused distribution of RF and microwave components as well as customer specific component-engineering support.

■ **RF Monolithics Inc.** announced it has expanded its distribution capability and increased product availability across all of Asia with the appointment of **Nu Horizons Electronics Corp.** as an authorized Asian distributor for its component products and its Cirronet ZigBeeT and proprietary wireless sensor networking modules and devices. Nu Horizons currently distributes the company's full line of products throughout North/South America, Germany and the United Kingdom.

■ **Digi-Key Corp.** announced that it has entered into a distribution agreement with **RF Micro Devices Inc.** (RFMD). Among the RFMD products stocked by Digi-Key are RF ICs and modules, including RF amplifiers and evaluation kits. These products are featured in Digi-

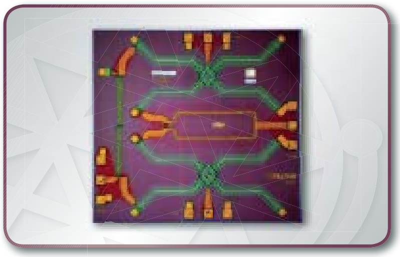
NEW MIXERS TO 90 GHz

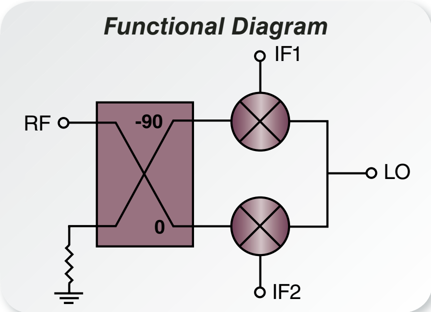


Analog & Mixed-Signal ICs, Modules & Subsystems

HITTITE MICROWAVE NOW OFFERS VELOCIUM PRODUCTS!

HMC-MDB172 GaAs MMIC I/Q Mixer, 19 - 33 GHz





- ♦ Functions as an IRM or a Single Sideband Upconverter
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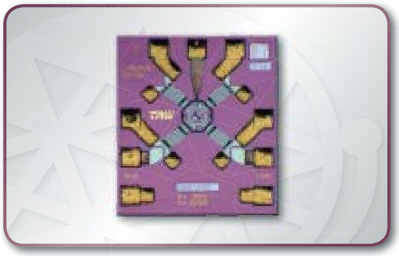
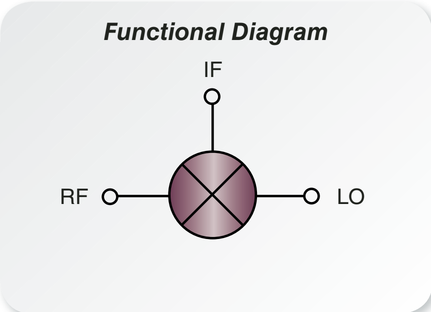
- ♦ High LO to RF Isolation: 35 dB
- ♦ High Input IP3: +17 dBm

4 NEW HITTITE - VELOCIUM I/Q & IMAGE REJECT MIXER CHIPS

	RF Freq. (GHz)	Function	IF Freq. (GHz)	Conversion Gain (dB)	Image Rejection (dB)	Input IP3 (dBm)	VELOCIUM Part Number	HITTITE Part Number
NEW!	19 - 33	I/Q Mixer / IRM	DC - 5	-8	25	17	MDB172	HMC-MDB172
NEW!	35 - 45	I/Q Mixer / IRM	DC - 5	-8	25	17	MDB171	HMC-MDB171
NEW!	55 - 64	I/Q Mixer / IRM	DC - 3	-9	30	16	MDB207	HMC-MDB207
NEW!	54 - 64	Sub-Harmonic I/Q Mixer / IRM	DC - 3	-12.5	30	7	MDB218	HMC-MDB218

HMC-MDB169 GaAs MMIC Fundamental Mixer, 54 - 64 GHz





- ♦ Upconversion & Downconversion
- ♦ Low Conversion Loss: 8 dB
- ♦ High LO to RF Isolation: 30 dB
- ♦ Double-Balanced Topology
- ♦ Wide IF Bandwidth: DC - 5 GHz
- ♦ Compact Die Size: 1.0 x 0.9 mm

2 NEW HITTITE - VELOCIUM DOUBLE-BALANCED MIXER CHIPS

	RF Freq. (GHz)	Function	IF Freq. (GHz)	Conversion Gain (dB)	LO / RF Isolation (dB)	Input IP3 (dBm)	VELOCIUM Part Number	HITTITE Part Number
NEW!	54 - 64	+13 LO, DBL-BAL	DC - 5	-8	30	13	MDB169	HMC-MDB169
NEW!	70 - 90	+14 LO, DBL-BAL	DC - 18	-12	-	-	MDB277	HMC-MDB277

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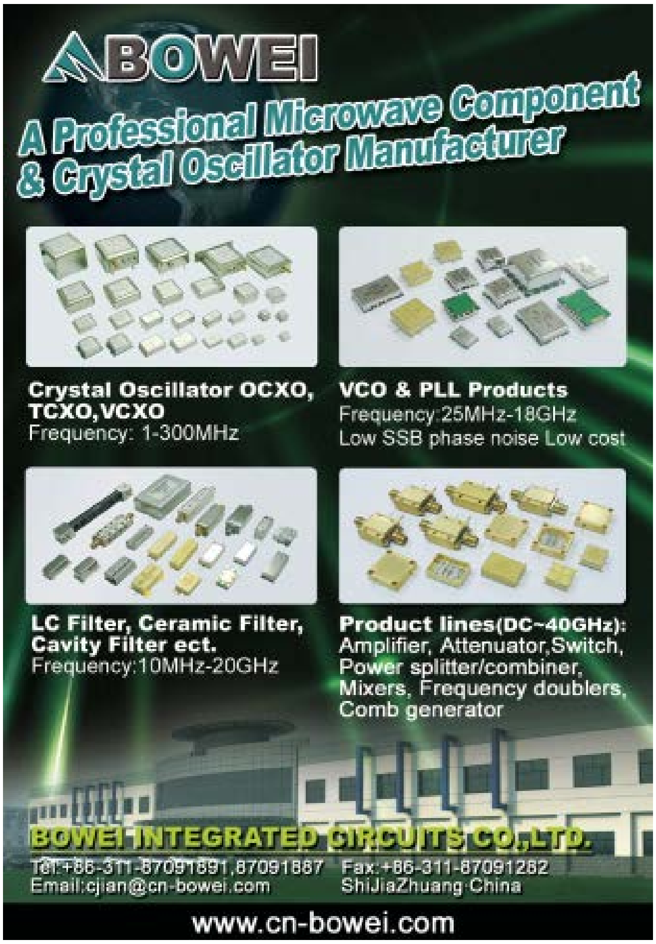

Key's print and online catalogs and are available for purchase directly from Digi-Key.

■ **Coaxial Dynamics** has appointed **Measuretest cc** as its representative in South Africa. Measuretest cc was formed and started trading in October 1984. The company's prime objective is to continue its business as an importer and distributor of professional electronic equipment, servicing the telecommunications, ATE, RF, microwave, manufacturing and broadcasting industries. Contact information: Measuretest cc, 47 Elephant Road, Monument Park, Pretoria 0105 Republic of South Africa, ph: 27-12 452 0400, fax: 27 12 452 0415, e-mail: sales@measuretest.co.za or visit: http://measuretest.co.za.

■ **International Manufacturing Services Inc.** (IMS), a manufacturer and supplier of high quality thick film resistors, terminations, attenuators, planar dividers and planar filters to the electronics industry, announced the appointment of **Jay Stone Associates** of San Jose as its northern California representative. Since 1959, Jay Stone Associates has been one of the area's pioneers in the RF and microwave business.

■ **San-tron Inc.**, a manufacturer of RF coaxial connectors and cable assemblies, has announced the hiring of new field sales representatives to handle customer relationships in southern California. **First Technical Sales**, Temecula, CA, will be servicing accounts from Los Angeles south to San Diego and east to Reno, NV. The company is located at 31938 Hwy 79 South, Suite #A-312, Temecula, CA 92592, ph: (951) 302-3972 or visit: www.first-technical.com. Leading the office in Temecula is Cipriano Mercado, technical sales manager. He can be reached via e-mail at cipriano@first-technical.com.

■ **Allied Electronics**, a subsidiary of Electrocomponents plc, has signed a distribution agreement with **Crystek Corp.** to distribute its portfolio of frequency control technology. Allied will carry a broad range of products from Crystek, including quartz crystals, clock oscillators, TCXOs, OCXOs, VCXOs and VCOs.

■ **Trompeter**, a wholly owned subsidiary of Emerson Network Power Connectivity Solutions, announced the appointment of a new sales rep organization, **Eastern Instrumentation of Philadelphia**. The organization has represented Trompeter's sister company Semflex since 1985. Eastern Instrumentation of Philadelphia's five sales engineers will cover the tri-state region of Pennsylvania, Delaware and New Jersey for Trompeter's entire line of RF interconnect products. The company can be reached by phone: (856) 231-0668 or e-mail: jerryl@eiphila.com.

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A SIMPLIFIED METHOD TO REDUCE DIMENSIONS OF PLANAR PASSIVE CIRCUITS USING DEFECTED GROUND AND DEFECTED MICROSTRIP STRUCTURES

In this work, a simplified and accurate mathematical method to predict the reduced dimensions of microstrip circuits by using planes with discontinuities such as defected ground structures (DGS) and defected microstrip structures (DMS) is proposed. The method is based on the increment of the slow-wave factor (SWF) for a microstrip with slotted planes. The procedure is successfully applied to reduce the dimensions of a rectangular patch antenna and a matching network implemented with an open-circuited stub.

The use of discontinuities in ground planes or in microstrip lines is currently employed to improve the performance of different passive circuits, such as the size reduction of amplifiers,[1] the enhancement of filter characteristics[2,3] and applications to suppress harmonics in patch antennas.[4] On the other hand, a new proposal, called defected microstrip structure (DMS), has been successfully used in reducing the size of, and as a tuning technique for, rectangular patch antennas.[5,6] The DMS is similar to the structure called spurline,[9] since both are etched in the microstrip line and behave as stop-band filters. The main difference, however, is that DMS achieves a greater associated inductance. DMS also presents a greater slow-wave effect, since it has more discontinuities, providing a longer trajectory to the electromagnetic wave. Simultaneously, DMS also performs a greater stop-band bandwidth compared to spurline, both having the same dimensions.

In a previous article,[5] the reduction of the antenna size, resonating at 1.77 GHz, was made by iterations with simulation software, just assuming a reactive load introduced by the DMS. That procedure is highly time-

J.A. TIRADO-MÉNDEZ AND H. JARDÓN-AGUILAR
Center for Research and Advanced Studies-IPN, Mexico, D.F. Mexico
E.A. ANDRADE-GONZÁLEZ AND M. REYES-AYALA
Metropolitan Autonomous University-Azcapotzalco, Mexico, D.F. Mexico

consuming compared to the method developed in this work and the antenna dimensions can be predicted perfectly with great accuracy. In another article,[6] the DMS was employed as a tuning technique for rectangular microstrip antennas, as an alternative procedure for lowering the resonance frequency in which a mathematical model was proposed to obtain the associated inductance introduced to the radiator with the defect. A 1.45 GHz antenna was designed and tuned by using that method.

In this article, a square patch antenna resonating at 3 GHz and a matching network with an open-circuited stub are developed to demonstrate the efficiency of the simplified method for reducing dimensions and the size reduction is predicted. Furthermore, such methods can be generalized in almost all microstrip circuits. The use of DMS or DGS consequently allows an increase in the slow-wave factor (SWF) in transmission lines in which they are introduced. This phenomenon can be used to reduce the size of passive planar circuits like microstrip line lengths, coupling lines and microstrip antennas, among other microstrip structures. However, no mathematical method has been explained so far to apply this phenomenon in such circuits. In the present work, a very simple and accurate method to describe how defected structures can be used in reducing the size of microstrip structures and predict their new dimensions is developed.

SLOW-WAVE FACTOR IN MICROSTRIP LINES WITH DEFECTED STRUCTURES

The SWF is the relationship between the wave number in free space, k_0, and the propagation constant, β, of the transmission line. For loss less microstrip line, the SWF is determined by

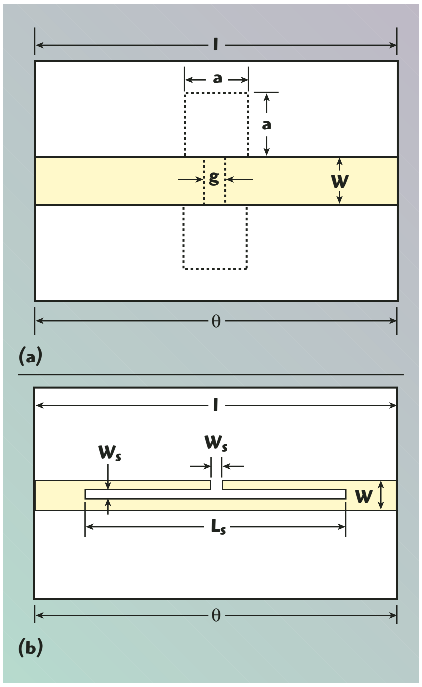
$$SWF = \sqrt{\varepsilon_e} \qquad (1)$$

where ε_e is the effective permittivity of the material, and the propagation constant is determined by

$$\beta = \sqrt{\varepsilon_e}\, k_0 \qquad (2)$$

The SWF of a microstrip line is raised when a discontinuity is introduced in the path of the electromagnetic wave, increasing the impedance of the line.[7] There are many works specifying diverse types of discontinuities applied in microstrip lines, including photonic band gap structures (PBG). Two of these structures are show in ***Figure 1***.

To show the behavior of the SWF in a microstrip line with a physical length l and an electric length θ, a 50 Ω microstrip line is designed using a substrate material with a dielectric constant of 2.2 and 1.27 mm thick. The line width is 4 mm and its physical length is 22 mm. The electrical length of this line is obtained by means of electromagnetic simulation (EM). A DGS unit-cell is subsequently introduced under the line and the cell dimensions are varied from a smaller to a larger size and the new microstrip line electrical length for those values is obtained. Finally, the SWF of the total structure is obtained. A similar procedure is used when a DMS unit-cell is introduced. The results are shown in ***Figure 2***. It is clear that both structures increase the SWF in the microstrip line, showing a greater increment with the DGS structure for a smaller unit-cell dimension. In spite of the apparent advantage of the DGS unit-cell, however, the DMS structure could be the unique solution for certain applica-



▲ *Fig. 1 Discontinuities in ground and microstrip surfaces; (a) DGS and (b) DMS.*

tions, particularly due to its geometric properties.

METHOD TO REDUCE DIMENSIONS OF MICROSTRIP CIRCUITS

Most applications of DGS and DMS structures have been successfully achieved purely by simulation. The method proposed in this work establishes a very simple and accurate procedure to find the new and reduced dimensions of conventional lines when a defect is introduced in the microstrip structure. These applications include filters, stubs and patch antennas among other microstrip circuits. To achieve the method, it is necessary to find the electrical length introduced in a microstrip line when a DGS or DMS unit-cell (or several unit-cells) are employed. Every circuit based on transmission lines presents an electrical length, and for microstrip lines the electrical length is given by

$$\theta = \beta l = \sqrt{\varepsilon_e}\, k_0 l \qquad (3)$$

Strictly speaking, microstrip circuits can be separated as cascaded black boxes and their respective electrical length calculated. On the other hand, these lines show a resonant frequency, f_r, by themselves. In many cases, lines can be seen as resonators, and in this case, for simplicity, a $\lambda_g/4$ line resonator is considered, where λ_g is the wavelength in the material, either in an open- or short-circuited configuration. In the case of microstrip lines, f_r is given by

$$f_r = \frac{c}{4l\sqrt{\varepsilon_e}} \qquad (4)$$

where

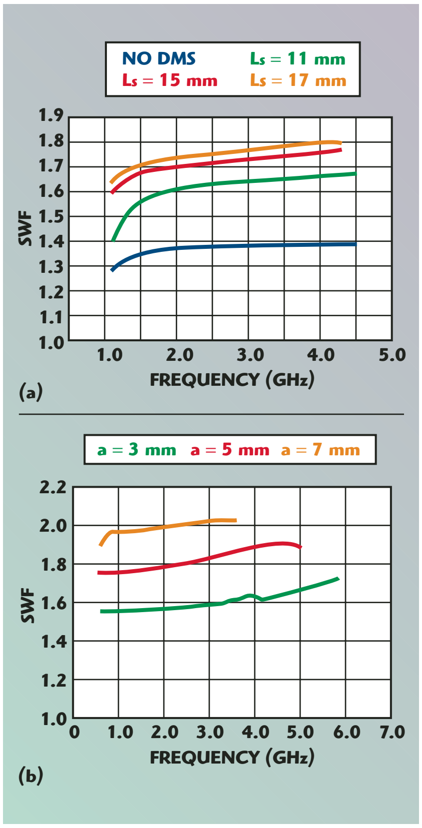
l = physical length of the line
c = speed of light in free space

For each line, the respective resonant frequency must be found and, at that frequency, the wave number in free space, k_0, is obtained. The next step is to propose a unit-cell dimension (or a pattern of unit cells). The structure can be either a DGS or DMS, and this is introduced in the microstrip line and for such a configuration, the electrical length, θ_c, at f_r is obtained by EM simulation. From these results, the SWF is

$$\text{SWF} = \frac{\theta_c(\pi/180)}{l k_0} = \sqrt{\varepsilon_{ec}} \qquad (5)$$

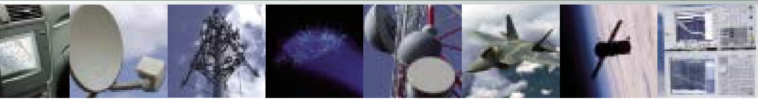
After introducing the unit-cell in the microstrip line, the substrate employed in the implementation presents an apparent effective dielectric constant, ε_{ec}, which is larger than the real effective dielectric constant ε_e. This apparent permittivity provides the tool to explain how the dimensions of microstrip circuits can be reduced, which means that for a higher dielectric constant the wavelength is shorter as well as the microstrip circuits, both being a function of this parameter. Since the original microstrip lines have an electrical length and introducing a DMS/DGS unit-cell into the structure increases it, a new dimension must be found to keep the electrical length equal to that of the non-defected lines. The new length that gives the original electrical length for the microstrip line with DMS/DGS unit-cell is obtained from

$$l_c = \frac{c}{4f_r \text{SWF}} = \frac{c}{4f_r\sqrt{\varepsilon_{ec}}} \qquad (6)$$



▲ *Fig. 2 Slow-wave factor for a microstrip line with DMS (a) and DGS (b).*

FREQUENCY MULTIPLIERS



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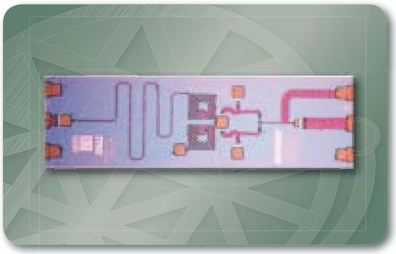
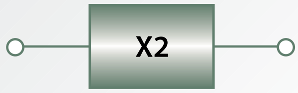
HMC-XDB112 Passive Frequency Doubler, 20 - 30 GHz Output

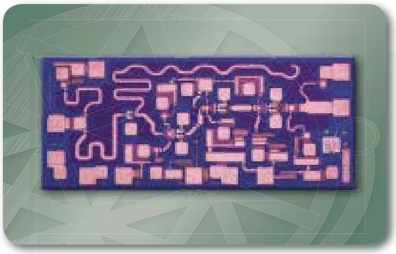


Functional Diagram

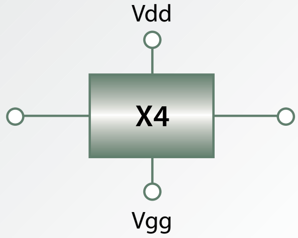


- ***Passive: No DC Bias Required***
- ***Conversion Loss: 13 dB***
- ***Input Drive: +13 dBm***
- ***High Fo Isolation: 30 dBc***

HMC-XDH158 Active x4 Frequency Multiplier, 56 - 64 GHz Output



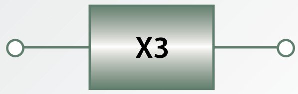
Functional Diagram



- ***Wide Input Power Range: 0 to +5 dBm***
- ***Output Power: -6 dBm***
- ***High Fo Isolation: 30 dBc***
- ***Low Conversion Loss: 8 dB***

HMC-XTB106 Passive x3 Frequency Multiplier, 72 - 90 GHz Output

Functional Diagram



- ***Passive: No DC Bias Required***
- ***Conversion Loss: 19 dB***
- ***Input Drive: +13 dBm***
- ***Balanced Topology***

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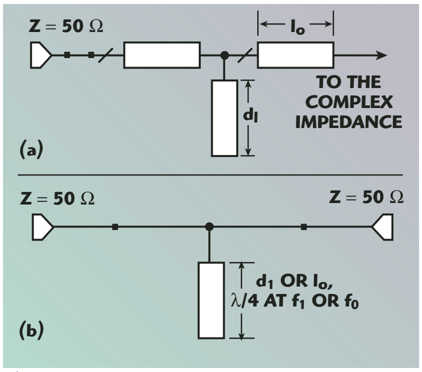
SIMULATION AND EXPERIMENTAL RESULTS

To exemplify the proposed method, two microstrip circuits were designed: a matching network with an open-circuited stub to match a load of 200+j100 Ω to a 50 Ω line at 2 GHz, and a rectangular patch antenna resonating at 3 GHz.

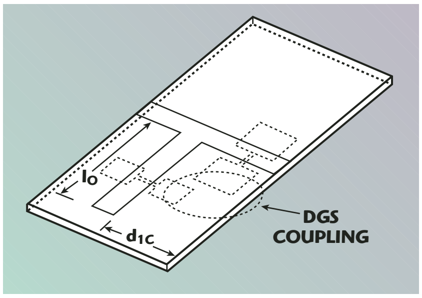
Matching Network

Considering the conditions previously mentioned, the matching network with an open-circuited stub has the dimensions $d_1 = 22.98$ mm and $l_o = 29.73$ mm, where d_1 is the line length from the complex load to the stub and l_o is the stub length. Both lines have, independently, electrical lengths θ_d and θ_1. Configured as a λ/4 line resonator, as depicted in ***Figure 3***, they present resonant frequencies f_d and f_1, respectively. The matching network is also displayed in the figure. The resonant frequency for each line is $f_d = 2.36$ GHz and $f_1 = 1.83$ GHz; the wave number at those frequencies is $k_{0d} = 49.42\ m^{-1}$ and $k_{01} = 38.32\ m^{-1}$, respectively. Following the procedure explained in the slow-wave factor in microwave lines with defected structures section, a DGS unit-cell is proposed to achieve a larger SWF, and therefore increase the electrical length and reduce the physical length of the lines. After some iterations in the procedure, a DGS unit-cell with a =7.5 mm is suggested for being used under the microstrip line with length d_1. By using EM simulation, the electrical length of the line with the DGS cell at 2.36 GHz is 145.88°. From Equation 5, SWF = 2.24; from Equation 6, the new dimension of the microstrip line with the DGS unit-cell is obtained, which is $d_{1c} = 14.17$ mm.

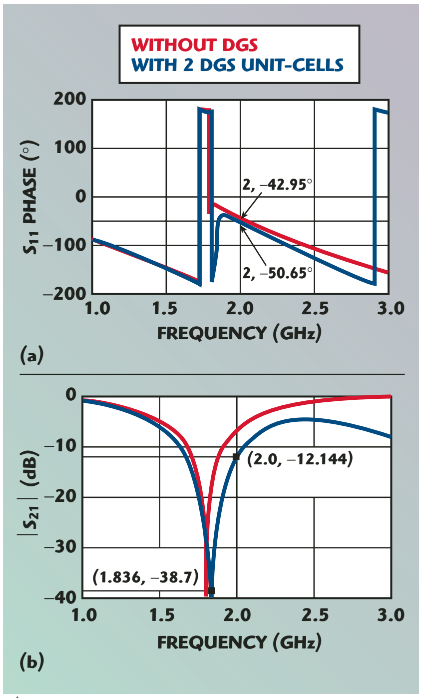
In the case of the microstrip with length l_o, another even larger DGS unit-cell could also be proposed since $l_o > d_1$, so the length can be diminished in a greater proportion. Following the same procedure, a 5 mm DGS unit-cell is proposed, obtaining a reduced dimension of $l_o = 23.5$ mm. The structure with two DGS unit-cells is shown in ***Figure 4***. To analyze the performance and behavior of the matching network with the open-circuited stub with and without imperfections, the structures are analyzed as two-port black boxes. The results are shown in ***Figure 5***, where a comparison with the conventional stub can be observed. It is shown that the response of the open-circuited stub is not adequate, since there is a difference of 8° in the phase response, and



▲ *Fig. 3 Matching network (a) and line as an open-circuited λ/4 resonator (b).*

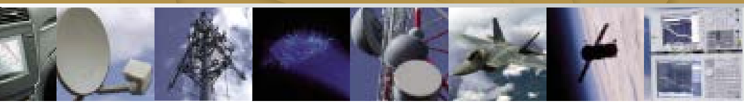


▲ *Fig. 4 Matching network with two DGS unit cells.*



▲ *Fig. 5 Comparison of phase (a) and magnitude (b) responses of an open-circuited structure with two DGS unit-cells and a conventional matching network.*

OPTICAL & MW AMPS



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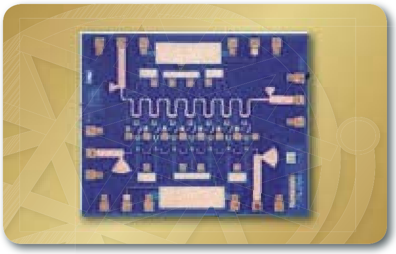

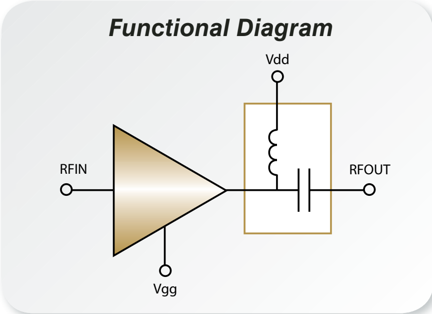

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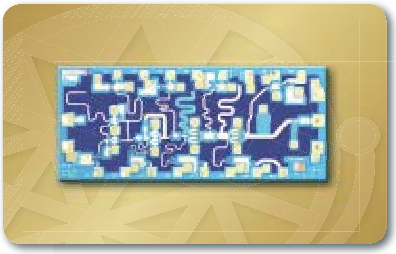
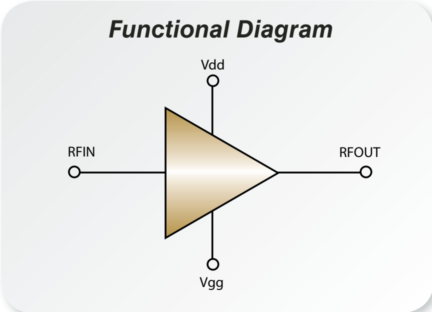
3 NEW HITTITE - VELOCIUM OPTICAL DRIVER AMPLIFIERS

	Frequency (GHz)	Function	Gain (dB)	Group Delay Variation (ps)	Additive Jitter (ps RMS)	Output P1dB (dBm)	Output Voltage Level (Vpk-pk)	VELOCIUM Part Number	HITTITE Part Number
NEW!	DC - 35	Wideband Optical Driver	15	±10	-	21	8	AUH249	**HMC-AUH249**
NEW!	DC - 45	Wideband Optical Driver	14	±10	0.4	16.5	8	AUH232	**HMC-AUH232**
NEW!	DC - 65	Wideband Optical Driver	10	-	-	8	2.5	AUH312	**HMC-AUH312**

HMC-AUH256 Microwave Driver Amplifier, 17.5 to 41 GHz





- ***Gain to 21 dB***
- ***P1dB Output Power: +20 dBm***
- ***Wideband Performance: 17.5 to 41 GHz***
- ***Psat Output Power: +23 dBm***
- ***Output IP3: +27 dBm***

3 NEW HITTITE - VELOCIUM WIDEBAND DRIVER AMPLIFIERS

	Frequency (GHz)	Function	Gain (dB)	Output IP3 (dBm)	P1dB (dBm)	Bias Supply	VELOCIUM Part Number	HITTITE Part Number
NEW!	17.5 - 41	Driver	21	27	20	+5V @ 295mA	AUH256	**HMC-AUH256**
NEW!	DC - 35	Wideband Driver	15	-	21	+5V @ 200mA	AUH249	**HMC-AUH249**
NEW!	DC - 45	Wideband Driver	14	-	16.5	+5V @ 180mA	AUH232	**HMC-AUH232**
NEW!	DC - 65	Wideband Driver	10	-	8	+8V @ 60mA	AUH312	**HMC-AUH312**

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	R&S®FSUP8	8 GHz
R&S®FSQ from 20 Hz	R&S®FSQ40	
	R&S®FSQ26	26.5 GHz
	R&S®FSQ8	8 GHz
	R&S®FSQ3	3.6 GHz
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R&S®FSG from 9 kHz	R&S®FSG13	13 GHz
	R&S®FSG8	8 GHz
R&S®FSP from 9 kHz (opt. 30 Hz)	R&S®FSP40	
	R&S®FSP30	
	R&S®FSP13	13.6 GHz
	R&S®FSP7	7 GHz
	R&S®FSP3	3 GHz
R&S®FSL from 9 kHz	R&S®FSL6	6 GHz
	R&S®FSL3	3 GHz
R&S®FSH from 9 kHz	R&S®FSH18	18 GHz
	R&S®FSH16	6 GHz
	R&S®FSH3	3 GHz
R&S®FS3x from 9 kHz	R&S®FS315	3 GHz
	R&S®FS300	3 GHz

*With external mixer

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Measuring receiver for signal generator and attenuator calibration with high linearity

R&S®FSUP
Phase-noise test set and signal source analyzer with integrated high-end spectrum analyzer

R&S®FSQ
Signal analyzer with integrated spectrum analyzer up to 40 GHz (similar to the R&S®FSU) and up to 120 MHz I/Q demodulation band-width

R&S®FSG
Signal analyzer for broadband com-munication applications with 28 MHz IQ demodulation band-width

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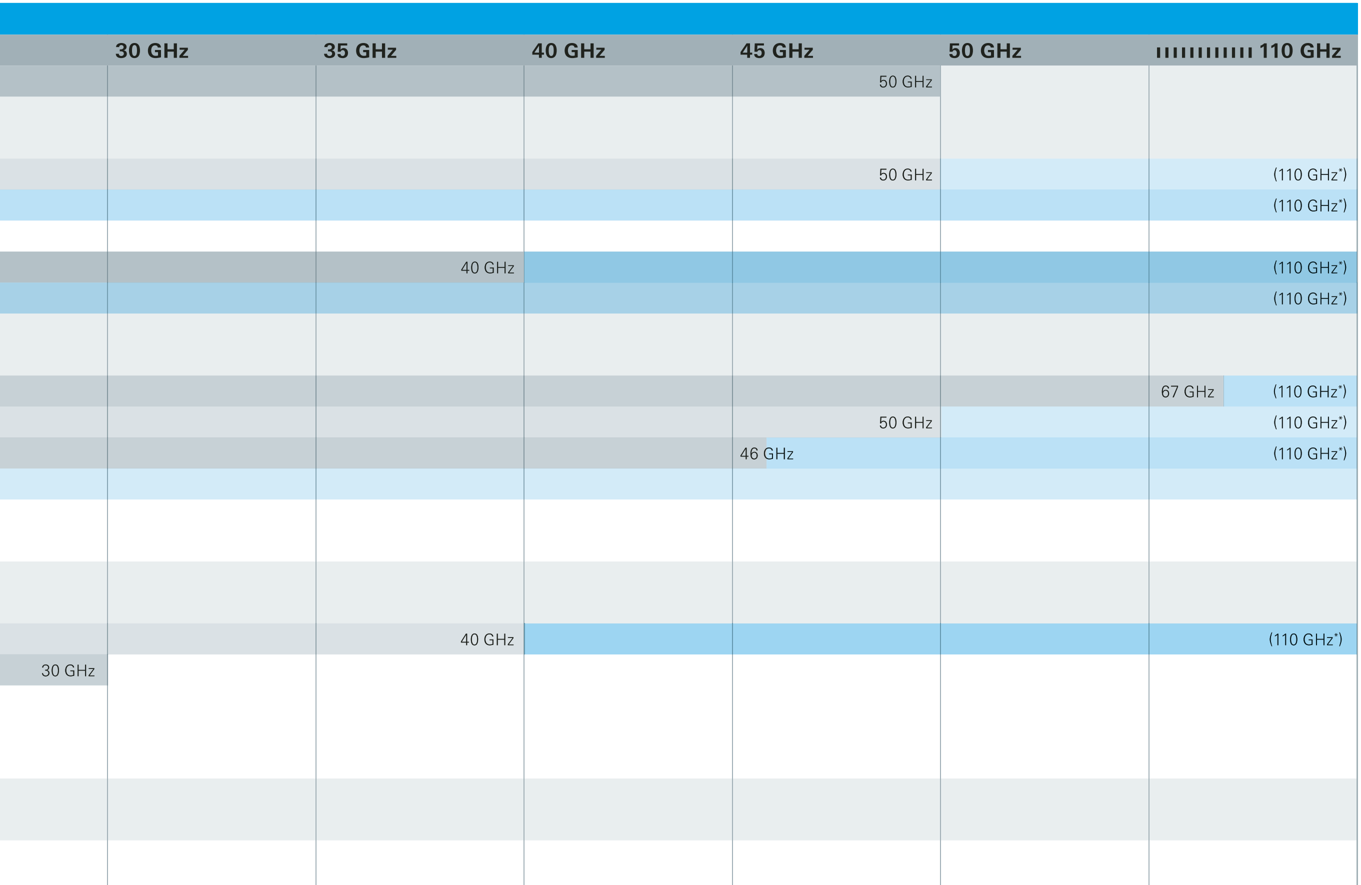

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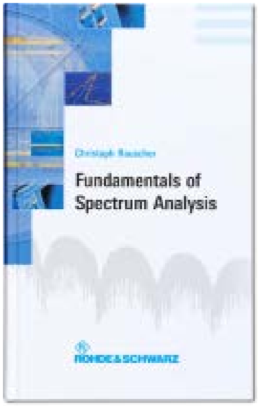

Christoph Rauscher: Fundamentals of Spectrum Analysis

One of the most common measurement tasks in communications engineering is the analysis of signals in the frequency domain. The spectrum analyzers required for this purpose are among the most important and commonly used test instruments in RF engineering. This book by Christoph Rauscher conveys the fundamentals for the proper and efficient use of these instruments. The material takes a close look at design and features, including the important internal relationships between the measurement parameters. In addition, the author covers typical applications and provides valuable tips for everyday lab work.

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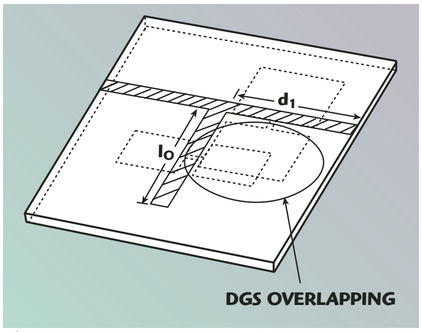
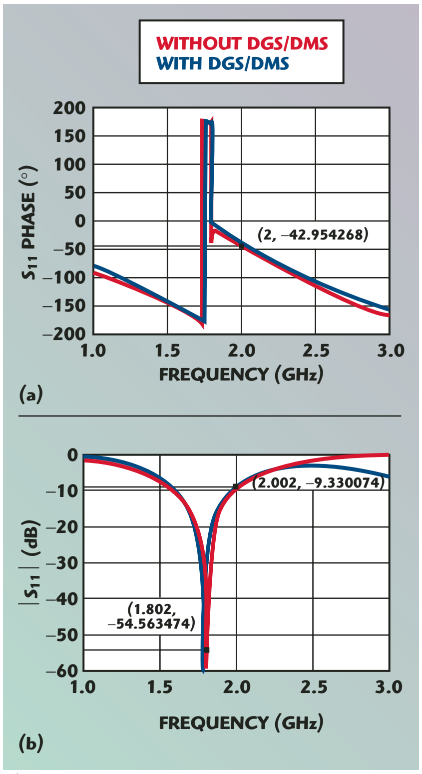
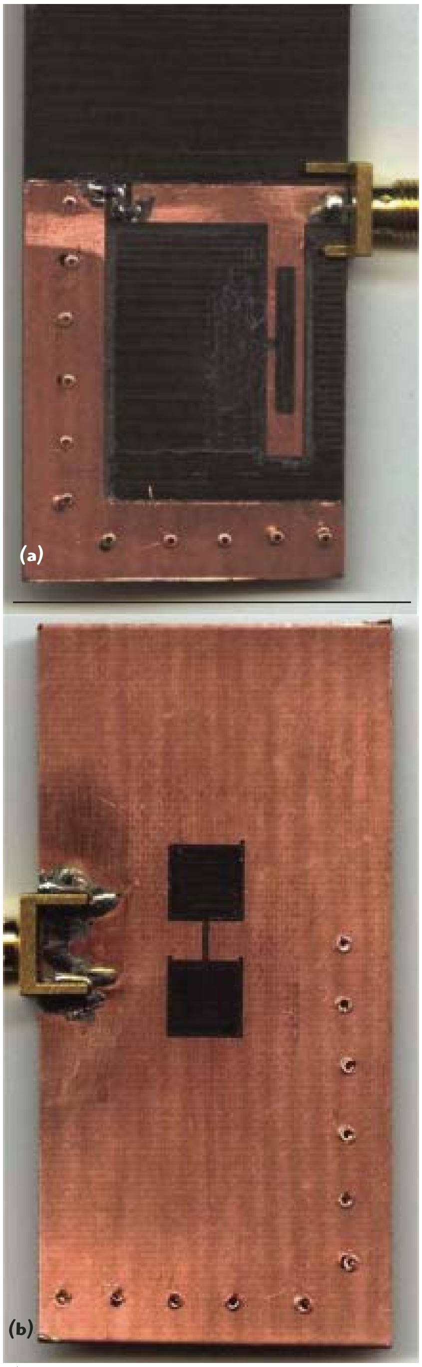
more than 7 dB in the magnitude response in comparison with the conventional stub. This divergence in the response is due to the fact that there is an interaction between the unit-cells because of their proximity in the ground plane, which gives rise to a coupling between the structures. The associated inductance of each one is modified, resulting in a different electrical length for the lines. Therefore, the use of two DGS unit-cells in this kind of structure would not be the most viable solution, since there could be a worst case: a cell overlapping, as shown in ***Figure 6***. Because of the problem described, the use of a DMS unit-cell instead of a DGS cell is proposed to reduce the length of the second line. This way there is no interference in the performance of each imperfection, now that one is located in the ground plane under the microstrip line with a length d_1 and the other is placed over the second microstrip line. After some iterations and analyses of the behaviour of the electric length, and in order to achieve a large reduction of dimensions, the unit-cell obtained is 15 mm long by 2 mm wide. The line with the DMS cell is simulated and the electrical length of the complete structure is obtained. This electrical length is 111.66° at 1.83 GHz. Using Equations 5 and 6, the SWF is 1.71 and the new reduced length is l_{0c} = 23.9 mm. The total reduction of both lines is 36 and 20 percent for d_1 and l_o, respectively. The results from simulation of the open-circuited stub with no defects and the structure with DGS and DMS unit-cells are shown in ***Figure 7***, in which a great convergence is observed, especially at 2 GHz, where the circuit was designed to operate. ***Figure 8*** is a photograph of the matching network with DSG and DSM unit-cells. The measured S_{11} response of both structures is shown in ***Figure 9***, showing similar performance at the design frequency and a better behaviour in the case of using an open-circuited stub with DGS/DMS unit-cells to implement the matching network, considering bandwidth and matching.



▲ *Fig. 6 DGS overlapping in a matching network application.*



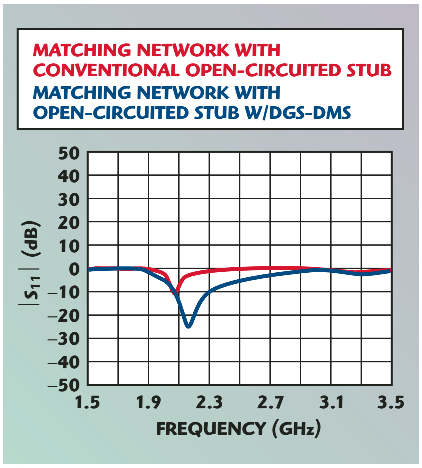
▲ *Fig. 7 Comparison of phase (a) and magnitude (b) responses of a matching network with DGS/DMS unit-cells and a conventional matching network.*



▲ *Fig. 8 Matching network with DGS and DMS unit-cells; (a) front view and (b) rear view.*

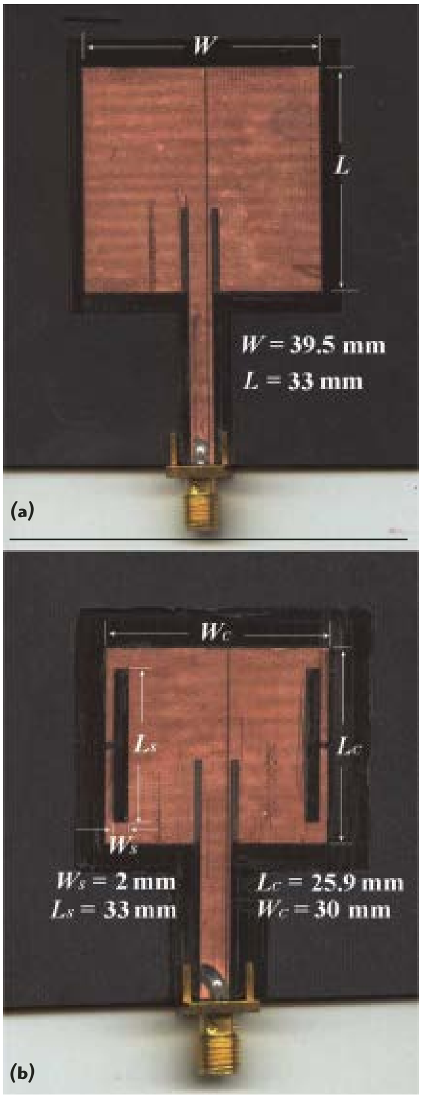
Square Patch Antenna

A microstrip rectangular patch antenna is an element that can be seen as a λ/2 line resonator. The dimensions of such a structure are L × W, where L is the element length and W is the element width, as shown in ***Figure 10***. To apply the size reduction method to these kinds of structures, a procedure similar to the one previously explained is followed. A conventional antenna is designed to resonate at 3 GHz and its performance is analyzed. The substrate material on which the antenna is built

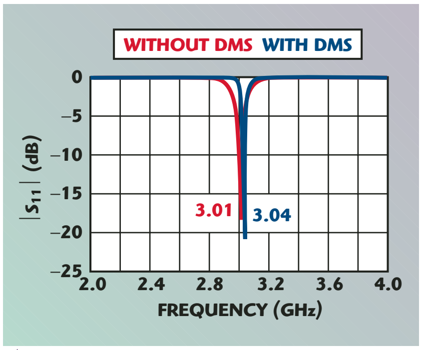


▲ *Fig. 9 Measured S_{11} response for the matching networks with open-circuited stubs and with DGS/DMS unit-cells.*

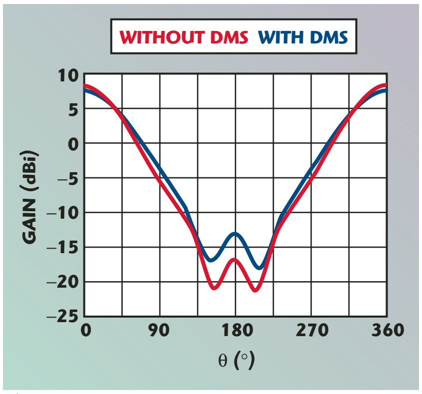
has a dielectric constant of 2.2 and a thickness of 1.27 mm. The calculated dimensions of the antenna are L = 33 mm and W = 39.5 mm and the feeding line is 4 mm wide. The antenna has a physical structure derived from a microstrip transmission line.[8] The patch antenna is modeled as a length of transmission line of characteristic impedance Z_0 and with a propagation constant $\gamma = \alpha + j\beta$. The fields vary along the length of the patch and remain constant across the width. Then, to simplify the analysis, the antenna can be seen as a microstrip line with length L and the width can be modified to handle a smaller magnitude. Therefore, a thinner element can be used. A line width of W_1 = 4 mm is proposed, considering the substrate's characteristics necessary to obtain a 50 Ω impedance, to facilitate the simulation procedure. With this line of length L = 33 mm and W_1 = 4 mm, by using Equation 4, the resonant frequency is obtained when the element is working as an open-circuited λ/4 resonator, f_r = 1.66 GHz and the wave number at this frequency is $k_0 = 34.76 m^{-1}$. To optimize the size reduction of the antenna, it is necessary to provide the largest possible SWF without degrading the performance of the device for which a large enough DMS unit-cell is proposed. The dimensions of such a cell are 20 mm long by 2 mm wide. In the next step, the electrical length of the structure with the unit-cell at f_r is obtained by EM simulation. In this case, θ_c = 113.5° at 1.66 GHz. By using Equations 5 and 6, the new length of the antenna with the DMS unit-cell is L_c = 25.9 mm. The ratio W/L is kept to maintain the cross-polarization levels sufficiently low; therefore, the new dimension of W is W_c = 30 mm, obtaining an area reduction close to 40 percent. The simulated reflection coefficient and gain of the conventional rectangular patch antenna and the reduced patch antenna with DMS unit-cell are displayed in ***Figures 11*** and ***12***. A good agreement is observed between the conventional and the reduced patch antenna, concerning matching and resonance. The difference between these two curves is very small, and a tuning technique can be employed to move the resonance of the patch antenna with DMS from 3.04 to 3.00 GHz. On the other hand, the gain and radiation pattern in both antennas remains almost the same. Consequently, introducing DMS slots in the non-radiating edges does not considerably modify the characteristics of these antennas. The measured resonant frequency of both antennas is shown in ***Figure 13***. These results are similar to those obtained by EM simulation. It is then clear that the method employed to determine the new reduced length and dimensions of a rectangular patch antenna is effective and accurate. The difference between the dimensions of unit-cells and line lengths obtained by formulas and by simulation for adequate performance is close to three percent in both microstrip circuits, which is a good trade-off.



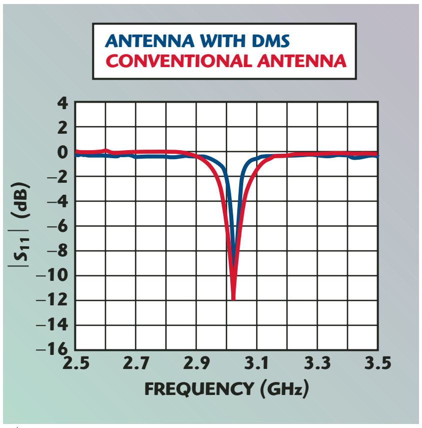
▲ *Fig. 10 Antenna without DMS (a) and with DMS (b).*



▲ *Fig. 11 Reflection coefficient of conventional and reduced patch antennas.*



▲ *Fig. 12 Gain of conventional and reduced square patch antennas.*



▲ *Fig. 13 Frequency response of conventional and reduced square patch antennas.*

CONCLUSION

In this work, a simplified method to foretell the reduced dimensions of microstrip circuits is proposed. The procedure is based on simple formulas, and EM simulation to obtain the SWF is introduced, when DGS or DMS cells are employed in passive planar circuits. The method is based on the reduction of the phase velocity in lines with discontinuities, which means increasing the SWF. Generally, this can be applied to most microstrip circuits and is also useful


contact

when one or more DGS/DMS unit-cells are used to increase the SWF. The limitation of this method is the geometry of the microstrip circuit itself, when defected structures cannot be employed. By using this procedure, the size reduction of a matching network with an open-circuited stub was successfully achieved, improving the performance of the circuit in which a wider coupled bandwidth was observed and a size reduction of 20 to 36 percent was achieved. The size of a square patch antenna was also reduced, obtaining great results without modifying the behaviour of the original structure, concerning resonance frequency, coupling, gain and radiation pattern, and achieving an area reduction close to 40 percent. The predicted size reduction differs by approximately three percent from the experimental one. ■

ACKNOWLEDGMENT

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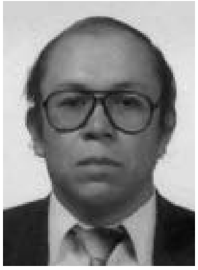
José Alfredo Tirado-Méndez *received his BS degree in electronics and digital systems from UAM-Azcapotzalco and his MSc degree in telecommunications from CINVESTAV in 1999 and 2001, respectively. He joined the Microwave and Remote Sensing Laboratory at the University of Massachusetts in 2001. In 2002, he joined the Telecommunications Section at CINVESTAV as a research assistant. He is currently working toward his PhD degree in telecommunications at CINVESTAV-Mexico. His research interests include electromagnetic compatibility and nonlinearities as well as RF and microwave circuit design, patch antennas and microstrip filters.*



Hildeberto Jardón-Aguilar *received his BS degree in electrical engineering from ESIME-IPN and his PhD degree in radio systems from the Moscow Technical University of Telecommunications and Informatics. He has been working at the Center of Research and Advanced Studies since 1985 and is currently a full professor. His research interests include analysis of nonlinearities in RF and microwave circuits, electromagnetic compatibility and photonic systems.*

Edgar Alejandro Andrade-González *received his BSEE degree from Autonomous Metropolitan University (UAM), Mexico, in 1994. He is currently working toward his master's degree in electrical engineering at CINVESTAV-IPN. He is a professor in the department of electronics and communications at Metropolitan Autonomous University-Azcapotzalco. His research interests include personal communications and the design of electronic circuits for high frequencies.*

Mario Reyes-Ayala *received his BSEE degree from Metropolitan Autonomous University (UAM), Mexico, in 1994, and his MSEE degree from CINVESTAV-IPN, Mexico, in 2005. From 1994 to 1996, he was a department head at AEG Mexicana in Mexico City. In 1999, he joined the electronic department at UAM and he has been engaged in studies on digital satellite communications and propagation models for radio communication systems. His research interests also include theoretical analysis in satellite interference phenomena.*

FILTERING CAPACITORS EMBEDDED IN LTCC SUBSTRATES FOR RF AND MICROWAVE APPLICATIONS

This article presents a new solution to build filtering capacitors embedded in low temperature co-fired ceramic (LTCC). A new low loss high-k dielectric (K = 80) tape compatible with DuPont low-k tapes has been developed and used in order to demonstrate embedded filter capacitors in LTCC substrates. The BZN powder with the chemical composition $Bi_2(Zn_{1/3}Nb_{2/3})_2O_7$ was prepared using a conventional ceramic process. Ceramic tapes were prepared by tape casting using the Doctor-Blade technique. Electromagnetic properties of the sintered ceramics and tapes were measured. At 2.9 GHz, the permittivity is 78 with $\tan\delta = 10^{-3}$. The LTCC manufacturing process was adapted to composite dielectric stacks. LTCC test vehicles including buried filtering capacitors were designed, manufactured and submitted to an evaluation program. The new technology allows a capacitance density of 15 pF/mm^2. Capacitors from 4 pF to 30 pF were characterized in the 300 MHz to 6 GHz frequency range showing satisfactory properties. Embedded capacitor structures were analyzed with a 3-D EM simulation software and a good agreement with measurements was obtained.

With the continuous trend to reduce the size of electronic modules and increase the integration levels, the integration of passive elements within the interconnection board or substrate becomes more and more a key factor. In addition to size reduction, passive integration leads to assembly cost reduction as well as potential module reliability improvements.

Among different substrate technologies, low temperature co-fired ceramic (LTCC), which offers performance suitable for RF and microwave applications, features unique capabilities with regard to passive integration. This article reports the evaluation of a new developed dielectric material and related process used to build an RF capacitor embedded in a LTCC multi-layer substrate.

JEAN-PIERRE BERTINET, EDDIE LELEUX AND JEAN-PIERRE CAZENAVE
THALES Microelectronics
Châteaubourg, France
JEAN-PIERRE GANNE, MICHEL PATÉ AND RICHARD LEBOURGEOIS
THALES Research & Technology
Palaiseau, France
EDDA MUELLER AND FRANZ BECHTOLD
Via-Electronic
Hermsdorf, Germany

LTCC TECHNOLOGY

LTCC is a ceramic-based technology using low resistivity conductor material such as silver, copper or gold. ***Figure 1*** shows the conventional process flow used to manufacture LTCC ceramic multi-layer substrates. With regard to integration of passive elements, LTCC offers the potential to build composite ceramic structures mixing low and high permittivity dielectrics as well as ferrite materials to enlarge its capabilities of capacitors and inductors.

TECHNICAL APPROACH

Several solutions are used to build integrated capacitors within an LTCC multi-layer substrate.[1] The two most common approaches are shown in ***Figure 2***. The first option consists of printing locally a high-k paste on the standard tape (a). In the second approach, the standard LTCC tape itself is used as the dielectric of the capacitor. With this technique, thinner tapes and several layers can be stacked to increase the capacitance density.[5] Due to the poor thickness accuracy of the printing process, solution (a) is not suitable to build high tolerance capacitors and is therefore not relevant for filtering applications. Due to the better thickness control of the tape casting process, option (b) can offer better capacitance accuracy. However, the low dielectric constant of the standard LTCC materials (7.8 for DuPont 951) limits the capacitance density to 2 to 3.5pF/mm^2/per layer depending on the tape thickness. The determination of the capacitance of a parallel capacitor is described in Equation 1.

$$C = \varepsilon_0 \varepsilon_r \frac{LW}{t} \quad (1)$$

edge effect excluded
rectangular electrodes

where

L = electrode length
W = electrode width
T = dielectric thickness
ε_0 = permittivity of the dielectric material

To offer better density together with a satisfactory thickness control, a third alternative can be considered consisting in using a high-k dielectric tape (see Figure 2). ***Figure 3*** compares the integration density of the high-k tape solution to the capability of the standard thin tape option. In the selected example, the capacitance density of the high-k layer is 15 pF/mm^2 for a single layer. As shown by the graph the high-k tape allows reduction of the number of layers, leading to potential cost savings and/or reduction of the size of the capacitor bringing module size reduction. As an example, to design a 10 pF capacitor, the high-k tape requires an electrode size of 0.82 × 0.82 mm with a single layer while 0.91 × 0.91 mm and six layers or 1.1 × 1.1 mm and four layers are necessary using the standard tape material. However, this approach needs a specific material featuring good compatibility with the standard LTCC material.

Evaluation of mixed-dielectric structures to build buried capacitors in LTCC have been reported,[2-4] mention-

ing dielectric permittivity in the 20 to 150 range. So far, however, only a few high-k tape materials are commercially available from conventional LTCC material suppliers. It was decided to develop and study a new material suitable for high frequency applications featuring low dielectric losses ($\tan\delta < 10^{-3}$), medium permittivity in the 80 to 100 range and limited dielectric constant drift over temperature (less than 250 ppm/°C).

DEVELOPMENT OF THE NEW HIGH-K TAPE

The high-k dielectric composition $Bi_2Zn_{2/3}Nb_{4/3}O_7$ was chosen, as it presents the targeted properties: sintering temperature below 1000°C, dielectric constant about 90, with temperature coefficient about 150 ppm/°C, and dielectric loss tangent lower than 10^{-3} at 1 MHz.[6–8]

BZN dielectric materials were produced using the standard ceramic process, as previously described.[9] The permittivity and dielectric losses of sintered material samples were measured using the dielectric resonator method. The following results were obtained:

- Permittivity: 77.8 at 2.9 GHz
- Dielectric losses: 1.10^{-3} at 2.6 GHz
- Thermal Coefficient: 230 ppm/°C at 1 kHz

In order to use this dielectric composition in LTCC multi-layer, 100 µm thick BZN tapes were prepared through the Doctor-Blade technique. Different composition/casting experiments were performed to obtain the optimal mechanical properties of the tape.[9]

BZN/DP951 multi-layer stacks were studied for co-firing with the standard LTCC process in order to analyze the diffusion at material interfaces as well as the sintering density.

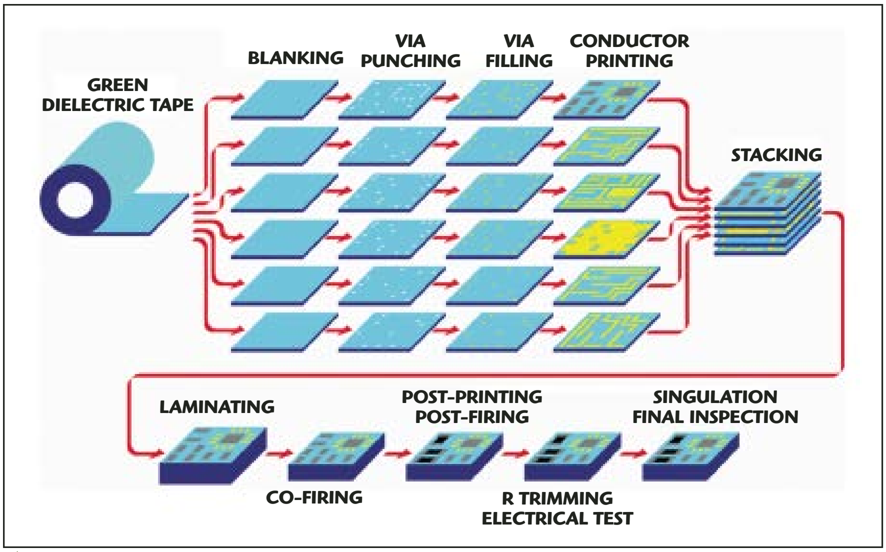
The results shows very good compatibility: the interface between materials is dense and smooth and a well-controlled diffusion zone between materials of about 2 microns thickness was observed through Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) techniques.

LTCC PROCESS ADAPTATION

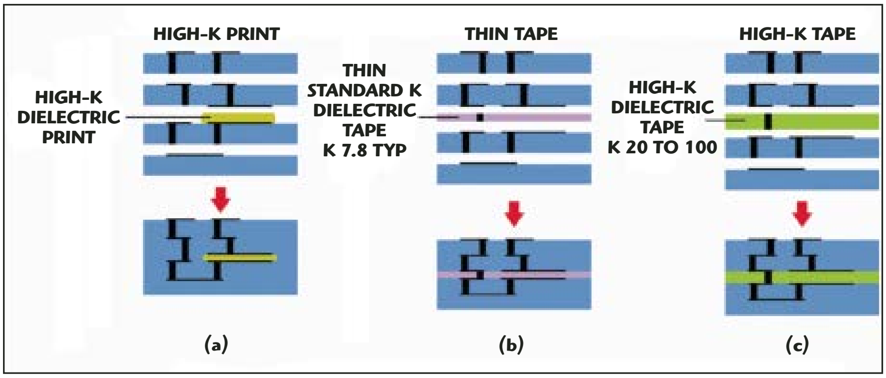
Starting from the conventional LTCC process, all the manufacturing steps were adapted to the new material as well as the mixed dielectric structure. A particular emphasis was dedicated to the sintering operation to allow the realization of flat substrates with the so-called free sintering option. Regarding the shrinkage in x and y of the substrate after co-firing, it was demonstrated that 951/BZN sandwiches such as 2 × 951A2/1 × BZN/2 × 951A2 allow the nominal shrinkage of the 951 dielectric to be preserved (that is, 12.7 percent).

TEST VEHICLES DESIGN AND REALIZATION

A specific test vehicle (TV2) was designed to perform the electrical characterization of the integrated capacitors. This test vehicle includes in total 42 capacitors featuring various electrode dimensions and configurations. ***Figure 4*** shows the typical vertical structure of an integrated parallel capacitor designed with a single BZN layer. The top



▲ *Fig. 1 LTCC manufacturing process.*



▲ *Fig. 2 High-k tape vs. high-k print technique.*

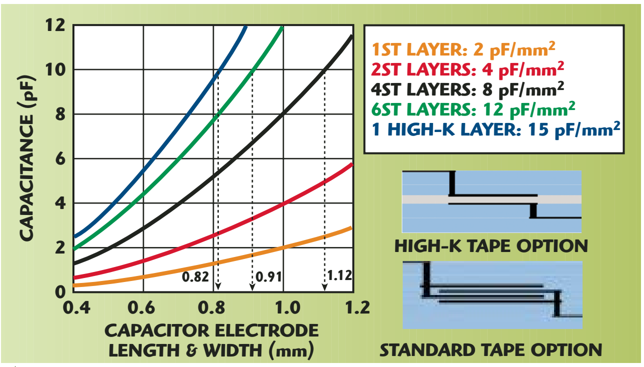
electrode width and length vary from 550 to 1650 µm while its resulting area varies from 0.30 to 1.8 mm². The bottom electrode is 100 µm larger than the top one (50 µm on both sides) to reduce the effect of possible misalignment between electrodes on capacitance variation. To allow RF measurement, the top electrode of each buried capacitor is connected via a microstrip line to coplanar access pads printed on the top surface of the LTCC substrate.

A set of RF calibration structures is also included in the test vehicle design.

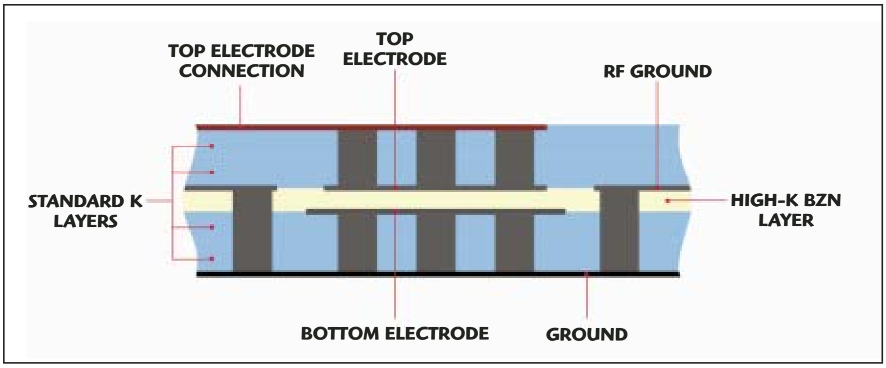
Several panels of this specific test vehicle were manufactured for technology evaluation and RF characterization purpose. A picture of a test vehicle sample is given in ***Figure 5*** showing its topside with the RF access pads.

The flatness of the test substrate was verified. The optimized sintering profile allows satisfactory results to be obtained, the overall camber being lower than 0.3 percent of the panel diagonal.

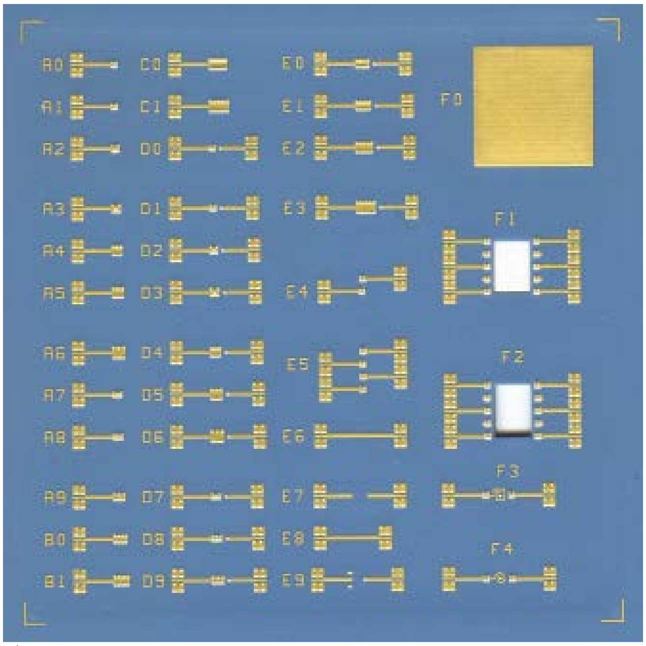
Several cross-sections of the test vehicle were realized to check the integrity of the multi-layer structure. The picture in ***Figure 6*** shows a typical cross-section of an integrated capacitor. No voids or delamination occurs at the high-k BZN/



▲ *Fig. 3 Capacitance vs. electrode size, number and type of dielectric layers.*



▲ *Fig. 4 Z structure of an integrated capacitor.*



▲ *Fig. 5 Test vehicle sample.*

951 interface. The average value of the high-k BZN dielectric thickness is 62 µm (between electrodes).

Building mixed dielectric multi-layer may degrade the mechanical performance. The flexural strength and the Young modulus of the substrate was therefore verified, performing three-point bending test on mixed structures as well as on pure 951 stacks. The two configurations did not show any significant difference giving average values of 250 MPa for flexural strength and 100 GPa for Young modulus.

RF CHARACTERIZATION

As previously mentioned, all the embedded capacitor test structures on test vehicles are connected to the top surface of the LTCC panel via the same interface made of a 50 Ω microstrip line terminated with a 50 Ω coplanar pad structure. Capacitor elements were measured from 50 MHz to 6 GHz with coplanar microwave probes (ground-signal-ground, 350 µm pitch, 40 GHz).

The vector network analyzer (VNA) was calibrated using the SOLT calibration kit included on the test panel, so the measurement reference plane is located at the edge of the top capacitor electrode. The S-parameters obtained from the VNA were processed via a microwave circuit simulation software.

Figure 7 gives the typical result obtained on the smallest capacitor structure A0 (electrode area = 0.30 mm^2). Considering the whole measured batch, the A0 structure gives the following average parameters:

- Capacitance at 300 MHz = 5.1 pF
- Quality factor at 300 MHz = 50
- First resonance frequency = 3.5 GHz

The different capacitor test structures featuring various electrode sizes and shapes were measured on several LTCC test panels. ***Table 1*** gives the synthesis of the overall results.

3-D ELECTROMAGNETIC SIMULATIONS

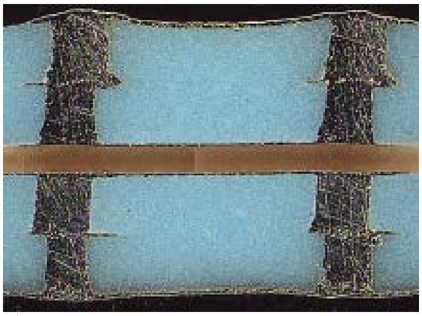
The embedded capacitor was described (see ***Figure 8***) and simulated with a 3-D Electromagnetic (EM) simulation software aiming to:

- Determine the parasitic elements and understand the influence of materials performance

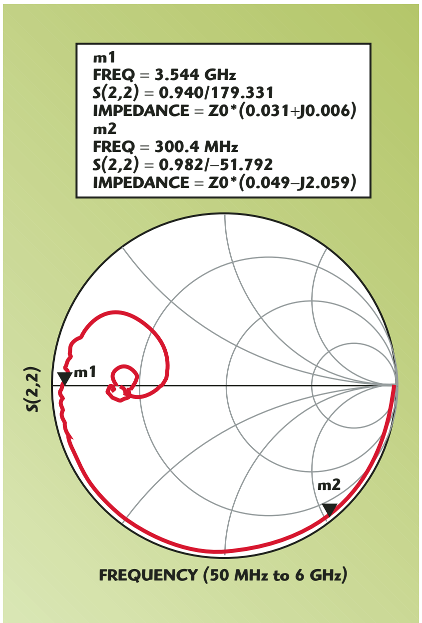
• Optimize the design of the capacitor structure limiting the number of the time-consuming and costly test vehicle design-manufacture-test iterations

The 3-D EM simulation software used presented some mode confusions when the structure was simulated with grounded coplanar ports. In order to overcome this issue coplanar and microwave probes were included in the simulated structure, as shown in ***Figure 9***. With this structure, the access port becomes coaxial and thus eliminates the mode confusion issue. To shift back the electrical reference plane to the capacitor element, the complete access structure was simulated as well to obtain the S2P parameter file. The S2P parameter file was then used to determine the de-embedded results with the microwave circuit simulator. Thanks to this method, satisfactory simulation results were obtained giving good correlation between RF measurements and simulation, as shown in ***Figure 10***.

Further simulation experiments allowed some routes to optimize the Q factor to be identified. In particular, it was demonstrated that additional grounding via-holes increased the Q factor significantly.



▲ *Fig. 6 Cross-section of a capacitor.*

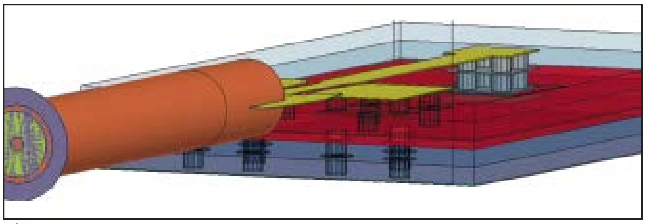


▲ *Fig. 7 Typical measurement result on Ao.*

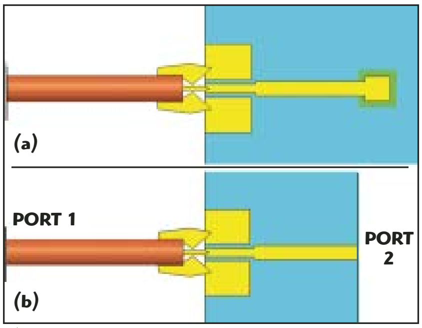
TABLE I

SYNTHESIS OF CAPACITOR MEASUREMENTS

Electrode area range (mm^2)	0.30 to 1.8
Capacitance range @300 MHz (pF)	5 to 30
Average capacitance density (pF/mm^2)	15
Q factor range @300 MHz	40 to 60
Resonance frequency range (GHz)	2 to 3.5



▲ *Fig. 8 Simulated structure.*



▲ *Fig. 9 Probe access simulation (a) and the structure for de-embedding (b).*

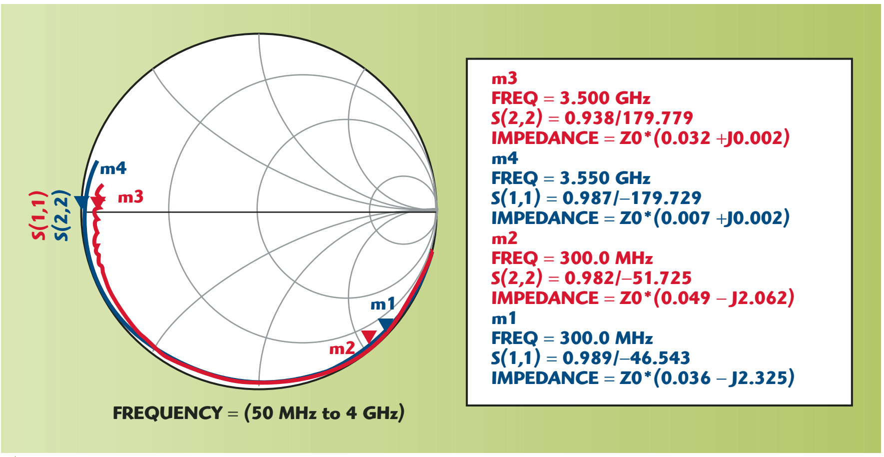
ELECTRICAL MODELING

An electrical model of the A0 capacitor structure was designed (see ***Figure 11***). In this model, the low frequency (before the first resonance) behavior is mainly modeled by the elements TL1, R3 and C1. The high frequency behavior (from the first resonance) is mainly modeled by the two resonant circuits SRLC1 and PRLC1.

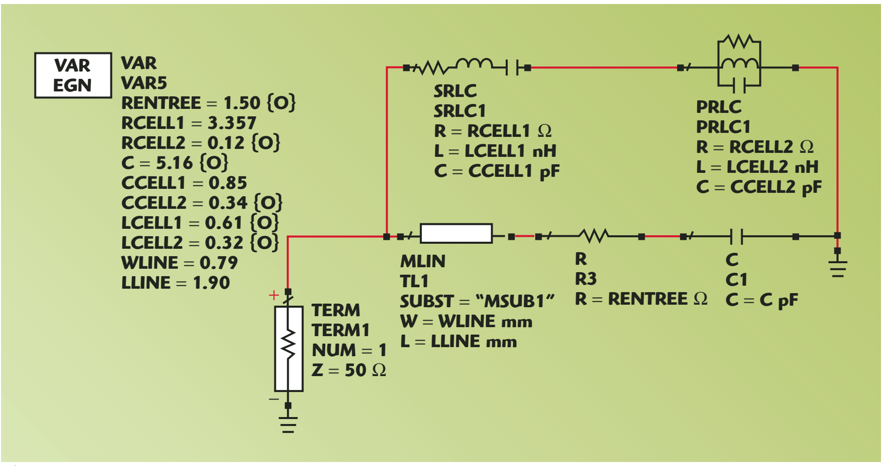
Figure 12 shows the correlation between the response of the electrical models and the RF measurement. In the same way this model can be fitted to different capacitor dimensions in order to design a parameterized model. Such a model, implemented on a microwave circuit simulator, allows one to perform the simulation and optimization of filter structures easier and faster.

ASSEMBLY AND ENVIRONMENTAL EVALUATION

The compatibility of the developed material and process with as-



▲ *Fig. 10 Comparison between 3-D EM simulation and RF measurement.*



▲ *Fig. 11 Typical electrical model.*

sembly and packaging techniques was evaluated by performing wire-bonding trials and flip chip assembly experiments as well as building BGA structures. A second test vehicle was designed for this purpose and two batches were manufactured: a first one with the high-k BZN layer and a second one without the high-k BZN layer as the reference (conventional LTCC). All the assembly trials performed did not point out any drawback related to the high-k BZN technology with regard to the different process aspects. As an example, ***Figure 13*** shows a cross-section of a flip chip assembly structure on a high-k BZN/DP951 test panel.

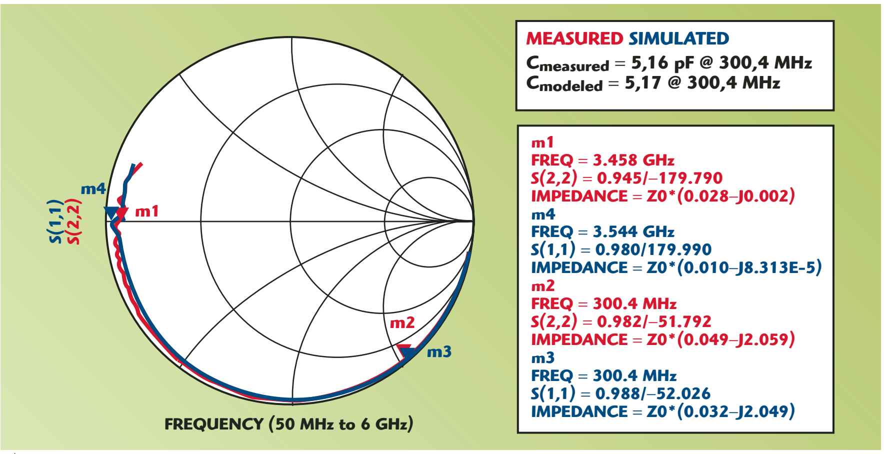
To evaluate the reliability of the developed integrated capacitor technology, several TV2 test panels were submitted to extensive environmental trials. Three groups were defined to go through the following tests:

- High temperature storage: 1000 hours @ 150°C
- Damp heat test: 1000 hours @ 85°C, 85% RH
- Thermal shocks (2-chamber test): 500 cycles –55°C/+125°C

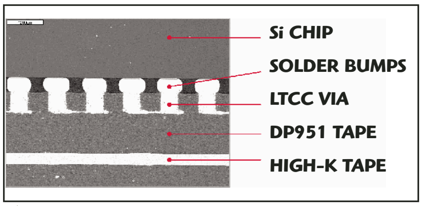
Each capacitor was measured before and after environmental tests as well as at intermediate steps. No failure occurred and no significant drift of the capacitance values was observed along the different tests.

CONCLUSION

A new high-k tape was developed to allow the integration of filtering



▲ *Fig. 12 Comparison between electrical simulation and RF measurement.*



▲ *Fig. 13 Cross-section of a flip chip assembly structure.*

capacitors in an LTCC substrate. This material is well adapted to the DuPont 951 base material system and inner silver conductors. Providing some specific process adaptations it is fully compatible with the conventional LTCC manufacturing flow and does not affect the assembly and packaging capabilities of the standard technology. In addition, good reliability of the mixed-dielectric structures was demonstrated through high temperature storage and a damp heat test as well as thermal shocks. The new material provides a nominal capacitance density of 15 pF/mm^2 with a single layer compared to 2 pF/mm^2 with the standard LTCC tape. Capacitor test structures from 4 to 30 pF were produced and characterized in the 300 MHz to 10 GHz frequency range showing satisfactory properties for use in RF applications up to 2 GHz. Finally, adapted electrical simulation models were defined providing a satisfactory agreement with the RF measurements. ■

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A MINIATURIZED GAAS MMIC BANDPASS FILTER FOR THE 5 GHZ BAND

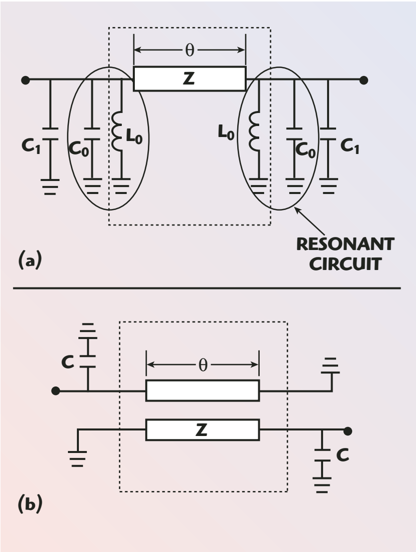
*A novel, miniaturized, GaAs-based bandpass filter for the 5 GHz WLAN band, using coupled lines end-shorted at their opposite sides and lumped capacitors, is proposed. The new filter has a compact size, as small as a few electrical degrees, and shows a wider stop band characteristic, greater than 35 dB up to 60 GHz. A two-stage bandpass filter with a planar structure was designed and fabricated at a center frequency of 5.5 GHz, with a chip size of only 0.54 × 0.78 mm. The fabricated filter has been implemented using the Knowledge*on GaAs process.*

In modern wireless communication systems, miniaturized MMIC microwave bandpass filters are required to reduce the cost and decrease the RF system design time, especially for a single RF transceiver chip. Therefore, many studies on reducing the large size of conventional bandpass filters have been made. The lumped element approach, which uses spiral inductors and lumped capacitors, is one of the solutions to this problem. However, the design of lumped element circuits is somewhat empirical and these circuit demonstrations have been confined to frequencies up to a few gigahertz due to the low quality factors (Q)[1] and low resonant frequencies of the elements. Folded hairpin resonator filters, stepped-impedance resonator (SIR) filters[2–4] and slow-wave open-loop resonator filters[5] have been developed. Using these methods, a relatively compact bandpass filter can be designed. However, they still take up quite a large circuit area. Another disadvantage of these traditional microstrip filters is that they cannot effectively suppress the spurious passband, which may seriously degrade the attenuation level in the stopband and passband response symmetry, and could restrict the applicability of the filters.

Combline filters, using low temperature co-fired ceramic (LTCC) or ceramic materials with a multi-layer technology, can be used as a reduced size bandpass filter.[6,7] Conventionally, however, their electrical length has been recommended to be 45° or less for efficient coupling.[8] Nowadays, SAW filters are widely used in the mobile communication market. But they are still not compatible with standard IC technology and are not presently available in the frequency range up to 3 GHz.[9] An active bandpass filter can be integrated in a single manufacturing process. In this case, the active circuit, which behaves as a negative resistance, is inserted[10] and has a drawback associated with nonlinearity and poor noise figure.[11] In this article, a novel, miniaturized, GaAs process-based MMIC filter for an RF

IN HO KANG, SHI WEI SHAN, XU GUANG WANG AND YOUNG YUN
Korea Maritime University
Busan, Korea
JI HOON KIM AND CHUL SOON PARK
Information and Communications University
Daejeon, Korea

single transceiver chip is introduced, which allows a complete module to be fabricated on a single chip, thus leading the way toward high volume components at an affordable cost. It is composed of simple planar coupled lines shorted at their opposite ends and lumped capacitors. The main advantages of this MMIC filter are as follows: The electrical length of the resonators can be reduced to as small as a few degrees. Consequently, most chip filters using this concept can be designed to be smaller than 2 × 1 mm. Good suppression of the spurious passband is another advantage. There is no spurious up to about ten times the center frequency in this structure. This property will be most powerful as the image rejection filter in a transceiver system. Moreover, this technology is available using any kind of standard fabrication process, because the topology of this circuit is only a planar two-dimensional structure. Finally, it is also broadly applicable up to the millimeter band because the electrical length can be arbitrarily controlled. A filter, using a GaAs process technology, was designed and fabricated at 5.5 GHz to maximize the effect of the size reduction method, because a SAW filter covers only frequencies below 3 GHz and a ceramic filter is still too large to be inserted in the RF transceiver system. Simulation and measurement results are provided to verify the miniaturized GaAs bandpass filter.



▲ *Fig. 1 Hirota's reduced size λ/4 line including artificial resonant circuits (a) and the equivalent coupled-line circuit (b).*

BANDPASS FILTER USING MINIATURIZED λ/4 SECTION

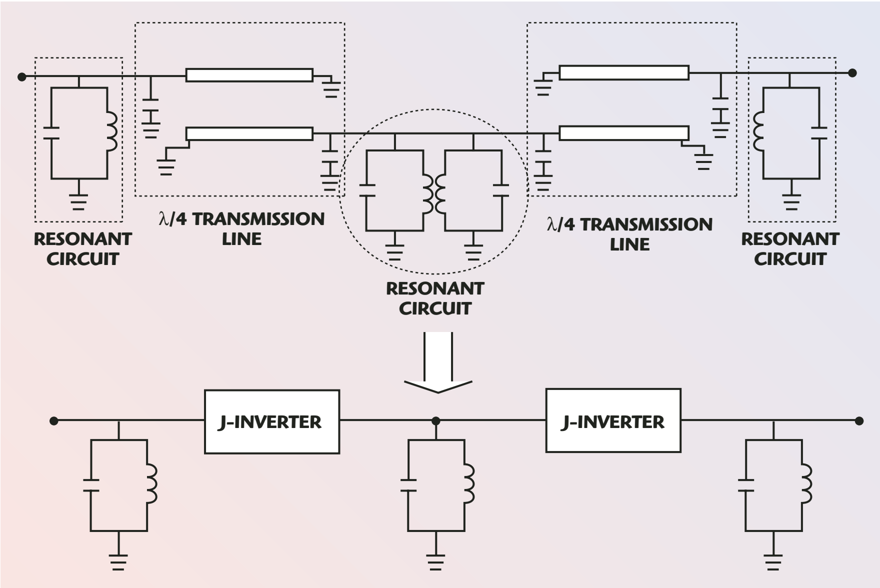
In ***Figure 1***, two artificial resonant circuits are inserted into Hirota's circuits.[12] The high impedance transmission lines with shunt lumped inductors can be replaced by coupled lines shorted at opposite ends, as shown. The two dotted networks are equivalent when the following equations are satisfied

$$\omega L_0 = Z_{oe} \tan\theta \qquad (1)$$

$$\omega L_0 = \frac{1}{\omega C_0} \qquad (2)$$

$$C = C_0 + C_1 \qquad (3)$$

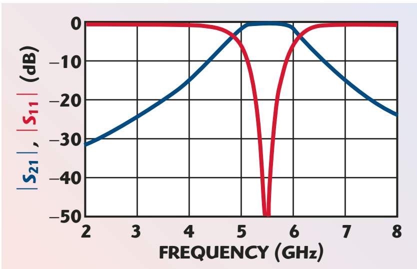
When the miniaturized λ/4 transmission lines are connected in series, they become a typical bandpass filter, with the λ/4 section as an admittance inverter. The circuit and its equivalent circuit are shown in ***Figure 2***. The bandwidth can be controlled by the coupling coefficient.[13]



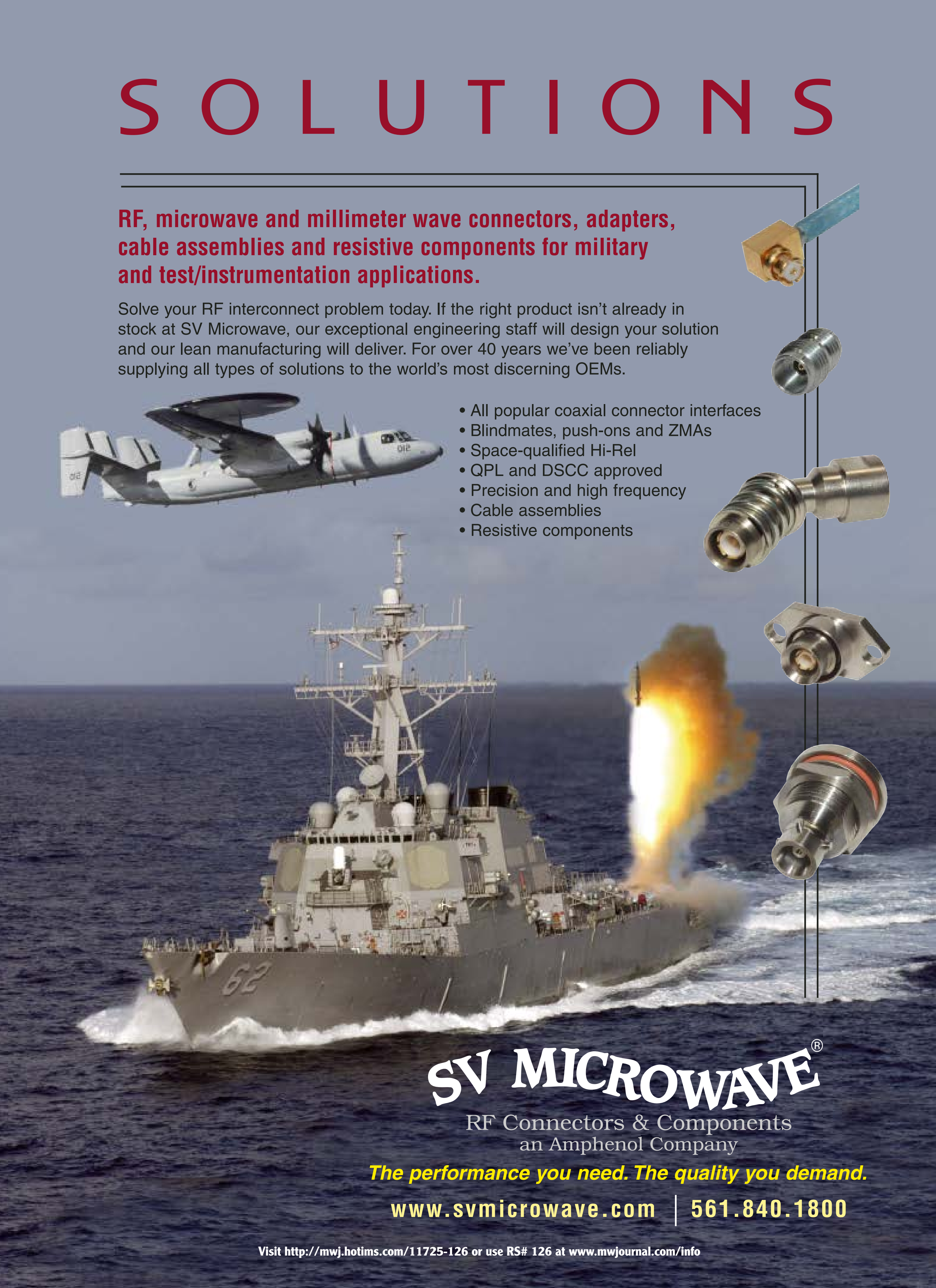
▲ *Fig. 2 The bandpass filter and its equivalent circuit.*

SIMULATION AND MEASUREMENT RESULTS

First, a one-stage GaAs process bandpass filter for 5 GHz WLAN band applications, with $Z_0 = 50\ \Omega$ and $f_0 = 5.5$ GHz, is designed. The electrical length of the coupled lines is set to 7°. An arbitrary Z_{oe} can be selected and Z_{oo} is derived. The selection of Z_{oe} is also related to the bandwidth. The specified response is achieved through circuit simulation with Agilent ADS and with the component values $Z_{oe} = 80\ \Omega$, $Z_{oo} = 58\ \Omega$ and C = 3.52 pF. The physical dimensions of the coupled lines are determined by Z_{oe} and Z_{oo}. ***Figure 3*** shows the calculated response of the filter, simulated with ADS. From the figure, it can be seen that the skirt characteristic is not acceptable even though the insertion loss is adequate. Two identical filter stages are then cascaded as a simple design. The two-stage bandpass filter behaves as a three-pole topology because an admittance inverter is formed by two resonators, one from each stage. If a conventional design technique is used, such as Butterworth or Chebyshev, the components (MIM capacitors and the coupled lines conditions) of each section are different. In extremely miniaturized circumstances, it is very difficult to fabricate each component exactly like the designed one, because of unexpected coupling between components. ***Figure 4*** shows the simulated ADS results. The wide band characteristic shows the good suppression of the spurious passband. Subsequently, the



▲ *Fig. 3 Simulated characteristics of one stage filter.*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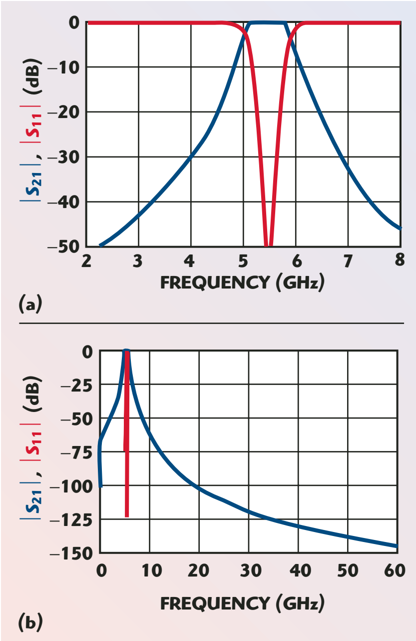
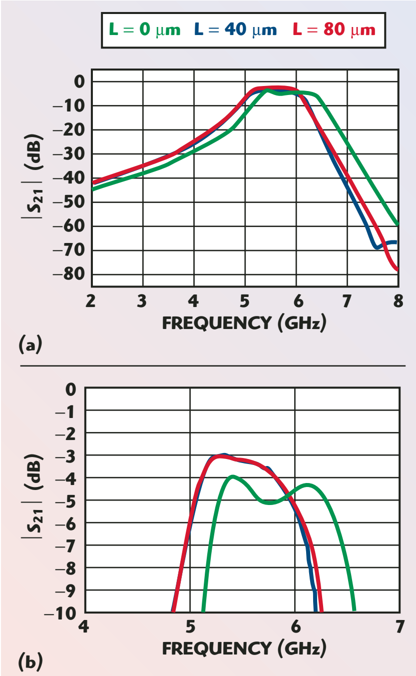
circuit was simulated with HFSS to obtain the overall response. For the actual circuits, an inter-stage connecting line has been used to prevent the unexpected coupling between the two neighboring stages. In order to investigate the inter-stage line length effect on the characteristics of the filter, a group of two-stage bandpass filters with different 50 Ω inter-stage line



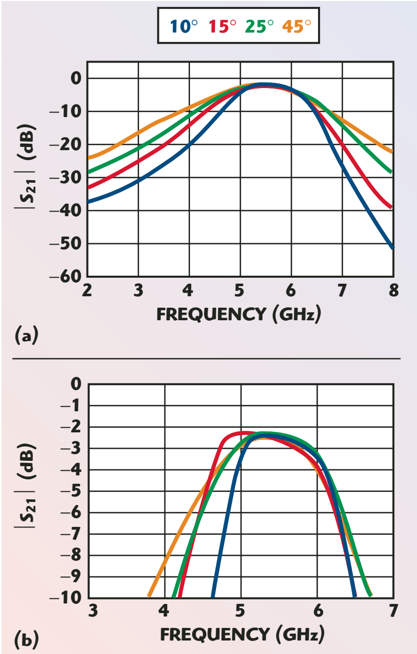
▲ *Fig. 4 Simulated characteristics of the two-stage bandpass filter; (a) narrow band and (b) broad band.*



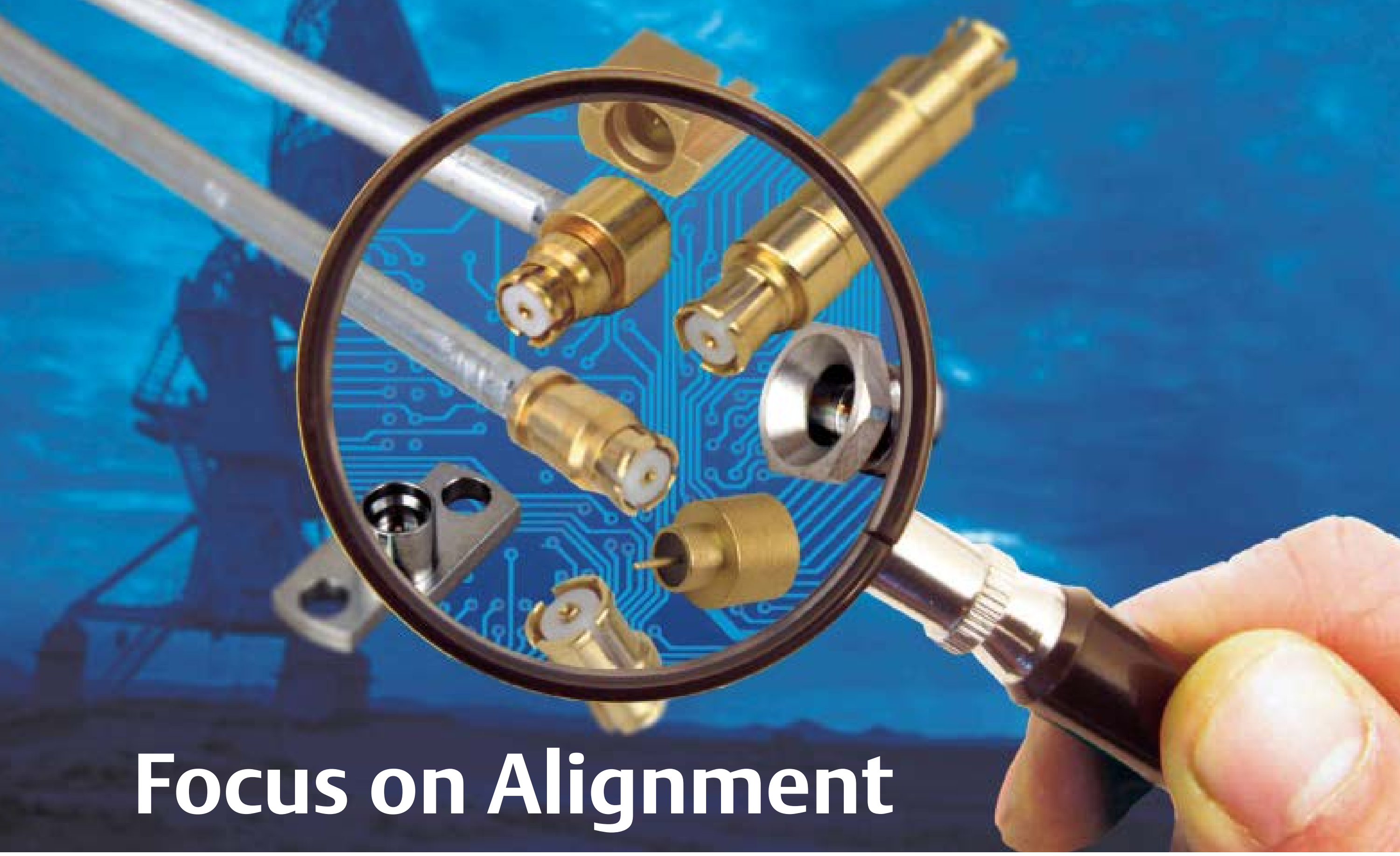
▲ *Fig. 5 S_{21} vs. frequency as a function of the interstage line length; (a) wide range and (b) narrow range.*

lengths have been simulated with HFSS. ***Figure 5*** shows the simulated results. It can be seen that if the inter-stage transmission line is not included between two stages (L = 0 μm), a distortion appears. It is indispensable and the filtering characteristics get better as the line length increases. This concept has been explained previously.[14] However, a compact size is desired, so a tradeoff between the size and good performance must be made. Another comparison was also made as a function of the electrical length of the coupled lines. ***Figure 6*** shows the simulated results for 10°, 15°, 25° and 45° coupled lines filters. Obviously, the skirt characteristics of long electrical length filters are worse than that of small electrical length filters. Considering all the above-discussed factors, a two-stage bandpass filter with a 7° electrical length of coupled lines and a 80 μm long inter-stage line was designed for fabrication. ***Figure 7*** shows the circuit layout in HFSS and the microphotograph of the MMIC. Its size is only 0.54 × 0.78 mm. As far as the authors know, this size is the most miniaturized filter for the 5 GHz WLAN band reported up until now.

According to the HFSS simulation results shown in ***Figure 8***, the effects of eight via holes in the filter circuit can be ignored. The figure also shows that the measured and simulated re-



▲ *Fig. 6 S_{21} as a function of the coupled lines electrical length; (a) wide range and (b) narrow range.*



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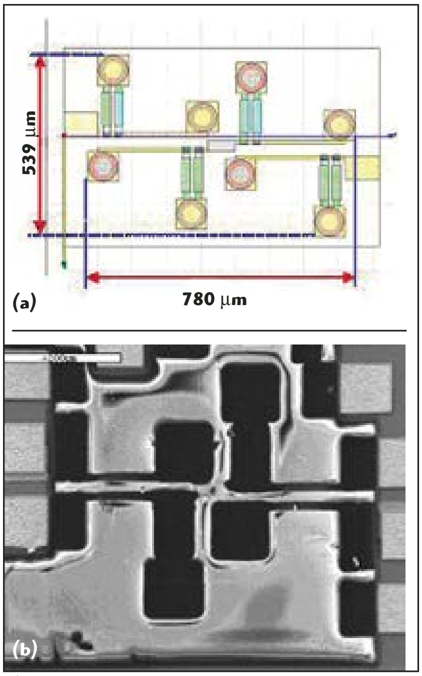
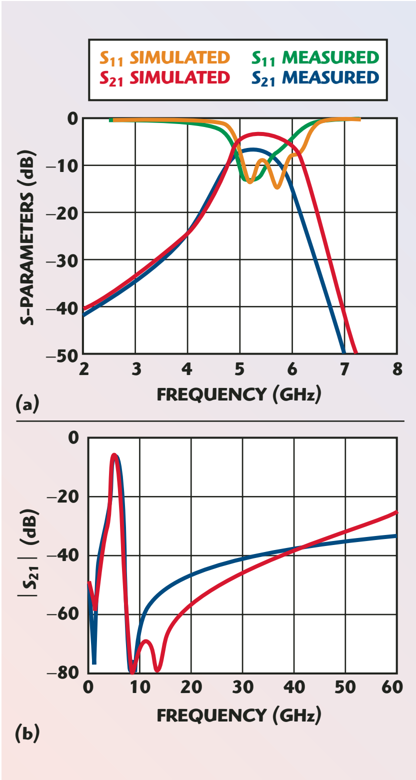
sults are in good agreement. The measured passband has a maximum insertion loss of 6.5 dB over a 0.9 GHz bandwidth, from 4.8 to 5.71 GHz and a 13 dB return loss.

The measured center frequency is shifted to a lower frequency by 0.15 GHz. It is presumed to result from the MIM capacitance fabrication accuracy and simulation error. The bandwidth of measured data is shrunk from 1.15 to 0.9 GHz. Simultaneously, the insertion loss also gets worse from 3.9 to 6.5 dB. The loss error results from the HFSS simulation accuracy using a bulk conductivity of $5.8.10^7$ Siemens/m and ignoring dielectric loss tangent of the GaAs substrate. It will be improved if the bandwidth is designed to be wider, because the wider bandwidth leads to a better insertion loss.

The lower band suppression is greater than 24 dB from 0 to 4 GHz and the upper band suppression is greater than 35 dB up to 60 GHz. This ultra-wide stopband characteristic is a special advantage, compared



▲ *Fig. 7 The miniaturized 5 GHz bandpass filter's (a) circuit layout and (b) microphotograph of the MMIC chip.*



▲ *Fig. 8 Comparison of the measured and simulated S-parameter of the bandpass filter; (a) narrow band and (b) broad band.*

TABLE I

SIZE COMPARISON OF DIFFERENT MMIC BANDPASS FILTERS

Reference	15	16	this work
Bandwidth (GHz)	11.4 to 12.5	25 to 35	5 to 6
S_{11} (dB)	–	< –12	< –13
S_{21} (dB)	–1.5	–3.17	–6.5
Physical size of a resonator (mm × mm)	0.38 × 1.32	3.8 × 0.225	0.54 × 0.78
Electrical length (°)	90	90	7
Technology	inter-digital capacitor and lumped inductor	finite ground coplanar	modified combline
Year	1983	2001	2006

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to the ceramic or SAW filters. Finally, a comparison of the sizes of different types of compact filters is made here to show the advantage of the proposed compact bandpass filter, as illustrated in ***Table 1***.

CONCLUSION

A novel, miniaturized, GaAs MMIC bandpass filter, using a combination of coupled lines end-shorted at their opposite ends and lumped capacitors, was proposed in this article. Using this method, the size of the MMIC bandpass filter for an RF single transceiver chip was reduced to 0.42 mm^2. This filter also has a wider upper stopband characteristic greater than 35 dB up to 60 GHz. The measured results agree well with the simulated performances. This technology can be extended to various fabrication processes because of its planar structure. ■

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In Ho Kang *received his PhD degree from Sogang University, Seoul, Korea, in 1995. He is now a professor in the division of radio and information communication engineering at Korea Maritime University, Busan, Korea. His research interests include LTCC filters and MMIC filters for RF single chip for 5.5 GHz WLAN, WiMAX and UWB applications, and MMIC filters for power amplifier harmonics suppression.*

Shi Wei Shan *received his BS degree from the Institute of Technology at Qingdao University, China. He is now working toward his MS degree in the radio science and engineering department of Korea Maritime University. His research interests include the design, analysis, optimization and measurement of microwave circuits, including MMICs.*

Xu Guang Wang *received his BS degree from the department of electronics at Qingdao University, China, in 2006. He is currently working toward his MS degree in the department of radio science and engineering at Korea Maritime University, Busan, Korea.*

Young Yun *received his BS degree from the department of electronic engineering at Yonsei University, Seoul, Korea, in 1993. He obtained his MS degree in electrical and electronic engineering from Pohang University of Science and Technology, Pohang, Korea, in 1995, and his PhD degree in electrical engineering from Osaka University, Osaka, Japan, in 1999. From 1999 to 2003, he worked as an engineer at Matsushita Electric Industrial Co. Ltd., Osaka, Japan, where he was engaged in the research and development of MMICs for wireless communications. In 2003, he joined the department of radio science and engineering, Korea Maritime University, Busan, Korea. He is now an assistant professor, whose research interests include the design and measurement of RF/microwave and millimeter-wave ICs, and the design and fabrication of HEMTs and HBT.*

Ji Hoon Kim *received his BS degree in electrical engineering from Yeunngnam University, Gyeongsan, Korea, in 2001, and his MS degree in electronic engineering from the Information and Communications University (ICU), Daejeon, Korea, in 2003, where he is currently working toward his PhD degree. His research interests focus on the analysis of the nonlinearity of RF power amplifiers, linearization and efficiency improvement techniques of power amplifier MMICs for wireless handset applications.*

Chul Soon Park *received his BS degree in metallurgical engineering from Seoul National University, Seoul, Korea, in 1980, and his MS and PhD degrees in material science from the Korea Advanced Institute of Science and Technology (KAIST) in 1982 and 1985, respectively. Since 1999, he has been with the Information and Communications University (ICU), where he is a professor in the engineering school and director of the Intelligent Radio Engineering Center. His research interests include power amplifiers and reconfigurable RFICs and their SoC/SoP integration.*


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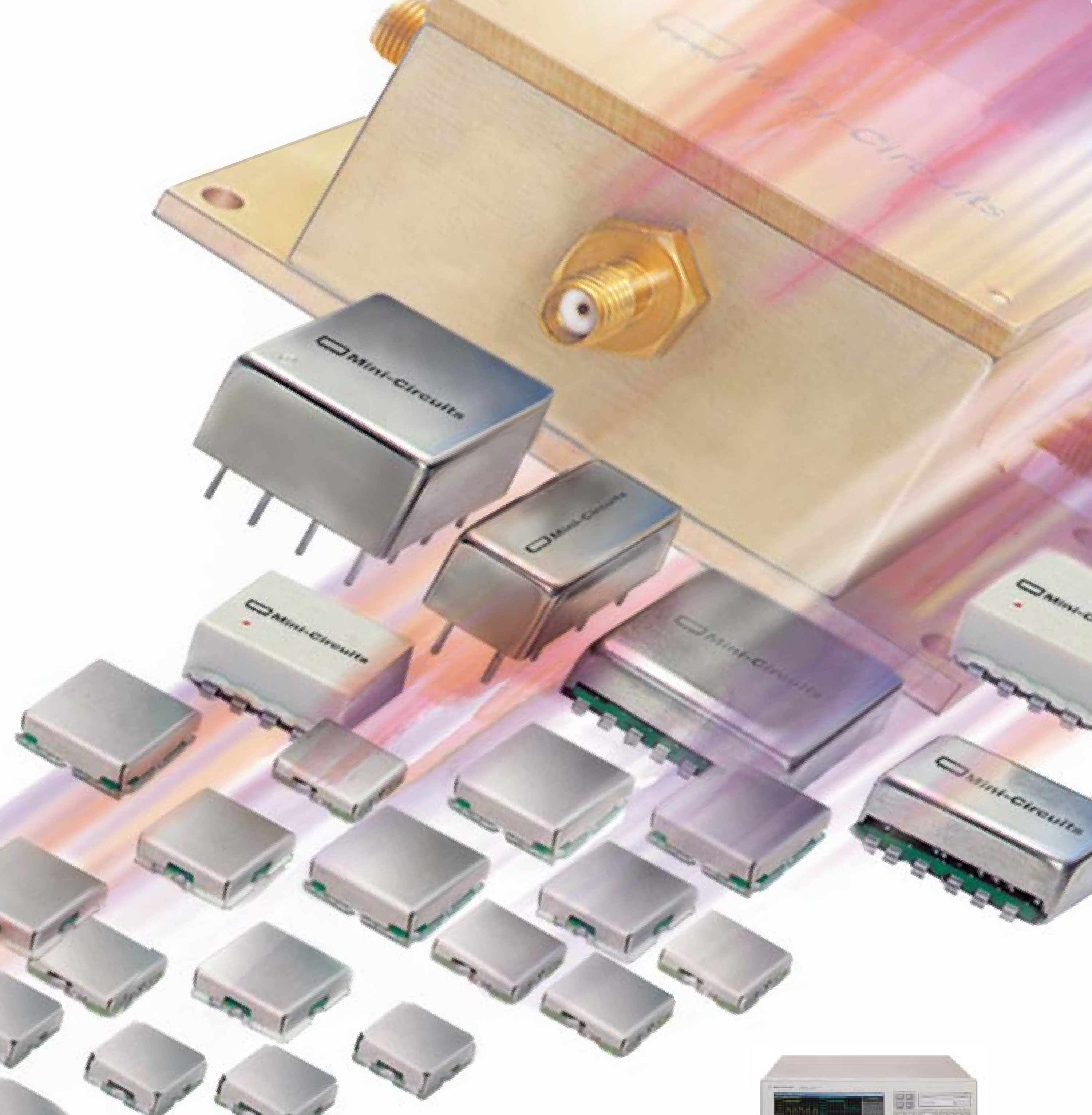
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A CPW-FED RHOMBIC ANTENNA WITH BAND-REJECT CHARACTERISTICS FOR UWB APPLICATIONS

In this design, a novel rhombic CPW-feed antenna is presented to achieve broadband operation. The antenna has dimensions of 28.5 × 17.0 × 0.8 mm and has good radiation characteristics. The proposed antenna uses a coplanar waveguide feed line with a rhombic radiation patch to cover the frequency band limited by the Federal Communications Commission (FCC) for the ultra-wideband (UWB) standard. The fabricated antenna achieved a –10 dB impedance bandwidth covering from 3.1 to 11.9 GHz (approximately 117 percent). However, the frequency band from 5.15 to 5.825 GHz is used in the IEEE 802.11a standard and HIPERLAN/2. A straight slit, embedded in one of the symmetrical ground plane, plays the role of a filter to eliminate the unwanted band. The effects of varying the location and length of the slit and the structure of the ground and monopole patch on the antenna performance have also been studied.

Recently, there has been much research on broadband and multi-band antennas for various wireless communication systems. The ultra-wideband (UWB) regulation released by the Federal Communications Commission (FCC) in 2002, "UWB Technology," holds great promise for a vast array of new applications that have the potential to provide significant benefits for public safety, businesses and consumers in a variety of applications, such as radar imaging of objects buried under the ground or behind walls and short-range, high speed data transmissions. The UWB systems have been allocated the frequency band from 3.1 to 10.6 GHz.[1,2] However, within the UWB frequency band, there is a wireless local area network (WLAN), which operates from 5.15 to 5.825 GHz and may cause interference with the UWB operations. A band-reject filter is therefore necessary in the RF circuit, although this will introduce complications for UWB systems. A shielded stripline-fed UWB antenna was proposed,[3] without a band-reject function, while its overall dimensions were 35.5 × 20 mm. A planar elliptical ring antenna, operating from 4.6 to 10.3 GHz, was also described,[4] with dimensions of 29 × 26 × 2.36 mm. A planar triangular monopole antenna was reported,[5] with an impedance bandwidth covering from 3.25 to 7.55 GHz and dimensions of 25 × 28.5 × 1.27 mm. A triangular monopole antenna with an impedance bandwidth from 4 to 10 GHz was described in the literature.[6] A UWB antenna, with a band

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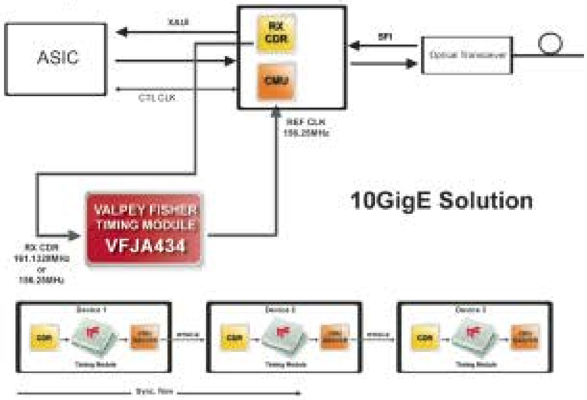

The VFJA434 is the only timing solution for synchronous Ethernet that does not require an external oscillator. It is available in a 19.5 x 15.5 mm FR4 package and it is fully compliant with Telcordia GR-253-CORE, GR-1244-CORE, ITU-T G.813, and ITU-T G.8261.

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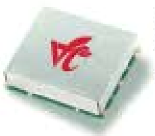

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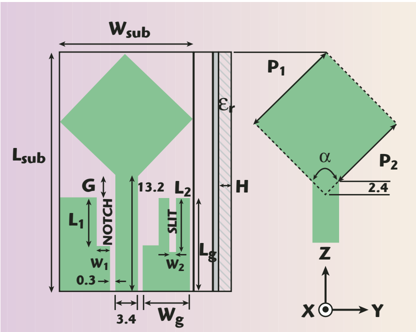
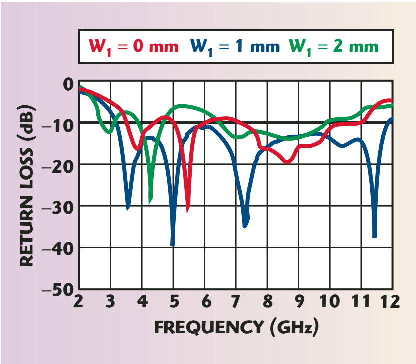
notch characteristic,[7] used a slot-type split ring resonator to reject the existing WLAN frequencies but caused the antenna gain to be less than 4 dBi. The dimensions of the CPW-fed printed antenna described by Xiaoning and Mohan[8] are 63.5 × 30 × 1.524 mm with a dielectric constant of 3.38. It has only half radiation patterns. As a result, these antennas with large size, insufficient bandwidth and/or with directional radiation patterns are not suitable for mobile applications of UWB systems.

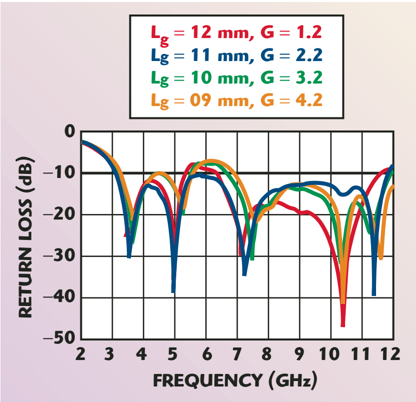
The CPW-fed antenna has the advantage of ease of fabrication, small size and wider bandwidth. It has been popular for various applications due to its low radiation losses, lightweight and compatibility with integrated circuits. In this design, to achieve the required bandwidth for UWB applications, a pair of the symmetrical notches is placed at the two corners of the ground plane. Furthermore, by inserting a straight slit at a proper location on the ground plane, the band-reject function can be obtained to suppress the 5.10 to 5.81 GHz band. In this article, a novel rhombic CPW-fed antenna is presented, with a small size of 28.5 × 17 × 0.8 mm, for use in UWB applications with band-reject function. The proposed antenna has the advantage of low cost, small size, omni-directional radiation patterns and ease of fabrication. These features and the small size make it attractive for mobile phone, laptop, receivers and UWB applications. Details of the antenna design and experimental results are presented and discussed.



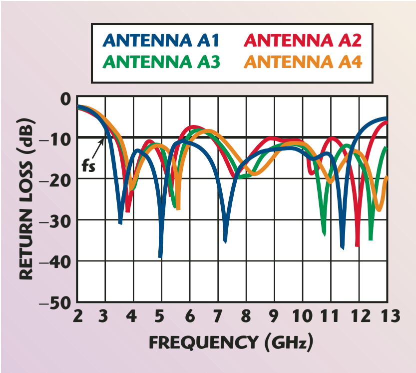
▲ *Fig. 1 Geometry of the proposed antenna for UWB applications.*



▲ *Fig. 3 Measured return loss of various notch widths (W_1).*



▲ *Fig. 2 Measured return loss for different L_g and G.*



▲ *Fig. 4 Measured return loss of the UWB antennas for various L_{sub}.*

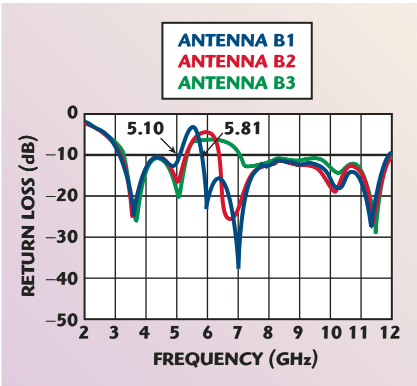
ANTENNA DESIGN

The proposed antenna configuration is shown in ***Figure 1***. Its dimension are W_{sub} = 28.5 mm, L_{sub} = 17 mm and H = 0.8 mm. The coplanar waveguide-fed antenna is printed on an FR4 substrate with a relative dielectric constant ε_r = 4.4. The CPW-fed line is connected to a 50 Ω standard miniature adapter (SMA). The antenna structure is selected to be a rhombic patch with dimensions of P_1 = 12.02 mm, P_2 = 9.62 mm and the flare angle of the antenna is α = 90°. The feed gap distance G is the distance between the radiation patch and the top edge of the ground plane. It determines the impedance matching, as shown in ***Figure 2***. The width W_g and length L_g of the symmetrical ground plane on the proposed antenna are 6.5 and 11 mm, respectively. By cutting the symmetrical two notches of proper dimension $W_1 \times L_1$ at the upper corner of the ground plane, it is found that a broader bandwidth can be achieved for the proposed antenna. This phenomenon occurs because the two notches affect the electromagnetic coupling between the radiation patch and the ground plane, which enhance the impedance matching bandwidth. In addition, the use of a straight slit, inserted into one of the ground planes, yields the band-reject characteristic. The length L_2 = 8 mm was chosen to

TABLE I

CHARACTERISTICS OF FOUR ANTENNA PROTOTYPES WITH DIFFERENT L_{sub}

	L_{sub} (mm)	Return Loss −10 dB Lower Frequency (GHz)	Return Loss −10 dB Upper Frequency (GHz)	Bandwidth (%)
Antenna A1	28.5	3.11	11.88	117.01
Antenna A2	27	3.33	12.47	115.70
Antenna A3	25	3.45	13.25	117.36
Antenna A4	23	3.51	13.69	118.31



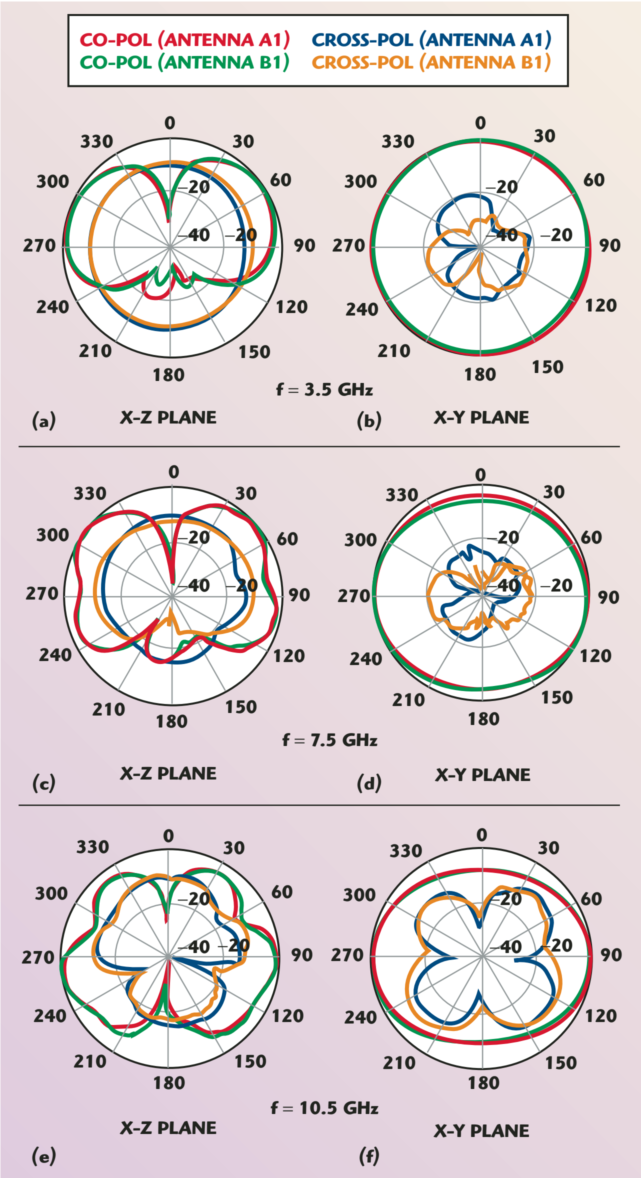
▲ *Fig. 5 Measured return loss of the UWB antennas with a band-reject function for various L_2.*

TABLE II

CHARACTERISTICS OF VARIOUS ANTENNAS AS A FUNCTION OF L_2

	L_2 (mm)	Return Loss −10 dB Lower-reject Frequency (GHz)	Return Loss −10 dB Higher-reject Frequency (GHz)	Bandwidth (%)
Antenna B1	8	5.10	5.81	13.01
Antenna B2	7	5.33	6.32	16.99
Antenna B3	6	5.37	6.96	25.79

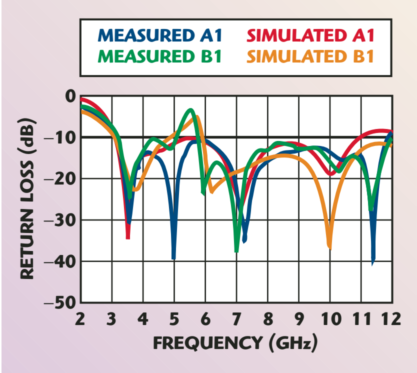
reject the limited band of 5.1 to 5.81 GHz, that is approximately λg/4 at the center frequency of the rejected bandwidth ($\lambda_g = \lambda/\sqrt{\varepsilon_{eff}}$). The rejected frequency bandwidth is determined by the width of the slit W_2, which is 0.5 mm. This antenna was constructed and experimentally studied and the measured results are given in the following section.



▲ *Fig. 7 Measured far-field radiation patterns in the X-Z and X-Y planes for antennas A1 and B1.*

EXPERIMENTAL RESULTS AND DISCUSSION

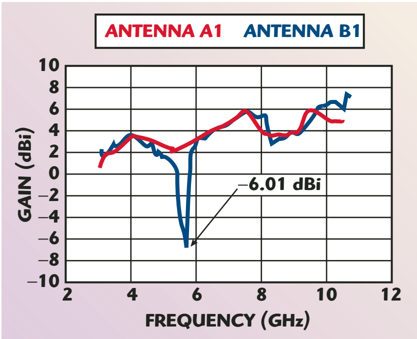
CPW-fed monopole antennas with various parameters (W_1, L_{sub} and L_2) were constructed and studied to demonstrate the proposed bandwidth enhancement technique and band-reject function. The simulated results are obtained with Ansoft High Frequency Simulation Software (HFSS). ***Figure 3*** shows the measured return loss for different width W_1, the other dimensions being W_{sub} = 17 mm, L_{sub} = 28.5 mm, H = 0.8 mm, G = 2.2 mm, L_g = 11.mm, W_g = 6.5 mm and L_1 = 5 mm. With the symmetrical notches width chosen as 1 mm, the −10 dB impedance bandwidth for the optimal proposed antenna is from 3.1 to 11.9 GHz. From the experimental results shown in ***Figure 4*** and ***Table 1***, as the length of



▲ *Fig. 6 Measured and simulated return losses of the proposed antennas A1 and B1.*

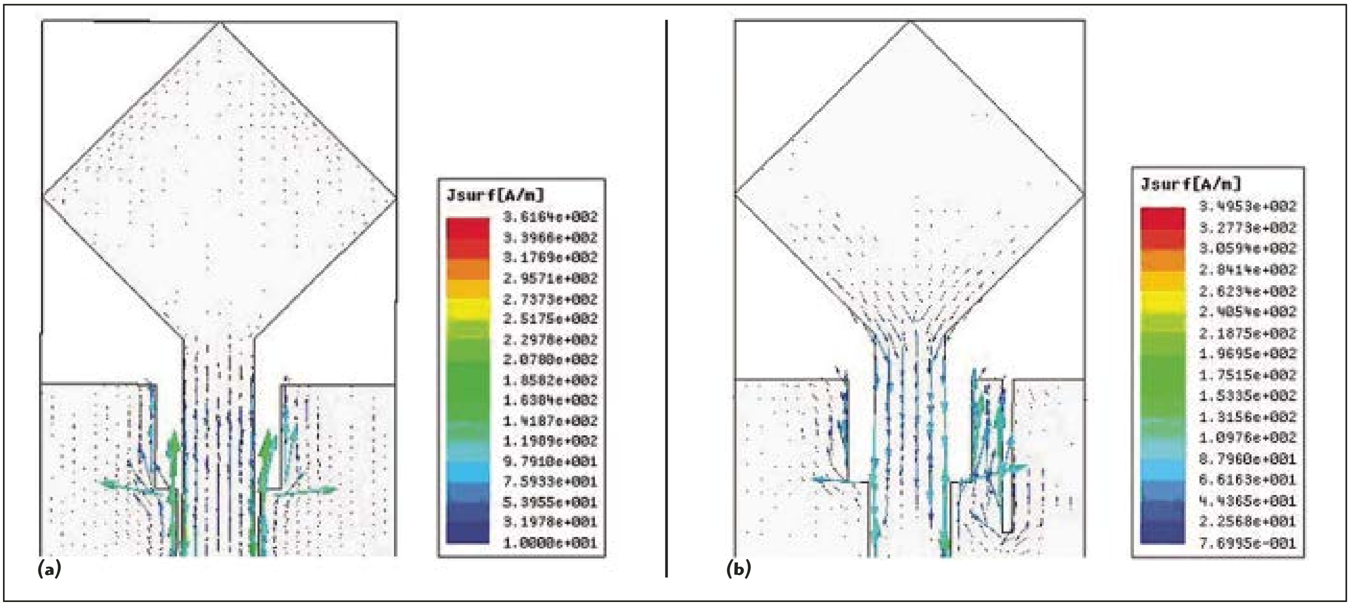
L_{sub} increases, the lower frequency is slightly higher and the upper frequency markedly increases. In this case, the other dimensions were: W_{sub} = 17 mm, H = 0.8 mm, G = 2.2 mm, L_g = 11 mm, W_g = 6.5 mm, L_1 = 5 mm and W_1 = 1 mm. The length of the substrate determines the lower frequency (f_s) and is equal to λg/2. ***Figure 5*** shows the measured return loss for various length of L_2. The other antenna dimensions are: W_{sub} = 17 mm, L_{sub} = 28.5 mm, H = 0.8 mm, G = 2.2 mm, L_g = 11 mm, W_g = 6.5 mm, L_1 = 5 mm, W_1 = 1 mm and W_2 = 0.5 mm. By embedding a straight slit in one of the ground plane, a 5.10 to 5.81 GHz rejection band was created. The related results are also listed in ***Table 2***. The measured and simulated return losses for the proposed antenna designs A_1 and B_1, with optimal dimensions, are shown in ***Figure 6***. The slight differences between the measured and simulated results are caused by fabrication variations.

The far-field radiation patterns were measured and calibrated in an anechoic chamber. ***Figure 7*** shows the measured radiation patterns with and without the slit at 3.5, 7.5 and



▲ *Fig. 8 Measured gain of antennas A1 and B1.*

10.5 GHz in both the X-Z and X-Y planes. Since the CPW-feed line is located parallel to the Z-axis, the X-Z plane radiation pattern of the proposed antennas has nulls in the Z-direction. In the X-Y plane the antennas are nearly omni-directional even at the higher frequencies. ***Figure 8*** shows the measured antenna gains versus frequency. The measured peak antenna gain for the antenna with slit (B1) is 7.54 dBi at 10.6 GHz. ***Figure 9*** shows the simulated surface current distribution at 5.45 GHz for the proposed antennas with and without a slit. These currents are concentrated near the notches in the UWB structure. Furthermore, in the UWB



▲ *Fig. 9 Simulated surface current distribution at 5.45 GHz of antennas A1 (a) and B1 (b).*

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structure with a slit, the surface currents are partly concentrated on the ground plane, causing the band-reject characteristic. As shown, the proposed antenna has good radiation characteristics.

CONCLUSION

The proposed antenna A1 exhibits a broad bandwidth of approximately 118 percent (3.1 to 11.9 GHz) for a –10 dB return loss and a good radiation performance, while retaining a small volume (28.5 × 17 × 0.8 mm). It uses a rhombic shape radiating patch and notches on the ground pads to achieve a broadband impedance match. The proposed antenna B1, with a straight slit embedded at the upper edge of one of the ground planes, shows a rejected 5.125 to 5.825 GHz band. The CPW-fed monopole antenna has a simple structure with low profile and small size. Both the proposed antennas (A1 and B1) maintain nearly omni-directional radiation characteristics over the operating frequency. They will be attractive candidates for UWB applications. ■

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

Yen-Hao Yu *received his BS degree from Chung Hua University, Taiwan, ROC, in 2006. He is currently a graduate student in the department of electronic engineering at Southern Taiwan University. His main research interests include printed antennas for wireless communications, especially printed antennas for UWB and WiMAX applications.*

A POWER AMPLIFIER MMIC USING CPW STRUCTURE TECHNOLOGY

This article presents the performance of a two-stage X-/Ku-band microwave monolithic integrated circuit (MMIC) power amplifier using a 0.15 μm gate length InGaP/InGaAs E-mode pseudomorphic high electron mobility transistor (PHEMT) and a coplanar waveguide (CPW) topology. The power amplifier, with a chip size of 2.3 × 0.87 mm, gave an output power of 20 dBm and a power gain in excess of 20 dB. The input third-order intercept point (IIP3) is 1.4 dBm and the output third-order intercept point (OIP3) is 24.5 dBm. The overall power characteristic exhibits high gain and linearity, which illustrates that the power amplifier is compact and exhibits favorable RF characteristics in the X-/Ku-band.

Communication systems in the RF band are becoming bandwidth limited. Thus, the providers of communication systems have become interested in the X-/Ku-band for the next-generation of terrestrial systems, such as satellite communications, wireless local area networks (WLAN) and local multipoint distribution systems (LMDS). The performance of high power amplifiers (PA) has been drastically improved on GaAs-based PHEMT MMICs. Moreover, the superior performances of InP-based PHEMTs can be improved significantly in satellite communication applications. CPW MMIC power amplifiers are usually adopted for use in transmitter communication systems.[1–3] Advantages in the novel CPW structures include the fact that the ground plane is placed on the top surface of the substrate, making the backside process unnecessary. Also, the ground planes between the CPW lines provide good isolation, which permits a compact circuit layout.

A high output power, with good thermal properties, was demonstrated in a number of microstrip MMIC amplifiers. On the contrary, the CPW structure was hardly used in power microwave applications, due to the poor power handling capability, which resulted from the high thermal resistance of the thick GaAs substrates and the elimination of the backside processing.[4] The backside fabrication contributes the heat removal in microstrip-based circuits significantly, and offers a higher power performance. However, the CPW technology can be made compatible by utilizing modern packaging techniques, such as flip-chip bond-

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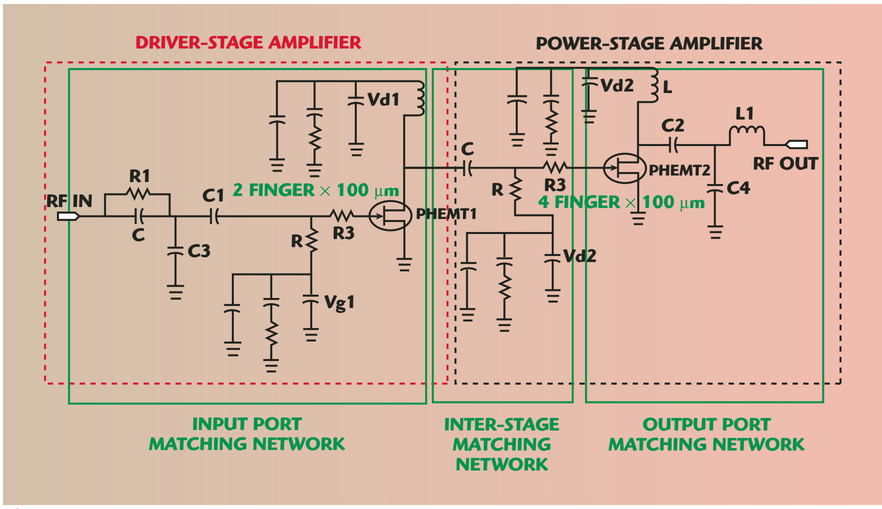
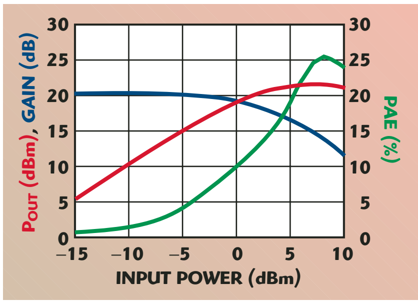


▲ *Fig. 1 Schematic of the power amplifier.*

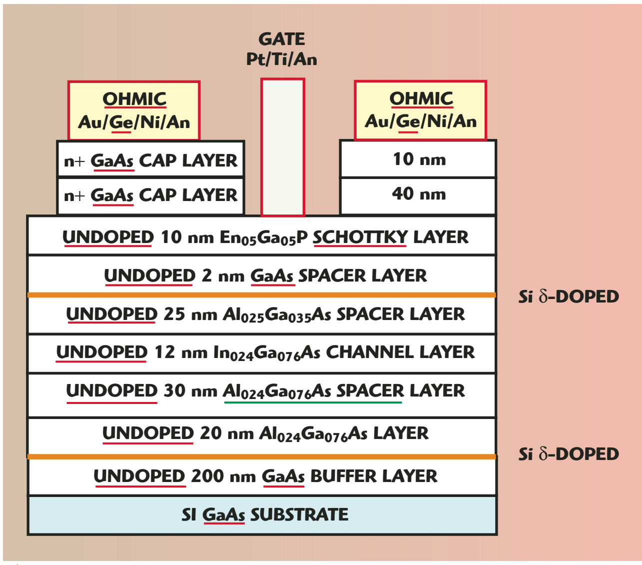


▲ *Fig. 2 Simulated output power, gain and efficiency of the power amplifier at 12 GHz.*

ing, and also provides a cost-effective solution for GaAs MMIC fabrication. In this article, the characteristics of an X-/Ku-band PA are presented, which uses a two-stage amplifier and a CPW structure in InGaP/InGaAs E-mode PHEMT technology. The amplifier is designed to fully match the 50 Ω input and output impedances without any external circuit, and exhibits a maximum output power of 20.7 dBm and a linear power gain greater than 20 dB, which is appropriate for microwave power integrated circuits.

DESIGN AND SIMULATION OF THE CPW MMIC AMPLIFIER

Figure 1 shows the schematic of the PA with the three-stage matching networks: input port, inter-stage and output port. The PA is designed as a two-stage, single-ended amplifier, in order to fully match to a 50 Ω impedance. First, the output matching network was designed for maximum output power and associated power efficiency in a 50 Ω load. The inter-stage network was then optimized to reduce the mismatching loss in the PA circuit; the output of the driver stage was matched to the input of the output-power stage. Finally, the input network matching was designed to achieve a uniform small-signal gain, and to improve the impedance matching for the proper input return loss. A conservative driver stage gain was chosen to ensure enough power to drive the output-power stage and to allow for process variations. An instability resulted from the CPW discontinuities and electromagnetic (EM) effects in the power circuit, caused by the various components coupling at high frequencies. It was beneficial that all passive components were evaluated by an EM field simulator.[5] Therefore, a circuit stability analysis was executed for each stage, in order to ensure having a sufficient margin in the X-/Ku-band. The gate resistors of each stage were also adjusted to improve the stability of the CPW power amplifier.[6] Consequently, the circuit parameters optimization and EM simulation based on these essential matching networks were performed, so as to



▲ *Fig. 3 Cross-section of the power InGaP E-mode PHEMT.*

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Surface-mount bandpass filter model SXBP-178+ provides high rejection of unwanted signals around a 170 to186 MHz passband. Out-of-band rejection is more than 30 dB at 150 MHz and more than 90 dB at 1 MHz. High-band rejection is more than 50 dB at 240 MHz and more than 60 dB at 2 GHz. The low-loss filter maintains insertion loss of less than 3 dB across the 170 to 186-MHz passband. Typical passband VSWR is 1.20:1. Group-delay variation across the passband is typically less than ±3 ns. The filter measures just 0.740 x 0.440 x 0.270 inches (18.89 x 11.18 x 6.86 mm) and handles RF power levels to 0.5 W.

Low-Noise VCO Covers 6-GHz Wireless Applications

Model ROS-6030C-219+ is an SMT voltage-controlled oscillator (VCO) that tunes from 5890 to 6010 MHz with tuning voltages of 0.5 to 5.0 V. Tuning sensitivity is 62 to 90 MHz/V with typical frequency pushing of 2 MHz/V and pulling of 0.7 MHz. The VCO delivers +2-dBm output power with low phase noise of -102 dBc/Hz offset 10 kHz and -144 dBc/Hz offset 1 MHz. Harmonics are -22 dBc or less and spurious is typically -90 dBc. It measures just 0.50 x 0.50 x 0.22 inches (12.70 x 12.70 x 5.59 mm). The broad 220-MHz 3-dB modulation bandwidth makes the VCO suitable for wideband modulation formats in point-to-point and other wireless systems.

Ceramic Mixer Handles 3.2 To 15 GHz

Surface-mount mixer model SIM-153LH+ offers broad frequency coverage from 3.2 to 15.0 GHz. Designed for +10-dBm LO drive, the double-balanced mixer boast a wide IF bandwidth of DC to 4 GHz with low conversion loss of typically 6.1 dB. Usable as an upconverter or downconverter in radar, wireless, and satellite communications systems, it achieves typical L-R isolation of 36 dB and typical L-I isolation of better than 15 dB. Protected by US patent, 7,027,795. The mixer achieves an IP3 of better than +12 dBm at midband. It is fabricated with proven LTCC technology and measures just 0.200 x 0.180 0.087 inches (5.08 x 4.57 x 2.21 mm).

4-Way, 50W Combiner Spans 0.6 To 2.3 GHz

Model ZB4PD-232-50W+ is a coaxial four-way power combiner that can also be used as a power splitter for applications from 600 to 2300 MHz. It handles power levels to 50 W CW at input and 12.5 W CW per port at outputs, with 0.8 dB typical insertion loss. Typical isolation between ports is 19 dB. Full band amplitude unbalance is 0.05 dB while typical phase unbalance is 0.9°. The combiner /splitter features excellent input and output impedance match, with typical input VSWR of 1.20:1 and typical output (summed) port VSWR of 1.10:1. The 0° combiner/splitter is supplied with SMA connectors on all five signal ports.

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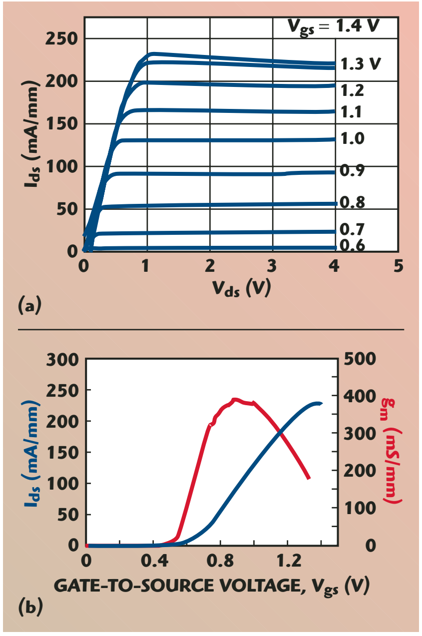
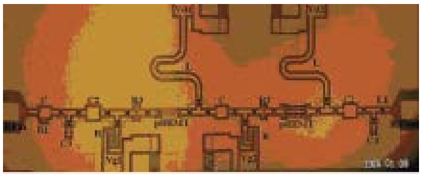
achieve the required circuit performance. The CPW was designed with a narrow size width = 20 μm and gap = 10 μm, to reduce the excitation of parallel-plate modes[7] and to eliminate discontinuity effects. Capacitors and resistive loading were used to prevent oscillations at low frequencies. The amplifier design eventually achieved unconditional stability over the whole X-/Ku-band. The S-parameters and power gain were simulated using the Advanced Design System (ADS). ***Figure 2*** shows the simulated output power, gain and power-added efficiency (PAE) at 12 GHz and V_{ds} = 4 V. It also shows that the 1 dB compression power points (P1dB) at the input and output are 0 and 19.2 dBm, respectively. The maximum power of this amplifier was approximately 21.8 dBm in the saturation region, with a maximum PAE of 25.5 percent.

DEVICE STRUCTURE AND CPW POWER AMPLIFIER MMIC FABRICATION

For PHEMT fabrication consideration, the InGaP/InGaAs E-mode PHEMT offers an excellent selective etching for the gate recess between InGaP and GaAs, which increases the device yield in mass production. Furthermore, InGaP does not form DX-centers, which cause less deep level defects. Consequently, the InGaP/InGaAs GaAs substrate exhibits great potential to improve the reliability of the GaAs PHEMT MMIC. ***Figure 3*** shows the epitaxial structure of the $In_{0.5}Ga_{0.5}P/In_{0.24}Ga_{0.76}As$ E-mode PHEMT, which is a sandwich PHEMT structure for high power consideration. The structure includes the double Si planar δ-doping layers, which sandwich the InGaAs undoped channel layer with AlGaAs spacer layers for high transconductance consideration. An undoped 100 Å InGaP Schottky layer was grown on an intrinsic GaAs to form a Schottky layer. Finally, two n^+–GaAs cap layers were grown to improve the ohmic contact's resistivity. The designed structure demonstrated a sheet charge density of 2.2 × 10^{12} cm^{-2} together with a Hall mobility of 6120 cm^2/V-sec at 300 K after removing the n^+–GaAs cap layer. In the device fabrication, the Au/Ge/Ni/Au ohmic contacts were deposited by e-beam evaporation and patterned by a conventional lift-off process. An ion-implant isolation technology was applied for mesa isolation to avoid sidewall gate leakage current. After the high selectivity succinic acid gate recess process,[8] the 0.15 μm gate metals Pt/Ti/Au (40 Å/500 Å/4000 Å) were deposited by a lift-off process. Typical DC drain-to-source current (I_{ds}) versus drain-to-source voltage (V_{ds}) characteristics of the fabricated InGaP/InGaAs E-mode PHEMT are shown in ***Figure 4***. As can be seen, the device can be operated with a gate voltage up to 1.4 V, which corresponds to an I_{ds} of 230 mA/mm when the drain voltage is 3 V. The V_{gs} dependence of transconductance (g_m) and I_{ds} at V_{ds} = 2 V are also shown. The threshold voltage (V_{th}) is 0.34 V (defined as I_{ds} = 1mA/mm) and the maximum I_{ds} and g_m are 235 mA/mm and 390 mS/mm, respectively. In addition, the matching inductors and MIM capacitors were also achieved during the circuit fabrication. Therefore, the two-stage power amplifier MMIC was realized with an InGaP/InGaAs E-mode PHEMT technology. A microphotograph of the two-stage CPW PA MMIC, with a chip area of 2.3 × 0.87 mm, is shown in ***Figure 5***.



▲ *Fig. 4 InGaP E-mode PHEMT DC characteristics; (a) I_{ds} vs. V_{ds} and (b) I_{ds}, g_m vs. V_{gs} @ V_{ds} = 2 V.*

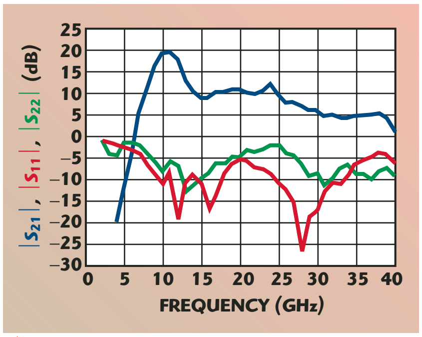


▲ *Fig. 5 The two-stage PA chip.*

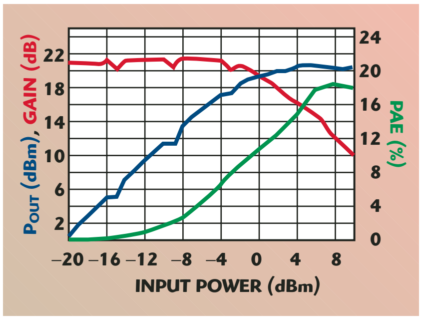
TESLA

MEASURED POWER RESULTS

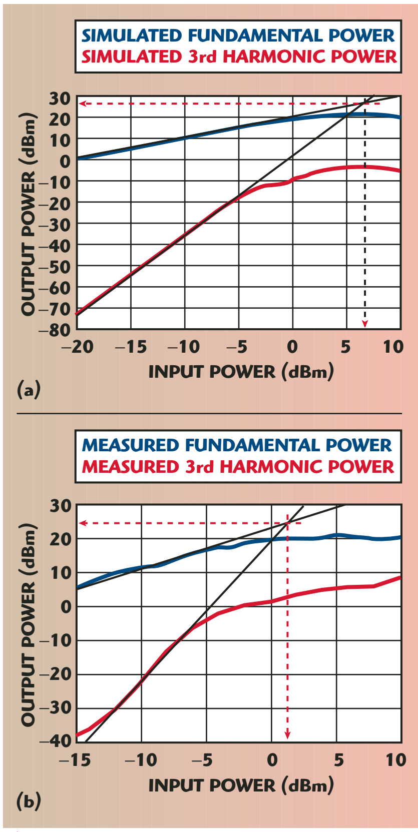
The S-parameter measurements were performed with an Agilent 8510C vector network analyzer. The total DC power consumption of the amplifier was 780 mW, which included an I_{ds} of 66 mA and V_{ds} of 4 V for the driver stage (gate width = 2 fingers x 100 μm), and an I_{ds} of 129 mA and V_{ds} of 4 V for the output power stage (gate width = 4 fingers × 100 μm). ***Figure 6*** shows the small-signal gain (S_{21}) of 17.6 dB, the input return loss (S_{11}) of 18 dB and the output return loss (S_{21}) of 7 dB at 12 GHz. ***Figure 7*** shows the on-wafer measured output power, gain and PAE at V_{ds} = 4 V, I_{ds} = 209 mA and 12 GHz. The P1dB was attained at approxi-



▲ *Fig. 6 Measured S-parameters of the two-stage PA.*



▲ *Fig. 7 Measured output power, gain and efficiency of the two-stage monolithic PHEMT amplifier at 12 GHz.*



▲ *Fig. 8 IP3 of the two-stage monolithic amplifier at 12 GHz; (a) simulated and (b) measured.*

TABLE I

MEASURED AND SIMULATED RF CHARACTERISTICS OF THE CPW MONOLITHIC POWER AMPLIFIER AT 12 GHz

RF Characterization	Simulation	Measurement
Supply voltage (V)	V_{ds} = 4	
DC current consumption (mA)	195	209
S_{21} (small-signal gain) (dB)	20.3	17.6
Gain @ P1dB (dB)	19.2	20.6
Input power @ P1dB (dBm)	0	–2
Output power @ P1dB (dBm)	19.2	18.6
Max. output power (dBm)	21.8 @ P_{in} = 6 dBm	20.7 @ P_{in} = 6 dBm
Max. PAE (%)	25.5 @ P_{in} = 8 dBm	18.3 @ P_{in} = 8 dBm
PAE @ P1dB (%)	10.3	8.8
IIP3 (dBm)	6.6	1.4
OIP3 (dBm)	26.4	24.5

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Ultra-Broadband

Freq. Range (GHz)	Gain (dB)	Gain Flatness (+/- dB)	NF (dB)	OP1dB (dBm)	OIP3 (dBm)	VSWR In/Out	Max. CW RF Input (dBm)	DC Current @ +12VDC (mA)	Model Number	Cost ($ USD) 1-10	11-20	20+
0.03-20	14	2.5	3.0	14	26	2.0:1	23	75	PUB-14-30M20G-14-LCA	850	750	650
0.03-20	15	2.5	3.0	20	30	2.0:1	23	180	PUB-15-30M20G-20-LCA	950	850	750
0.50-20	14	1.75	3.0	14	26	2.0:1	23	75	PUB-14-500M20G-14-LCA	750	650	550
0.50-20	15	1.75	3.0	20	30	2.0:1	23	180	PUB-15-500M20G-20-LCA	850	750	650

Broadband

Freq. Range (GHz)	Gain (dB)	Gain Flatness (+/- dB)	NF (dB)	OP1dB (dBm)	OIP3 (dBm)	VSWR In/Out	Max. CW RF Input (dBm)	DC Current @ +12VDC (mA)	Model Number	Cost ($ USD) 1-10	11-20	20+
2-20	15	1.75	3.0	12	24	2.0:1	23	75	PBB-15-220-12-LCA	750	650	550
2-20	28	2.25	3.0	12	24	2.0:1	23	150	PBB-28-220-12-LCA	850	750	650
2-18	10	1.75	4.0	16	26	2.0:1	23	75	PBB-10-218-16-LCA	650	550	450
2-18	15	2.0	3.0	20	30	2.0:1	23	180	PBB-15-218-20-LCA	800	700	600
2-18	20	2.0	4.0	16	26	2.0:1	23	150	PBB-20-218-16-LCA	800	700	600
2-18	28	2.5	3.0	20	29	2.0:1	23	250	PBB-28-218-20-LCA	850	750	650

Octave Band

Freq. Range (GHz)	Gain (dB)	Gain Flatness (+/- dB)	NF (dB)	OP1dB (dBm)	OIP3 (dBm)	VSWR In/Out	Max. CW RF Input (dBm)	DC Current @ +12VDC (mA)	Model Number	Cost ($ USD) 1-10	11-20	20+
2-4	10	1.0	4.0	10	18	2.0:1	10	75	POB-10-24-10-LCA	450	350	300
2-4	15	1.0	3.5	15	26	2.0:1	23	75	POB-15-24-15-LCA	500	450	350
2-4	17	1.0	3.5	22	34	2.0:1	23	180	POB-17-24-22-LCA	550	450	400
2-4	28	1.25	3.5	15	26	2.0:1	23	150	POB-28-24-15-LCA	550	450	400
4-8	10	1.0	3.0	10	18	2.0:1	10	75	POB-10-48-10-LCA	450	350	300
4-8	15	1.0	3.0	15	26	2.0:1	23	75	POB-15-48-15-LCA	500	450	350
4-8	16	1.0	3.0	22	32	2.0:1	23	180	POB-16-48-22-LCA	550	450	400
4-8	28	1.25	3.0	15	26	2.0:1	23	150	POB-28-48-15-LCA	550	450	400
8-18	10	1.5	3.0	8	16	2.0:1	10	75	POB-10-818-8-LCA	600	500	400
8-18	15	1.5	3.0	13	25	2.0:1	23	75	POB-15-818-13-LCA	650	550	450
8-18	15	1.75	3.0	20	26	2.0:1	23	180	POB-15-818-20-LCA	700	600	500
8-18	28	1.75	3.0	13	24	2.0:1	23	150	POB-28-818-13-LCA	750	650	550

Low Noise

Freq. Range (GHz)	Gain (dB)	Gain Flatness (+/- dB)	NF (dB)	OP1dB (dBm)	OIP3 (dBm)	VSWR In/Out	Max. CW RF Input (dBm)	DC Current @ +12VDC (mA)	Model Number	Cost ($ USD) 1-10	11-20	20+
1-2	18	1.0	1.5	15	28	2.0:1	0	65	PLN-18-12-15-LCA	500	400	300
2-4	18	1.0	1.5	15	28	2.0:1	0	65	PLN-18-24-15-LCA	550	450	350
4-8	17	1.25	1.75	15	28	2.0:1	0	65	PLN-17-48-15-LCA	600	500	450
6-8	32	1.25	1.0	2	10	2.0:1	10	40	PLN-32-68-2-LCA	650	550	450
8-10	32	1.25	0.8	2	10	2.0:1	10	40	PLN-32-810-2-LCA	650	550	450
8-12	25	1.0	1.8	10	18	2.0:1	20	75	PLN-25-812-10-LCA	700	600	500
10-12	30	1.5	0.8	2	10	2.0:1	10	40	PLN-30-1012-2-LCA	650	550	450
1-10	17	1.5	2.0	15	28	2.0:1	0	65	PLN-17-110-15-LCA	750	700	650

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mately 18.6 dBm, the saturated output power was achieved with 21 dBm and the maximum PAE was obtained at 18.3 percent for P_{in} = 8 dBm. The third-order intercept inter-modulation (IP3) describes the nonlinearity of the circuit. In other words, when a two-tone input signal is fed to the amplifier, it will produce power at the fundamental frequencies and high order harmonic inter-modulation products. Consequently, a two-tone evaluation was performed at frequencies of 12.000 and 12.001 GHz, which were mixed to produce inter-modulation products in the power amplifier. ***Figure 8*** shows the comparison between the simulated and measured IP3. The simulated input third-order intercept point (IIP3) is 6.6 dBm and the output third-order intercept point (OIP3) is 26.4 dBm. The measured IIP3 and OIP3 are 1.4 and 24.5 dBm, respectively. ***Table 1*** compares the simulated and measured RF characteristics of the amplifier. These power characterizations revealed a little inconsistency between the simulated and measured performance. The input return loss (S_{11}) was poorer than expected. This result might be caused by fabrication variations, such as the elimination of backside via-hole processing. However, this CPW PA exhibits favorable RF characteristics in the X-/Ku-band and demonstrates that the InGaP/InGaAs E-mode PHEMT technology is an excellent approach.

CONCLUSION

In this article, a two-stage MMIC power amplifier, using an InGaP/InGaAs E-mode PHEMT technology and CPW topology, has been demonstrated. It exhibits an appropriate RF performance in the X-/Ku-band. The MMIC power amplifier gives an output power of 18.6 dBm, a linear power gain of approximately 20 dB and an output third-order intercept point (OIP3) of 24.5 dBm. The overall power characteristics exhibit high gain and linearity at 12 GHz. In summary, this CPW power amplifier has favorable RF characteristics and is very suitable for X-/Ku-band microwave integrated circuit power transmission applications. ■

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Chia-Song Wu *received his MSEE degree from Tsing Hua University, Hsinchu, in 1985, and his PhD EE degree from National Central University, Chungli, Taiwan, in 1998. In 1986, he joined the Chung Shan Institute of Science and Technology (CSIST), where he focused on infrared detector technology. In August 2003, he joined the EE department of Vanung University and currently performs research on microwave and millimeter-wave integrated circuits. His research interests include OEIC and MMIC, such as laser diode, sub micron technology, microwave, millimeter devices and MMIC.*

Hsien-Chin Chiu *received his BS and PhD degrees in electrical engineering from National Central University, Chungli, Taiwan, in 1998 and 2003, respectively. In 2003, he joined Win Semiconductors Corp., Tao Yuan, Taiwan, where he was engaged in the research and development of six-inch GaAs PHEMTs and related integrated circuits. In June 2004, he joined the faculty of the EE department at Chang Gung University and focused on microwave, millimeter-wave integrated circuits, fiber communication circuits and nanotechnology. His research interests include deep submicron electron-beam lithography, solid-state physics, compound semiconductors, microwave, millimeter devices and integrated circuits.*

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• ZHL-20W-13	20-1000	50	+41	+43	3.5	+50	24	2.8	1395.00
• ZHL-50W-52	50-500	50	+46	+48	4.0	+55	24	9.3	1395.00
• ZHL-100W-52	50-500	50	+47	+48.5	6.5	+57	24	9.3	1995.00
▲ *Without Heat Sink/Fan*									
ZHL-5W-2GX	800-2000	49	+37	+38	8.0	+44	24	2.0	945.00
• ZHL-10W-2GX	800-2000	43	+40	+41	7.0	+50	24	5.0	1220.00
• ZHL-20W-13X	20-1000	50	+41	+43	3.5	+50	24	2.8	1320.00
• ZHL-50W-52X	50-500	50	+46	+48	4.0	+55	24	9.0	1320.00
• ZHL-100W-52X	50-500	50	+47	+48.5	6.5	+57	24	9.0	1920.00

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CIRCUIT MODELING OF SPURLINE AND ITS APPLICATIONS TO MICROSTRIP BANDSTOP FILTERS

Simple bandstop filters (BSF) are introduced in this article. The filters consist of one spurline and a pair of cross-junction open stubs. This spurline exhibits bandstop characteristics at a resonant frequency, which can be explained and modeled by one LCR-resonator. The proposed BSF was designed and measured. The experimental results verify the design method and circuit modeling. Additionally, this BSF is compact and its total length is equal to λg/6.

Bandstop filters (BSF) play an important role in rejecting higher harmonics and spurious responses for microwave and millimeter-wave applications. The conventional method to implement bandstop filters involves the use of shunt stubs or stepped-impedance microstrip lines with large circuit size.[1] To reduce the filter area, certain slow-wave structures, such as open-loop resonators, are widely adopted.[2] Recently, some periodic structures such as electromagnetic bandgap (EBG),[3] defected ground structure (DGS)[4] and left-hand material[5] exhibit good bandstop characteristics and are popularly applied to the design of bandstop filters. Their stopband bandwidth and sharp cut-off frequency response are enhanced by using four or more cells; however, this leads to a larger size and more transmission loss in the stopband. Moreover, EBG and DGS require an etching process on the backside ground plane and additional position calibration, which increases time-consumption and adds difficulties in machining.

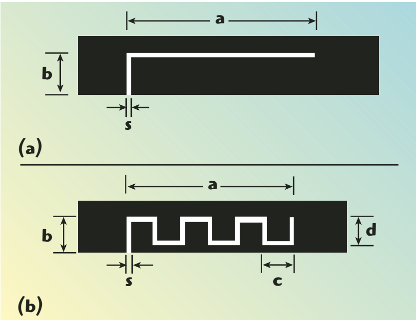
A spurline is a simple defected structure, which is realized by etching an L-shaped slot in the microstrip line. It provides excellent bandgap characteristics and can be applied to antenna and filter designs.[6,7] However, very limited research on its equivalent circuit has been reported. In this article, an equivalent circuit model of a spurline in a microstrip structure will be derived, based on circuit

HAI-WEN LIU
Institute of Optics and Electronics, Chinese Academy of Sciences
Chengdu, China
ZHIGUO SHI
Zhejiang University
Hangzhou, China
R.H. KNOECHEL
Kiel University
Kiel, Germany
K.F. SCHUENEMANN
Technische Universitat Hamburg-Harburg
Germany

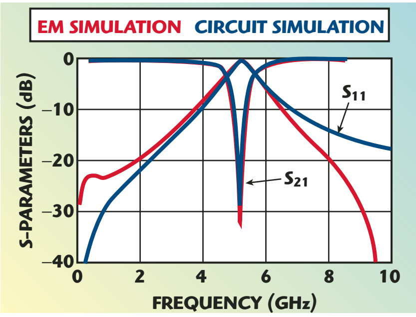
analysis theory and verified by electromagnetic (EM) simulations. Two compact microstrip BSFs using spurline and cross-junction open stubs will then be designed, fabricated and measured. The measurements verify the validity of this methodology. Finally, conclusions are given.

CIRCUIT MODELING OF A SPURLINE

Based on previous work,[8] a schematic view of spurlines is shown in ***Figure 1***. The configuration of the proposed spurline is described by the slot width s, the slot length a and the slot height b. The meander line has two adjustable parameters, c and d. In general, the slot gap provides a capacitive effect while the narrow line exhibits an inductive effect. A meander line provides a slower-wave effect than the straight slot. To study the spurline's transmission characteristics, it was simulated with Ansoft Ensemble 8.0. The dimensions of the spurline structure are s = 0.1 mm, a = 9 mm and b = 0.4 mm. A Rogers TMM10 substrate, with a relative dielectric constant of 3.38 and a thickness of 0.508 mm, is used in the simulations and measurements. The spurline is etched on a 50 Ω microstrip line with a width of 1.17 mm and its frequency characteristics are shown in ***Figure 2***. There is an obvious bandgap at the resonant frequency of 5.17 GHz. A simple circuit model with one LCR-network resonator for a spurline is proposed in ***Figure 3***. The resonant characteristics are modeled by one LC-resonator and the radiation effect and loss are considered by including a resistor, R. Based on transmission line theory and the spectral domain approach, the circuit parameters can be extracted using the following equations.



▲ *Fig. 1 Spurline (a) straight and (b) meandered configurations.*



▲ *Fig. 2 Frequency characteristics of the proposed spurline.*

$$R = 2Z_0\left(1/\left|S_{21}\right| - 1\right)\Big|_{f=f_0} \quad (1)$$

$$c = \frac{\sqrt{0.5\left(R + 2Z_0\right)^2 - 4Z_0^2}}{2.83\pi Z_0 R\Delta f} \quad (2)$$

$$L = \frac{1}{4\left(\pi f_0\right)^2 C} \quad (3)$$

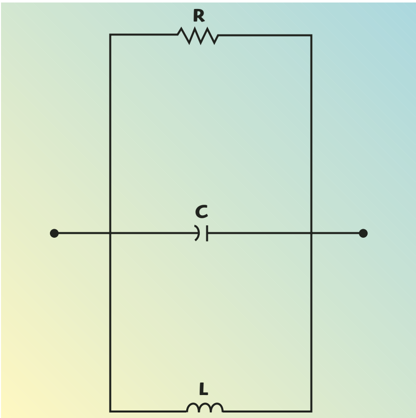
where

Z_0 = characteristic impedance of the transmission line (50 Ω)
f_0 = resonant frequency
S_{21} = insertion loss
Δf = –3 dB bandwidth of S_{21}

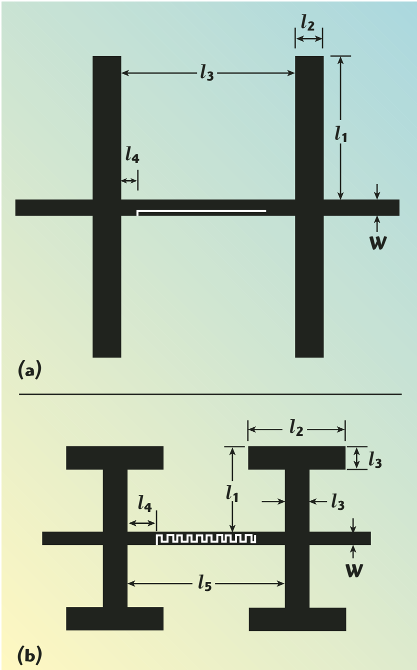
Based on the simulated results, the extracted circuit parameters are L = 0.5626 nH, C = 1.6818 pF and R = 3.9032 kΩ. The circuit simulation, using Agilent ADS, has been compared previously to the EM simulation. From 0.1 to 10 GHz, a good agreement between the EM and circuit simulations can be observed.

BANDSTOP FILTER AND RESULTS

Two new BSFs were designed by employing one spurline structure on a 50 Ω microstrip line with a pair of cross-junction open stubs. The design flow of this filter proceeded as follows. First, the start point is to design the spurline resonator at f_0. This resonator can be modeled by the LC model. f_0 is controlled by the slot width s, the slot length a and the slot height b. Then, constructing the open stub, which works as a capacitor, follows. The length of the open stub is chosen to improve the stopband's bandwidth and is adjusted using ADS. The open stub geometry is determined by l_1 and l_2, while the distance between the two open stubs is l_3. Fourteen is the distance between the left open stub and the spurline. The 50 Ω microstrip line has a width of w. The structure of the cross-junction open stubs is optimized using ADS. The physical parameters l_1, l_2, l_3, l_4 and w of this BSP are chosen to be 10, 2, 12.1, 1.2 and 1.17 mm, respectively, as shown in ***Figure 4***. The physical parameters l1, l2, l3, l4, l5 and w, of the second BSP, with a meandered spurline, are chosen to be 7, 8, 2, 2.4, 13 and 1.17 mm, respectively, with the dimensions of the meander spurline being s = 0.2 mm, a = 7.9 mm, b = 0.8 mm, c = 0.7 mm and d = 0.6 mm. Its photograph is shown in ***Figure 5***. The filters characteristics were simulated and compared with measurements. In ***Figure 6***, the measured results show that the filter with a straight spurline has a stopband from 2.84 to 6.02 GHz with S_{21}

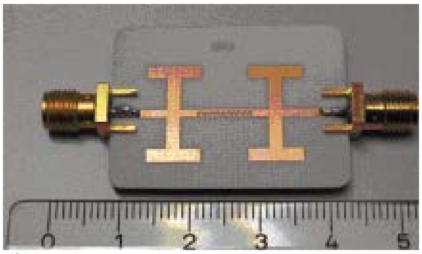


▲ *Fig. 3 Equivalent circuit model for a spurline.*

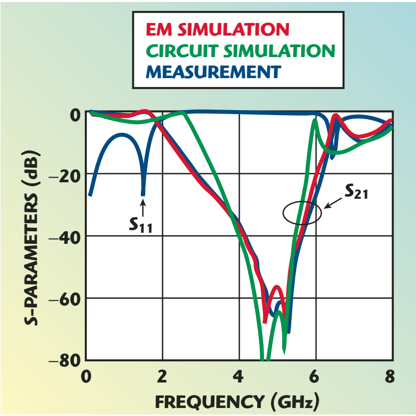


▲ *Fig. 4 Layout of the proposed BSFs; (a) straight spurline and (b) meander spurline.*

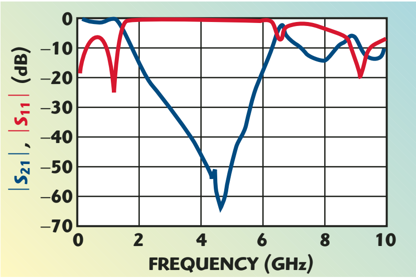
less than –20 dB. Furthermore, it is found that two transmission poles are located at 4.7 GHz with S_{21} = –66 dB and at 5.3 GHz with S_{21} = –71 dB. The deep bandstop characteristics are excellent for practical engineering applications. In addition, the total length of this BPF is 17 mm, which is approximately λg/6 (λg is the guided wavelength at the –3 dB cut-off frequency). Without any periodic structures, the circuit size is reduced dramatically. Good agreement between EM simulations, circuit simulations and measurements validate the proposed design methodology of the microstrip BSF with a spurline structure. In ***Figure 7***, the measured results, for the BSF with a meandered spurline, show that the filter has a stopband from 2.3 to 5.6 GHz with S_{21} less than –20 dB. The maximum insertion loss within the passband is 1.0 dB. Furthermore, there are two transmission zeros on the stopband. They are –54 and –63 dB at the frequencies of 4.3 and 4.6 GHz, respectively. The measurements were performed with a vector network analyzer (HP8722D) over the frequency range 0.1 to 40 GHz.



▲ *Fig. 5 The proposed BSF.*



▲ *Fig. 6 Transmission characteristics of the BSF filter with a straight spurline.*



▲ *Fig. 7 Measured characteristics of the BSF filter with a meandered spurline.*

CONCLUSION

This article describes simple and compact BSFs that were implemented and measured. The filters consist of one spurline and a pair of cross-junction open stubs. The bandstop characteristics of this spurline at its resonant frequency is characterized with one LCR-resonator and good agreement between EM and circuit simulations, based on the extracted parameters, was demonstrated. The proposed BSFs were measured and show that excellent bandstop characteristics are obtained. The proposed circuit model of a spurline will help in developing microwave circuits by computer-aided design (CAD) techniques and the new BSF can be widely used for harmonics suppression in microstrip circuit applications. ■

ACKNOWLEDGMENT

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Hai-wen Liu *received his BS degree in electronic systems and his MS degree in radio and remote-sensing science from Wuhan University, Wuhan, China, in 1997 and 2000, respectively, and his PhD degree from Shanghai Jiao Tong University, China, in 2004. From 2004 to 2006, he was a research assistant professor at Waseda University, Japan. From 2006 to 2007, he was with Technische Universitat Hamburg-Harburg and Kiel University, Germany, as a Humboldt research fellow. He is currently a professor at the Institute of Optics and Electronics, Chinese Academy of Sciences, Chengdu, China.*

Zhiguo Shi *received his BS and PhD degrees from the department of information and electronic engineering, Zhejiang University, China, in 2001 and 2006, respectively. He is currently a post-doctor at the same university.*

Reinhard H. Knoechel *received his Dipl.-Ing degree in electrical engineering and his Dr.-Ing degree from Technische Universitat Braunschweig, Braunschweig, Germany, in 1975 and 1980, respectively. He has held the chair in microwave engineering at Technische Fakultat, Christian-Albrechts University of Kiel, Kiel, Germany, since 1993. His research interests include active and passive microwave components, microwave measurement techniques, industrial microwave sensors and radar.*

Klaus F. Schuenemann *received his Dipl.-Ing degree in electrical engineering and his Dr.-Ing degree from Technische Universitat Braunschweig, Braunschweig, Germany, in 1965 and 1970, respectively. He has been a full professor of electrical engineering and the director of Arbeitsbereich Hochfrequenztechnik, Technische Universitat Hamburg-Harburg, Germany, since 1983. His interests include nonlinear microwave circuits, semiconductor device modeling, solid-state oscillators, digital communication systems and integrated-circuit technologies*

RF AND MICROWAVES IN ASIA: TECHNOLOGICAL AND ECONOMIC DIVERSITY

Asia's prominence and influence in the global marketplace continues to grow. This article considers the role that RF and microwave technology plays, its development and global impact.

In the commercial and technological arena, Asia is the continent that elicits strong opinions and provokes debate. Is it an all-consuming predator with an insatiable appetite, sustained by low-cost mass production, intent on devouring the lion's share of the market? Or is it the goose that will lay and incubate the golden egg of prosperity through technological development, the harnessing of an emerging academic and skills resource, and the exploitation of economic growth stimulated by a booming domestic market?

Of course, the reality lies somewhere midway between these two extremes and different perspectives of the region's technological and commercial prosperity and development will no doubt be proffered at the 2007 Asia-Pacific Microwave Conference (APMC 2007), being held from 11 to 14 December, in Bangkok, Thailand. APMC 2007 is devoted to the research, development, and application of RF and microwave theory and techniques, and aims to continue and accelerate the momentum of research into the microwave sector, bringing together researchers from the Asia-Pacific region as well as other parts of the world to discuss and exchange views.

The host country, Thailand, is renowned as the Land of Smile, so what does Asia have to smile about in terms of technological innovation, developing markets and commercial success? How does it fit and interact with the global microwaves and RF community and what are its future prospects?

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

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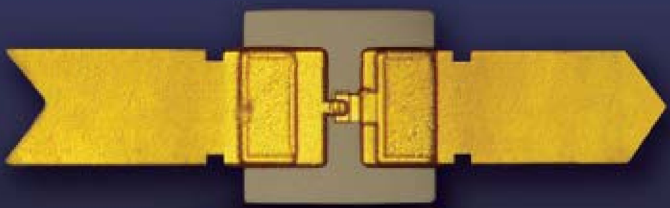

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MOBILE/TELECOMMUNICATIONS

The Asia-Pacific region is the largest mobile subscription market in the world. It is growing steadily, and according to research by Frost & Sullivan is envisaged to reach 1.14 billion subscribers by the end of this year. However, the bare figures mask the reality that the region is a complexity of individual countries at different stages of mobile technology innovation and commercial uptake.

Mature markets such as Japan, Hong Kong, South Korea and Taiwan are at the higher end of the technological spectrum where subscribers have access to state-of-the-art phones and the latest services that operators can provide. The result, however, is near saturation of mobile subscriptions.

Conversely, emerging markets such as China and India, which together account for a third of the world's population, along with other heavily populated and developing countries such as Pakistan and Indonesia, will continue to see rapid growth in mobile subscriptions. Such markets with relatively low income per capita are witnessing network expansion and an increased demand for cheaper handsets. There is a booming market second hand device market in Indonesia in particular, with other similarly placed countries set to follow suit.

In India the mobile phone subscriber base has exceeded the 100 million mark according to In-Stat, who predict that this will more than double to 265.2 million by 2010. Significant contributory factors include an unpenetrated market, low tariff structure, operators investing in network expansion and greater affordability for a larger proportion of the population.

Technologically, 3G has made significant inroads in Asia, which now has the largest number of 3G mobile users worldwide, with In-Stat reporting over 130 million 3G users in the Asia-Pacific region in 2005.

With regards to 3G in China, the introduction of the homegrown TD-SCDMA system has been laboured to say the least. The government's hesitancy has stalled what is a significant opportunity for China to establish a global communication standard, to lead the development of the technology and to own more intellectual property rights. Progress is now being made, though, with China Mobile constructing TD-SCDMA trial networks in Beijing and other key regions, and China Telecom and China Netcom also launching their TD-SCDMA network expansion programmes.

WIRELESS TECHNOLOGIES

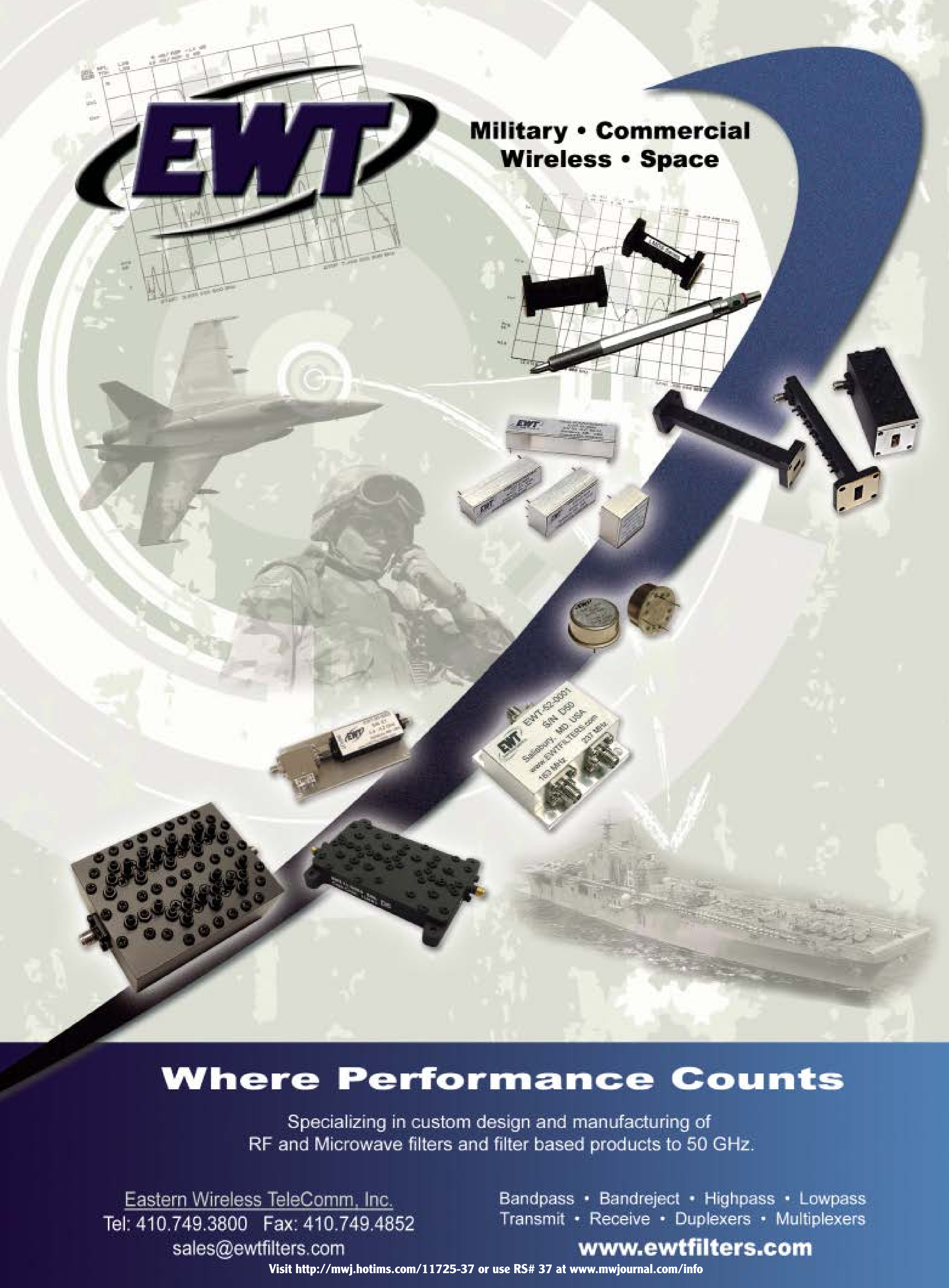
Last year's *Microwaves in Asia Special Report* highlighted that Asia has taken the lead in WiMAX development. That has continued, with the foundations for commercial fulfilment having been laid through telecommunication industry regulators giving the go-ahead and service providers viewing it as the perfect opportunity to generate broadband and wireless business. Trial and commercial deployments are ongoing. In fact, In-Stat reports that from a sparse base of 0.27 million in 2006, total subscribers in 16 Asia-Pacific countries are expected to reach 31.43 million by 2012, which will be worth $8 B.

A leader in WiMAX development in the region is South Korea, which, in 2006, was the first country to launch mobile WiMAX, or Wireless Broadband (WiBro), as it is known domestically. However, despite low cost full-scale network deployment, high data rates and defined QoS for both data and voice applications, take up has initially been disappointing due to limited network coverage and a deficit of user devices. This is being addressed and efforts are being made to grow business and move towards expansion.

Looking further into the future, WiMAX has great potential in China where it can expand the country's market for fixed, portable and mobile broadband access. The fixed market will be important, but it is the mobile market where the long-term potential lies.

SEMICONDUCTORS/ICS

Asia's dominance in the semiconductor market continues. According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to the spring 2007 forecast of the World Semiconductor Trade Statistics (WSTS), the global semiconductor market is expected to grow 2.3 percent annually to $253.5 B in 2007 with Asia-Pacific exhibiting growth rates well above the global average.

Asia is the world's semiconductor manufacturing hub that has capitalised on low labour costs to attract both domestic and global system manufacturers to set up base in the region. Supply is high but so too is demand as domestic semiconductor consumption increases to satisfy the population's appetite for mobile handsets, computers and consumer electronic items. Consequently, Asia is now the largest semiconductor market in the world.

The key contributors to this consumer growth are China and India. However, their semiconductor industries are very different. China was a prime beneficiary of the market downturn in the early 2000s, which led to the closure of unprofitable plants in Europe and North America and accelerated migration to the Asia-Pacific. For chip suppliers to be able to be close to OEM, ODM and EMS customers made relocating and partnering attractive. It is invaluable for companies wanting to profit from the Chinese chip market to have a presence in the country. Also, the Chinese Government puts great store by developing advanced technology and continues to offer financial incentives for investment in the semiconductor industry.

Such government support is not so forthcoming in India, where the infrastructure is relatively poor, with the result that semiconductor manufacturing and fabrication does not have a strong base from which to develop. Where the country is strong and is making its presence felt in the global market is in semiconductor design. India now houses the design and development centres for many major integrated device manufacturers (IDM) and fabless companies.

Cost advantages, allied to readily available skilled manpower have enticed many IDMs to either outsource some of their design activities to third-party design firms in India or to set up their own design centres in the country. Much of that work is piecemeal at present, but natural progression is likely to see design companies moving towards providing the complete design process. These developments have prompted predictions that India's IC design services sector will continue to grow at over 20 percent per year through 2010. However, the industry has recognised that to realise such predictions will mean continuing to provide the skilled manpower that is so vital to continued progression and it is therefore fostering close ties with academia.

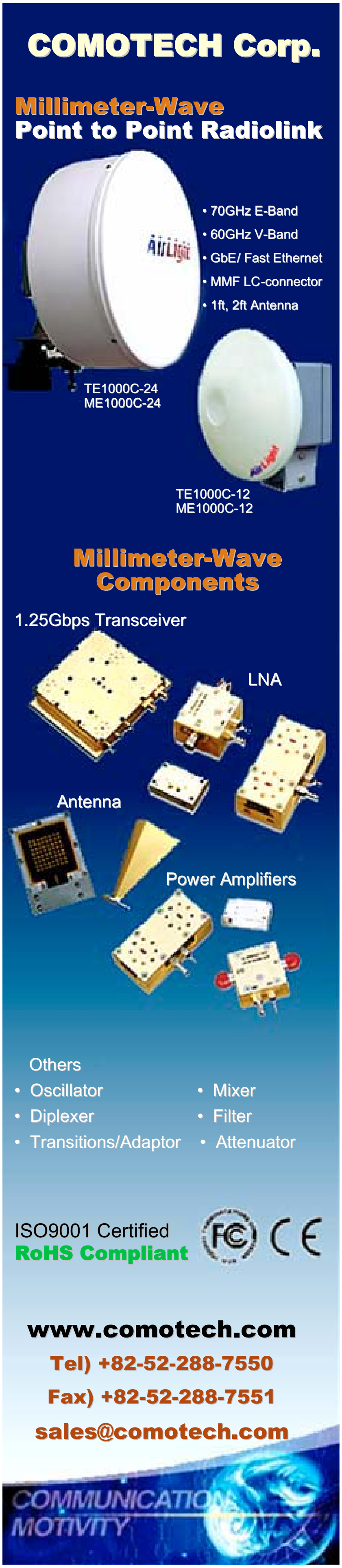
FOUNDRIES

The Asian semiconductor foundry industry continues to dominate the global market. It has benefited from migration from declining markets in other regions and being able to support a flourishing semiconductor manufacturing industry that itself is being buoyed by an increasing local consumer market.

Capacity has grown dramatically, especially in recent years with the ramping up of 300 mm fabs. The market has tended to be dominated by a number of large players offering advanced technology products while smaller companies have tended to rely on standard process technologies to produce generic semiconductor ICs. To advance process technologies and expand manufacturing capacity such companies need to carefully manage their resources and investments. Some are advancing by providing a mix of foundry-compatible processes along with well-supported specialized processes.

As far as different countries are concerned, Taiwan has the highest fab density worldwide and is the home of the leading two foundries, TSMC and UMC, while Japan has a long-standing foundry service industry dominated by IDMs that have their own in-house wafer fabs. South Korea is emerging as a serious rival to Taiwan and Japan. It has an established semiconductor manufacturing infrastructure, a wealth of technically skilled personnel, can offer a comprehensive range of testing and packaging services, and has a reputation for complying with trademark and copyright laws.

China has shown its intent to be a key player in the foundry industry with the emergence of the likes of SMIC and Grace Semiconductor,



which have the potential to be competitive with the big names in the region. China has a huge untapped local market and while aggressive technological development and pricing ensure competitiveness it does not have a significant infrastructure and skills base. It is fettered by the restrictions that countries including Japan and the US put on the transfer of technology and equipment into China, and in order to attract foreign investment and business the country needs to address concerns over piracy.

COMPANY SURVEYS

Technologically and economically the above briefly sets the context in which the Asian microwaves and RF industry is currently functioning, but what are the realities for companies developing, manufacturing and marketing new products in the region? To provide insight into current market conditions and technological development, a commercial perspective is offered via the 'company survey' of executives from companies representing a cross-section of industry. The format is generally a brief overview of the company's activity, followed by comments on technological and market initiatives.

JAPAN

Orient Microwave Corp.

Since its foundation in 1983, the company has strived hard to improve its offering, develop its skills and contribute to society through the many products it has developed for microwave use. These now include various coaxial connectors, adaptors, cable assemblies, terminators, couplers, power dividers, attenuators, waveguide to coaxial adaptors, filters, antennas, switches, phase shifters, limiters, amplifiers, oscillators and circulators/isolators.

They are all made to suit specific customers' needs, and are used extensively in modern, state-of-the-art electronic devices in the fields of space, aeronautics, radar, wireless communications, mobile communications and measuring. They also range from small orders through to mass-produced devices and from standard through to customized items.

Geographically the company has traditionally concentrated on its domestic Japanese market, but has also been active in other Asian countries and Oceania. The decision was recently taken to widen its reach when attending the 2007 MTT-S event in Hawaii, where it forged new relationships with North American and European businesses.

In breaking into new markets Orient proffers that Asian companies can capitalise on being rich in manpower, providing high quality products and offering competitive lead times at low prices. Also, utilising flexibility and endeavouring to meet all customer requirements, particularly for customised products, delivers a commercial edge.

In terms of technological innovation the company says that it is witnessing moves towards compact RF and circuit design on multi-layer PCBs and the development of mm-wave technology. With regards to microwave devices such as antennas, filters and mm-wave devices the company believes that higher frequencies, greater power, super low noise and broadband technology will stimulate the global microwaves and RF market in the future.

SOUTH KOREA

Prewell

The company's main activity is the design and assembly of RFIC and MMICs, particularly the development of high performance gallium arsenide integrated circuits for modern wireless telecommunications, telecommunication infrastructure and CATV applications. It takes advantage of state-of-the-art GaAs, InGaP/GaAs processes, utilizing HBT and PHEMT devices to develop new products.

Prewell is currently working to develop an RF amplifier with greater than 2 W of power and an ultra-wideband RF amplifier using HFET and PHEMT devices for telecommunication infrastructure. The company has also developed LNA, VCO and PLL modules for mobile infrastructure applications. These are all aimed at easing the task of the RF system designer, which together with quality and reliability are seen as the means for obtaining new customers and retaining existing ones.

Such customers are worldwide as the company strives to be a global business. It currently has one repre-

sentative and 13 international distributors. A specific target market is close to home, in China, where it has a branch office to address the country's expanding RF and CATV markets. Prewell believes it is important to be in contact and react to its distributors and customers in order to cater for different market requirements and provide the right products quickly at a competitive price.

The company proffers that, generally, Asian RF product manufacturers have the capability to produce new designs for new markets and have the manpower and experience to adapt to changing markets.

Technologically, Prewell is seeing significant activity in the development of WiMAX and CATV products using PHEMT and HFET, for which it hopes to provide a solution for the RF designer through the development of a mixer, digital controlled attenuator, regulator and operational amplifier.

The company sees the development of new technology and design skills as the means for delivering cheaper products, making design simpler and providing more powerful operating systems. It envisages higher frequency and ultra-wideband products fuelling the growth of the microwaves and RF industry in the future.

TAIWAN

Daa-Sheen Technology

For over 20 years the company has been designing and manufacturing SMA, SMB, SMC, MMCX, MCX, N, BNC, TNC, FME, 7/16, 1.6/5.6, SMZ, SMP, MIMI UHF, VHF and CATV/satellite RF and microwave coaxial connectors and adaptors. As well as standard designs the company also offers customised designs in all sectors, including telecommunications, military, aerospace, automotive and medical. As well as developing its own products the company also manufactures under license if required.

A key market is Europe, where Daa-Sheen is active in Germany, Holland, the UK, France, Switzerland, Italy, Belgium, Finland and Spain. Expansion into Eastern Europe has resulted in business in Poland and that has encouraged the company to target other European countries. Wider still it is active in the US, Australia, South America and Japan. The company likes to keep its operations under one roof, so it does not have partners but does have distributors.

The company attributes its success in so many regions to building close customer relationships and adapting to individual needs and specifications. This is particularly important for customised products and the company relies on customer feedback.

Daa-Sheen operates good production management with a flexible workforce. Therefore, it can offer quality and reliable products at an affordable price that gives its customers a competitive edge in their marketplace.

Commercially, the company believes that the East and West should work together to forge good working relationships. Technologically it feels that with the move towards miniaturised components there is the necessity to develop miniaturised connectors and adaptors too.

THAILAND

Aerotek

Established in 1989, the company designs and manufactures passive microwave and RF ferrite components. Interestingly, the company has developed its design and production capability through technical consultation with the Thai-German Institute and the National Electronics and Computer Technology Centre (NECTEC).

Its main products are coaxial and drop-in type isolators and circulators covering the 80 MHz to 20 GHz frequency range. However, to meet the demand from customers needing to address higher operating frequencies it has recently added circulators and isolators for frequencies up to 26.5 GHz to its standard coaxial products. The company also caters for the demand for wideband and high power handling of circulators and isolators.

Aerotek exports its products worldwide, but its main customers are system providers and leading suppliers of test and measurement instruments in Europe and Japan, with India also a key outlet. In all three the company takes advantage of the well-established business rela-

tionships it has forged with leading distributors to handle its products for their local customers. The company also exports directly to other countries.

Geographical considerations are taken into account when developing new RF and microwave products. The main focus is to offer products that can fulfil customers'/end users' requirements for quality and delivery worldwide, and although the company's standard products are global it works closely with its sales representatives in each country and/or the end users to offer customized products, which can specifically meet their needs. Furthermore, the company is also looking for new opportunities to forge joint ventures or business partnerships with regards to licensing agreements.

Aerotek believes that in general Asian manufacturers offer design and production capabilities, allied to quality, reliability, and short and prompt delivery times. However, not only is Asian industry taking a more prominent role as suppliers to the RF and microwave industry, but its demand for new technologies in wireless applications is also a target market for European and US companies.

The company believes that the alliance between foreign and Asian companies will stimulate the growth of the RF and microwave industry worldwide because technologies transferred from foreign companies to their Asian partners will create economical production and global marketing. Sectors that could benefit from such alliances and which Aerotek identifies as having potential for technical development are WiMAX and high frequency and wideband applications.

CONCLUSION

Asia-Pacific continues to be a source of technological and commercial activity, epitomised by stark contrasts between individual countries that have developed and progressed at varying rates. The more established countries have been innovators and models for commercial development, while the emerging countries offer competition through low cost and large scale mass production. They also nurture booming home consumer markets eager to consume the latest technologies.

That hunger is particularly evident in the mobile communications market where subscriptions are large. However, the mature markets are reaching saturation, relying on new phone technology and services for growth, while emerging countries are seeing cheap handsets and network expansion as the conduits for growth.

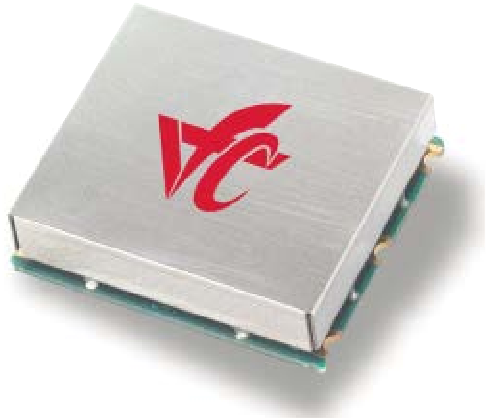
Technologically 3G has made great strides with Asia now boasting the largest number of 3G mobile users worldwide. China's TD-SCDMA system has not taken off as expected, but has the potential for growth. Asia has taken the lead in WiMAX development, where it is viewed as a means for generating broadband and wireless business. Trials and commercial development are up and running.

Asia remains the powerhouse of global semiconductor manufacturing and foundry services. By exploiting low labour costs it has been able to satisfy an increasing demand both globally and from growth economies. Established industries in Taiwan, Japan and South Korea continue to dominate, but face strong competition from China and India. The former is expanding its chip manufacture while India is using its skilled manpower to carve a niche in IC design.

The growth in the Asian market shows no sign of slowing down. Indigenous industry is at the forefront, but global players have also recognised the potential for gaining significant business through forging alliances and partnering agreements. All of which adds to the dynamism of an already diverse and complex region. ■

ACKNOWLEDGMENTS

The author would like to thank the company executives who shared their in-depth knowledge and expertise. Their contributions have given a rare insight into the Asia-Pacific RF and microwave industry from those working at the forefront of the industry. Thanks also to the following companies for sharing their statistics on the market: WSTS (www.wsts.org) and In-Stat (www.instat.com).



A JITTER ATTENUATOR FOR SYNCHRONOUS ETHERNET APPLICATIONS

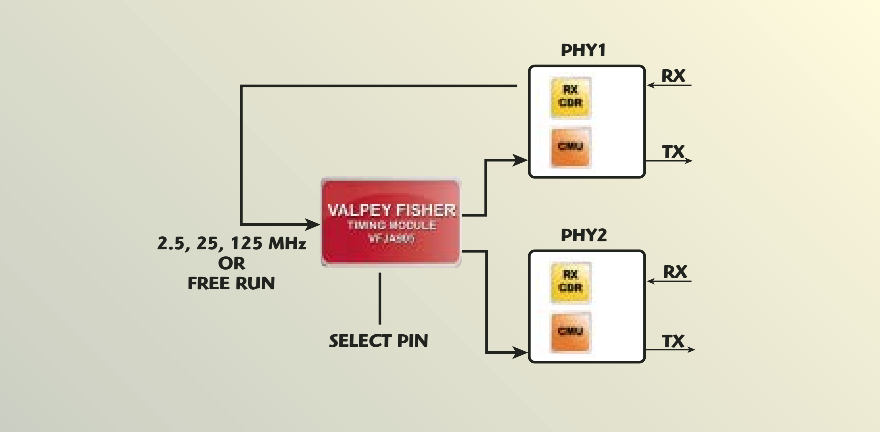
While Synchronous Optical Networks (SONET) have been widely adopted for use in long-haul applications, Ethernet is preferred in edge routers and access points due to its lower cost. Ethernet is a packet-based network architecture that is asynchronous, while SONET networks are synchronous. Hence, the two networks cannot communicate seamlessly with each other, representing a significant operating problem. The solution is Synchronous Ethernet (Sync-E). Sync-E makes it possible to connect synchronous and asynchronous networks using point-to-point connections (see ***Figure 1***).

With any transmission system that carries its own synchronizing timing signal over long distances, bit error rates increase due to the degradation of the synchronizing clock signal. Thus, the elimination of jitter associated with the clock signal is critical to successful operation of such a system. Valpey Fisher introduced the Jitter Attenuator for both Single GigE and 10G applications to meet this requirement.

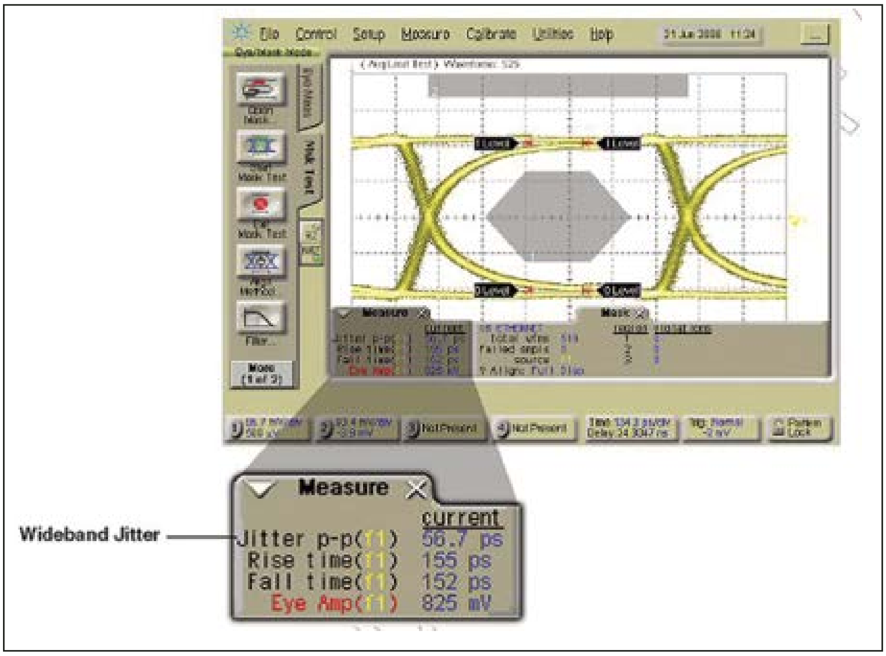
The recently introduced VFJA905 Jitter Attenuator provides two LVCMOS outputs with a frequency of 25 MHz that can be locked to an input reference frequency. Two select inputs, S1 and S0, allow the user to select one of three preset input frequencies or a free-run mode. In free-run mode the device outputs a 25 MHz clock that is not locked to the input reference frequency.

In the synchronized mode the VFJA905 unit receives its reference clock typically for a downstream recovered clock. It then attenuates the jitter in the recovered clock signal and provides the Master PHY with an ultra-low jitter sync clock signal. The slave PHY recovers the clock, which becomes the reference for the VFJA905, which in turn provides the reference clock to the next master PHY.

VALPEY FISHER CORP.
Hopkinton, MA

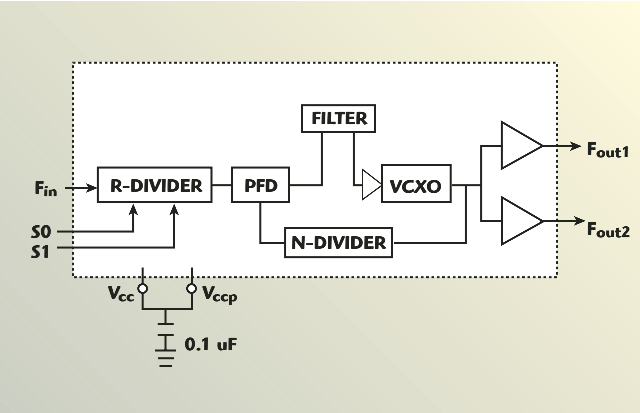


▲ *Fig. 1 A 1 GigE solution using the VFJA905 jitter attenuator.*



▲ *Fig. 3 An eye-diagram of the PHY with the VFJA905.*

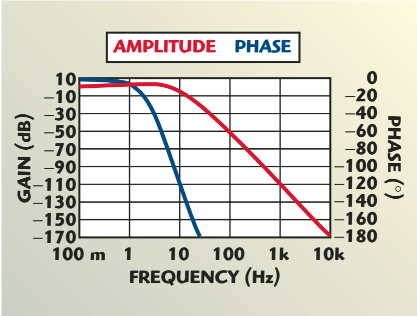
Figure 2 shows the VFJA905 unit's typical jitter transfer gain and phase response. At approximately 10 Hz the jitter transfer gain is –10 dB. At 1 kHz and beyond the jitter is attenuated to negligible levels. The VFJA905's jitter bandwidth is much lower than that of the Ethernet PHY; therefore, the combined jitter transfer gain is dominated by the Jitter Attenuator.



▲ *Fig. 4 The VFJA905 jitter attenuator's block diagram.*

The OC-48 specification requires a maximum wideband jitter of 80 ps peak-to-peak. ***Figure 3*** shows an eye-diagram of a PHY with the VFJA905 in operation. The wideband jitter is 56.7 ps peak-to-peak, providing ample margin.

Figure 4 displays the VFJA905 jitter attenuator's block diagram. It represents a single device solution that requires no external reference oscillator. It features ultra-low output jitter (sub 0.18 ps RMS) and is compliant with GR-253-CORE, GR-1244-CORE, ITUT-G.813 and ITUT-G.8261. With its user-selectable free-run mode the device can set to run either as a stand-alone device or locked to the input. Multiple outputs eliminate the use of an external buffer. Also, with its selectable input the same device can be used for multiple applications.



▲ *Fig. 2 Typical jitter transfer gain.*

The VFJA905 operating specifications include a 10 to 200 MHz output frequency range, an 8 kHz to 200 MHz input frequency range, and ultra-low jitter and phase noise (0.18 ps RMS and –143 dBc/Hz at 1 kHz). The device operates from a +3.3 V DC power supply and typically consumes 150 mW. The VFJA905 is available in a 19.5 × 15.5 mm surface-mount package and is RoHS 6/6 compliant.

Additional information may be obtained from the Valpey Fisher web site or by contacting the company directly.

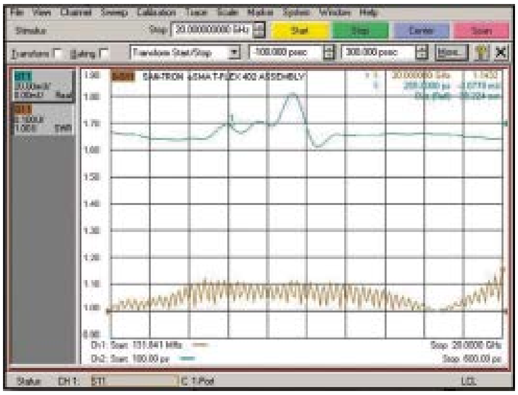
Valpey Fisher Corp.,
Hopkinton, MA (508) 435-6831
www.valpeyfisher.com.

RS No. 305

RUGGED, FLEXIBLE, HIGH PERFORMANCE CABLE ASSEMBLIES

Communication systems, test equipment and avionics are among the systems that often need to interconnect various RF modules with high performance coaxial cables. Semi-rigid cables have long been the traditional way to achieve the necessary VSWR performance at RF and microwave frequencies when delay lines or signal routing between modules call for customized cable connections. Unfortunately, these cable types sacrifice their flexibility for the benefit of electrical performance and ruggedness. Semi-rigid assemblies may even lack mechanical integrity at the cable-to-connector solder joint. In systems with numerous RF cable interconnects, the effort to design and assemble a network of inflexible cables with fixed turns and bends can be both challenging and time-consuming. While flexible customized cables circumvent this problem, they often sacrifice ruggedness and electrical performance—until now.

Fig. 1 Electrical performance of the eSMA connector showing VSWR up to 20 GHz and time domain reflectometry results.



Santron's new eSMA connector features an innovative internal design for unprecedented performance from a flexible custom cable. These new cable connectors utilize a unique extended ferrule that addresses fragile solder joints associated with semi-rigid assemblies. This connector also features: failure-proof coupling nuts; EZ style, solder free, captivated center contacts; and a solder damming positive cable stop.

ELECTRICAL PERFORMANCE

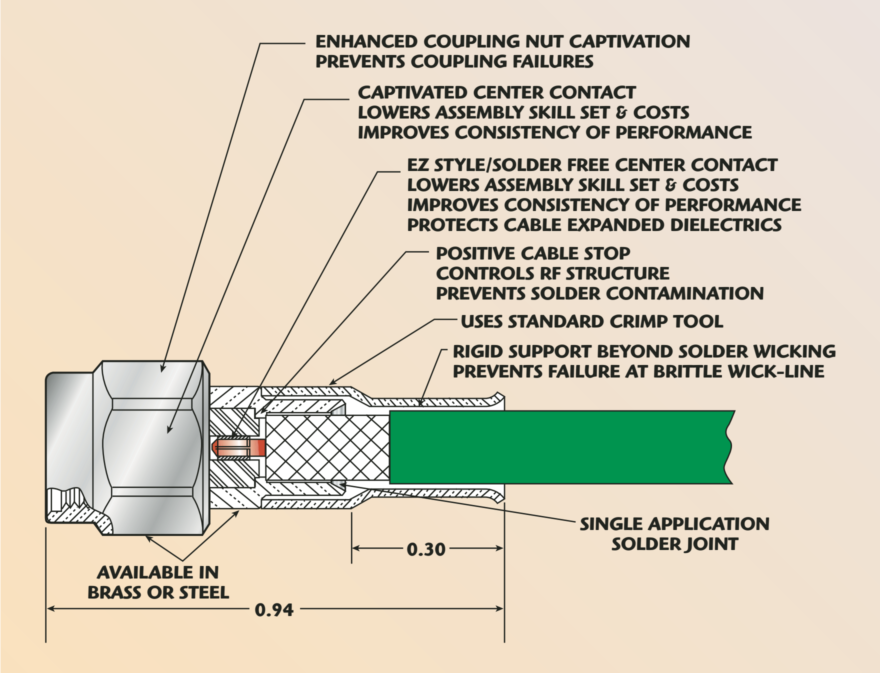
Santron eSMA connectors feature typical VSWR performance of 1.17 through 20 GHz or 1.10 up to 12.4 GHz for specific frequency ranges (see ***Figure 1***). The eSMA assemblies demonstrate passive intermodulation performance of < –150 dBc typical (2 × 20 W carriers). They also weigh less and have comparable loss to standard semi-rigid coax.

SAN-TRON INC.
Ipswich, MA

MECHANICAL CONSIDERATIONS

Like the popular high performance subminiature SMA connectors which are generally intended for use with semi-rigid cables, the new eSMA connectors employ a screw type coupling mechanism and have precision-butted dielectric interfaces for consistently low VSWR values. The eSMA connectors are gold-plated brass with gold-plated center contacts. They are weatherproof and provide 50 Ω constant impedance.

Cable assemblies, shown in ***Figure 2***, are delivered with these eSMAs professionally installed on Times Microwave Systems TFlex™ cable. They can be bent firmly even up close to the connector, where many solder joints in hand-formable assemblies often break or lose electrical integrity. The TFlex cable is a lightweight, FEP-jacketed, corrosion resistant, coaxial interconnect that is both phase and attenuation stable, while providing excellent shielding.



▲ *Fig. 2 Mechanical configuration of the eSMA connector showing internal design features and the new extended ferrule for rigid cable.*

The combined mechanical design of this new eSMA and TFlex cable assembly creates a unique solution when performance, cost and flexibility are key application requirements.

The mechanical construction of any connector is critical to ensuring good electrical performance, that is, low reflection coefficient. Several mechanical features in the internal design of the eSMA specifically address proper connector mating, such as the enhanced coupling nut captivation to prevent coupling failures as well as the EZ style center contact to ensure proper assembly and improve consistency of performance. The positive cable stop controls the RF structure and prevents solder contamination while the rigid support beyond solder wicking prevents ground failure at the brittle wick-line.

The flexible TFlex cables eliminate the need for hand or precision machine bending, allowing cables to be routed through the most convenient or desired path. eSMA assemblies are built-to-spec in desired lengths and delivered with short lead times. They are available in cable sizes 0.086" (TFlex 405) and 0.141" (TFlex 402).

Prices start at $24.95 in one foot lengths in quantities of 10 to 50. Sample requests can be made online at www.santron.com.

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

RS No. 302

ULTRA NARROWBAND NOTCH FILTER

With the current concentration of RF and microwave activity it is becoming increasingly important to eliminate unwanted signals so that the desired signal can come through loud and clear. Given the importance of providing users with filters to enable them to offer high performance equipment, Reactel Inc. has developed a line of ultra narrowband notch (band reject) and bandpass filters. These ultra narrowband units are offered for frequencies from a few megahertz to 10 GHz. Leading the charge in this endeavor is model number 4R9-2000-X1.45S11.

TECHNICAL CONSIDERATIONS

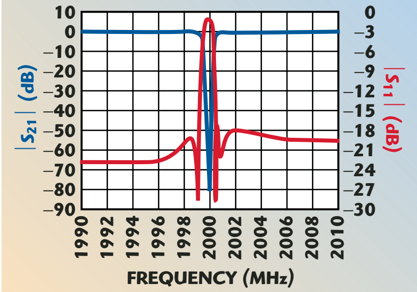
The model 4R9-2000-X1.45S11 is a notch filter which is centered at 2000 MHz, with a 1.45 MHz 3 dB bandwidth. This calculates to an eye popping 0.0725 percent bandwidth.

The new notch filter is able to achieve such a narrow percent bandwidth by utilizing a precise blend of traditional notch filter design and high Q cavities. This approach combines the best of all worlds: low loss, ultra high selectivity and extremely deep attenuation. Using a standard design, the narrowest bandwidth one could hope for would be along the lines of 10 MHz or so with a center frequency of 2000 MHz.

Figure 1 represents actual measurements of this unit. The unique design yields a 3 dB bandwidth of 1.45 MHz and rejection of greater than 85 dB at the center of the notch. Additional specifications include insertion loss of less than 0.15 dB and a size of 2.5" × 2.5" × × 18.0". Connector options are virtually limitless as all traditional coaxial RF connectors can be utilized (see ***Table 1***).

REACTEL INC.
Gaithersburg, MD


MAKE THE RIGHT CONNECTIONS



▲ *Fig. 1 Model 4R9-2000-X1.5S11 measured performance.*

TABLE I
MODEL 4R9-2000-X1.5S11 SPECIFICATIONS

Center of notch (MHz)	2000
3 dB BW (MHz)	1.45
Insertion loss (dB)	≤ 0.15
Rejection (dB)	≥ 85 @ 2000 MHz
Connectors	SMA female in/out
Size (inches)	2.5" high × 2.5" wide × 18" long, nominal excluding connectors

APPLICATIONS

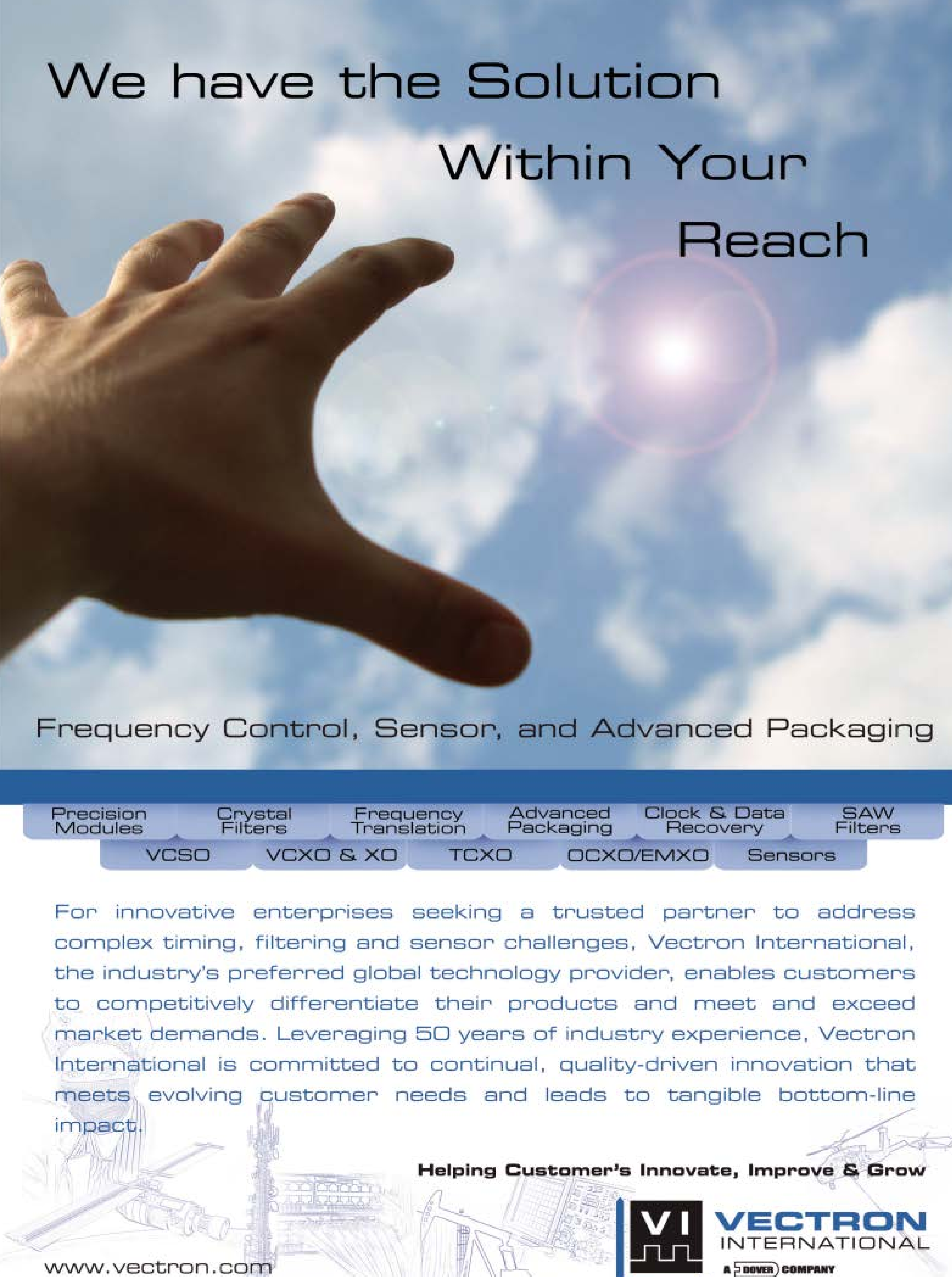
This particular unit was intended for a test equipment manufacturer. However, units have been manufactured that are also suitable for military, commercial and industrial applications. Typical uses for ultra narrowband units include GPS applications for any of the GPS frequencies, spot frequencies for a unique application, or in any instance where there is close-in interference that must be eliminated.

CONCLUSION

The Reactel model 4R9-2000-X1.45S11 notch filter offers a unique approach to solving co-location interference problems. The industry leading performance allows users to utilize as much of their spectrum as possible resulting in superior system performance. Additional information on this notch filter or any of the company's co-location interference ultra narrowband units or any Reactel product may be obtained via e-mail at reactel@reactel.com.

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

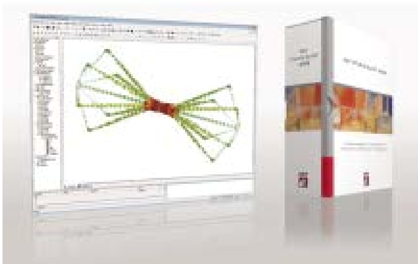
RS No. 303


We have the Solution
Within Your
Reach
Frequency Control, Sensor, and Advanced Packaging
Precision Modules
Crystal Filters
Frequency Translation
Advanced Packaging
Clock & Data Recovery
SAW Filters
VCSO
VCXO & XO
TCXO
OCXO/EMXO
Sensors
For innovative enterprises seeking a trusted partner to address complex timing, filtering and sensor challenges, Vectron International, the industry's preferred global technology provider, enables customers to competitively differentiate their products and meet and exceed market demands. Leveraging 50 years of industry experience, Vectron International is committed to continual, quality-driven innovation that meets evolving customer needs and leads to tangible bottom-line impact.
Helping Customer's Innovate, Improve & Grow
VECTRON
INTERNATIONAL
A DOVER COMPANY
www.vectron.com

EMC TEST SOFTWARE

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

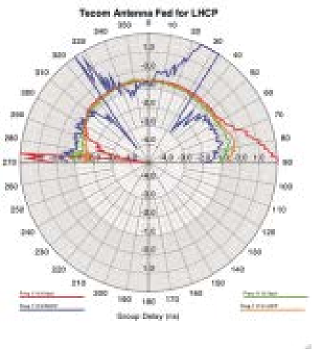
AR RF/Microwave Instrumentation,
Souderton, PA (215) 723-8181, www.ar-worldwide.com.
RS No. 310



3D EM TIME DOMAIN TOOL

CST MICROWAVE STUDIO® 2008 (CST MWS) is the leading edge tool for the fast and accurate simulation of high frequency (HF) devices such as antennas, filters, couplers, planar and multi-layer structures and SI and EMC effects. With a user-friendly interface, easy data exchange to and from other software tools, a choice of first class solvers and excellent post-processing tools, designers can leverage the latest developments in 3D electromagnetics to bring designs to market faster and with lower risk.

CST of America® Inc.,
Framingham, MA (508) 665-4400, www.cst.com.
RS No. 311



ANTENNA PATTERN RECORDER

Version 5.21 of this program is a complete software package for making antenna pattern measurements with standard vector and scalar network analyzers. The program can control single and two axis positioners, and it can make pattern measurements without the need for a physical interface to a positioner. The new program features an extensive set of math functions that allow data to be manipulated after it has been collected. One can do post calibrations, add frequency dependent magnitude and phase offsets, and add or subtract time delay signals. The program displays gain, phase, axial ratio, tilt angle and group delay.

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

PARAMETRIC PRODUCT SEARCH TOOL

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

Hittite Microwave Corp.,
Chelmsford, MA (978) 250-3343, www.hittite.com.
RS No. 313

FILTER SYNTHESIS AND SELECTION TOOL

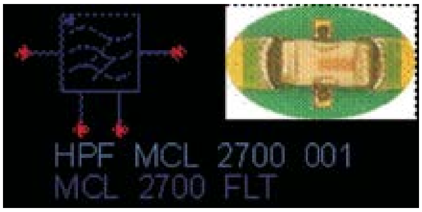
Filter Wizard[SM] has been enhanced to incorporate tubular filters in bandpass and low pass search results and to improve the low pass and high pass search interface. The web-based selection tool's bandpass search results now include tubular filters, chip & wire filters, ceramic filters, cavity filters (combline and interdigital), high-Q ceramic puck filters, and waveguide filters, as well as KeL-fil, KeL-com, Mini-Max and Mini-Pack options. Filter Wizard accelerates user progress from specs to RFQ for RF and microwave filters spanning an ever-increasing range of response types, bandwidths and unloaded Q values from 300 kHz to 40 GHz.

K&L Microwave,
Salisbury, MD (410) 749-2424,
www.klmicrowave.com, www.klfilterwizard.com.
RS No. 314

SOFTWARE PLATFORM FOR RF WAVEFORM GENERATION

The release of SignalMeister™ Waveform Creation Software is designed for the company's line of RF vector signal generators. SignalMeister is a free PC-based software tool that creates arbitrary waveform (ARB) files that can be downloaded to its model 2910 RF vector signal generator. SignalMeister is an expandable software platform with a common user interface that will allow integration of multiple signal creation libraries with flexibility to handle multiple signal standards as they become available.

Keithley Instruments Inc.,
Cleveland, OH (800) 688-9951, www.keithley.com.
RS No. 315



SYSTEM COMPONENT LIBRARY

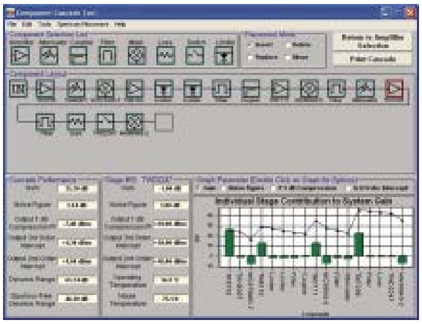
The System Component Library (SCL) consists of a unique collection of accurate and reliable system block models and is available for use in ADS. Each model is well-documented with its own data sheet that describes the valid range of the model and its advanced features. The SCL includes a combination of measurement-based behavioral and circuit models for amplifiers, mixers, switches, couplers, resonators, filters and attenuators.

Modelithics Inc.,
Tampa, FL (813) 866-6335, www.modelithics.com.
RS No. 316

MEASUREMENT AND AUTOMATION SOFTWARE

NI LabVIEW 8.5 delivers power of multicore processors to engineers and scientists. Building on nearly 10 years of investment in multithreading technology, LabVIEW 8.5 simplifies multicore as well as FPGA-based application development with its intuitive parallel dataflow language. As processor manufacturers look to parallel multicore architectures for performance improvements, LabVIEW 8.5 running on these new processors can deliver faster test throughput, more efficient processor-intensive analysis and more reliable real-time systems on dedicated processor cores. LabVIEW 8.5 also extends the LabVIEW platform further into embedded and industrial applications with the new statechart design module for modeling and implementing system behavior as well as new I/O libraries and analysis functions for industrial monitoring and control.

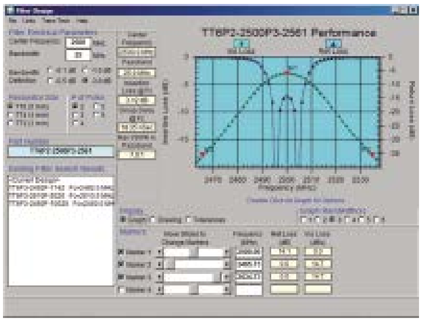
National Instruments, Austin, TX (888) 280-7645, www.ni.com.
RS No. 317



CASCADE SOFTWARE SUITE FOR DESIGN OPTIMIZATION

CASCADE is a free program whereby engineers can quickly predict a system response by either selecting standard components (Drag and Drop) or typing in their unique values. The software then calculates the chain's performance in both numerical and graphical results, as well as graphs showing each individual component's contribution to gain, noise, output power and intercepts (individually and cumulatively). Engineers can efficiently visualize a block diagram concept and optimize their design by viewing individual component contribution to overall system performance and quickly evaluate trade-offs in component selection and their impact on system performance. CASCADE is available as a CD or as a download at www.spectrummicrowave.com/cascade.

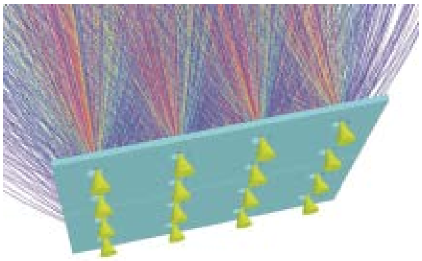
Spectrum Microwave,
Palm Bay, FL (888) 553-7531, www.spectrummicrowave.com.
RS No. 318



CERAMIC BANDPASS FILTER SELECTION TOOL

A window-based software design tool that assists in the selection of ceramic bandpass filters. With CRaFT (Ceramic Resonator Filter Tool), the designer can select from two- to six-pole filters in three different ceramic profiles in up to four different ceramic materials. The program also searches for existing filter designs in the requested frequency band, and displays measured data when available.

Trans-tech Inc.,
Adamstown, MD (301) 695-9400, www.trans-techinc.com.
RS No. 319



ELECTROMAGNETIC SIMULATION TOOL

The latest release of the well-known electromagnetic simulation tool, Opera v. 12 includes some radical improvements. A new sophisticated optimization tool has been added, which automatically seeks the best solution for single or multiple goals. In addition, the capability to model space-charge devices has been enhanced with secondary emission and dielectric charging. The ability to model electric machines in 2D and 3D has been extended with a new electric machines interface and improved solvers that allows users to readily analyze both standard and bespoke motors and generators. Opera 12 is available for Windows (32 and 64-bit) and Linux.

Vector Fields Inc.,
Aurora, IL (630) 851-1734, www.vectorfields.com.
RS No. 320

ONLINE CONFIGURATOR TOOL

This high flex round cable has been added to the company's online design tool and provides equipment designers even more standard cable solutions. When demand is uncertain or small order quantities are needed, Gore has cable for applications that demand flex life reliability. The tool provides simple step-by-step instructions for configuring GORE™ High Flex Cables (Flat or Round) or GORE Trackless Cable from standard components, with quick lead times. The GORE High Flex Cable and Trackless Cable Configurator—available at www.gore.com/designacable—simplifies the cable design process via a quick, streamlined step-by-step process. Users can design a cable and submit an RFQ using the simple configuration tool.

W.L. Gore & Associates Inc.,
Elkton, MD (800) 445-4673, www.gore.com.
RS No. 321


NEVER
COMPROMISE
YOUR
CONNECTION

NEW WAVES: Passive and Control Components

SMA Attenuators

Designed for volume applications and available from stock, the AHC family of SMA attenuators offers performance at a truly affordable price. These 2 W units operate in a frequency range from DC to 6 GHz with a 1.20 VSWR while providing excellent attenuation flatness. Built for ruggedness the AHC attenuators are available in dB values of 1–12, 15, 20 and 30.

Aeroflex Inmet Inc.,
San Jose, CA (877) 367-7369,
www.rfmw.com/inmet.

RS No. 216

Programmable Attenuator

The model DVAT-0518-60-8-SK-196 is a programmable attenuator that operates in a frequency range from 0.5 to 18 GHz. This attenuator incorporates a new driver circuit with faster switching and more accurate attenuation. This model has low insertion loss and provides stable operation over temperature extremes. Switching between all attenuation levels is typically within 1 dB in 1.5 µs at 25°C. This attenuator offers sinewave scan modulation small- and large-signal bandwidth of 150 kHz and 75 kHz, respectively. The model DVAT-0518-60-8-SK-196 has temperature stability of ±2.5 dB over –10° to 85°C and ±3.5 dB over –40° to 95°C. Size: 2" × 1.81" × 0.5".

American Microwave Corp.,
Frederick, MD (301) 662-4700,
www.americanmicrowavecorp.com.

RS No. 218

Waveguide Filter

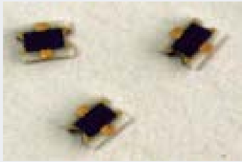
The model WH220 is a WR112 'Waffle-Iron' waveguide filter designed to handle 600 W average/1000 W peak. This space flight worthy filter features typical insertion loss of < 0.10 dB and 1.15 maximum VSWR over the 7 to 9 GHz bandwidth while providing > 25 dB attenuation of the second and > 60 dB attenuation of the third harmonic. Through utilizing the company's extensive modeling and in-house part machining capabilities the machined part requires no post assembly tuning leading to enhanced reliability.

Channel Microwave Corp.,
Camarillo, CA (805) 482-7280,
www.channelmicrowave.com.

RS No. 219

Wideband Temperature Variable Attenuator

This wideband temperature variable attenuator is optimized for performance from DC to 20 GHz. Using EMC's patented Thermopad technology, the WTVA offers the best performance to date for high frequency applications including optimal temperature coefficients of attenuation (TCA) at frequencies from 12.4 GHz up to 20 GHz. These devices have been noted for their good performance and small size, measuring only 0.125" × 0.095" (3.17 × 2.41 mm). The WTVA wideband temperature variable attenuator is available in a wire bond gold finish with dB values from 2 to 6 dB and negative coefficients slopes from 0.003 to 0.006.

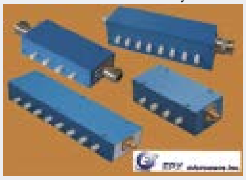


EMC Technology,
Stuart, FL (772) 286-9300, www.emct.com.

RS No. 220

Push-button Variable Attenuators

These ESA push-button attenuators are now available to manually insert attenuation in test and simulation applications. Attenuations up to 70 dB in 1 dB steps can be manually set as well as 0 to 10 dB in steps as small as 0.1 dB. Two frequency ranges are available, DC to 1 GHz or DC to 2.5 GHz. The attenuators can handle average powers ranging from 2 to 10 W. Connector options include N, BNC, SMA, TNC or 7/16. Delivery: stock to four weeks.

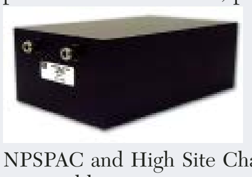


EPX Microwave Inc.,
San Carlos, CA (650) 692-2198,
www.epxmicrowave.com.

RS No. 221

Weather Sealed Notch Filter

The WSN-00280 is a weather resistant, high performance notch filter, providing low loss in frequencies from DC to 846.5 MHz and 869 to 891.5 MHz, while rejecting the 851 to 866 MHz NPSPAC and High Site Channels. When non-compatible systems are operating adjacent to one another (for example, across a freeway, in a tunnel and/or in a building) potential problems exist with interference due to their close proximity. These systems, either Public Safety and/or cellular sites, may have significant transmit energy enter their receive channels, and in many, case receiver de-sensitization occurs resulting in blocked transmissions. Size: 12.74" × 7.36" × 4.28", excluding connectors.



K&L Microwave,
Salisbury, MD (410) 749-2424,
www.klmicrowave.com.

RS No. 222

Surface-mount Notch Filter

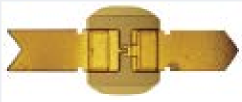
The SDN series of ceramic, surface-mount notch filters range in center frequencies from 400 to 3500 MHz. Designed for standard industry bands, the typical insertion loss is 1.4 dB/1.75 dB (maximum) with a typical return loss of 14 dB/10 dB (maximum). Dimensions vary from 0.44"L × 0.55"W (maximum) × 0.20"H (maximum) to 1.1"L × 0.55"W (maximum) × 0.28"H (maximum).

Lark Engineering Co.,
San Juan Capistrano, CA (949) 240-1233,
www.larkengineering.com.

RS No. 223

Zero Bias Beamlead Detector Diode

The model MZBD-9161 is a GaAs beamlead detector diode designed for zero bias detecting applications at frequencies through 110 GHz. The MZBD-9161 offers low junction capacitance, superior stability and lower temperature coefficient than comparable silicon zero bias diodes.



Aeroflex/Metelics Inc.,
Sunnyvale, CA (408) 737-8181,
www.aeroflex-metelics.com.

RS No. 217

Hybrid Dielectric Notch Filter

The 5BRX-830/40-S is a hybrid dielectric notch filter with bidirectional inputs. This filter features low passband insertion loss with a typical 3 dB bandwidth of 40 MHz. The VSWR is 2.0 from DC to 1200 MHz excluding the notch area. The notch depth is specified as 50 dB minimum over the central 12 MHz span. The unit features a 3.0 × 1.25 × 0.5 package size with SMA-female connectors.

Lorch Microwave,
Salisbury, MD (410) 860-5100,
www.lorch.com.

RS No. 224

Modular Coax Isolators and Circulators

These modular design isolators and circulators provide coax units with the inherent advantages of drop-in devices, including good heat sinking and high power terminations. Three models span frequency bands from 800 MHz to 14 GHz. Isolators can be equipped with 10 or 50 W terminations. Optional mounting hole geometries are provided. Additional designs are available with 200 W terminations and reverse power monitor-

ing tabs. All models can be encapsulated for high peak power applications.
M2 Global Technology Ltd.,
San Antonio, TX (210) 561-4800,
www.m2global.com.
RS No. 225

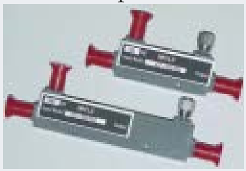
3 dB Hybrid Couplers

These high power, 3 dB hybrid couplers are useful in BTS applications for combining two transmitters to share one antenna or for use to distribute signals for in-building applications. Available in three bands: 400 to 520 MHz, 800 to 1000 MHz and 1700 to 2200 MHz. Unique airline construction provides lowest possible insertion loss while delivering high isolation (30 dB typical), exceptional VSWR (1.10 typical) and superior phase balance (3 deg maximum). Rated for 500 W (maximum). These couplers are made in the US and are available from stock (36-month warranty).

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

Directional Couplers

Two new models of low cost, fast delivery directional couplers are now available. These octave directional couplers operate in a frequency range from 0.5 to 1 GHz and 1 to 2 GHz. Other specifications include 30 dB coupling (±1.5 dB), 0.090 dB maximum insertion loss, 18 dB minimum directivity and 1:17 maximum VSWR. The development of these components has resulted in MCLI being overstocked and willing to offer extremely low pricing. These items are available for delivery today.



Microwave Communications Laboratories Inc. (MCLI),
Saint Petersburg, FL (727) 344-6254,
www.mcli.com.
RS No. 227

Broadband Fixed Attenuators

These VAT, HAT and UNAT fixed attenuators provide precision performance at economical prices. Covering from DC up to 6 GHz and available with attenuation values from 1 to 30 dB, the rugged attenuators feature innovative unibody construction for outstanding reliability. Manufactured to exacting tolerances, these low-cost fixed attenuators offer the low VSWR, outstanding attenuation flatness, and repeatability that make them ideal for a wide range of laboratory and production applications, including for level control and impedance matching. Best of all, they provide high performance without a high price, with off-the-shelf availability to meet your needs now. Designer's Kits are also available for immediate shipment.

Mini-Circuits,
Brooklyn, NY (718) 934-4500,
www.minicircuits.com.
RS No. 228

Threshold Detector

The model TD-30T-SHS-218-30DBAMP Options DAC, DS, is an ultra-high speed, high sensitivity threshold detector. This detector is designed for broadband applications in the 2 to 18 GHz frequency range and offers an eight-bit digital control to adjust the threshold level and has TTL output. The size is 2.5" × 2.0" × 0.5" and the power supply is ±12 V.

Planar Monolithics Industries Inc.,
Frederick, MD (301) 631-1579,
www.planarmonolithics.com.
RS No. 229

AMPS Diplexer

The part number 2DP-AMPS-75 is a diplexer with passbands of 824 to 849 and 869 to 894 MHz. Passband insertion loss comes in at less than 1 dB, a passband return loss of less than 16 dB, minimum channel-to-channel isolation of 75 dB, and is rated for input power of up to 500 W. It has a stellar IMD performance of less than –120 dBc. This unit can come with most any RF connector and is sized at only 2.65" high × 6.5" wide × 8.7" long.

Reactel Inc.,
Gaithersburg, MD (301) 519-3660,
www.reactel.com.
RS No. 230

3 dB Hybrid

This broadband quadrature hybrid handles 100 W and covers many popular telecom, P25/PMR, military and homeland security applications. The new unit operates in a frequency range from 500 to 2500 MHz and offers typical insertion loss of 0.4 dB, directivity of 15 dB minimum, VSWR of 1.3 maximum and coupling of 3±0.9 dB typical. Power handling is 100 W CW. The device has standard SMT launches; however, connectivity options are available upon request. The package size is 1.55" × 1.40" × 0.77" and accommodates environmental extremes from –40° to +80°C.

Response Microwave Inc.,
Devens, MA (978) 772-3767,
www.responsemicrowave.com.
RS No. 231

Miniature Ultra-flat Schottky Detectors

These miniature ultra-flat detectors utilize a zero-bias Schottky design. The microwave power is coupled directly to the extremely small components reducing package parasitics and transition mismatches. This design results in a low VSWR and a flat, smooth output over a wide bandwidth. Options available include negative or positive output, a choice of three output connectors and operation to 26.5 or 40 GHz.

RLC Electronics Inc.,
Mount Kisco, NY (914) 241-1334,
www.rlcelectronics.com.
RS No. 232

IMD Isolators and Circulators

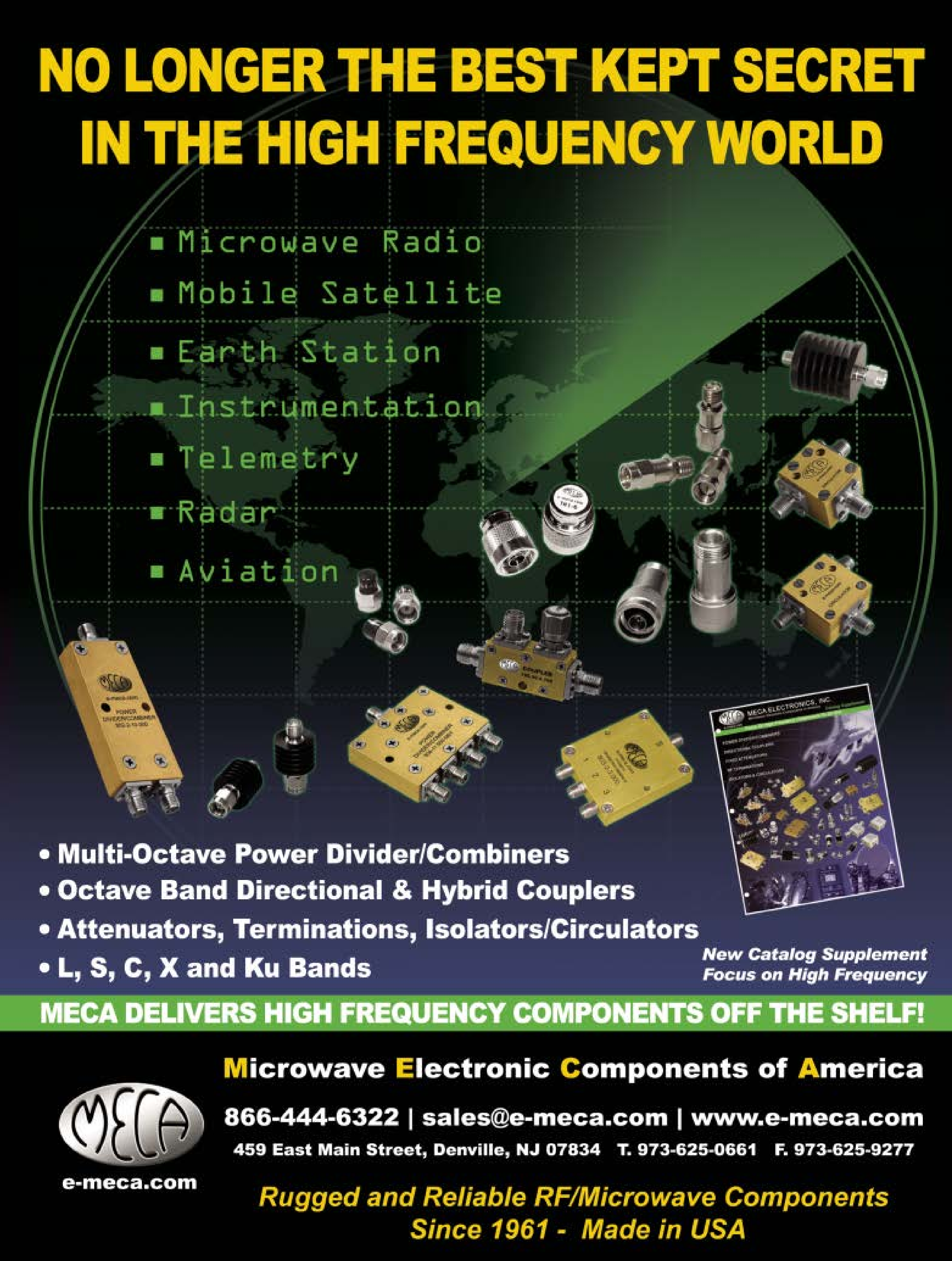
This line of subminiature low loss and low IMD isolators and circulators is designed for the emerging WiMAX market. These isolators and circulators complement the company's existing line of low loss and low IMD subminiature devices. This line operates in a frequency range that covers 2.5 to 2.7 GHz and 3.4 to 3.6 GHz. Specifications include: insertion loss of 0.15 dB maximum, isolation of 23 dB minimum, VSWR of 1.15 maximum and IMD of –82 dBc minimum at 2× tones 40 W (46.1 dBc) each. Size: 0.75" × 0.75" × 0.30" for circulator and 0.75" × 1.00" × 0.30" for isolator.

Star Microwave Inc.,
San Jose, CA (408) 286-6994,
www.starmwi.com.
RS No. 233

RF Circular Connectors

The RF Circular connector family is designed for high performance applications. The insert arrangements are maximized to hold more impedance controlled size 16 type RF contacts than any other circular connector on the market today. The product line consists of shell sizes 15-25 and is based on the D38999 specification. The HDR-FI™ RF contacts are press-in style and the connectors can accommodate standard D38999 back-shells and hardware.

Tensolite Co.,
St. Augustine, FL (800) 458-9960,
www.tensolite.com.
RS No. 234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NEW PRODUCTS

COMPONENTS

2.4 GHz Diplexers

This family of point-to-point and wireless band products includes the company's newly released 2.4 GHz diplexers. These units feature a combline cavity structure allowing high performance within a compact package. These diplexers are designed for low combining loss and high port-to-port isolation. The diplexers are frequency scalable from 2.2 to 2.6 GHz covering the Wireless Local Loop and WCS bands.

ClearComm Technologies LLC,
Fruitland, MD (410) 860-0500,
www.clearcommtech.com.

RS No. 258

30 W Termination

The model 559-247-030 is a 50 Ω termination with a QN female bulkhead connector (other impedance values and connector types are available). QN connectors mate quickly without tools. This termination was developed for a base station application and offers low intermodulation distortion. These terminations are ideal for commercial, aerospace/military and test applications. This device is optimized for DC to 2500 MHz frequencies and the maximum VSWR is 1.15 (1.10 nominal). The average power is 30 W with an operating temperature range of –40° to +70°C.

BroadWave Technologies Inc.,
Franklin, IN (317) 346-6101,
www.broadwavetech.com.

RS No. 235

High Power Termination

This high power termination will dissipate 200 W and operates in a frequency range from DC to 1 GHz. This device is available in two mounting styles, a two-hole flange 32-1201 and chip 82-3060. Each device is also available RoHS-compliant. Both versions represent a significant size reduction as compared to currently available 200 W components.

Florida RF Labs,
Stuart, FL (800) 544-5594,
www.rflabs.com.

RS No. 236

Test Cables

These SilverLine™ TuffGrip™ test cables have been recently improved. The previous high flex life PVC/steel spring armor has been replaced with a full, 100 percent steel armor with anti-torque structure. The armor is then covered with an abrasion resistant, high temperature TPE jacket. TuffGrip is designed specifically to meet the field and testing needs of cellular infrastructure site test technicians.

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

RS No. 238

AMPLIFIERS

High Power Amplifier

The model AMF-5B-09001050-40-39P is a high power amplifier (PA) that provides 7 W of X-band power. This model has an output P1dB of about 39 dBm from 9 to 10.5 GHz and 38 dBm from 7.5 to 11 GHz. Gain is 36 dB minimum, ±1 dB flat and typical noise figure is 3.5 dB. The model operates from –10° to +60°C base temperature range and draws about 4A from 15 V. It has internal regulation and protection, and a footprint of only 3.3" × 3.3".

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

RS No. 244

10 to 20 GHz Solid-state Amplifiers

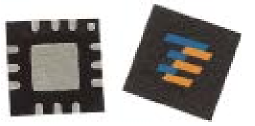
These two solid-state amplifiers operate in a frequency range from 10 to 20 GHz. Models 5S10G20A and 20S10G20A, 5 and 20 W respectively, are 100 percent VSWR tolerant, have superior linearity and are ideal for EMC and wireless testing. At new price points of $21,500 for the 5 W model and $64,500 for the 20 W unit, the S10G20A amplifiers deliver both superior performance and exceptional value.

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

RS No. 257

ISM Power Amplifier

The M/A-COM MAAPSS0081 is a new 2.4 to 2.5 GHz ISM three-stage power amplifier specifically designed for cordless applications that require both low control voltage and high performance.



With its wide voltage operating range, the MAAPSS0081 is a dual-mode power amplifier that maximizes system performance while reducing DC power consumption. In the high power mode, the amplifier generates 25 dBm of output power while drawing 300 mA of current. In the low power mode, the output power is 17 dBm with a current of 110 mA. The amplifier is housed in a RoHS-compliant 3 mm 12-lead PQFN package. Price: $0.35 (100,000).

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

RS No. 243

Solid-state Power Amplifier

The model BCPA-20-1000-25J is a solid-state power amplifier suitable for delivering reliable output power over the instantaneous frequency range of 20 to 1000 MHz. This PA is ideal for military communications and jamming platforms as well as commercial applications. The PA utilizes the latest in silicon LDMOS push-pull RF devices. These amplifiers feature: solid-state Class A/AB, silicon LDMOS RF technology, 20 to 1000 MHz 25 W, RF input signal of CW, FM, AM, PM, pulse, multi-tone and power gain at P1dB of 46 dB. Size: 6.40" × 3.40" × 1.1".

BC Systems Inc.,
Setauket, NY (631) 751-9370,
www.bcpowersys.com.

RS No. 240

ALC Log Amplifiers

The ALC Log Amplifiers™ are designed for use in early warning radar receivers, threat detection equipment, electronic countermeasures and missile guidance systems.

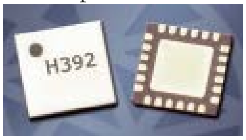
A logarithmic amplifier (or "log amplifier," for short) is a specialty amplifier subsystem that is primarily used as an amplitude detector of input signal strength on the front-end of pulsed radar and other wideband electronic warfare systems. As a log amplifier provides an output voltage proportional to the logarithm of its input voltage (which is mathematically equivalent to the input power in dBm), the amplitude information is converted to a more usable format than other linear detection schemes.

Endwave Corp.,
San Jose, CA
(408) 522-3100,
www.endwave.com.

RS No. 241

Low Noise Amplifier

The model HMC392LC4 is a GaAs MMIC low noise amplifier that is rated from 3.5 to 7 GHz, and delivers 16 dB gain, 2.5 dB noise figure and +30 dBm output IP3.



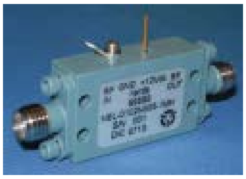
The HMC392LC4 is housed in a 4×4 mm leadless ceramic SMT package, operates from a +5 V supply voltage and features RF I/Os that are DC blocked and matched to 50 Ω with no external components. Ideal for use as a low noise front end or as a LO driver amplifier for Hittite's mixer products, the HMC392LC4 functions well in surface-mount, high reliability industrial, military and space applications.

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

RS No. 242

Low Noise Amplifiers

These low noise amplifier modules cover up to 18 GHz in bands, with noise figures as low as 1.8 dB, gain as high as 28 dB (±2 dB or less) and P1dB output power up to 20 dBm.



These amplifiers are excellent choices for applications ranging from broadband test equipment to various aerospace and defense systems, and meet MIL-STD-883. The NEL-0618T620-5MH low noise broadband amplifier, for example, covers 6 to 18 GHz, with P1dB output power of at least 20 dBm, gain of 28 dB ±2 dB or less and a noise figure of 4 dB. The NEL-0102N305-1MH low noise broadband amplifier covers 500 MHz to 2 GHz with a noise figure of

2 dB or less, gain of at least 28 dB ±0.5 dB and P1dB output power of at least 5 dBm.

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

RS No. 245

10 W Linear Power Amplifier

The model SM0825-40 is an 800 to 2500 MHz solid-state GaAs amplifier designed for multi-purpose use in wireless markets.

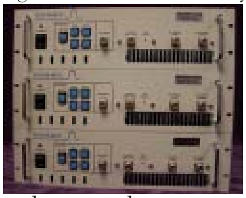
With 1.7 GHz of bandwidth, this small amplifier can be used in most wireless applications. This module provides 39 dB of linear gain, +40 dBm of output power at P1dB and an OIP3 of +50 dBm. The gain slope over the full band is just ±0.75 dB. It comes standard in modular form with six thru-holes.

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

RS No. 246

100 W Power Amplifiers

These 100 W power amplifiers with integrated signal source are currently available in three



bands including 925 to 960 MHz, 1805 to 1880 MHz and 1930 to 1990 MHz. Each power amplifier has 50 dB of gain. An RF sample port, power detector and temperature sensor are included. The signal source can be configured to drive the RF power amplifier for a cost-effective test solution. The unit operates from 110 VAC. Customized versions are available.

Telemakus LLC,
Folsom, CA (916) 458-6346,
www.telemakus.com.

RS No. 247

3D EM Solver

Utilizing the ability of the Graphics Processing Unit (GPU) in modern computer graphics

cards to stream floating point calculations, Remcom's XFdtd full wave 3D EM solver achieves extremely fast calculation speeds via the XStream® Hardware FDTD option. The new Version 3.0 of XStream Hardware FDTD is now based on the NVIDIA FX 5600 GPU with 1.5 GBytes of accelerated memory. Calculation speed is comparable to an efficiently balanced computer cluster with between 16 and 64 nodes depending on problem size. There are three versions of XStream V 3.0 available: XStream V 3.0, XStream MicroCluster V 3.0 and XStream MiniCluster V 3.0.

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

RS No. 250

CLASSIFIED

MATERIAL

High Frequency Circuit Laminates

The RO4500™ laminates is a new addition to Rogers' RO4000® product family of high performance antenna-grade materials. RO4500 glass reinforced hydrocarbon/ceramic laminates provide the controlled dielectric constant, low loss and passive intermodulation (PIM) response required by the wireless infrastructure market. They are designed for high volume commercial antenna applications, including communications cellular base stations and WiMAX networks. RO4500 laminates provide high thermal conductivity and uniform mechanical properties for improved power handling over a broad frequency range. They are fully compatible with conventional epoxy/glass (FR4) circuit board processing techniques.

Rogers Corp.,
Rogers, CT (480) 961-1382,
www.rogerscorporation.com.

RS No. 248

SOFTWARE

Electromagnetic Design Software

AXIEM electromagnetic (EM) design software is an innovative and unprecedented design tool that delivers EM analysis as a true upfront design technology, where it benefits designers most by helping to diagnose issues early, thereby significantly shortening the design process. The AXIEM product was developed specifically for three-dimensional (3D) planar applications such as RF printed circuit boards (PCB) and modules, low temperature co-fired ceramic (LTCC), monolithic microwave integrated circuit (MMIC) and RFIC designs, which are the heart of today's electronic designs.

Applied Wave Research Inc.,
El Segundo, CA (310) 726-3000,
www.appwave.com.

RS No. 249

SOURCES

Wideband VCO

The model CVCO55CW-0100-0200 is a voltage-controlled oscillator (VCO) that operates

from 100 to 200 MHz with a control voltage range of 0 to 5 V. This VCO features a typical phase noise of –108 dBc/Hz at 10 kHz offset and has excellent linearity. The model CVCO55CW-0100-0200 is packaged in the industry standard 0.5" × 0.5" SMD package. Input voltage is 5 V, with a maximum current consumption of 25 mA. The CVCO55CW-0100-0200 is ideal for use in applications such as digital radio equipment, fixed wireless access, satellite communications systems and base stations.

Crystek Corp.,
Fort Myers, FL
(800) 237-3061,
www.crystek.com.

RS No. 251

Frequency Synthesizers

The HLX series of phase-locked oscillators and frequency synthesizers are hermetically sealed, hybridized surface-mount products for use in

military and other high-reliability ground mobile, shipboard and airborne applications. The products are available as fixed-frequency or serially-programmable frequency sources with outputs ranging from 50 MHz to over 12.5 GHz. Temperature ranges between –40° to +85°C and these synthesizers have a small package size of 0.81" × 0.81" × 0.15".

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

RS No. 252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17. Signature and Title of Editor, Publisher, Business Manager, or Owner: Carl S. Sheffres, Publisher — Date: October 23, 2007

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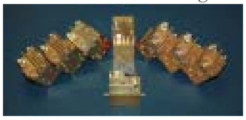
IPS Form **3526**, September 2007 *(Page 2 of 3)*

Amplified Multipliers



Series AMC (Active Multiplier Chain) is MMIC-based amplified multipliers that extend the range of sweepers and synthesizers. Three new models offer greater options and complete the frequency coverage of the AMC product line from 18 to 140 GHz in seven waveguide bands. The new AMC-12 and AMC-08 provide coverage across their entire respective frequency bands and an 18 to 40 GHz model provides K connector I/O for coaxial applications. These amplified multipliers can provide sufficient power for fundamental mixer LO drive when used with a low frequency fixed or tunable source. The AMC is a single compact module that can also be integrated with other Millitech multipliers to extend the frequency range up to 220 GHz.

Millitech Inc.,
Northampton, MA (413) 582-9620, www.millitech.com.

RS No. 253

Miniature VCOs

This DCO and DXO micro series of miniature voltage-controlled oscillators (VCO) are designed for C-band and X-band applications. These VCOs are based on Synergy's proprietary patented technology and patents pending, which enhances bandwidth, reduces phase noise and improves immunity to phase hits. Several models are available with starting frequency at approximately 4 to 9 GHz, in tuning bandwidths of approximately 1000 MHz and tuning voltages ranging from 0 to a maximum of 24 V DC. These new series of VCOs are packaged in tiny VCO surface-mount packaging measuring 0.3"L × 0.3"W × 0.1"H, RoHS-compliant, and can be delivered in tape and reel for automatic assembly processes.

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

RS No. 254

Frequency Converters

The C3430 frequency controlled crystal oscillator (FCXO) family is designed for use in wireline infrastructure, test and measurement, military applications and wireless infrastructure such as GSM, CDMA and W-CDMA base stations and point-to-point radio. Leveraging an integrated crystal-based phase-locked loop (PLL) circuit, the C3430 FCXO enables customers to convert one input frequency into as many as four independent output frequencies to simplify clock distribution, while its plug and play functionality helps organizations reduce total cost of ownership and research and development cycles. The C3430 frequency converter offers output frequencies up to 700 MHz in a unique oscillator design, leveraging a proven FR-4 surface-mount packaging design.

Vectron International,
Hudson, NH (888) 328-7661, www.vectron.com.

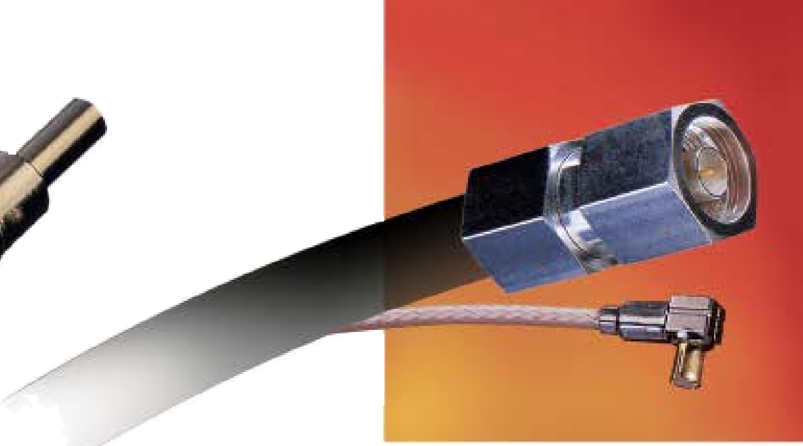
RS No. 255

C-band Smart Synthesizer

The model SFS5280A-LF is an ultra-small smart synthesizer that eliminates external programming. This synthesizer is designed as a high quality, fixed frequency stable signal source that makes life simpler for the system designer. The smart design takes care of locking every single time the circuit is switched on, or even every time it fails to lock due to external factors. The design includes features like lock detect. SFS5280A-LF delivers clean stable signal with reference spurious suppression better than –65 dBc and phase noise of –92 dBc/Hz from 1 to 10 kHz offset. SFS5280A-LF is designed to provide a stable signal source at 5280 MHz. The harmonic suppression of this smart unit is better than –20 dBc. This product is lead free and RoHS-compliant. Size: 0.60" × 0.60". Price: $49.00/unit (5 pcs min). Delivery: stock to four weeks.

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

RS No. 256



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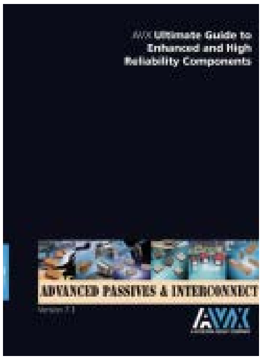
TECHNICAL HANDBOOK

This 200-page, full-color technical handbook provides an overview on building test systems, including a strong emphasis on LXI. Topics include an introduction to test-system design, selection of software and hardware architecture, how to maximize system throughput, and exploring the range of networking options available for test system automation.

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

RS No. 200

HIGH-RELIABILITY CATALOG



This high-reliability catalog highlights the company's wide range of products specifically designed for defense, aerospace and space applications. The catalog showcases AVX's comprehensive range of rugged, military qualified products including ceramic capacitors, resistors, filters, integrated passive components, timing devices, module devices and connectors, which are well suited for harsh environments.

AVX Corp.,
Myrtle Beach, SC (843) 448-9411,
www.avx.com.

RS No. 201

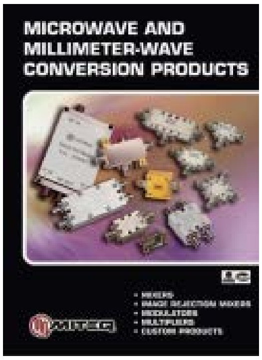
PRODUCT CATALOG

The 2007 product catalog features the company's terminations, resistors and attenuators, in various configurations including flanged, leaded or as a chip only. The products are available in BeO, BeO Free™ and aluminum nitride, including products for WiMAX and Wilkinson applications. To download a free copy, visit the company's web site.

Barry Industries Inc.,
Attleboro, MA (508) 226-3350,
www.barryind.com.

RS No. 202

PRODUCT CATALOG



This 515-page microwave and millimeter-wave conversion products catalog features the company's latest state-of-the-art mixers, image rejection mixers, modulators, multipliers and custom products. This reference manual features product specification sheets including typical test data, outline drawings, questions and answers, technical applications and notes. There are also sections discussing quality assurance, manufacturing flow diagrams, MITEQ's Space Heritage, and options available to the customer.

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

RS No. 203

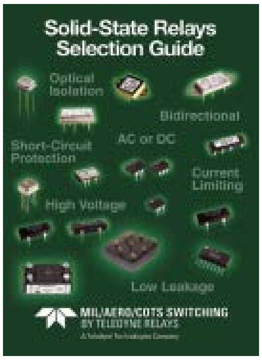
SHORT FORM CATALOG

This components short form catalog showcases the company's complete line of filters, chokes, feed-through and power-quality components and pulse transformers for electronic systems. The 12-page catalog offers an easy-to-use product selection chart highlighting Schaffner's extensive line of single phase and three phase products.

Schaffner EMC Inc.,
Edison, NJ (732) 225-9533,
www.schaffnerusa.com.

RS No. 204

SELECTION GUIDE

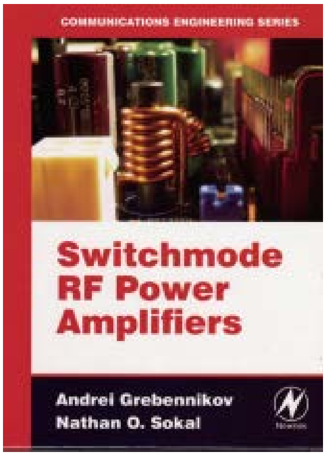


This solid-state relays selection guide is designed for military, aerospace, COTS and high reliability industrial parts (HRIP) applications. The catalog features 76 families in a tabular format designed in an easy to use format. The 20-page digest provides detailed information about the relays, which include AC, DC and bidirectional relays with output ranging from 0.25 to 10 amps.

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

RS No. 205

Switchmode RF Power Amplifiers



Andrei Grebennikov and Nathan O. Sokal
Newnes, an imprint of Elsevier • 448 pages; $89.95
ISBN: 978-0-7506-7962-6

The main objective of this book is to present all relevant information required to design high-efficiency RF and microwave power amplifiers, including well-known and novel theoretical approaches and practical design techniques. The introductory Chapter 1 describes the basic principles of power amplifier design procedures. Based on the spectral-domain analysis, the concept of a conduction angle is introduced with simple and clear analyses of the basic Class A-, AB-, B- and C-power amplifiers. In Chapter 2, the voltage-switching and current-switching configurations of Class D-power amplifiers are presented, the increased efficiency of which is a result of operating the active devices as switches. Chapter 3 describes the different Class-F techniques using lumped and transmission line elements, including a quarter-wave transmission line. Chapter 4 describes the different inverse Class-F techniques using lumped and transmission line elements, including a quarter-wave transmission line. Chapter 5 presents the historical aspects and modern trends of Class-E power amplifier design. In Chapter 6, the switch-mode second-order Class-E configurations with one capacitor and one inductor and generalized load network, including the finite DC-feed inductance, shunt capacitance and series reactance, are discussed and analyzed. Chapter 7 presents the results of exact time-domain analysis of the switched-mode tuned, Class-E power amplifiers, with a quarter-wave transmission line. Chapter 8 offers alternative and mixed-mode configurations of high-efficiency power amplifiers. Chapter 9 focuses on five CAD programs for analyzing the time-domain and frequency-domain behavior of the switched-mode high-efficiency power amplifiers in frequency ranges from high frequencies to microwaves.

To order this book, contact:
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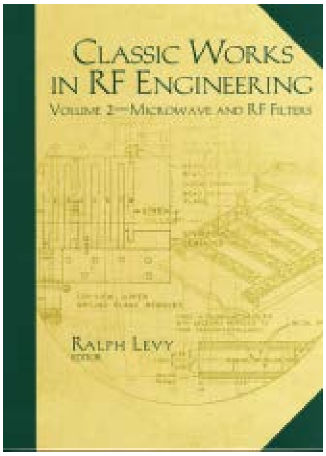
Burlington, MA 01803
(781) 221-1615

Classic Works in RF Engineering, Volume 2: Microwave and RF Filters



Ralph Levy, Editor
Artech House • 418 pages; $129, £61
ISBN: 978-1-59693-212-8

The object of this book is to present the reader with a selection of the many papers on RF and microwave filters that is most relevant to the requirements that exist today. Some early papers, considered to be breakthroughs at the time they were published, are not included if they have become superseded by later work. The reprints are grouped in ten categories, each one preceded by an introduction giving an overview of the particular class of filters in a given category. Chapter 1 is concerned with basic bandpass filters of the simple Chebyshev or Butterworth type. Modern filter design relies to a considerable extent on so-called transformed-variable synthesis, which is the subject of Chapter 2. Chapter 3 is devoted to cross-coupled and pseudo-elliptic filters. Chapter 4 describes parallel-coupled line, hairpin-line and microstrip bandpass filters. Chapter 5 is concerned with dielectric-resonator filters, which are used for two purposes: to reduce the size of filter cavities and to increase the unloaded Q, resulting in much lower loss. Bandstop filters are the subject of Chapter 6, while Chapter 7 is concerned with low pass filters. Suspended substrate stripline filters are described in Chapter 8. It is not always realized that lumped element filters may be built to operate at frequencies up to 18 GHz. Chapter 9 offers examples of this kind of filter. Chapter 10 comprises papers on power handling, insertion loss, group delay and tuning.

To order this book, contact:
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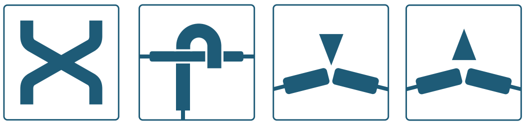

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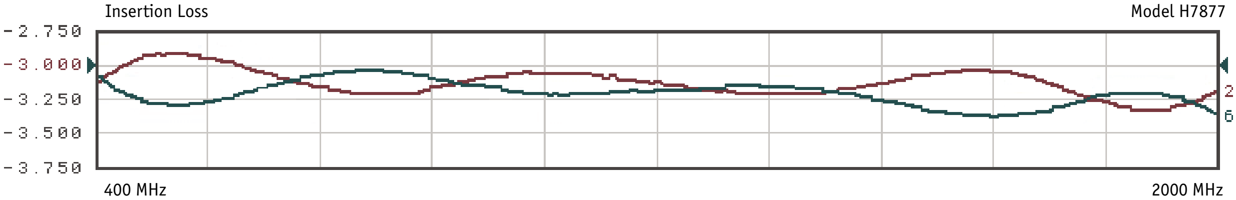

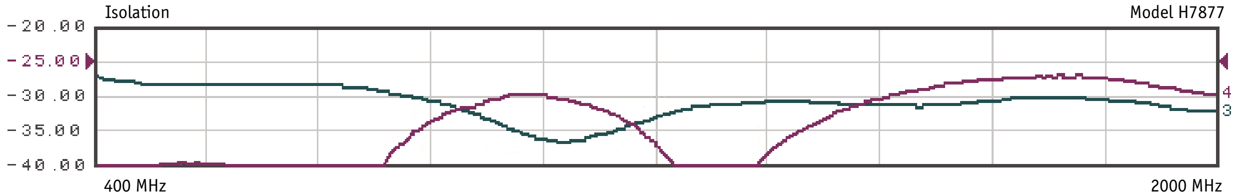

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H6751	20-512	50	0.8	1.40:1	25	4 X 1.6 X 0.8
H7450	100-500	200	1.0	1.35:1	20	6 X 5 X 2.25
H7733*	100-500	2000	0.2	1.30:1	20	15 X 10 X 2
H3670	200-400	400	0.2	1.40:1	20	5 X 3 X 2.25
H7498*	200-1000	750	0.3	1.30:1	20	8.5 X 5 X 1.5
H7877*	400-2000	300	0.35	1.25:1	20	4.5 X 2.5 X 1.2
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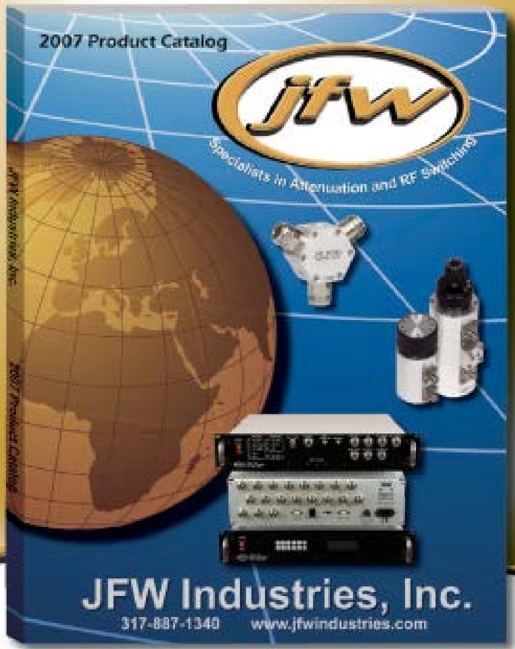

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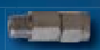

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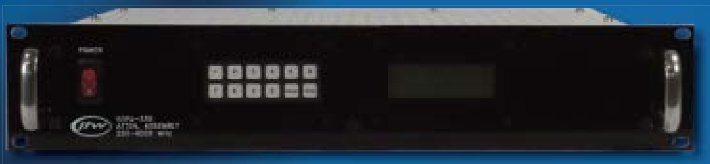

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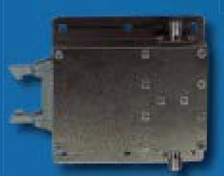

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Making Sense of WiMAX

JOSH RAHA AND MARK ANDREWS
TriQuint Semiconductor, Hillsboro, OR

When peering in at the still-evolving world of WiMAX from the outside, it is easy to be confounded by the cloud of information swirling around as the technology works to launch itself into the mainstream. To the layperson, it is possible to conclude that WiMAX has already become hopelessly complex, and it has not even been launched. In an ironic twist, some of the very companies and standards organizations with the most to gain from the success of WiMAX are often, perhaps unwittingly, involved in spreading confusion when they could be fostering clarity. For example, the WiMAX Forum™—the industry consortium that promotes this new, standards-based approach to Broadband Wireless Access (BWA)—talks of Fixed and Mobile standards, while the IEEE has standards with monikers that include 802.16d, 802.16-2004, 802.16e and 802.16-2005; and there are accounts of new releases like 802.16m and 802.16p that further muddy the waters. The casual observer must ask whether these things are the same or different? Further, the potential for confusion grows when terms like 'Nomadic WiMAX' and 'Portable WiMAX' are introduced to the global conversation about WiMAX and the technology behind it. Some equipment vendors have even co-opted 'WiMAX' to refer to any BWA product, further blurring the line between the standards-based approach championed by the Forum and the pedestrian proprietary products that have been on the market for years. Trying to understand it all is enough to turn even the most seasoned technologist into a closet technophobe. All labeling issues aside, there is a seemingly endless parade of technologically-focused issues that also swirl around WiMAX. Consider all the frequency bands that WiMAX has been purported to use. Then there are the WiMAX Profiles, the WiMAX Releases and the multiple waves of Certification. And even though first-generation WiMAX products are just now taking hold in some regions, there is the irresistible urge on the part of some to speculate about what comes next: the unfortunately named—but inevitable—'WiMAX 2.0.' Before we all drown in this eddy of profiles and releases and waves, let us try to stem the flow of confusion, separate the wheat from the chaff, and identify what is essential knowledge in tracking this market.

So, let us boldly go where few have gone before in an effort to understand WiMAX, its fixed and mobile variations; how the standards organizations work to bring harmony to the system; and how releases, profiles and certification are designed to foster both interoperability and market growth. It does not have to be as complicated as some might make it seem.

THE WiMAX FORUM AND THE IEEE

The first thing to understand about WiMAX is the definition and purpose of the WiMAX Forum,™ and how this differs from the role of the IEEE. The IEEE and the Forum are separate entities. The former defines itself as a "professional association for the advancement of technology," while the latter is a consortium of companies across the wireless ecosystem (component suppliers, radio vendors, service providers, test equipment manufacturers, software developers, etc.). The Forum brings these players together to help ensure interoperability in a relatively new approach to mobile broadband wireless and helpfully gives us this defining passage on its web site:

"The ultimate goal of the WiMAX Forum is to promote and accelerate the introduction of cost-effective broadband wireless access services into the marketplace. Standards-based, interoperable solutions enable economies of scale that, in turn, drive price and performance levels unachievable by proprietary approaches, making WiMAX Forum Certified™ products the most competitive at delivering broadband services on a wide scale" (http://www.wimaxforum.org/certification/certification_program).

Like any association or trade group made up of for-profit corporations, it would be naïve to think that all participants in the WiMAX Forum are at the table merely to foster the common good. The Forum's message is sometimes obscured by individual players' own tactics as they push proprietary solutions or publicize their own approach; to wit, much of the information about WiMAX in the trades media is clever misdirection generated to point the reader towards 'ABC Company's' better WiMAX mousetrap. That any company invested in WiMAX success would seek to turn the market in a way that favors its own position should not come as a surprise. However, in order for WiMAX to succeed it must be based on common standards, or else this latest attempt at realizing universal BWA will go the way of the turn-of-the-century efforts that were swallowed in the morass of proprietary solution dead-ends. When an approach or equipment solution is championed, the best guidance is 'caveat emptor': buyer beware. Is the solution interoperable with those from other vendors? Is it WiMAX Forum Certified (more on that later…)? Is it really WiMAX or just another solution offered for a limited area or market? As indicated in its charter, the Forum's main goal is to ensure interoperability between all WiMAX equipment. Step one is defining a set of performance standards for a WiMAX radio; step two is the ability and authority to formally certify products that meet those standards. A vendor cannot call its product a "WiMAX" radio unless it is awarded Certification by the Forum—and here we have our first source of confusion. Multiple vendors—including those that are active members of the Forum—have already begun marketing their uncertified products as "WiMAX" radios. The term "WiMAX" has been co-opted by some to refer to any BWA radio, whether it is based on Forum standards or on a proprietary design. If it is a tissue, it's not necessarily a Kleenex-branded tissue; likewise, just because someone manufactures a broadband radio, it's not necessarily a WiMAX radio. In fact, it is probably not, since there are only a handful of products that have official Forum Certification to date: http://www.wimaxforum.org/kshowcase/view.

THE ALPHANUMERIC WiMAX SOUP: 802.16 AND ITS MANY CHILDREN

Clearly, the IEEE does the world a great service in its approach to advancement and standardization of technologies. However, in doing so, the alphanumeric soup of standards that it produces tends to confuse the uninitiated when internal working group terms get thrown around. Certainly, the 802.16 standard specifically refers to Wireless Metropolitan Area Networks (WMAN, similar to WLAN—it is the same idea; see ***Figure 1***). But what of 802.16d, 16e, 16f, 16m, 16-2004, 16e-2005? What needs to be known? What can be discarded by the analyst or layperson? Unless membership in an IEEE standards committee or working group is in your future, keep this summary handy. All the standards shown in ***Table 1*** have been referred to by their WiMAX Forum labels (Fixed, Mobile or Release 2.0) for the sake of clarity in the list that follows.

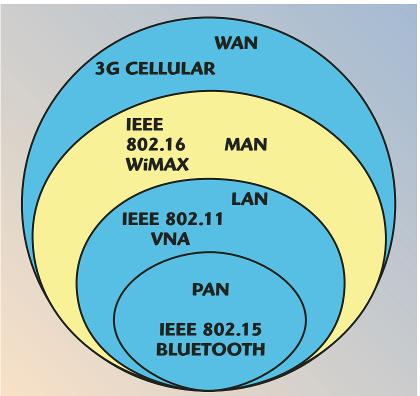

Fig. 1 The wireless universe.

TABLE I

IEEE TO WiMAX FORUM TRANSLATION

IEEE Standard	Common Name from the WiMAX Forum
802.16-2004	Fixed WiMAX
802.16e-2005	Mobile WiMAX
802.16m	Mobile WiMAX Release 2.0

• 802.16d has been terminated. It was the basis for Fixed WiMAX, but it is no longer. Any published reference to it is out of date.

• 802.16-2004 is alive and well, and is the new basis for Fixed WiMAX. To be clear, for all but the most fastidious, 'Fixed WiMAX' and '802.16-2004' are different labels for the same thing.

• 802.16e-2005 is the IEEE standard on which Mobile WiMAX is based. It is released and the WiMAX Forum's Mobile WiMAX Certification efforts will begin at the end of this year. To investigate Mobile WiMAX further, visit http://ieee802.org/16/published.html.

• 802.16m is in the very early stages of definition, but is expected to be the basis for Mobile WiMAX Release 2.0 (Why does there always have to be a two-point-oh? More on that later…). WiMAX Detractors—those that champion other broadband wireless technologies—have seized upon the m in 802.16m and have been telling the market Mobile WiMAX is still in the early committee stages at the IEEE. This is patently untrue; rather, 812.16m is the second generation of Mobile WiMAX.

• 802.16f-2005, 812.16.2-2004, 812.16k-2007… Investigate these further through the IEEE if there is an interest, but there is nothing there that will engender a better understanding of the WiMAX market as it exists today.

FREQUENCY BANDS

When looking at any wireless technology, the first set of questions any analyst ought to ask concerns frequency: what frequency band(s) will this new technology use? Is it licensed or unlicensed? Where will this frequency be available? Where will it not be available? The initial simplistic declaration on WiMAX was that it would run at 2.5, 3.5 and 5.8 GHz. The reality is, of course, slightly more intricate than that. While there are still a number of outstanding questions regarding the allocation of licensed frequency for WiMAX, it is generally understood that the United States and Canada will have released licenses in the 2.305 to 2.320, 2.300 to 2.400, 2.345 to 2.360 and 2.469 to 2.690 GHz bands (simplified: this is the 2.5 GHz band). Sprint, incidentally, and its well-publicized \$3 B US-wide network, will use the 2.469 to 2.690 GHz band. NextWave Wireless, which owns the lion's share of the 2.305 to 2.320 GHz (the WCS spectrum) in the United States, has also committed to WiMAX. South Korean provider Korea Telecom™ has already deployed a WiBro system in the 2.3 to 2.4 GHz band and Indian telecom companies have used the 3.4 to 3.8 GHz band (call it 3.5 GHz if that makes it easier) for their early Fixed WiMAX networks in their deliberate but forward-looking deployment strategy. Meanwhile, European Union countries are likely to issue licenses in the 3.3 to 3.4 and 3.4 to 3.8 GHz bands (again, 3.5 GHz). Japan has made available a 4.9 GHz band and, finally, China has not yet formally committed spectrum for WiMAX applications. It should also be noted that while most of the world's major telecom companies have yet committed to building out with WiMAX, a number of small operators and start-up service providers have begun offering 'WiMAX-like' services.

Not mentioned above are the 700 MHz and 5.8 GHz bands, which are unlicensed in most countries. There are two schools of thought for these spectrum blocks. Proponents of the first say, "These bands are unlicensed, so who's going to want to deploy networks in them? There's no demand for WiMAX here." Their opponents say, "These bands are unlicensed, so anyone and everyone can and will deploy networks there. The demand for WiMAX in this spectrum is clearly here." To date, the WiMAX Forum has not yet released any profiles for these bands, which tells you that the first school of thought has won this argument… so far. Moving forward, Fixed WiMAX will be effectively available worldwide in the 3.5 GHz bands—except for North America, which will use the 2.5 GHz bands. Meanwhile, Mobile WiMAX will likely be at 3.5 GHz in the EU and at 2.5 GHz everywhere else; this will be true if China commits to the plan followed by other key international players instead of charting its own course. In order to get to this level of alignment, the WiMAX Forum has had to address the muddle of frequencies with a two-pronged strategy. First, the Forum works with the world's governmental regulatory bodies to align available spectrum along a limited set of frequencies, minimizing the need for multiple radio architectures. Second, it provides an environment in which equipment vendors and service providers can work together to determine the bands that the first WiMAX radios will use. This second prong of the attack is manifested in the Profiles discussed later in this article.

FIXED/MOBILE/PORTABLE/NOMADIC

WiMAX is necessarily split into two basic categories: Fixed and Mobile, the key difference being that the 'fixed' services do not support hand-off, while 'mobile' services do. Fixed WiMAX, based on the IEEE 802.16d standard, is well defined and WiMAX Forum-certified radios have been deployed in various markets across the globe. There is a lot of chatter in the industry about "portable" or "nomadic"—or even "luggable"—devices. This is more of a mental exercise in hair-splitting than a division based on legitimate operational differences. For all but the most exacting mind, these two superfluous categories can be lumped into the 'fixed' camp. Perhaps a better word for Fixed WiMAX is 'Fixed-Nomadic WiMAX,' as the protocol covers both truly-fixed scenarios like "wireless DSL" as well as laptop-based "extended WLAN" nomadic settings in which a subscriber using the network shuts down his/her laptop, moves to another area with service, and then restarts and reconnects. In any case, Fixed WiMAX has a head start: it has already been deployed. Mobile WiMAX is based on IEEE 802.16e-


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2005 and, just as in the cellular world, allows a subscriber to move from one coverage area or 'cell' to another through a series of seamless hand-offs. To date, the only build-out of Mobile WiMAX is in Seoul, where Korea Telecom has launched its WiBro-branded service. There has been agreement within the Forum to meld WiBro and Mobile WiMAX into a single standard, eliminating the confusion of two names describing essentially the same service. Do not expect WiBro to die, though—KT has created a valuable and identifiable brand, and one would expect that Korean WiMAX networks will continue to carry the moniker.

PROFILES

It should be noted that WiBro devices have not yet been approved for interoperability by the WiMAX Forum. A good reason for this is that the Forum has not yet released any of its mobile profiles for certification. That said, the March Mobile WiMAX Plugfest (a closed-door event held by the Forum to bring together competing equipment vendors with the goal of testing interoperability) in Southern France included nearly 100 unique successful connections of base stations and mobile stations from approximately 25 different equipment vendors. These vendors worked with six different certification profiles in three frequency bands. At the time of this writing, the October Plugfest in Taiwan was forecast to improve on these numbers. The lesson is that positive progress has been made—and continues to be made—in the development of interoperable devices from varying vendors. All well and good, but what is a profile? Profiles may be one of the most commonly misunderstood topics surrounding Forum activities. As mentioned before, certification remains at the core of the Forum's 'cause d'être' because of the basic premise that interoperability accomplishes little if the consumer doesn't have confidence that his new WiMAX PCM/CIA card will work on the new WiMAX network in his neighborhood. Certification equals confidence to the average end user. Given the importance of a formal certification, the Forum is releasing profiles for certification: sets of requirements that must be passed by a given vendor's base station or subscriber station in order to get Certification: the Forum's stamp of approval. The multiple RF bands in which WiMAX may be deployed were covered earlier. In order to define a profile, the Forum identifies an RF band, then couples this with a specific channel size as well as a particular duplex mode. For example, one Fixed WiMAX profile for which certified equipment is available is 3.5/3.5/TDD: the 3.5 GHz band, a 3.5 MHz channel, Time Division Duplex mode; the other duplexing mode available for Fixed WiMAX is FDD: Frequency Division Duplexing. ***Tables 2*** and ***3*** illustrate the profiles that have been formally defined by the Forum to date. The text in the mobile WiMAX table refers to the name assigned by the Forum to a particular profile. All profiles for mobile WiMAX are TDD.

TABLE II

FIXED WiMAX PROFILES DEFINED BY THE WiMAX FORUM

RF Spectrum (GHz)	Duplexing	Channel Bandwidth (MHz)
3.5	TDD	3.5
3.5	TDD	7
3.5	FDD	3.5
3.5	FDD	7
5.8	TDD	10

RELEASES AND WAVES

There is a natural conflict between implementing innovative new ideas (which often takes longer than initially estimated) and getting products to market quickly. In order to balance this conflict, the Forum has decided to introduce its certification profiles incrementally, allowing for improvements in functionality and features over time. This incremental or 'staged' approach is manifested in the Forum's introduction of Profiles in Releases and Waves. Very simply, Releases and Waves define a set of functionality, with a 'Wave' being a subset of a 'Release.' The first iteration of WiMAX is Release 1.0—fairly straightforward, really, while Release 2.0 (called WiMAX 2.0 by some wags) is still being developed by the IEEE. Remember 802.16m? This will eventually become Release 2.0—but for the time being, Release 1.0 is all the market really has. Waves are subsets of Releases. The first set of Mobile WiMAX products (certified under Release 1.0, Wave 1) includes support for real-time applications, full mobility, high throughput, and well-defined security and power save mechanisms. Release 1.0, Wave 2 will include advanced features, such as Multiple Input Multiple Output (MIMO) radios, Beamforming, and Multicast Broadcast Services. It should be noted that all subsequent Releases and Waves will be fully backwards compatible. In addition, they will be incremental in nature. For example, Forum certification for Wave 2 will include all the same tests as Wave 1, plus new ones.

POWER AMPLIFIER REQUIREMENTS—FLEXIBILITY

Power amplifier technology will be a key to the proliferation of WiMAX. Early WiMAX-based hand-

TABLE III

MOBILE WiMAX PROFILES DEFINED BY THE WiMAX FORUM

		Channel Bandwidth (MHz)				
		3.5	5	7	8.75	10
RF Spectrum (GHz)	2.305–2.320	2.A	2.B			2.C
	2.3–2.4		1.B		1.A	1.B
	2.345–2.360	2.A	2.B			2.C
	2.469–2.690		3.A			3.A
	3.3–3.4		4.A	4.B		4.C
	3.4–3.8		5.A	5.B		5.C

sets, for example, have proved problematic for widespread usage because of deficient battery life and the fact they tended to heat up during extended use—critical shortcomings. In addition, these devices could stand to have more powerful transmission signals: longer transmission distances from the device will allow for fewer base stations, reduced cost of network build-out, and a quicker ROI for service providers. Heat, battery life and transmission power are all controlled—to a major extent—by the efficiency and linearity of the PA in the user device. An efficient PA uses less power and emits less heat; a PA with high linear output power will necessarily transmit further.

The beauty of the WiMAX Forum mission is that it brings together the parties designing networks, those designing radios, and those creating components to ensure that the right parts are being developed for overall market success. But for all this togetherness, there are still a wide variety of requirements—sometimes conflicting requirements—for the PA and other components. In some regards, the power amplifier has become one of those 'make-or-break' components in the system. In a very real way, a good PA is necessary for the success of the whole WiMAX market because without it, more base stations will be required to support large-scale WiMAX deployments. Battery life drains more quickly in mobile devices if the PA efficiency is, in effect, 'deficient' and heat build-up becomes a headache for the mobile subscriber. Any negatives along this chain spell trouble for new products in a new market. To the list of PA 'must-haves', that includes good output power, efficiency and linearity, one has to also consider the various band requirements (2.305 to 2.320, 2.300 to 2.400, 2.345 to 2.360, 2.469 to 2.690, 3.3 to 3.4 and 3.4 to 3.8 (while this doesn't even take into account the unlicensed bands at 700 MHz, 4.9 GHz and 5.8 GHz.). Plainly stated, current generation PAs cannot meet these requirements. In addition, WiMAX products also have to fit into various form factor requirements. For example: a fixed WiMAX CPE for a desk at home or in the workplace (think of it as a wireless DSL modem) will need to have different efficiency and bias voltage requirements than a device performing the same function in a mobile PDA or handset. A PA needs to meet this whole suite of requirements while at the same time being cost-effective. The upshot is that a PA must be flexible enough to deliver power in multiple bands, meet varying efficiency versus linearity versus power output requirements, and function in differing bias conditions in different form factors. And it must do all of this at a price that allows the WiMAX market to thrive.

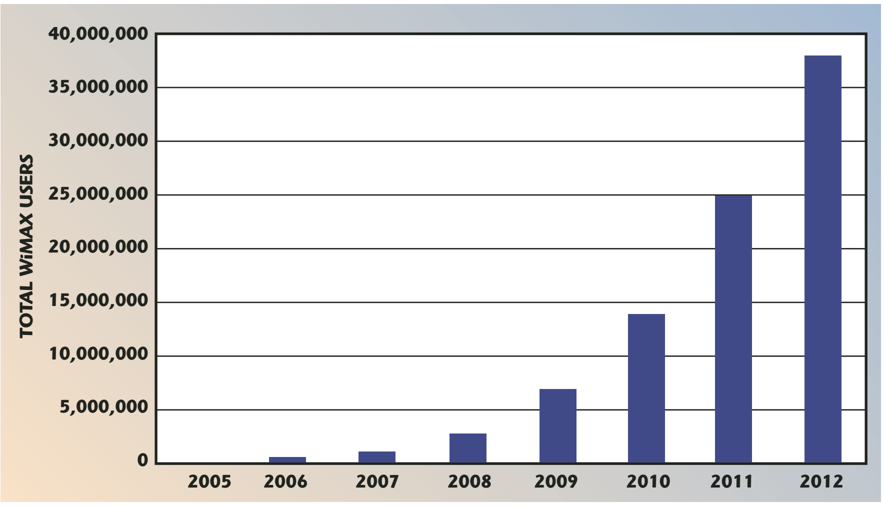


Fig. 2 Projected WiMAX users through 2012.

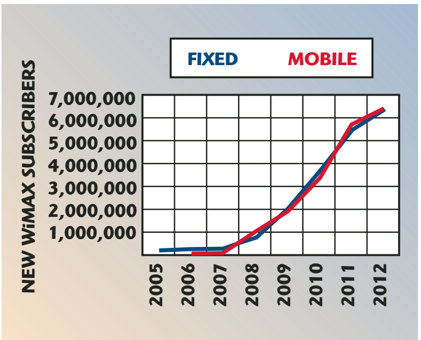


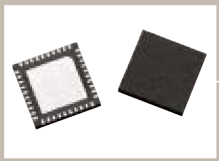
Fig. 3 New WiMAX subscribers in fixed and mobile environments.

THE WiMAX FUTURE

While coming to grips with the ins and outs of WiMAX takes some determination, it would all be for naught if the service doesn't meet global demand for universal broadband wireless access. What that demand is, incidentally, has been described as a desire to take today's Internet experience on the road. Nortel calls it "Hyperconnectivity;" NextWave calls it "WiMAX 2.0;" and the well publicized Xohm (pronounced "zome") service from Sprint calls it "Personal Broadband." In every case the concept is remarkably straightforward: providing connectivity to any online application, anywhere, at any time, on any device. At the Mobile Broadband Executive Summit this preceding September's WiMAX World show, Sprint's Atish Gude pointed out that those looking for the so-called killer application that will drive the market are missing the devastatingly simple point that "Access is the killer application." Underscoring this point at the same event, the Yankee Group's Phil Marshall shared survey data indicating that approximately 40 percent of consumers would like a wireless broadband service, but only a quarter of these people actually subscribe to any of today's options. Overwhelmingly, the reason for this gap is a price/speed tradeoff—nearly 70 percent of the remaining three-quarters believe that current options are too expensive and/or do not realize the broadband data rates required to replicate the wired Internet experience. With the assumption that the standardization efforts of the Forum will bring prices down and engender widespread network deployment, TriQuint Semiconductor's own product marketing group projects strong growth through 2012 based on its understanding of the forces shaping demand and the availability of Certified equipment (see ***Figures 2*** and ***3***). But just as wading through the swirl of information around WiMAX takes time, so does any analysis of the market forces that will affect uptake by the consuming public. As has been demonstrated before, even technically sound ideas supported by well-financed development and market roll-outs do not always reap immediate success. But for market watchers, there is general agreement that the overall worldwide economic outlook favors continued expansion of wireless communications, with wireless broadband access being the main component of that growth. While no one can say what the full impact of LTE, 'super 3G' or other flavors of 4G technology will be, as cellular vies to meet the demand for broadband service, it is clear at the same time that WiMAX offers advantages that make it a strong contender for a healthy portion of the BWA market. WiMAX offers advantages across what has been called the 4 Cs: Cost (favorable cost structure through mass standardization); Capacity (higher order modulation schemes, wider channel bandwidth); Coverage (Orthogonal Frequency Division Multiplexing provides superior non-line-of-sight-performance); and Convergence (the 802.16 family and WiBro/Mobile WiMAX enable rapid evolution of globally standardized technology). It is most likely that the future of broadband access will include a number of vehicles for service delivery involving both the 'legacy' worldwide cellular network as well as both fixed and mobile WiMAX solutions. As has been seen with almost anything involving data storage, data rates and the public's demand for communications services, 'good' always demands 'better', and 'slow' is intractably replaced by 'faster.' With demand for data rates continually growing, and since the nature of global communications is becoming increasingly mobile, wireless broadband access will continue to be a growth market into the second decade of the 21st century. ■

Josh Raha *is a product marketing manager focusing on the WiMAX, Bluetooth and GPS markets for TriQuint Semiconductor in Orlando, FL. Before joining TriQuint, he was in product management for Triton Network Systems. He holds a BS degree in electrical engineering from the University of Pennsylvania and an MBA degree from the University of Southern California.*

Mark Andrews *is marketing communications manager for TriQuint Semiconductor in Orlando, FL. He has authored numerous papers and articles focusing on the needs of technology-focused communications industries since 1993. He has a BS degree in fine and applied arts from Central Michigan University.*



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Examining the Design and Test Challenges of 3GPP LTE

SANDY FRASER
Agilent Technologies Inc.

Long Term Evolution (LTE) is the project name given by 3GPP to the evolution of the UMTS 3G radio standards. The original UMTS Terrestrial Radio Access (UTRA) is based on W-CDMA technology, which has been continuously enhanced to include HSDPA & HSUPA (HSPA). The work on UMTS continues in Release 8 of the 3GPP standards with enhancements to HSPA. In addition, Release 8 includes E-UTRA an entirely new air interface based on OFDM technology. Offering higher data rates and lower latency for the user, a simplified all-IP network for the operator and improved spectral efficiency, E-UTRA—or LTE as we will refer to it from now on—promises to provide many benefits. This article reviews some design challenges specific to LTE, and looks at the emerging test equipment being developed to help in the realisation of this new technology.

LTE TIMELINE

LTE is already more than a concept, with the study phase having started in late 2004 and a great deal of work being done to complete the release 8 standards. The many possible deployment options for LTE present one of the biggest challenges in designing and testing early user equipment (UE). The core specifications are currently scheduled to be complete by early 2008, and the first conformance test specifications should be available by late 2008. Limited quantities of working UEs may be available for field trials in 2009/2010. This is a very aggressive timescale for a new mobile technology, which will demand the availability of early and comprehensive test equipment (see ***Figure 1***).

BASEBAND

Current High Speed Packet Access (HSPA) device performance makes large demands on processing power in a mobile device package. Prototype HSPA devices available today have difficulty providing these high data rates unless connected to a mains adapter, so LTE with significantly higher target data rates than today's 7.2 Mbps will further challenge platform design.

The processing power required to support these data rates is phenomenal, particularly in baseband where all the error handing and signal processing occurs. LTE baseband functions include:

- Channel coding and scrambling
- Channel interleaving
- Adaptive modulation and Coding: QPSK, 16QAM and 64QAM
- Physical-layer hybrid-ARQ processing (HARQ), retransmission, incremental redundancy and chase combining
- Discrete Fourier Transform (DFT)

Baseband designs will likely be modeled using PC simulation on both the UE and network sides and reduced speed emulation of hardware prototypes is also likely.

RF

There are currently 11 defined Frequency Division Duplex (FDD) paired bands and six Time Division Duplex (TDD) bands listed in 3GPP TR 36.803. All of these bands are also defined for GSM and UMTS and to date there is no specific spectrum allocated to LTE. Will LTE be expected to co-exist in the same bands with W-CDMA or GSM systems or will entire bands be re-allocated for LTE? All that is certain at this stage is that the LTE spectrum situation is uncertain. The number of combinations complicates the work required for co-existence studies and the resulting requirements and tests. The lack of a single defined band for LTE significantly complicates early development compared to the single band introductions for GSM and UMTS (W-CDMA).

Although there remains much uncertainty about which bands LTE may be deployed in we do know much more about the underlying air interface. By the time LTE mobile devices require RF test, there will have been significant understanding gained from WiMAX, which shares a very similar orthogonal frequency division multiplexing (OFDM) downlink. However, the LTE uplink differs somewhat from WiMAX and uses single carrier frequency division multiple access (SC-FDMA) to reduce peak-to-average power ratio (PAPR). This will create some specific LTE test needs. From TR 36.803 the expected requirements upon which tests will be based include:

Transmitter Requirements: maximum output power (MOP) and maximum power reduction (MPR); frequency error; power control (minimum output power, transmit ON/OFF power, out-of-synchronization handling of output power); control and monitoring functions; occupied bandwidth; UE spectrum emissions mask and ACLR for LTE; spurious emission requirements for LTE; transmit intermodulation; transmit modulation (EVM).

Tests based on these requirements will enable elimination of many typical RF impairments including I/Q imbalance, PA nonlinearities, oscillator phase noise, timing jitter in IF/RF sampling and mixing.

Receiver Requirements: reference sensitivity level; Maximum Sensitivity Reduction (MSR); maximum input level; adjacent channel selectivity (ACS); in-band blocking; out-of-band blocking; narrow band blocking; spurious response; wide band intermodulation; narrow band intermodulation; spurious emissions.

Performance Requirements: dual-antenna receiver capability; antenna correlation and gain imbalance; simultaneous unicast and MBMS operations; and dual-antenna receiver capability in idle mode.

One new challenge facing LTE UE will be the need to handle variable channel bandwidths. All previous 3GPP systems have had one channel bandwidth but LTE is being defined with eight different channel bandwidths varying from 1.4 to 20 MHz. Such flexibility allows for a rich set of new possibilities in deployment. However, this flexibility also presents significant new challenges in the way in which in-channel and out-of-channel requirements are specified, in the number of permutations for testing and in operational aspects related to Radio Resource Management (cell selection/re-selection, handover etc.).

One of the consequences of LTE's variable channel bandwidth and the fact that a UE will typically be allocated a subset of the available resource blocks in the channel means that it is necessary to define limits on the energy a UE is allowed to transmit in unused resource blocks. The definition and requirements for this in-channel test are still under discussion but the vector signal analyser plot in **Figure 2** shows the principle. This impaired signal has been generated using 0.1 dB IQ gain imbalance distortion in the transmitter. The impact of this distortion on an OFDM signal is to generate images of the allocated resource block in the

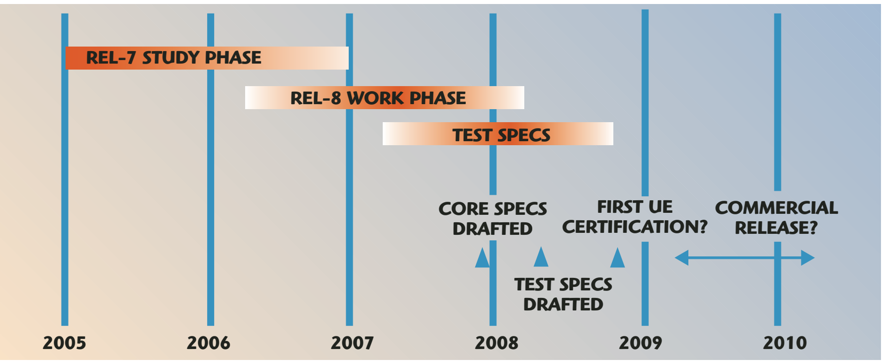

Fig. 1 LTE timeline.

other half of the signal equidistant from the centre frequency. The upper plot shows the subcarrier power and the lower plot shows EVM per subcarrier.

LAYER 2/3

LTE Layer 2 is split into the following sub-layers: Medium Access Control (MAC), Radio Link Control (RLC) and Packet Data Convergence Protocol (PDCP). The functions of L2 include:

- Mapping between logical channels and transport channels
- Multiplexing/demultiplexing of RLC Packet Data Units (PDU)
- Traffic volume measurement reporting
- Error correction through HARQ
- Priority handling
- Transport format selection
- Segmentation and re-segmentation of PDUs that need to be retransmitted
- Header compression and decompression
- Ciphering of user and control plane data

Two significant design challenges will be the ciphering of significant amounts of data in PDCP, and the MAC turnaround time, which at 2 ms is six times faster than for HSDPA. Testing at high throughputs will be necessary to stress and highlight problems in these two key areas.

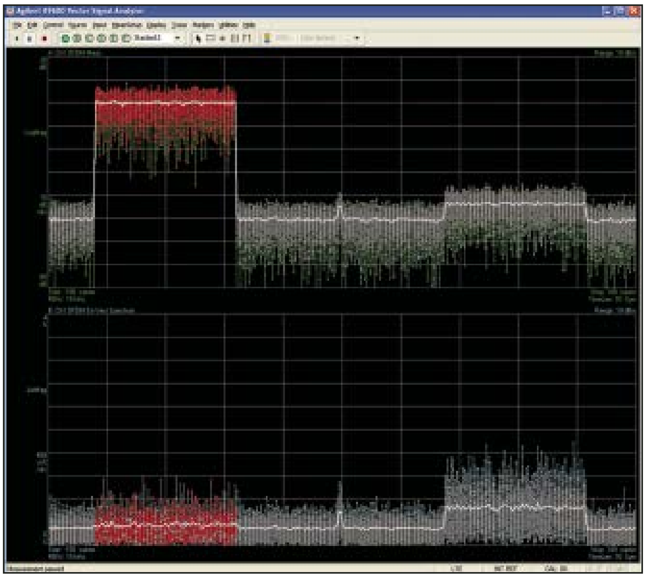

Fig. 2 Distortion of OFDM signal causes mirrored noise image.

LTE Layer 3 includes the sublayers Radio Resource Control (RRC), Mobility Management (MM) and Call Control (CC). L3 essentially deals with the main service connection protocols, such as:

- Broadcast of System Information and Paging
- Establishment, maintenance and release of an RRC connection
- Configuration of signalling radio bearer(s)
- Security functions including ciphering
- Mobility functions such as cell reporting for inter-cell and inter-RAT mobility and handovers, UE cell selection and reselection, and control of cell selection and reselection
- QoS management functions

The detailed specifications behind this broad overview of LTE L2 and L3 are still under discussion. Although early L2/L3 development will be accomplished with full-speed or low-speed simulation, it is not until L2 and L3 are integrated with baseband and the RF at full speed that the integrity of device design can be determined.

TESTING THE COMPLETE DEVICE

Test solutions for complete devices such as base station emulators with real-time protocol stacks or procedural script-based solutions cannot today be designed without a significant degree of proprietary input to account for the gaps in the specifications. Early solutions will be available within the next six to 12 months, but these will require modification until the specifications are finalised. Unlike previous generations of radio standards, the LTE conformance tests should be available well in advance of commercial service. This should help alleviate the interoperability issues, which commonly plague new technology at introduction. The expected availability of the conformance specifications during 2008 means that test equipment providers will be challenged to provide the necessary test coverage much earlier than would be normal, forcing an overlap with finalising the development of existing test solutions, for example, for HSPA+, EDGE Evolution and WiMAX.

USER EXPERIENCE AND REAL WORLD TESTING

Sustained user demand for new technology or applications is highly dependent on first impressions. The availability of web browsing via slow circuit-switched services or low data-rate early GPRS devices turned many potential users away from "surfing the mobile internet." It is only now, with the advent of W-CDMA and HSPA, that data applications are gaining credibility. It is critical therefore that LTE delivers from the very start. Voice quality via the packet network needs to be at least as good as current circuit-switched systems, data services need to be both high speed and low latency, and inter-working with legacy systems needs to be seamless. Such perfectly reasonable customer expectations demand a thorough test regime prior to commercial launch.

The early availability of conformance test specifications will help with some of the basic testing, and ensure interoperability, but like today's conformance tests, they will not be sufficient to ensure the perfect customer experience. As with 2G and 3G devices, much more functional test and verification will be required. While there are several hundred formal conformance tests for 2G and 3G there are perhaps ten times as many proprietary performance tests used by designers to stress test UEs in a similar way that they may be used in real life, using real data in real time.

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MAAMSS0073	2.5/3.5	22/20	30/30	23/23	490/5	4 mm PQFN
MAAPSS0096	4.9–6.0	20.5	28	19	230/5	4 mm PQFN
Power Amplifiers						
MAAPSS0103	2.5	34	32	26	600/5	4 mm PQFN
MAAPSS0104	3.5	32	32	26	600/5	4 mm PQFN
MAAP-008170	2.5/3.5	10/8	37/37	27/27	210/12	3 mm PQFN
MAAP-008171	2.5/3.5	8/7	40/40	30/30	420/12	4 mm PQFN

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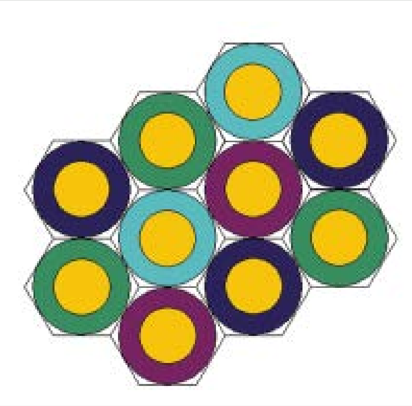


▲ *Fig. 3 LTE frequency re-use at cell edges.*

THROUGHPUT

Perhaps the most visible capability LTE aims to provide is a much higher peak data rate, 50 Mbps uplink, 100 Mbps downlink, for single antenna rising to over 170 Mbps for 2×2 downlink MIMO. These figures represent the upper limit for the system design and practical figures will be scaled back as UE capabilities are defined. However, even at significantly reduced rates there will be many design and test challenges to overcome. Although not a UE design issue, cell edge throughput is very important. It is expected that LTE will be deployed using a single frequency network; however, in order to minimise adjacent cell interference and maintain cell-edge performance, a pattern of frequency re-use will likely be used at the cell edges.

Figure 3 shows the centers of all cells using the entire channel bandwidth (yellow), while the border zone of each cell uses a sub-set of the available resource blocks (multiple colors) based on a reuse pattern. Users near the cell centers will be able to utilize the entire channel bandwidth due to physical separation from adjacent cells. Users at the cell edge will be able to obtain good C/I on a sub-set of the channel bandwidth due to frequency clearance. More advanced methods of frequency clearing are possible based on location-specific resource block scheduling at the cell edges.

Performance targets for LTE are still to be defined, but it is important that a variety of scenarios are specified in order that performance in different conditions can be understood. The nature of the OFDMA air interface with its variable bandwidth, variable modulation depth, variable resource block allocation and variable adjacent cell interference profile compared to W-CDMA means that the number of possible test combinations is large.

MIMO

Multiple Input Multiple Output (MIMO) is required in order to achieve the headline peak data rates. Two types of MIMO are defined in the LTE specifications. Single User MIMO (SU-MIMO) is where two or more data streams are allocated to one user with the intent of increasing peak data rates. Throughput improves when the radio channel exhibits uncorrelated transmission paths. Multiple User MIMO (MU-MIMO) relies on the same principle of uncorrelated transmission paths, but in this case the paths belong to different users with the intent being to increase the capacity of the cell rather than increase peak data rates. Since MIMO requires multiple transmitters and receivers it was decided for UE cost reasons to only mandate 2×2 SU-MIMO for the downlink. This requires two UE receivers. For the uplink, only 2×2 MU-MIMO is assumed, which avoids the added cost and power consumption of two UE transmitters needed for 2×2 SU-MIMO. Although 4×4 MIMO is defined in the standards, this is probably only going to be practical for PC-based devices. For handheld devices, even the baseline two receiver configuration will place additional demands on battery life, and the extra heat generated will certainly provide additional thermal management design issues.

In the same way that peak data rates are often quoted without reference to the necessary channel conditions, the same is often true for MIMO. The headline figures quoted are usually a linear multiplier on the number of transmission paths. This is the theoretical potential but reality will be determined by the correlation between the paths. MIMO will probably work best indoors where there are slow changing conditions and no line of sight. MIMO cannot function with significant line of sight since it means the paths are highly correlated. In many outdoor environments line of sight is quite normal and at the cell edge, performance benefits are achieved using receive diversity rather than MIMO.

MIMO performance targets will be defined for specific channel conditions and although these will be carefully chosen there are reasons these will not be representative of real conditions. Actual performance will be highly dependent on unspecified antenna performance, polarisation aspects, body and head loss, and different mechanical use modes as well as the dynamic conditions of the real channel. Antenna performance is further compromised by the need to support multiple frequency bands. With so many variables, specifying performance "over the air" to ensure satisfactory user experience is not realistic. MIMO receiver conformance testing will be straightforward; however, there is little information available today on how this simple form of test and the real world correlate. Real world testing of MIMO performance will be possible in due course with a visit to the local LTE network, although provision of repeatable real world emulation for early R&D using test equipment will prove to be much more challenging.

BATTERY LIFE

We live in a world where battery technology is struggling to keep up with ever more power-hungry mobile devices. GSM phones typically have a standby life of approximately seven to ten days, W-CDMA devices three to five days, and WLAN GAN devices using OFDM (albeit with little power control sophistication) are down to one to two days. What will be the battery life of an LTE UE with MIMO, capable of

170 Mbps? Optimising the battery life particularly when transferring at high data rates under realistic channel conditions will be critical to ensuring initial customer acceptance.

CONCLUSION

The design challenges presented by LTE are significant. However, the difficulties encountered during the introduction of new technology always appear far greater at the time than with hindsight. Fifteen years ago designers struggled with far less computing power, design tools, simulation and test equipment to provide us with GSM, which is now seen as simple compared to the technologies that have followed. And so it is likely to be with LTE.

Agilent's unique LTE "Connected Solutions" brings together Agilent's range of signal generation and analysis equipment with the ADS simulation environment to create a comprehensive test solution for the R&D engineer. LTE signals can be created in simulation using the ADS LTE Wireless Library and downloaded to an ESG or MXG vector signal generator to create real-world physical test signals for R&D device testing. UE output can be captured with an Agilent MXA Signal Analyzer, a PSA Series Spectrum Analyzer, or a logic analyzer, and then post-processed using the ADS LTE Wireless Library to perform measurements on RF and mixed-signal DUT hardware. Battery drain can be tested with existing Agilent analysis software and suitable power supplies.

These test solutions are just the start for LTE design and verification, with protocol development, protocol conformance tests and network emulation solutions yet to come. LTE may have many challenges, but with early and powerful test equipment solutions, the LTE challenge can be met. ■

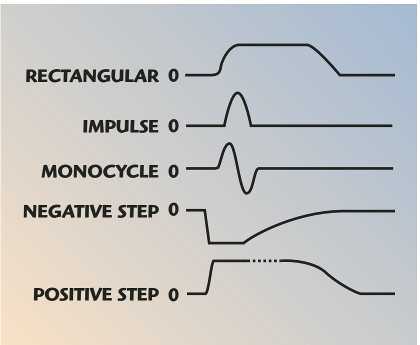
Sandy Fraser *joined Agilent Technologies (formerly Hewlett-Packard) in 2000 as a product marketing engineer. Prior to joining Agilent, he worked as a business development manager for TRAK Inc. for its Military and Space Division. During his career with Agilent Technologies, he has worked with One Box Manufacturing Test Instruments, including the Agilent 8922 and the Agilent E5515B/C. Today he is the product manager for GSM, GPRS, EGPRS and IS-136 test solutions for manufacturing and R&D.*

Generating UWB Waveforms

BOB MCLAUGHLIN AND KIPP SCHOEN
Picosecond Pulse Labs (PSPL), Boulder, CO

The generation of ultra-wideband (UWB) waveforms is of great interest for applications ranging from communications to position sensing. Research and development engineers working in UWB are faced with the challenge of generating unique waveforms that meet their application requirements. Often this also requires high-performance waveforms (very fast transition times with significant amplitudes) and flexible performance. Some of the most common UWB waveforms are presented in this article along with techniques and equipment that may be used to generate them. In this article, UWB waveforms have been classified into four categories: step, rectangular, impulse and monocycle. These waveforms are shown in ***Figure 1***.

Fig. 1 Basic UWB waveforms.



Each type of waveform will have its own particular properties. For example, a monocycle has a narrower frequency spectrum than the other waveforms shown and no DC component. Consequently, it is often used with bandwidth-limited antennas. The shape of a waveform also determines its spectral energy.

The graphs in ***Figure 2*** show time domain waveforms and frequency spectra for step pulse generators with added impulse forming networks (IFN). A step generator, producing a 10 V 45 ps risetime step, was used for the measurements. Adding a single IFN to the output of the generator produced the 3 V 50 ps

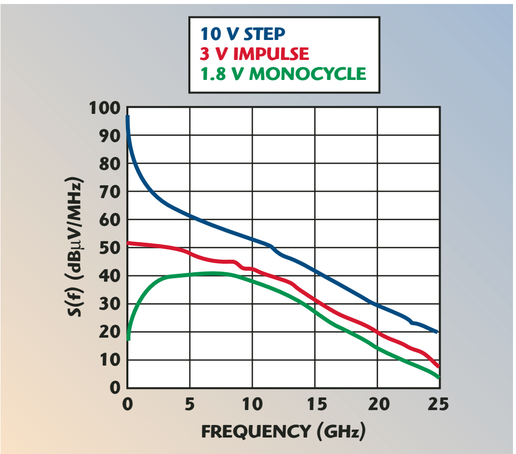


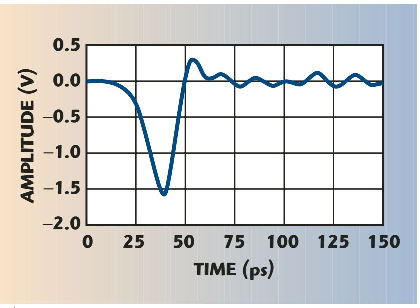
Fig. 2 Spectrum of step generator output alone and with added impulse forming networks (1 or 2).

duration impulse. Adding a second IFN resulted in a 1.8 V monocycle. Since the risetimes of the step, the impulse and the monocycle are very similar in this example, the spectra above 10 GHz have the same basic shape. The curves are offset vertically because of resulting amplitude differences (there is some loss in each IFN used). Note, waveforms with slower risetimes will have similar shapes but will be shifted toward lower frequencies.

Three basic hardware tools will be discussed and presented in this article:

- Signal generators, step (positive, negative), rectangular and impulse
- Impulse forming networks (IFN)
- Risetime filters

Together, these tools allow an engineer to generate and shape a waveform while providing a great deal of flexibility. For example, a 10 ps step generator can be combined with risetime filters to produce transition times ranging from 10 ps to many nanoseconds. The same generator may also be combined with IFNs to produce ultra-fast impulses and monocycles (see ***Figure 3***). This type of hardware provides both the highest performance and a wide range of waveform properties with a single set of equipment.



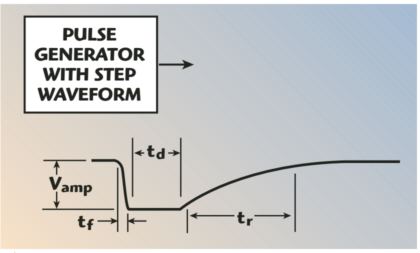
▲ *Fig. 3 PSPL model 4005 with IFN (impulse has 15 ps FWHM).*

As another example, impulse generators offer a unique combination of impulse amplitude and full-width-half-maximum (FWHM). ***Figure 4*** shows a plot of the generator producing impulses with 60 ps FWHM and 8 V amplitude. In addition, there is often more than one possible implementation for generating the same waveform. For example, an impulse can be generated with a step generator and an IFN, with a rectangular generator and a risetime filter, or directly with an impulse generator. The best choice will depend on the waveform parameters required by the application (for example, transition time, amplitude, duration).

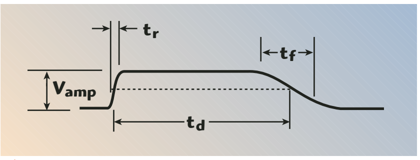
STEP GENERATORS

Step waveforms typically have an extremely fast leading edge, a flat topline and a much slower (> 10x) trailing edge. Step generators provide the world's fastest transition times for commercial electronic pulse generators. Generally, for these generators, a fixed charge line sets the step duration. However, with some step generators the step duration may be adjusted by changing the length of an external charge line.

A typical negative polarity fast step generator waveform is shown in ***Figure 5***. This example produces steps with an ultra-fast falltime at the leading edge (< 5 ps), followed by a fixed duration at $-V_{amp}$. Note, the risetime of the signal at the trailing edge is significantly slower than the leading edge falltime and the pulse duration cannot be changed (with this generator architecture). An example positive polarity step generator waveform is shown in ***Figure 6***. ***Table 1*** summarizes the characteristics of several step generators products offered by Picosecond Pulse Labs (PSPL).



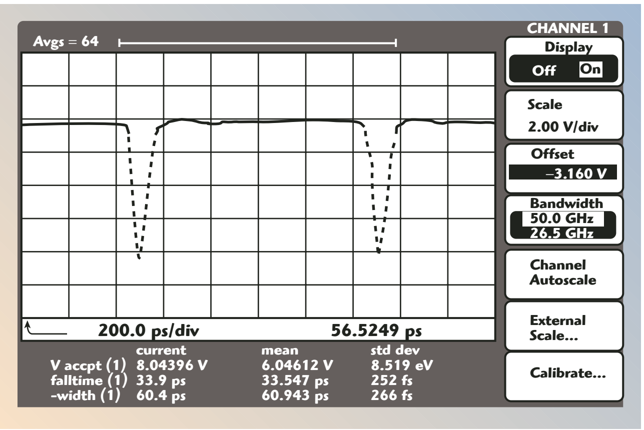
▲ *Fig. 5 Typical PSPL model 4005 step generator waveform.*



▲ *Fig. 6 Typical model 4050B step generator waveform.*

RECTANGULAR PULSE GENERATORS

Rectangular pulses with positive polarity have a fast leading edge transition or "risetime" and flat top line. The trailing edge transition or "falltime" is often slower by some amount. A typical rectangular pulse is shown in ***Figure 7***. Rectangular pulse generators are generally program-



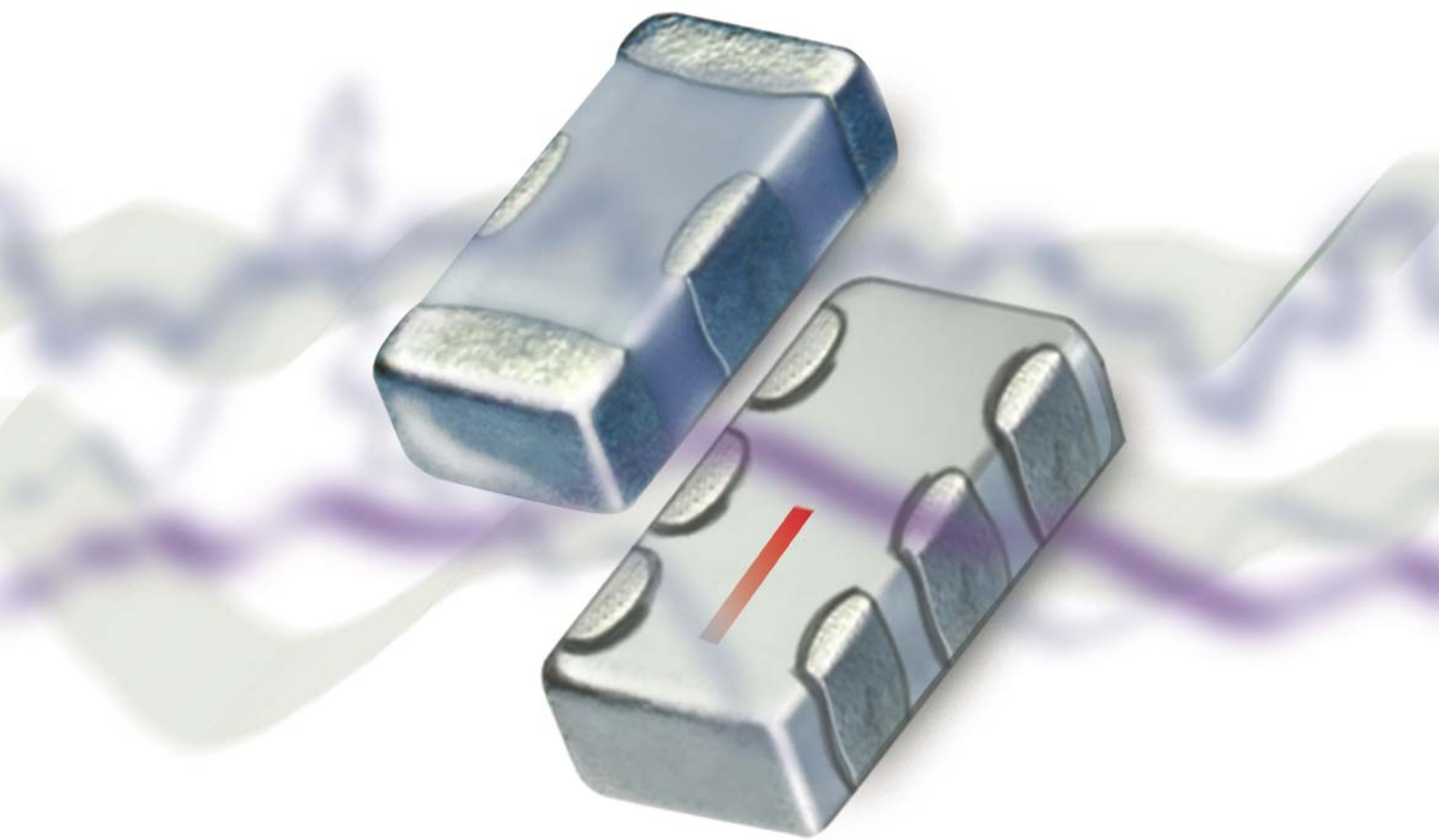
▲ *Fig. 4 PSPL model 3600 impulse generator (impulse has 60 ps FWHM and 8 V amplitude).*

TABLE I

PSPL STEP GENERATORS

Model	V_{amp}	Polarity	t_r	t_f	td
Negative Polarity Step Generators					
4005	–5 V	negative	20 ns	< 5 ps	16 ns
4015D	–5 V	negative	20 ns	12 ps	5 ns
Positive Polarity Step Generators					
4050B	+10 V	positive	45 ps	500 ps	10 ns[1]
4500E	+35 V	positive	100 ps	1 ns	20 ns[1]

[1]The pulse duration, t_d, is set by the length of an internal charge line. An external charge line may be attached to create different pulse durations.



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U.S. Patent 6,943,646 except LFCN-800+, -1325+, -2000+ & -2400+. ***RoHS compliant*** mable over a continuous range of amplitude, offset, duration and frequency. This programmability affords a greater degree of waveform flexibility. The pulse duration or width, t_d, is measured at the 50 percent amplitude level. This is often referred to as FWHM. Risetimes and falltimes are specified as the transition duration from 10 to 90 percent of V_{amp}. ***Table 2*** shows these characteristics for PSPL's rectangular pulse generators.

IMPULSE GENERATORS

An impulse generator (waveform shown in ***Figure 8***) has the advantage that it produces a single pulse with no opposite polarity impulse corresponding to the trailing edge of the generator's

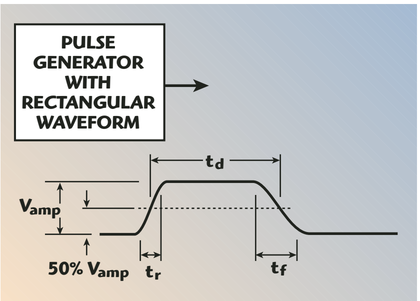

Fig. 7 Characteristics of a rectangular pulse.

waveform (compared to a rectangular pulse generator with added IFN). Impulse generators may also produce a differential output. Differential outputs are useful for exciting the two arms of a dipole.

An impulse waveform has a relatively flat spectrum from DC to approximately f_{-3dB}, where

$$f_{-3dB}(\text{GHz}) \approx \frac{320}{t_d(\text{ps})}$$

The useful energy extends to more than three times f_{-3dB}. The characteristics of PSPL impulse generators are listed in ***Table 3***.

IMPULSE FORMING NETWORKS (IFN)

An impulse forming network (IFN) is a component that may be connected to the output of a generator. An IFN produces an output that is approximately the derivative of the input. If the input is a step, the output will be an impulse. If the input is an impulse, the output will be a monocycle. Multiple IFNs may be cascaded (for example, to produce a monocycle from a step).

Figure 9 shows the output when an IFN is added to a positive rectangular pulse. Two impulses are created. A positive impulse corresponds to the rising portion of the input signal shown in Figure 6. The V_{amp1} is about 25 to 35 percent of V_{amp} of the input pulse. The duration of the impulse t_{d1} will be slightly wider than the risetime of the input signal.

The output amplitude of an IFN is proportional to dV/dt of the signal at the input. The falltime of the trailing edge of the waveform in Figure 6 is approximately twice as long as the risetime. As a result, V_{amp2} of the negative impulse will be 50 percent of the positive one, and t_{d2} for the negative impulse will be about twice as long as t_{d1}.

It is important to choose an IFN that is appropriate for the risetime of the signal. If a slow transition signal is combined with an IFN that is designed for fast risetimes, the IFN will not efficiently couple the signal, and the output will be very small. If the risetime of the input signal is too fast for the IFN, the impulse duration will be lengthened, and the waveform shape may be distorted. The recommended risetimes for PSPL's line of IFN products overlap to give comprehensive risetime coverage, as shown in ***Figure 10***. As an example, one could choose model 5210 or 5212A for use with a 50 ps rise-

TABLE II
PSPL RECTANGULAR PULSE GENERATORS

Model	V_{amp}	Polarity	t_r	t_f	t_d
10,050A	10 V fixed	positive	45 ps	110 ps	100 ps–10 ns
10,060A	0 to +10 V	positive	55 ps	115 ps	100 ps–10 ns
10,070A	0 to ±7.5 V	positive or negative	65 ps	80 ps[1]	100 ps–10 ns
2600C-Turbo	0 to +50 V, –45 V	positive or negative	250 ps	800 ps	< 1 ns–100 ns
10,300B	0 to +50 V, –45 V	positive or negative	300 ps	750 ps	< 1 ns–100 ns

[1]20%–80% for this generator and characteristic only.
All other transitions are 10%–90%.

TABLE III
PSPL IMPULSE GENERATORS

Model	V_{amp}	Polarity	t_r	t_f	t_d	f_{-3dB}
1000D	35 V fixed	positive and negative	250 ps	370 ps	500 ps	640 MHz
3500D	0 to ±8 V	positive or negative	70 ps	45 ps	65 ps	4.9 GHz
3600[1]	–7.5 V fixed	negative	–	–	70 ps	4.9 GHz

[1]Model 3600 uses an external frequency source up to 2.5 GHz repetition rate.

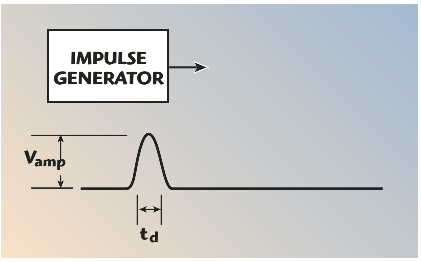

Fig. 8 Impulse generator waveform.

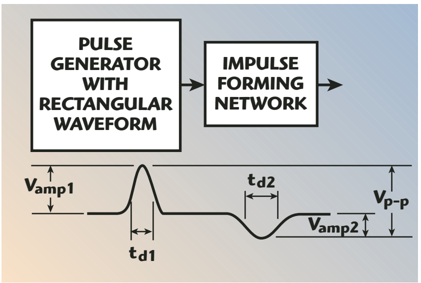

Fig. 9 Output when an impulse forming network is added.

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time pulse. The 5212A will produce a larger amplitude output (more efficient coupling), but the impulse duration for the 5210 will be narrower (faster coupling).

IFNs are also very useful when working with fast step generators. In this case, the combination of the fast step transition and the IFN produce a very narrow impulse. ***Figure 11*** shows a typical waveform for a step generator (e.g. PSPL Model 4005) with an added IFN. The negative transition at the leading edge creates a negative polarity impulse. There is effectively no measureable impulse from the much slower trailing edge of the step generator.

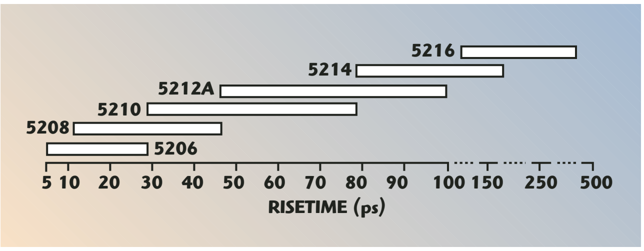

Fig. 10 Recommended risetimes for use with PSPL impulse forming networks.

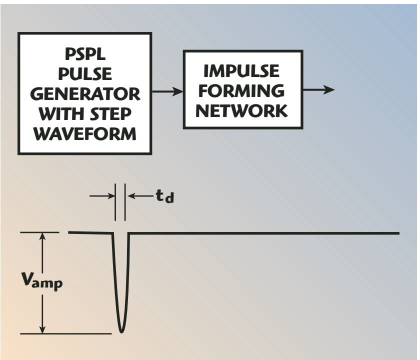

Fig. 11 Typical impulse created by a step generator plus an IFN.

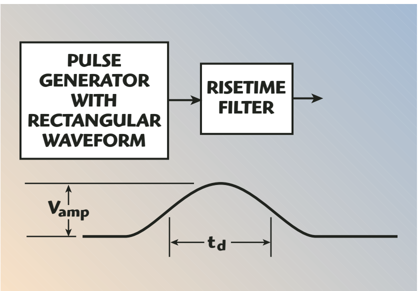

Fig. 12 A rectangular pulse generator and risetime filter can be used to create large amplitude impulses.

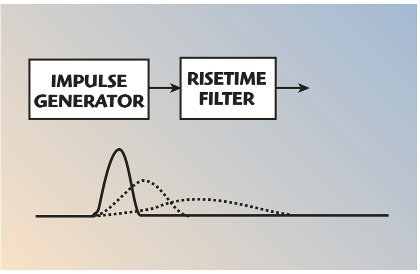

Fig. 13 Adding risetime filters will increase the duration and decrease the amplitude of the impulse.

Adding two IFNs to a step generator will create a monocycle. When the IFNs are matched to the risetime of the step, one can expect a monocycle with $V_{peak\text{-}peak}$ that is between 16 and 25 percent of V_{amp} for the step. A monocycle may also be created by adding an IFN to the output of an impulse generator. It has been found experimentally that the spectrum of a monocycle created with these techniques is relatively flat over the frequency range of

$$\frac{1}{8t_d} < f < \frac{1}{2t_d}$$

RISETIME FILTERS

A risetime filter is also a component that can be connected to the output of a generator. A risetime filter may be used to slow a signal's risetime and falltime. A fast pulse generator and risetime filters may be used to produce signals over a wide range of frequency content. In theory, for a Gaussian signal and filter, the aggregate risetime of the pulse and filter is given by

$$t_r(\text{total}) = \sqrt{t_r(\text{pulse})^2 + t_r(\text{filter})^2}$$

For example, adding a 100 ps risetime filter to a pulse with t_r of 45 ps should produce an output with 110 ps risetime. Realistically, pulses and filters are not perfect. However, in practice, the risetime of the combination will be close to this prediction.

The configuration shown in ***Figure 12*** is particularly useful for generating impulses for UWB antenna testing. When the duration of the rectangular pulse is set to about 1.84 times the risetime of the combination of the filter plus the generator, the filter slows the leading and trailing edges so that the output is an impulse instead of a square wave.

There are two advantages to this approach. First, the impulse amplitude is nearly as large as the amplitude of the rectangular pulse. Recall that when an IFN is used, the resulting impulse amplitude is 25 to 33 percent of the amplitude of the rectangular waveform. Second, there is no negative impulse created from the trailing edge of the rectangular pulse, as there would be if an IFN were used.

Risetime filters may also be added to an impulse generator to slow the rising and falling edges. In this case, the impulse duration will increase and the amplitude will decrease. To a first approximation, the area under the impulse curve will remain constant (the product of the amplitude, V_{amp}, and duration, t_d, will remain constant).

Figure 13 shows the result of adding a filter with a risetime of $2 \times t_d$ and one that is $4 \times t_d$. The amplitude without a filter is V_{amp}. The amplitude with the $2 \times t_d$ filter will be about $0.5 \times V_{amp}$. The amplitude with the $4 \times t_d$ filter will be about $0.25 \times V_{amp}$.

CONCLUSION

Many tools for generating UWB signals are readily available to engineers that are capable of producing step pulses, rectangular pulses, impulses and monocycles. These waveforms can be very high-performance, with step pulses with risetimes < 5 ps and flexible. A combination of generators, impulse forming networks and risetime filters provide a toolbox for both generating a variety of waveform shapes and frequency content. (Note: additional papers entitled "UWB Signal Sources, Antennas & Propagation" and "Picosecond Pulse Generators for UWB Radars" are available on the Picosecond Pulse Labs web site.) ■

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Mobile Fading Simulation

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When communication systems are established engineers must account for numerous real world effects and maintain reliable communication systems. Information such as path loss from the transmitter to the receiver, immunity to interference (calculating and testing the effects of non-intended signals on the intended communications signal or effects of a high density of intended signals), multi-path reflections (effects of signals reflected off of buildings/structures/mountains), speed/movement of cars/trains and atmosphere losses.

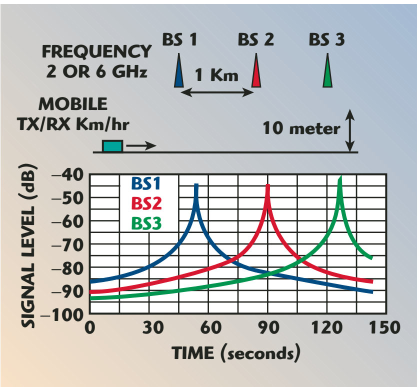

Fig. 1 Calculated signal level from each base station (train moving at 100 km/hr).

While real world testing in the exact location of the deployed communication system will yield the best overall information, this is not practical in most cases. Setting up signal conditions in a controlled laboratory environment allows for many different signal situations and repeatable "Communications Interoperability" test results. This also allows the system engineers the ability to adjust hardware performance parameters to yield high reliability communication systems.

Attenuation Matrix units are used as signal simulation tools to simulate interoperability testing. The signal path loss and channel interaction for multiple communication signals are input into the Attenuation Matrix to simulate real world field conditions in a repeatable, controlled laboratory environment.

Aeroflex/Weinschel has designed an Attenuation Matrix configuration to simulate the connectivity between a mobile (train) running along a line of three base stations spaced from 250 to 1000 meters apart (see ***Figure 1***). This test subsystem needed to be able to simulate the variation of the RF signal from the base stations reaching the moving train (as well as the signal from the moving train reaching the base stations) when the train is moving at speeds of up to 250 km/h.

The simulator attenuates the base station signal through three independent attenuators, as shown in ***Figure 2***, then

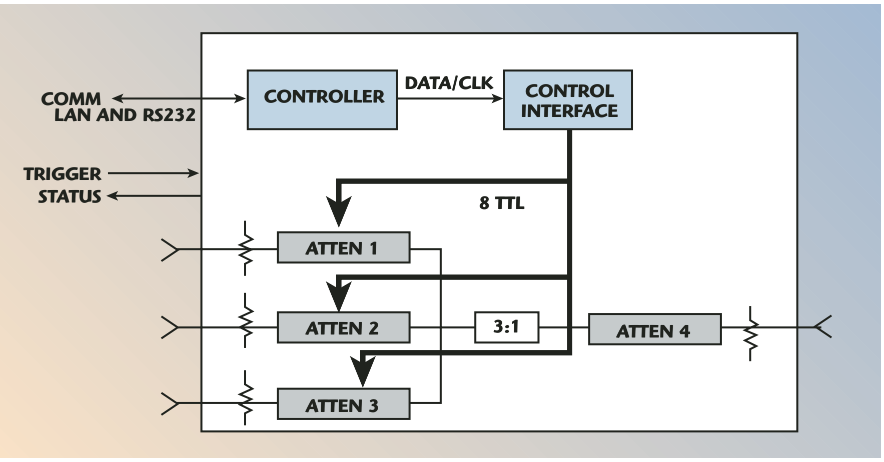

Fig. 2 RF attenuation matrix.

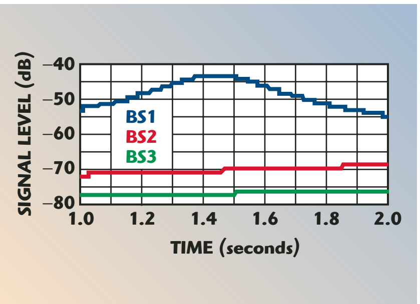

Fig. 3 Signal level with train speed at 250 km/hr, base station spacing at 250 m and 10 m from track.

combines the signals. Each attenuator has a dynamic range of 60 dB in 1 dB steps. The operation of the unit is via a RS-232 or LAN interface. ASCII commands are used to input parameters into the controller. Upon receiving a trigger the controller executes the program to simulate the link loss to all three base stations as seen from the train transceiver.

The switching speed of the attenuators limits the resolution of the simulator for extreme situations. The digital attenuators quantize the levels of attenuation in decibels. ***Figure 3*** shows the case of a train, at 250 km/hr, with the base stations 250 meters apart and placed 10 meters from the path. The PIN attenuators step in 1 dB increments and the controller switches the attenuator at a one millisecond rate. The graph shows that for this scenario, the attenuators need to be updated every 28 milliseconds, therefore the time resolution will not be noticeable.

The Roaming System simulator operates by the customer inputting the parameters listed below. These values will generate data to control the attenuators to simulate the signaling link. Each of these parameters is interactive.

TABLE I
PARAMETER RANGES

Base station positions (X meters, A station, B station, C station, + offset from the track)	0–3000 meters for station positions and 10–100 meters for offset from the track
Mobile transceiver start/stop position (x, y meters)	0–10,000 meters
Mobile velocity (Y km/hr)	0–250 km/hr
Time resolution	(1,10,100,1000 ms or auto to fill memory)
Frequency	2.44 GHz, 5.8 GHz
Antenna gain for mobile and base station	transmitter antenna gain –10 to +10 dB
Receiver antenna gain	–10 to +10 dB
Loop command	used to simulate the train running in a continuous loop

The parameter ranges listed in ***Table 1*** must be evaluated interactively with all other parameters.

The parameters listed use a Friis Equation for calculation of link loss plus the correction factors associated with the antenna. This simulation is for 2D and does not account for multi-bounce or environment. For more advanced link-loss profiles, the user can externally compute the attenuation vs. time profile and directly load this data via RS-232 into the controller data tables for execution, effectively over-riding the built-in function. This allows arbitrary profiles to be generated.

Figure 4 shows the geometry used in the LinkLoss calculation.

$$\text{LinkLoss} = \left(\frac{\lambda}{4\pi R}\right)^2 + G_t + G_r$$

Friis Transmission Equation

where

$$R^2 = (y_{BS}^2 + x^2)$$

For some system simulations the engineering team needs more repeaters to be able to be simulated. Using the configuration shown in ***Figure 5***, six repeaters can be simulated by interconnecting two Roaming Systems.

The Roaming simulator functions as a stand alone simulation system. The LAN or RS-232 control interface is used to load test setup parameters such as mobile position (X or Y position), mobile speed, time, antenna gain and frequency. The system simulates the mobile moving past three repeater sights, thus the three inputs. If the operators would like to simulate more repeater sights multiple roaming simulators can

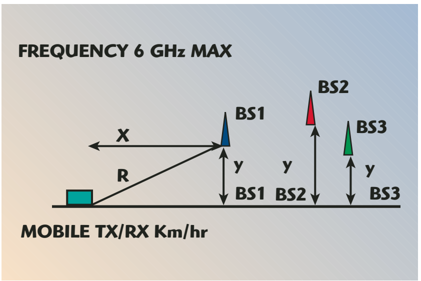

Fig. 4 Geometry of the link loss calculation.

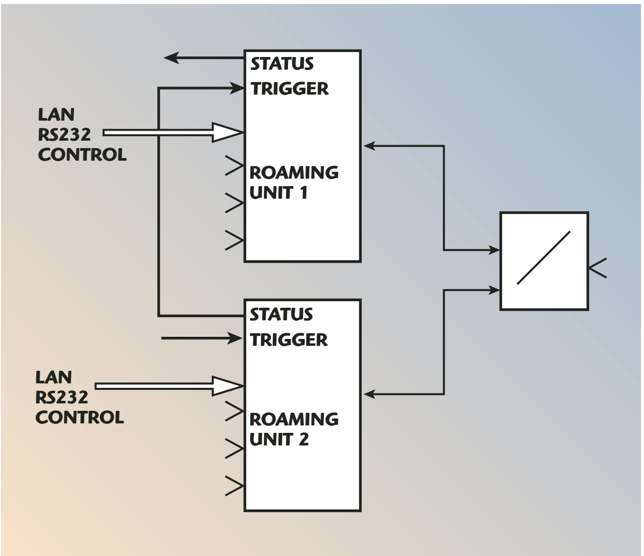

Fig. 5 Simulating additional repeaters.

TABLE II
BASE STATION POSITIONS

System 1	
Distance (m)	0–6000
Positions (m)	1000 = x, 20 = y 2000 = x, 30 = y 3000 = x, 10 = y
Velocity (km/hr)	100
Time resolution	auto
Antenna gain (dB)	Tx = 0 Rx = 3
Frequency (GHz)	2
System 2	
Distance (m)	0–6000
Positions (m)	4000 = x, 20 = y 5000 = x, 30 = y 6000 = x, 10 = y
Velocity (km/hr)	100
Time resolution	auto
Antenna gain (dB)	Tx = 0 Rx = 3
Frequency (GHz)	2

be connected together to perform the test. For up to a six input simulation, the operators must connect the outputs together using a power combiner.

Next the digital status line (indicating the start and stop of a mobile test) is connected from one system to the second system trigger input. This allows both units to start at the same time. The system can then be triggered (or started) either using the hardware trigger input (on the first system) or via a software command.

After the start command is issued the status line will trigger the second system to start the sequence. The operator can load the commands to each of the units with the proper test set-up information. An example of this is shown in ***Table 2***. This will simulate six repeaters while the mobile is moving from 0 to 6000 meters at 100 km/hr.

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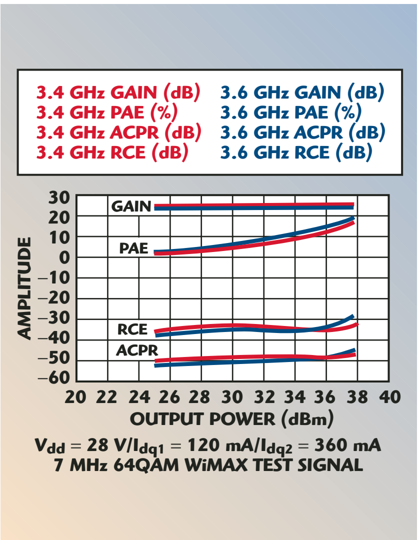
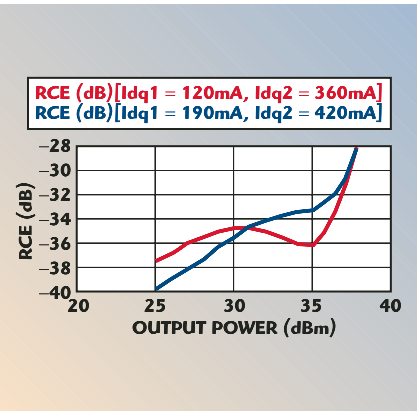
From a product perspective, single stage discrete transistors offer a very flexible environment to design a power amplifier, as they offer numerous options for impedance matching, line up optimization and architectural choices. Counter to that, a line-up made of discrete elements is costly, consumes real estate and is prone to performance variation problems.

As an alternative to LDMOS discrete solutions, Freescale Semiconductor has been leading the way into RF integrated circuits, still based on LDMOS process technology. The addition of capacitor, inductor and resistor process modules compatible with the LDMOS process flow brings the capability to pack multiple RF stages, high impedance matching networks and additional useful analog functions into a single silicon chip. As LDMOS RFICs do not require any additional supply voltage, they can be used in conjunction with traditional discrete transistors or replace them entirely. They do not require any system level changes.

As more and more functionalities are concentrated on a single piece of silicon, LDMOS RFICs can be packaged with industry standard, cost-effective over-molded packaging technology. This creates a significant opportunity for cost reduction over traditional discrete transistors which are typically built with custom processes and materials. With initial focus on medium power driver applications, Freescale's LDMOS IC portfolio now covers power levels up to 100 W at operating frequen-



▲ *Fig. 1 The MW7IC3825N IC's RF performance.*



▲ *Fig. 2 Impact of bias settings on linear performance of the MW7IC3825N IC.*

cies up to 2.1 GHz, making them an obvious choice for traditional applications such GSM, GSM EDGE, CDMA and W-CDMA. The MW7IC18100NB and MWE6IC-9100NB products, both optimized for GSM EDGE applications, have been released to production in the early part of 2007.

Wireless communication standards evolve continuously to enable multimedia-centric applications and additional voice channels. In particular, WiMAX (Worldwide Interoperability for Microwave Access) technology has recently emerged as a potential disruptor in the wireless communication space. The WiMAX standard brings the promise of higher data rates, both in a fixed and mobile environment, thanks to orthogonal frequency division multiple access (OFDMA) modulation and straight Internet protocol compatibility. At the same time, WiMAX brings a new level of challenges in terms of the RF amplifier: this new modulation scheme creates a stringent linearity requirement for the power amplifier which also affects the RF device specifications. In addition, due to lack of available spectrum below 2 GHz, WiMAX systems will be deployed at frequencies ranging from 2.3 up to 3.8 GHz depending on the location. This clearly raises the bar on semiconductor manufacturers to keep performance (gain, efficiency, linearity) and cost in line with existing W-CDMA solutions, which are often used as reference points.

In order to enable future WiMAX networks, Freescale is releasing to the market a family of LDMOS RF integrated circuits, which have been specifically optimized for this application. The MW7IC2725N and MW7IC2750N cover frequencies ranging from 2.3 to 2.7 GHz, while the MW7IC3825N can be used from 3.3 to 3.8 GHz. All of these ICs are built into a multi-lead over-molded plastic package, and therefore can be produced in a cost-effective manner. Moreover, they come in different lead configurations enabling both insertion mounting (bolt down, reflow or clamping) and true surface mount. Finally, the over-molded assembly process results in very tight mechanical tolerances. As WiMAX amplifiers will be operating at frequencies close to 4 GHz in some cases, the mechanical aspect of the design becomes critical in order to maintain performance yields in a high volume environment.

Beside cost, another critical aspect of power amplifier design is RF performance. In order to match the performance benchmarks of traditional discrete transistors, the WiMAX ICs are designed by combining on-chip high quality passive components with Freescale's seventh generation of LDMOS active transistors. Two stages of amplification are connected with a broadband inter-stage matching network. The input and output sections also include a matching network to raise the impedance level yet provide some flexibility to externally select the optimum source and load impedance values. External impedance matching in conjunction with bias current optimization of the first and second stages are important tuning factors to maximize the device performance under a given set of conditions. In particular, different settings can be chosen to operate these ICs as an output stage device with emphasis on power, gain and efficiency (see ***Figure 1***) or as a linear driver device (see ***Figure 2***).

These performance figures can not be directly compared to single-stage discrete solutions since ICs are effectively multi-stage, high gain solutions. Through methodical characterization of the output section of the IC device, performance parity with the latest generation of 2.7 and 3.8 GHz discrete transistors has been demonstrated. Freescale WiMAX ICs can be cascaded and paralleled to create attractive line-up configurations. They can be operated in class AB mode as well as in high efficiency Doherty mode, which greatly benefits from the high gain characteristic of these multi-stage devices.

The introduction of these initial RFICs for WiMAX base station applications sets the stage for future product development. The MW7IC2725N, MW7IC2750N and MW7IC3825N have good power capability but still do not match popular discrete transistors such as the MRF7S27130H (130 W) or the MRF7S38075 (75 W) in that respect. This creates an opportunity to design higher power IC solutions, as a key enabler to standardize WiMAX power amplifier architectures across all bands and all power levels.

Freescale Semiconductor Inc., Austin, TX (800) 521-6274, www.freescale.com.

RS No. 300

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A 13.5 to 17.0 GHz GaAs MMIC Doubler with Integrated Gain, Doubler and Driver Stages

MIMIX BROADBAND INC.
Houston, TX

Any product today that can both save money and save space is a much needed commodity in today's communication system designs. With systems getting ever more compact, board real estate is at a premium, hence the drive to integrate more functions in less space and keep the support structure simple and concise.

Mimix Broadband, no stranger to these requirements, has introduced an active doubler in a RoHS-compliant 3 × 3 mm QFN surface-mount package that doubles the 13.5 to 17.0 GHz frequency band to 27.0 to 34.0 GHz and delivers +20 dBm saturated output power with 35 dBc suppression of the fundamental.

Using 0.15 µm gate length GaAs psuedomorphic high electron mobility transistor (PHEMT) device model technology, this new device integrates a gain stage, passive doubler and driver amplifier onto a single chip. The XX1007-QT MMIC includes on-chip ESD protection and an integrated bypassing capacitor, thus eliminating the need for external support components. In addition, the device features a self-bias configuration that requires only a positive 5 VDC supply for operation.

Eliminating the need for a negative supply and external bypassing elements greatly simplifies the PCB layout and significantly reduces time to

TABLE I

XX1007-QT ELECTRICAL CHARACTERISTICS (AMBIENT TEMPERATURE T = 25°C)

Parameter	Min.	Typ.	Max.
Input frequency range (f_{in}) (GHz)	13.5	–	17.0
Output frequency range (f_{out}) (GHz)	27.0	–	34.0
Input return loss (S_{11}) (dB)	–	–8.0	–
Output return loss (S_{22}) (dB)	–	–10.0	–
Fundamental suppression (dBc)	–	–35.0	–
RF input power (RF P_{in}) (dBm)	–	7.0	–
Output power at 5.0 dBm P_{in} (P_{out}) (dBm)	–	+20.0	–
Drain bias voltage (V_d) (VDC)	–	+5.0	+5.5
Supply current ($I_{d1,2,3}$) (V_d=5.0 V typical) (mA)	–≠	200	240

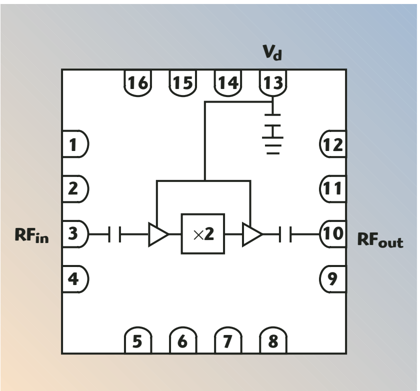


Fig. 1 The XX1007-QT's functional block diagram.

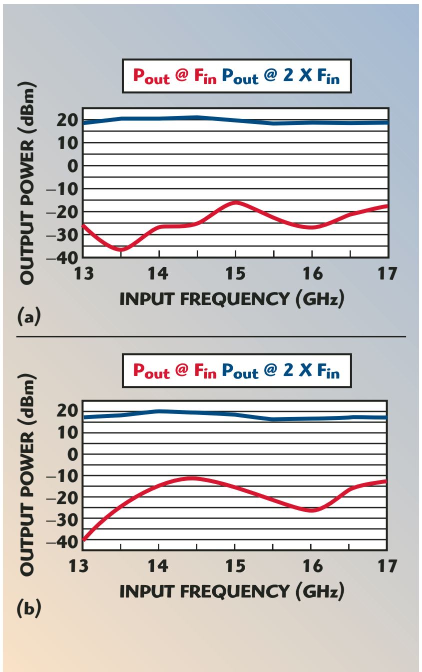


Fig. 2 The XX1007-QT doubler's power output at F_{in} and $2F_{in}$ with P_{in} set to (a) 10 dBm and (b) 5 dBm at V_d = 5 V.

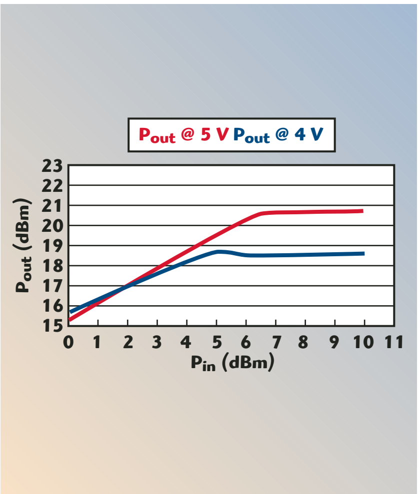


Fig. 3 The XX1007-QT doubler's P_{out} vs. P_{in} at 14.5 GHz.

market. ***Table 1*** lists the XX1007-QT doubler's performance specifications and ***Figure 1*** shows its functional block diagram.

Mimix Broadband performs 100 percent RF testing on the XX1007-QT devices. ***Figures 2*** and ***3*** display its output power versus input frequency and output versus input power characteristics.

This new active doubler is well suited for millimeter-wave point-to-point radio applications as well as LMDS, SATCOM and VSAT uses. The high output power of the XX1007-QT makes it ideal for use as a driver stage to the final system power amplifier in VSAT transmit systems. Its rugged surface-mount package makes it compatible with high volume solder and pick and place installation.

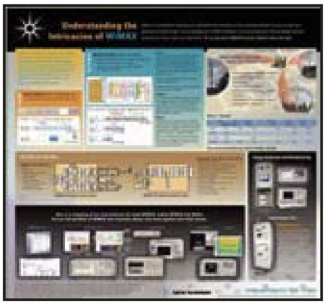
The XX1007-QT's data sheet and additional information may be obtained for the company's web site. Production quantities are currently available from stock.

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

RS No. 304

WiMAX LITERATURE SHOWCASE AND EMERGING TECHNOLOGIES

WiMAX Poster and Brochure

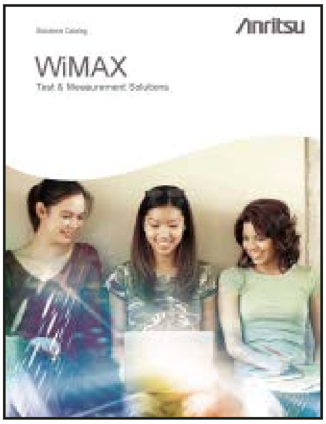


Agilent now has available a new poster and brochure. The wall poster is designed as a reference tool to help engineers understand the evolving communication standard by describing detail and contrasting fixed and mobile WiMAX technologies. The eight-page full-color brochure describes Agilent's portfolio of design and test solutions for WiMAX covering the entire lifecycle from R&D, design verification & pre-conformance, conformance, manufacturing, and installation & maintenance.

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

RS No. 325

WiMAX T&M Solutions Catalog



This eight-page brochure features the company's full line of fixed and mobile WiMAX test instruments. The literature provides test solutions supporting R&D, manufacturing and maintenance of WiMAX user equipment (UE), base stations and devices.

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

RS No. 336

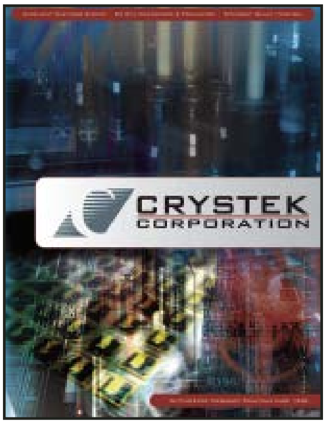
VSS WiMAX Design Solution

AWR's Visual System Simulator™ (VSS) WiMAX Design Solution supports 802.16d-2004 and 802.16e-2005 specifications for both fixed and mobile WiMAX communications design. The software enables RF and baseband SoC designers, component suppliers, OEMs, user equipment companies, and infrastructure and network equipment providers to quickly and accurately design and verify WiMAX-certified products.

Applied Wave Research Inc.,
El Segundo, CA (310) 726-3000, www.appwave.com/vss.

RS No. 326

VCOs and PLL Synthesizers

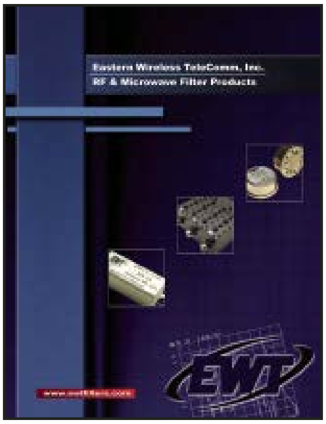


Request Crystek literature for innovative frequency control technology. Crystek Microwave offers VCOs and PLL synthesizers in a wide mix of frequency ranges, standard packaging and custom design options. Product highlights include low phase noise, microstrip and coaxial designs, and octave tuning. Since 1958, Crystek has been an industry leader in engineering, manufacturing, support and service.

Crystek Microwave,
Fort Myers, FL (239) 561-3311, www.crystek.com.

RS No. 327

Filter Catalog

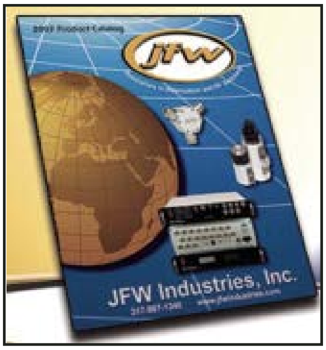


This new short form catalog features a sampling of the company's RF and microwave filter products to 40 GHz utilized in military, commercial and wireless applications. The catalog also highlights some of the company's diverse filter design and manufacturing capabilities.

Eastern Wireless TeleComm Inc.,
Salisbury, MD (410) 749-3800, www.ewtfilters.com.

RS No. 328

Product Catalog



This product catalog highlights the company's passive RF components and application-specific test systems. The catalog features model 50P-1708 SMA, a programmable attenuator that operates in a frequency range from 200 to 6000 MHz; model 50PA-330 SMA, a programmable assembly that operates in a frequency range from 200 to 6000 MHz; model 50S-1505, a high power solid-state switch that operates from 20 to 2500 MHz; and model 50PD-634, a power divider that operates from 2000 to 6000 MHz.

JFW Industries,
Indianapolis, IN (317) 887-1340, www.jfwindustries.com.

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WiMAX AND EMERGING TECHNOLOGIES

Antenna Solutions for Aerospace and Defense

This new M/A-COM antenna capabilities brochure covers high performance solutions for aerospace and defense applications including C3, CNI, telemetry, data links, ECM, PGM, missiles, EW and GPS. With full in-house design, analysis, engineering, fabrication, qualification, testing and production, the company can meet most any antenna need for custom or build-to-print antennas.

M/A-COM,
Lowell, MA (800) 366-2266, www.macom.com.

RS No. 330

Components Guide

The 2007 IF/RF Microwave Signal Processing Components Guide is available for free from Mini-Circuits. The 144-page catalog offers the RF/microwave industry's most comprehensive listings of RF, IF and microwave components with essential performance specifications for each product. In addition to the extensive component data, the catalog also provides a listing of Mini-Circuits' patents and the product model numbers to which they apply.

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

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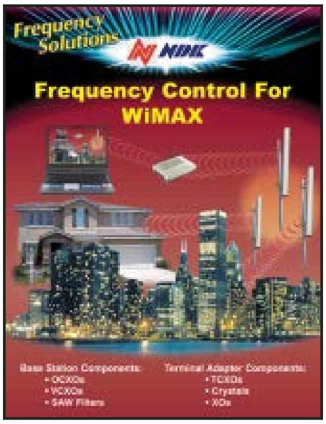

Frequency Control for WiMAX

This four-page color brochure details the company's products utilized in WiMAX equipment. Products for base station applications include: OCXOs, VCXOs and SAW filters. Products for terminal applications include: TCXOs, crystals and XOs.

NDK America Inc.,
Belvidere, IL (800) 635-9825, www.ndk.com.

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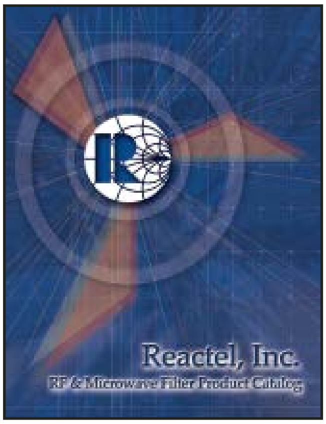

RF and Microwave Filters

This catalog features the company's full line of RF and microwave filter products. The catalog highlights high reliability filters, multiplexers and switched filter banks that cover DC to 50 GHz and are tailored to meet the military market. To request a complimentary copy, e-mail: catalog@reactel.com.

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

RS No. 333

2007 Designer's Handbook

Available in hard copy and CD, the Designer's Handbook showcases RFMD's broad product portfolio of RF systems and solutions for applications that drive mobile communications. Includes technical data on RFMD's industry-leading power amplifiers, front end modules, transceivers, SoCs and other integrated components for mobile handset, cellular base station, WLAN and GPS applications – all backed by RFMD's commitment to service, technical support and quality. Visit the company's web site for the most current product information.

RFMD®,
Greensboro, NC (336) 678-5570, www.rfmd.com.

RS No. 334

Selection Guide

This 36-page product selection guide features new RF products for existing and emerging RF markets, and catalog parts ranging from signal source and signal processing components, and the company's amplifiers, which include patented active-bias gain blocks, LNAs, award-winning WiMAX amplifiers, LDMOS and others. Also look for new passive devices from Premier Devices and new ISM transceiver and networking solutions from Micro Linear.

Sirenza Microdevices,
Broomfield, CO (303) 327-3030, www.sirenza.com.

RS No. 335

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AND EMERGING TECHNOLOGIES

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Unraveling Modulation Quality in Mobile WiMAX™ Uplink and Downlink with Multiple Zones and Bursts

By: VISWANATHAN GANESAN
WiMAX Application Engineer, Agilent Technologies

Mobile WiMAX is progressing quickly from inception to deployment with trials currently taking place, spectrum being allocated, chipsets validated and devices tested for interoperability. End users are looking forward to experiencing anytime, anywhere broadband service. Service providers are anticipating additional revenue streams based on this service. But while great progress has undoubtedly been made, challenges still lie ahead - especially for the designer working to bring new radio designs to market ahead of the competition. Of particular difficulty is how to ensure that the modulation quality of the radio is sufficient for optimum RF performance and that it will perform according to industry standards. To address these challenges the designer needs to have access to the right test and measurement equipment at the right time.

This article delves into the complexities associated with digital demodulation of Mobile WiMAX uplink (UL) and downlink (DL) signals. It covers the modulation quality measurement required for Mobile WiMAX transmitters and provides a recommendation of the best tools to use for developing Mobile WiMAX products.

The complexity of a Mobile WiMAX radio

Digitally modulated signals allow lots of data to be packed into limited spectrum. As a result, modulation schemes can get quite complex. This is especially true for Mobile WiMAX with its Orthogonal Frequency Division Multiple Access (OFDMA) modulation, which supports many users with different data requirements and levels of mobility. In Mobile WiMAX, the frame structure is rather complex compared to single carrier systems. Each frame contains permutation zones, Media Access Protocol (MAP) and the Frame Control Header (FCH). Each zone may have one or more bursts *(see Figure 1)*. The bursts cater to the data demands of different users in a network. Mobile WiMAX allows different modulation types on adjacent sub-carriers. For example, a single Mobile WiMAX zone could have Quadrature Phase Shift Keying (QPSK) and 16 Quadrature Amplitude Modulation (QAM), on different bursts within the same zone.

Given the complexity of the radio, it can be daunting for the designer to carry out the tests needed to ensure adequate modulation quality. This task requires a good knowledge of the Mobile WiMAX frame structure and familiarity with the use of digital demodulation tools. For the purposes of this article, we will focus solely on demodulation measurements of a Mobile WiMAX signal with data bursts.

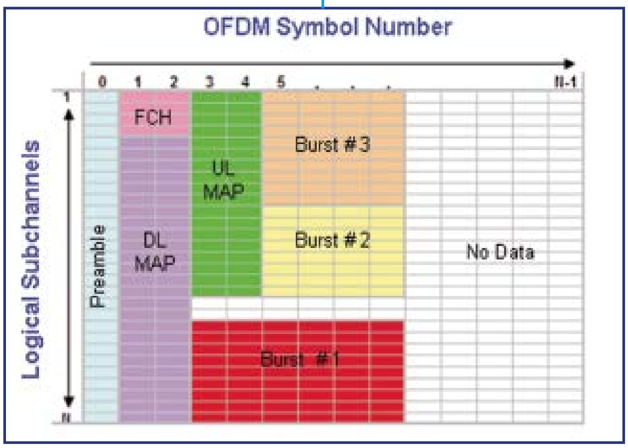

Figure 1. *Zone Definition Grid for a Mobile WiMAX Subframe*

Digital demodulation measurements

When analyzing OFDMA signals there are two approaches that can be taken. The first approach involves limiting the signal to one type of modulation and one power level throughout the permutation zone being analyzed. This technique minimizes signal creation and digital signal processing (DSP) errors and is a good first step when performing digital demodulation. The second approach involves a signal containing multiple zones with data bursts, each of which may contain a different digital modulation type. This technique enables creation of a realistic Mobile WiMAX signal and provides a more rigorous test of the radio.

Downlink modulation quality measurements

Before learning how to make a downlink modulation quality measurement, it is first important to gain a clearer understanding of the Mobile WiMAX downlink signal. As previously noted, Mobile WiMAX employs the OFDMA digital modulation scheme, thereby allowing simultaneous transmission (e.g., data bursts) from several users. This ability for data bursts to overlap in time has two advantages. It allows the maximization of data capacity to multiple users and it enables support for handovers, which in turn allows for mobility in a complex RF environment.

With OFDMA, the frame structure is two-dimensional. In other words, data from multiple bursts is available on different subchannels, which are logical - as opposed to physical - arrangements of subcarriers. Note that the logical subchannels help maintain good noise immunity and reduce the likelihood that one user's session will suffer due to narrowband interference or fading. Because adjacent subcarriers may belong to different subchannel groupings, their respective modulation formats may differ. In contrast, each data burst can only use one modulation format. Its pilot locations though, will be at many different subcarrier locations. As a result, Mobile WiMAX signals are extremely complex to measure and accurate digital demodulation becomes all the more critical. It is therefore important for the layout of the frame to be fully known by the OFDMA receiver. In this case, the structure of the downlink is transmitted in the DL-MAP. In turn, the base station transmits the UL-MAP to let subscribers know which symbols and subchannels can be used for uplink signal transmission.

To make a downlink modulation quality measurement consider the example of a signal which contains two zones and is 23 symbol times in length. The first zone is a Partial Used Sub Channels (PUSC) and has a Frame Control Header (FCH), DL-MAP, UL-MAP, as well as three data bursts: one each of QPSK, 16QAM, and 64QAM. It occupies 12 symbols, though no data bursts occupy the last four symbols. The second zone is a Fully Used Sub Channels (FUSC) and contains three data bursts: one each of QPSK, 16QAM, and 64QAM. It occupies the first four symbols of the 10 symbol FUSC zone, leaving the last six symbols unoccupied. Note that you can see any of these unoccupied symbols on a time trace. The total downlink subframe is then 22 symbols plus the preamble.

For the purposes of this example, the measurements are performed using Agilent Technologies' Vector Signal Analysis (VSA) software. The signal in question is available as a signal recording with file name *i80216e_DL10MHz.sdf*, with the Agilent 89600 Vector Signal Analysis software version 7.20. The data burst analysis for this example is performed using the *Zone Definition Map* file that is supplied with the signal recording as part of the normal 89600 VSA software installation. With data bursts, the analyzer demodulates the signal according to a subchannel-by-symbol ("slot") Zone Definition grid that the user creates or provides in the form of a setup file. This grid indicates the type of modulation used for each logical subchannel and each symbol of the subframe, allowing the analyzer to demodulate and display the individual data bursts. The user could also use the "Auto" detect feature in the Zone Definition grid to have the analyzer automatically decode the signal from the MAP.

Because of the complexity of Mobile WiMAX signals, the approach to demodulation measurements should be very methodical. It is important to have all parameters set correctly to enable accurate measurements. Therefore, it is generally helpful to make vector (e.g., time envelope and spectrum, or gated spectrum) measurements on a signal before setting up to perform digital demodulation. Once successfully completed, the user can proceed with greater confidence.

The first step in any digital demodulation measurement is the setup. Some tools require the user to define every specific parameter about a signal before the analysis can begin. Agilent's 89600 VSA requires the user to define just a few key parameters.

To perform data burst analysis, select the digital demodulation mode in the 89600 VSA software tool. Change the *Use Preamble* Index to 14. This is necessary because the signal in this example uses a nonzero preamble index and will cause the synchronization to fail. Following this setup, the only thing being measured is the FCH. This is important as without using a map file or otherwise defining data bursts, the only burst whose modulation and location is known (e.g., by the analyzer and from the standard) is the FCH. To verify this, examine the constellation display in *Figure 2*. Note that only QPSK and BPSK modulation are present.

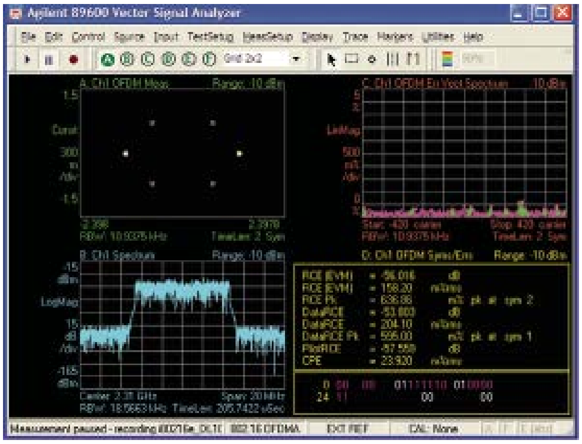

Figure 2. *As indicated by the constellation display and color-coding, this measurement of a downlink PUSC signal only includes the BPSK pilots and the QPSK modulation of FCH. The color coding of the data bursts is consistent across all traces.*

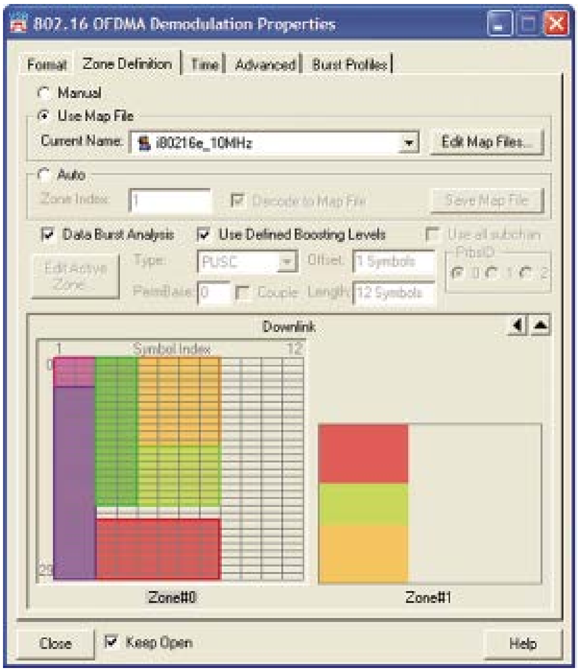

Figure 3. *Zone Definition shows FCH, DL-MAP, UL-MAP and three data bursts in colors.*

At this point, the actual digital modulation measurement on the downlink can be made. In the downlink, the frame starts with the mandatory DL-PUSC zone. It begins with the preamble, FCH, and MAP messages, followed by user data bursts, and may be followed by one or more zones that start on a symbol boundary. To make the measurement, select the *Zone Definition* tab of the *Demodulation Properties* dialog box. The default Zone Definition Grid map is shown at the bottom of this tab; again, only the FCH has been defined. While data bursts can be defined manually, for this measurement a zone definition map file is used which has already been constructed for this recording. This map file shows logical subchannels on the Y axis and OFDM symbols on the X axis. In addition to the FCH, three data bursts are defined and color-coded as shown in *Figure 3*.

After selecting the map fle, the default is for display and analysis of all data bursts in the map. In other words, all measurement displays and the error statistics summary table reflect the composite of all the data bursts in the map. This can be seen graphically in the constellation trace, where BPSK (e.g., pilots), QPSK, 16QAM and 64QAM constellations are overlaid, along with small circles as targets for the symbol states.

Data burst analysis is often used to display and analyze single data bursts or selected groups - a useful feature when examining the modulation quality of a complex Mobile WiMAX signal. To conduct this analysis using the example signal designated above, simply select a specific data burst by clicking the colored tile in the *Zone Definition Grid*. The analyzer display will then change to reflect the measured characteristics and data of the selected burst. The user can also measure multiple data bursts at once, or even all data bursts.

One diagnostic clue for the proper configuration of a transmitter is the absence of symbols at the center or origin of the constellation when measuring downlink signals. Symbols in this location indicate that the analyzer is expecting a modulated subcarrier at a frequency where it is receiving little or no signal energy. This phenomenon indicates that one or more data bursts are configured to expect logical subchannels or individual subcarriers which are not being transmitted. To diagnose the specifics of this problem, couple the analyzer's markers, setting the marker on one or more of the center constellation symbols. Then, determine whether the symbols are all associated with subcarriers which can be identified with specific logical subchannels.

Data burst information table

Given the complexity of a Mobile WiMAX signal, it is often useful to quickly view a summary of the burst information. In this example, this can be accomplished via the VSA's OFDM Data Burst Info table. This table illustrates both the measurement data type and its associated display format. Example results from the nonuniform downlink PUSC recording are shown in *Figure 4*.

Note that this display is used for data burst analysis and is most useful when measuring multiple data bursts. It provides a list of the subframe's data bursts, including the FCH. Reported values for each data burst include the format, the burst size (length), average power, and the average Relative Constellation Error (RCE, in dB) of the entire signal or the data subcarriers only (DataRCE). Like the rest of the displays available, when in data burst analysis mode, this table reflects only the results of the data bursts selected for analysis.

Figure 4. *Data Burst Info Trace lists FCH and all measured bursts in the subframe with slots occupied and power level.*

Uplink signal modulation quality measurements

At the end of the Mobile WiMAX downlink transmit signal, a transmit/receive transition gap (TTG) exists to provide time for the base station to switch to receive mode. This is followed by the uplink subframe consisting of one or more zones. Next comes the receive/transmit transition gap (RTG) which allows the base station time to switch back to transmit mode to start the next frame.

The Mobile WiMAX uplink signal can be measured in much the same way as the downlink signal, although data burst analysis is much simpler on the uplink signal due to the presence of a single data burst. To illustrate an uplink modulation measurement, consider the example of an uplink signal recording with file name *i80216e_UL10MHz.sdf*, as supplied by the 89600 VSA software.

As with the downlink measurement, to begin making uplink measurements it is necessary to do some initial set up. Select the same setup file used for downlink analysis (e.g., *i80216e_10MHz.set*), and choose the appropriate Uplink subframe type in the *OFDMA Demodulation Properties* dialog box. Change measurement result trace B from spectrum to error vector time. This will produce a display similar to that shown in *Figure 5*.

After switching to the uplink subframe type, the analyzer automatically defaults to measurement of the first zone of the subframe - a PUSC zone - and detects the modulation type of the single data burst in this zone. The *Zone Definition Grid* shows that the data burst is in "wrapped format," covering the first 15 symbols of the subframe and does not use all of the logical subchannels. Many of the OFDM subcarriers are therefore not used for this burst and can in fact be used for other bursts — a common occurrence for Mobile WiMAX signals.

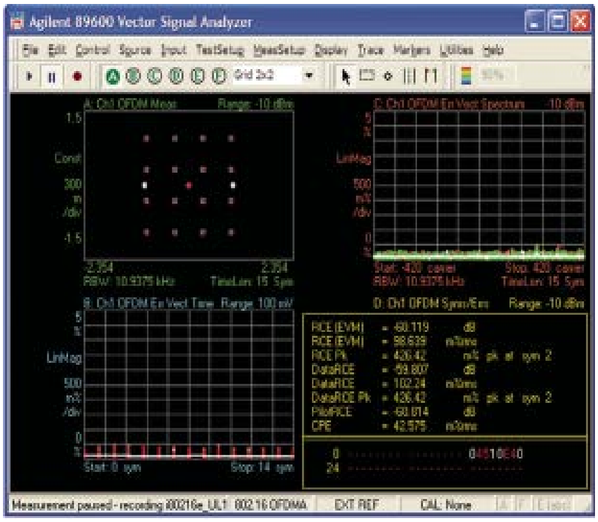

Figure 5. *Demodulation of the PUSC zone of a 16 QAM uplink signal, includes BPSK pilot and a symbol target at the center for subcarriers not used by the mobile station.*

In the constellation display, the signal (or lack of a signal) from the unused subcarriers is designated by symbol states and a symbol target at the center of the constellation diagram. Indeed, the ideal location for the symbols associated with unused OFDM subcarriers is the exact center of the constellation diagram as this signifies that no power is transmitted on these unused subcarriers or any associated logical subchannels. Power transmitted on these subchannels tends to interfere with the reception of intended transmissions on these frequencies by other mobile stations, especially in unfavorable near/far configurations of transmitters and receivers.

Note that in uplink measurements, the 89600 VSA measurement solution defaults to an Error Vector Magnitude (EVM) measurement, which includes the contribution of unused subchannels. It automatically reports the RCE of unmodulated carriers in the Syms/Errs table. In some ways this measurement is similar to a noise power ratio or code domain error measurement. To view only the active subchannels associated with the selected data burst, the user need only change the display configuration.

The signal used in this example actually contains two zones: 15 symbols of PUSC (Zone #0), and 6 symbols of OPUSC (Zone #1). To measure the OPUSC zone, the user simply selects "Zone #1" during the initial setup. The analyzer will then automatically locate the RF burst and begin analysis of the OPUSC zone.

Conclusion

Ensuring adequate RF performance of a Mobile WiMAX radio via digital demodulation can be challenging. Using the appropriate test and measurement equipment (e.g., a signal analyzer, signal generator and signal analysis software) is key to overcoming this challenge. Mobile WiMAX downlink and uplink signals can be created with the Agilent MXG Vector Signal Generator and N7615B Signal Studio, and demodulated with the Agilent MXA Signal Analyzer running the 89600 VSA Software, as illustrated here. Measurement solutions like these make it possible for today's designers to more easily and accurately perform modulation quality measurements on the DL and UL transmit signals of a Mobile WiMAX radio.

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