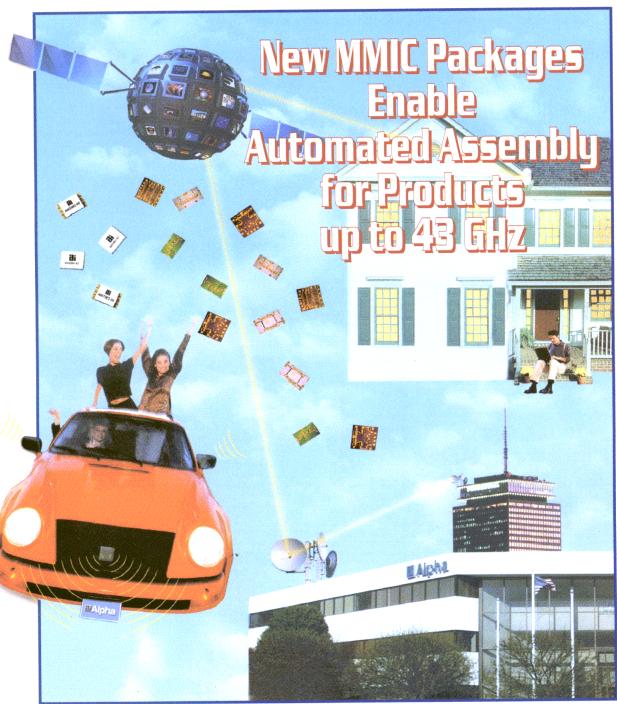
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Enhancing the MMDS Transport Layer

A Look at Recent Test Equipment Introductions

Design Ideas

Transmission Zeros in Filter Design

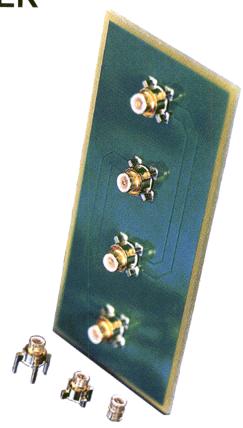
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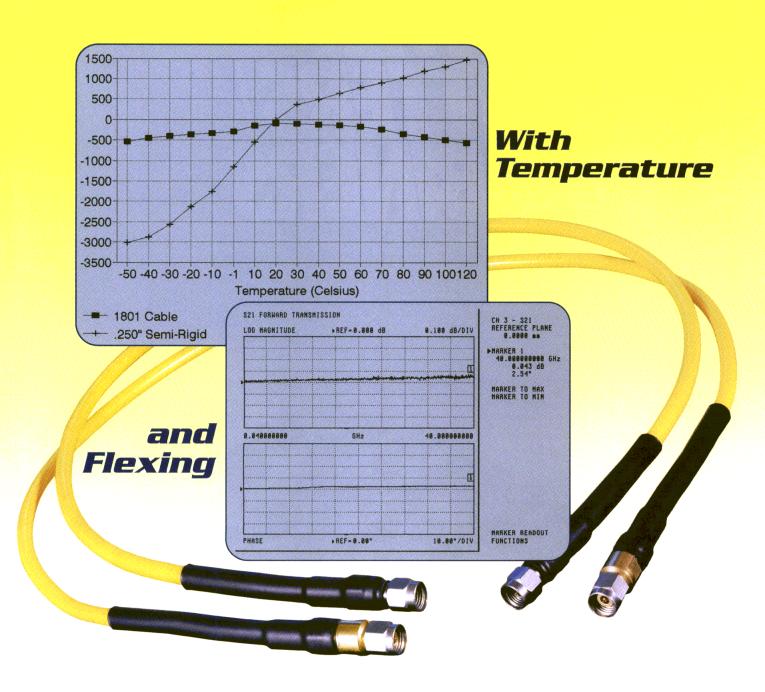
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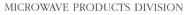


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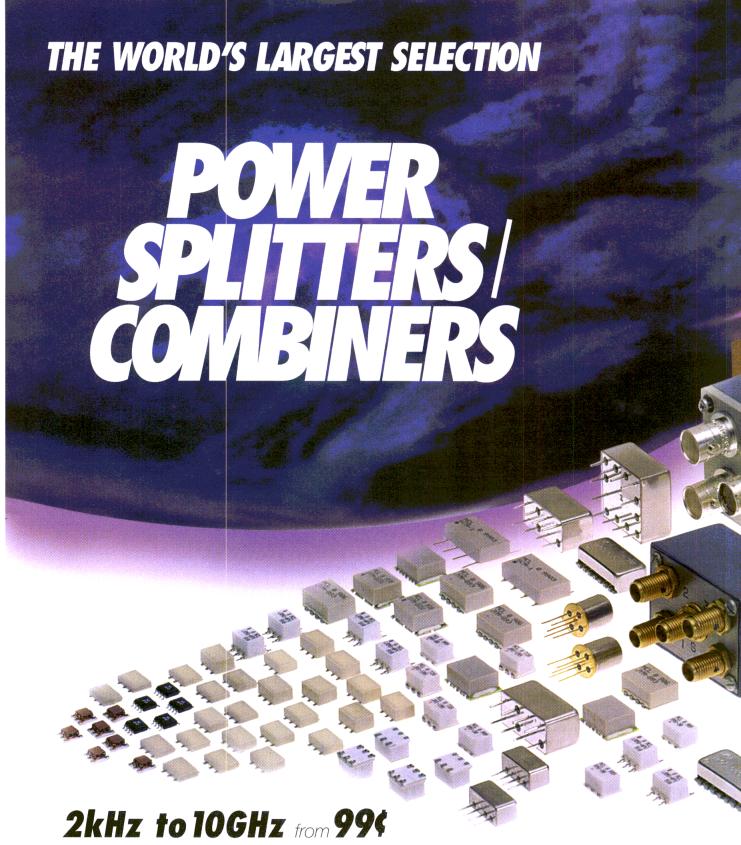


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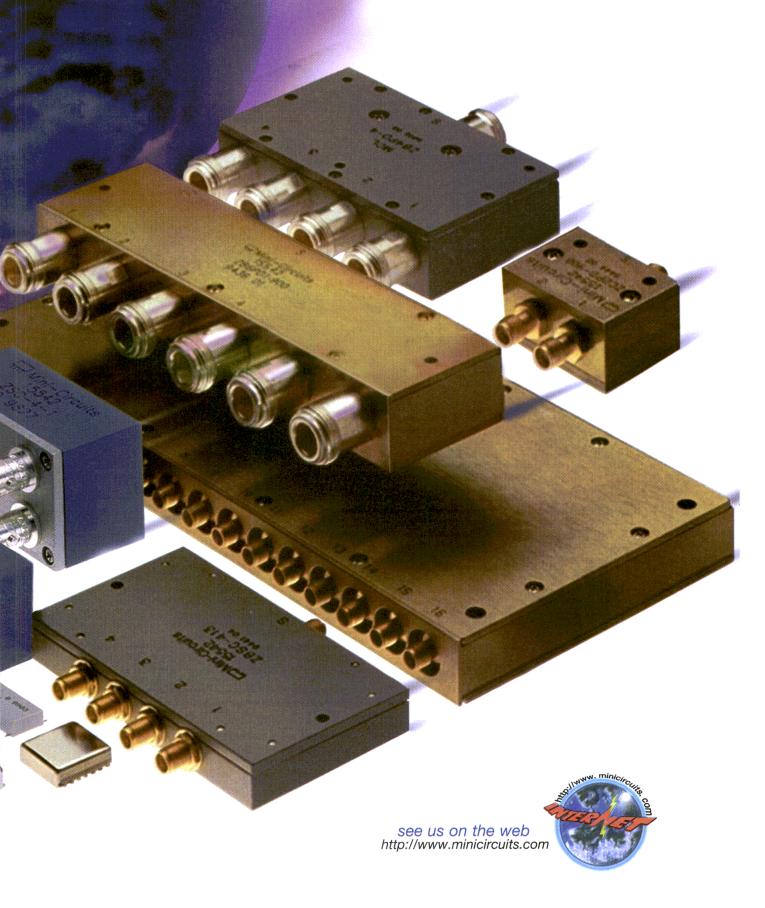






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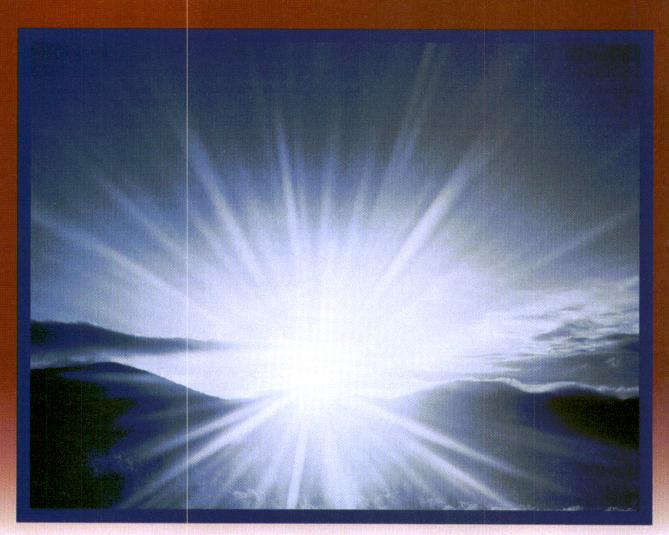




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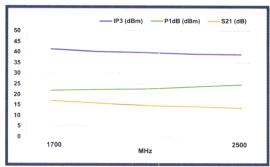


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NGA-386	0.1-5.0	4.0	35.0	20.8	14.5	25.8	144
NGA-486	0.1-6.0	5.0	80.0	14.8	18.3	39.5	118
NGA-586	0.1-6.0	5.0	80.0	19.9	18.9	39.6	121
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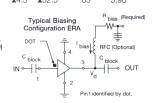


Model	* Freq. (MHz)	Gain (dB)	Max. Power Out (dBm, @1dB Comp)	Dynam NF(dB)	ic Range IP3(dBm)	@Device Current (mA)	① Price \$ea. (30 Qty.)
ERA-1SM	DC-8000	11.8	11.3	5.5	26.0	40	1.42
ERA-21SM	DC-8000	13.2	12.6	4.7	26.0	40	1.57
ERA-2SM	DC-6000	15.2	12.4	4.6	26.0	40	1.57
ERA-33SM	DC-3000	17.4	13.5	3.9	28.5	40	1.72
ERA-3SM	DC-3000	20.2	11.5	3.8	23.0	35	1.72
ERA-6SM	DC-4000	11.3	▲17.9	▲8.4	▲36.0	70	3.90
ERA-4SM	DC-4000	13.5	▲16.8	▲5.2	▲33.0	65	3.90
ERA-51SM	DC-4000	16.1	▲18.1	▲4.1	▲33.0	65	3.90

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Using these packages, the cost savings of automated assembly can be realized for mm-wave broadband wireless products. Cover photo provided by Alpha Industries.

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MICROWAVE & WIRELESS

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Wireless Suppliers Have Mixed Views on the Economic Slowdown

Recent economic conditions have raised questions about sustainable growth and long-term business prospects. Here is a summary of the main views that are discussed among participants in the wireless communciations industry.

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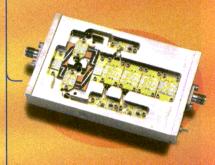
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			A DOMED	AAADUIEI	EDC /UD TO	0 MAIATTC)					
				AMPLIFI	ERS (UP TO			000			
JCA01-P01	0.5-1.0	25	3.5		30	40	2.0:1	250			
JCA12-P01	1.0-2.0	32	3	1	30	40	2.0:1	800			
JCA34-P01	3.7-4.2	30	3	1	30	40	2.0:1	750			
JCA56-P01	5.9-6.4	30	3	_1_	30	40	2.0:1	850			
JCA78-P01	7.9-8.4	30	4	_1_	30	40	2.0:1	900			
JCA812-P02	8.3-11.7	40	5	1.5	33	40	2.0:1	1700			
JCA910-P01	9.5-10.0	30	4	1	33	40	2.0:1	1300			
JCA1011-P01	10.7-11.7	30	4	1	30	40	2.0:1	950			
JCA1819-P01	18.1-18.6	30	5	1	27	37	2.0:1	800			
	RADAR & COMMUNICATION BAND LOW NOISE AMPLIFIERS										
JCA23-302	2.2-2.3	30	0.8	0.5	10	20	2.0:1	80			
JCA34-301	3.7-4.2	30		0.5	10	20	2.0:1	80			
JCA56-502	5.4-5.9	50	1 - 1	0.5	10	20	2.0:1	160			
JCA78-305	7.25-7.75	27	1.2	0.5	13	23	2.0:1	100			
JCA910-305	9.0-9.5	27	1.4	0.5	13	23	1.5:1	150			
JCA1112-305	11.7-12.2	27	1.5	0.5	13	23	1.5:1	150			
JCA1415-305	14.0-14.5	26	1.6	0.5	13	23	1.5:1	160			
JCA1819-305	18.1-18.6	22	2.0	0.5	10	20	1.5:1	160			
JCA2021-600	20.2-21.2	30	2.2	1	13	23	1.5:1	240			
			DI DANID A	MDI ICICI	RS (5.85 TO	14.5)					
JCA514-201	5.85-14.5	8	TOANU A	1.5	10	20	2.0:1	100			
JCA514-201 JCA514-300	5.85-14.5	14	6	1.5	10	20	2.0:1	150			
JCA514-300 JCA514-302	5.85-14.5	22	6	1.5	20	30	2.0:1	350			
JCA514-302 JCA514-400	5.85-14.5	25	6	1.5	10	20	2.0:1	250			
JCA514-400 JCA514-403	5.85-14.5	32	6	1.5	23	33	2.0:1	500			
JCA514-501	5.85-14.5	35	6	1.5	16	26	2.0:1	375			
JCA514-503	5.85-14.5	41	6	1.5	23	33	2.0:1	500			
307014-303	J.03-17.J	71	•	113			EIGH	300			
					LIFIERS (2.0						
JCA218-200	2.0-18.0	15	5	2.5	10	20	2.0:1	90			
JCA218-300	2.0-18.0	23	5	2.5	10	20	2.0:1	110			
JCA218-400	2.0-18.0	29	5	2.5	10	20	2.0:1	150			
JCA218-500	2.0-18.0	39	5	2.5	10	20	2.0:1	180			

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Circle 39

Editorial

It's Fun to Discover Interesting New Ways to use RF and Microwaves

By Gary A. Breed Publisher

Although wireless communications applications are the mainstay of the RF and microwave engineering profession, radio waves are being used in many other fascinating ways.

The non-communication uses of our favorite type of energy include controlling the flow of corn flakes as they are blown through the cereal factory, by measuring the absorption of microwaves passing through the duct in which they are transported. The betterpaid among us can be proud that the floor mats on that new Mercedes used RF energy to bond the rubber onto the carpeting.

In the November 2000 issue of *Scientific American*, Franklin Chang Diaz describes his development work on the VASIMR rocket.

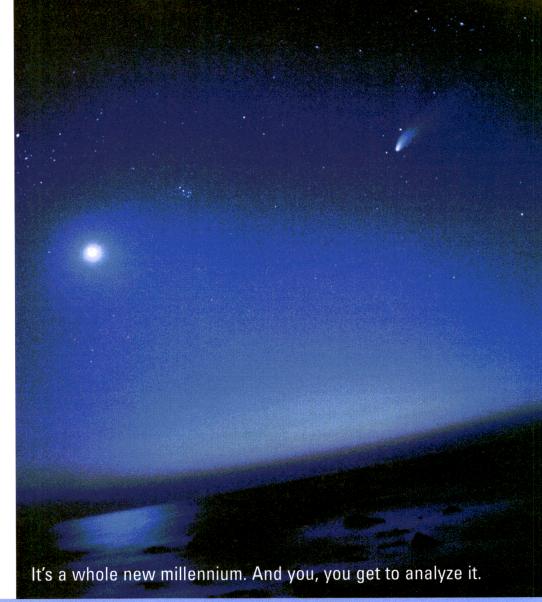


The VASIMR (VAriable Specific Impulse Magnetoplasma Rocket) is a descendent of the early plasma rockets that had too litle thrust to be practical. This design, with its first space flight planned for 2004, accelerates a hydrogen or helium plasma to 300,000 feet per second to provide useful thrust for interplanetary travel. Since this velocity is 60 times that of a chemical rocket exhaust, the amount of mass for the same thrust is 60 times less in the VASIMR, which can either reduce the mass of the vehicle or increase the duration of the rocket motor operation.

All this is powered by RF! Energy at 10 to 50 MHz ionizes the gas, which is accelerated by high power RF at slighly lower frequencies. The first trial spacecraft will have a 10 kW rocket motor, but future models are envisioned with megawatt and gigawatt power. It's going to take a lot of RF devices to generate that much power.

As one of the fundamental forces of nature, electromagnetism finds many uses in physics research. This particular project is a spinoff of fusion research, with contibutions from particle accelerator physics, both of which are already big consumers of RF and microwave power.

I'm not trying drive home some dramatic message with this month's comments. I just believe an occasional look at the unusual and interesting work going on within our chosen profession can be fun. It is too easy to become narrowly focused on today's engineering project; I think it's important to be reminded that you don't even need to look outside the realm of your own specialty to find a wide world of new ideas.





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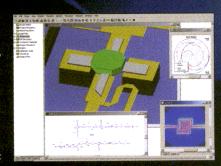
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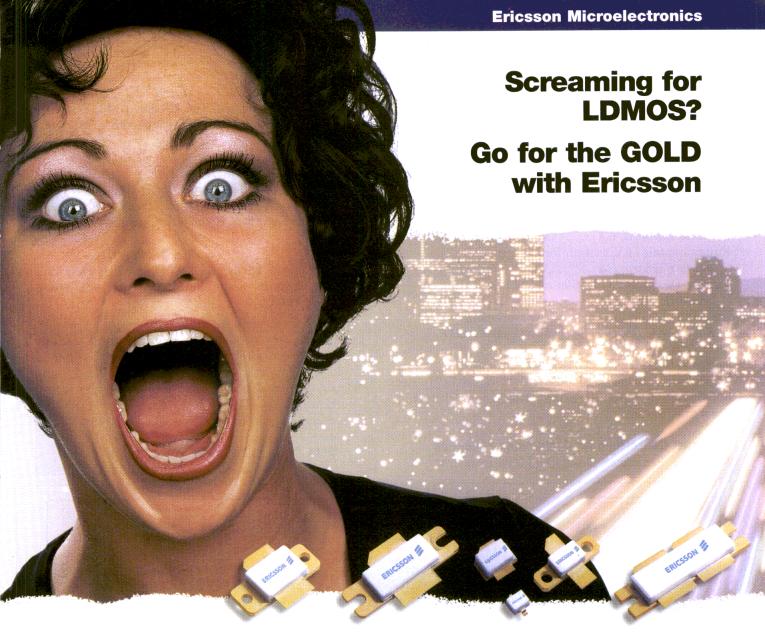
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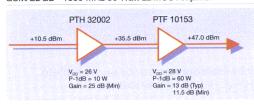
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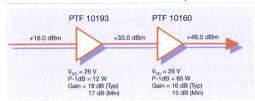
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Mountain View, CA January 12, 2001	Digital Avionics Systems
Global System for Mobile Communications (GSM)	Los Angeles, CA Jan. 29-Feb. 2, 2001
Orlando, FLJanuary 22-23, 2001	Information: UCLA Extension, Short Course Program
Applied RF Techniques I	Office, Tel: 310-825-3344; Fax: 310-206-2815.
Orlando, FL January 22-26, 2001	, 101, 010 020 0011, 141. 010 200 2010.
Mountain View, CA February 5-9, 2001	RTT Programmes Limited
Phoenix, AZ	RF Design
Wireless Measurements: Theory and Practice	London, England January 15-17, 2001
Orlando, FL January 22-26, 2001	3G DSP
Mountain View, CA March 12-16, 2001	London, England January 22-24, 2001
GPRS/EDGE Applications for GSM	3G System Engineering
Orlando, FL January 24-26, 2001	London, England February 5-7, 2001
RF and High-Speed PC Board Design Fundamentals	RF Amplifier Design
Orlando, FL January 24-26, 2001	London, England February 12-14, 2001
DSP Made Simple for Engineers	
Mountain View, CA January 24-26, 2001	London, England March 12-14, 2001 RF Oscillator Design
Frequency Synthesis and Phase-Locked Loops	
Orlando, FL January 29-30, 2001	London, England February 19-21, 2001 RF/IF Processing Design
Short Range Wireless and Bluetooth	
Mountain View, CAJan. 31-Feb. 2, 2001	London, England March 5-7, 2001 Information: Lowering Conner Tele + 44 181 844 1811
Advanced Wireless and Microwave Techniques	Information: Lorraine Gannon, Tel: +44 181 844 1811;
Mountain View, CA February 12-16, 2001	Fax: +44 181 751 2616; E-mail: seminars@rttsys.com;
	Internet: www.rttsys.com.
Phoenix, AZ	
Phoenix, AZ	R.A. Wood Associates
Phoenix, AZ	R.A. Wood Associates Introductory RF & Microwaves
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TTI Technology Training Initiative (Tustin Technical Institute, Inc.)

Fundamentals of Vibration for Test Las Vegas, NVJanuary 29-31 Santa Barbara, CA March 19-21, 2001 Thermal Analysis and Heat Transfer Huntsville, ALFebruary 12-14, 2001 Climatic Environmental Testing Procedures Huntsville, ALFebruary 15-16, 2001 Santa Barbara, CA March 22-23, 2001 Fundamentals of Vibration for Design Santa Barbara, CA March 12-14, 2001 Fixture Design for Vibration and Shock Testing Santa Barbara, CA March 14-16, 2001 Instrumentation for Test and Measurement Santa Barbara, CA March 26-28, 2001 Metrology Concepts Santa Barbara, CA March 28-30, 2001

Northeast Consortium for Engineering Education Antennas: Principles, Design and Measurements

Information: Brian P. Slatery, Tel: 805-682-7171; Fax:

805-687-6949; E-mail: brian@ttiedu.com; Internet:

Information: Kelly Brown, Tel: 407-892-6146; Fax: 407-892-0406; E-mail: stcloudof1@aol.com; Internet: www.usit.com/antenna.

University of Missouri-Rolla

Grounding and Shielding Electronic Systems Circuit Board Layout to Reduce Noise Emission and Susceptibility

Information: Sue Turner, Tel: 573-341-6061; Fax: 573-341-4992; E-mail: suet@umr.edu; Internet: www. umr.edu/~conted.

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

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Advanced Wireless and Microwave Techniques

February 12-16, 2001

RF Test Equipment Operation (Lab) February 20, 2001

RF Testing for the Wireless Age (Lab) February 21-23, 2001 Practical Design of Integrated and **Discrete Wireless Circuits** February 26-28, 2001

RF CMOS Design March 1-2, 2001

RF Transceiver Design March 5-8, 2001

Nonlinear Device Model Extraction **Techniques for Circuit Designers** March 8-9, 2001

Wireless Measurements: **Theory and Practice** March 12-16, 2001

Electromagnetic Shielding for Wired and Wireless Technology March 19-22, 2001

Mobile Communications and Wireless **Data Networks** March 26-29, 2001

Fiber Optics Made Simple April 2-3, 2001

Broadband Networking Made Simple April 4-5, 2001

Antennas and Propagation for Wireless Communications April 9, 2001

Phoenix, Arizona

RF and Wireless Made Simple March 19-20, 2001

Applied RF Techniques I March 19-23, 2001

Advanced RF and Wireless Techniques March 19-23, 2001

RF and Wireless Made Simple II March 21-22, 2001

Bluetooth: Operation and Use March 26-27, 2001

Frequency Synthesis Technology: **Wireless Applications** March 28-30, 2001

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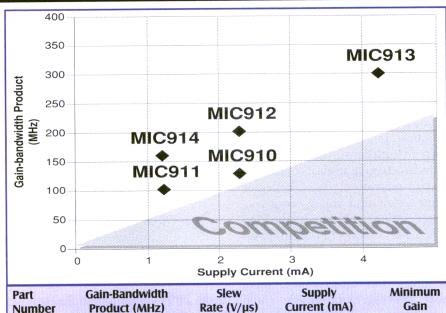
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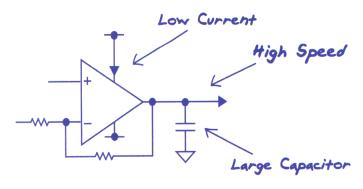
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Authors should submit an electronic file (.pdf), a camera-ready hard copy and three paper copies of a four-page paper, including all references and figures. A signed copyright form and cover letter are also required. Complete submission guidelines are available at the conference Web site, given below. Submit to:

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2001 Technical Program Committee Co-Chair

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Internet: http://ieeeaps.org/2001APSURSI

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ISSSE 2001 — 2001 International Symposium on Signals, Systems and Electronics

July 24-27, 2001 — Tokyo, Japan

Topics: Software-oriented radio transmitters/receivers, wireless channel equalization, advanced wireless radio networks, RF synthesizers, DSP, integrated modules and elements, advanced technologies for RF circuits, devices for microwaves and photonics, device modeling and design, millimeter-wave applications and full-scale systems on a single chip.

Send submissions to:

ISSSE 2001

E-mail: issse01@ee.kagu.sut.ac.jp

Internet: http://issse01.ee.kagu.sut.ac.jp

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ISMOT '01 — 8th International Symposium on Microwave and Optical Technology

June 20-24, 2001 — Montreal, Quebec, Canada

Topcs: WDM/DWDM in optical communications, CAD of microstrip and CPW antennas, nonlinear design of power amplifiers and multi-port devices and circuits for advanced system design.

Authors should submit one original and three hard copies of a four-page manuscript, along with a diskette. Online electronic submission is preferred. Complete information is available at the conference Web site, given below.

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Technical Program Chair

Department of Electrical Engineering/260

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Deadline: February 15, 2001

GaAs 2001 — European Gallium Arsenide And Other Semiconductors Application Symposium

September 24-25, 2001 — London, England

Topics: Compound semiconductor materials, device and circuit technologies and technology CAD, silicon MMICs, high speed digital devices and circuits, MEMS and MOEMS, MMICs and power amplifiers.

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E-mail: ali.rezazadeh@kcl.ac.uk

Internet: http://www.eumw.com

Deadline: March 16, 2001

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September 25-27, 2001 — London, England

Topics: Passive and active imaging systems, millimeterwave and sub-millimeterwave component circuits and systems, phased arrays, CAD of passive circuits, EM field theory, microwave and millimeterwave packaging and interconnects, microwave, millimeterwave and sub-millimeterwave measurements; electromagnetic compatibility, and radar technologies and systems.

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Calendar

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ECWT 2001 — European Conference on Wireless Technology

September 27-28, 2001 — London, England

Topics: RFICs and MMICS for wireless front ends; developments in receiver architectures and technology; propagation modeling for wireless systems; linearization techniques; new modulation and coding schemes; smart antennas and spatial diversity; software radio; bluetooth and short range networking; WLAN, HIPER-LAN2 and UNII; third generation systems; location technologies and systems; broadband wireless access; testing to new wireless standards; system level design and simulation; new and developing technologies and materials; electromagnetic compatibility; and biological and medical effects.

Authors should submit an author information form, available at the conference Web site, and either six hard copies or an electronic file (.doc or .pdf) of a summary for each paper submitted. Electronic submission is strongly encouraged. Submit to:

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RAWCON 2001 — IEEE Radio and Wireless Conference

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Topics: Third generation (3G) and fourth generation (4G) cellular; wireless LAN; broadband fixed wireless; Bluetooth/HomeRF/Personal Area Networks; ultrawideband (UWB) communications; modeling and simulation; active and passive device technology; propagation and channel modeling; signal processing and system performance; and system architecture.

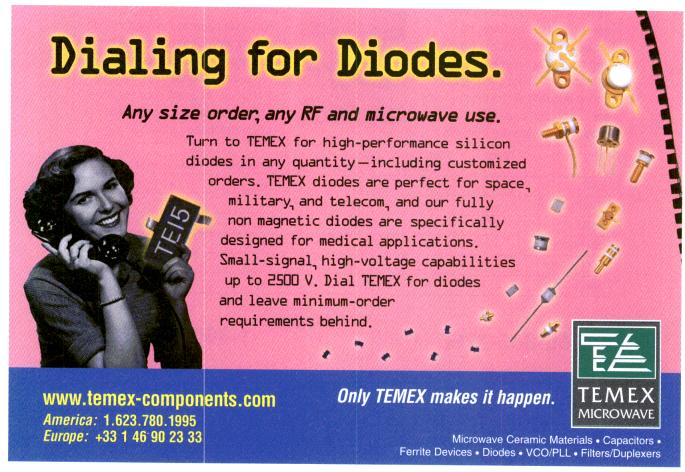
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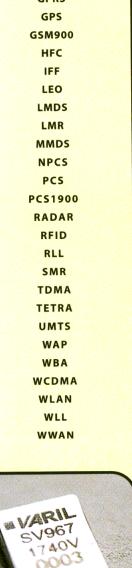
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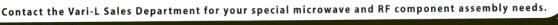
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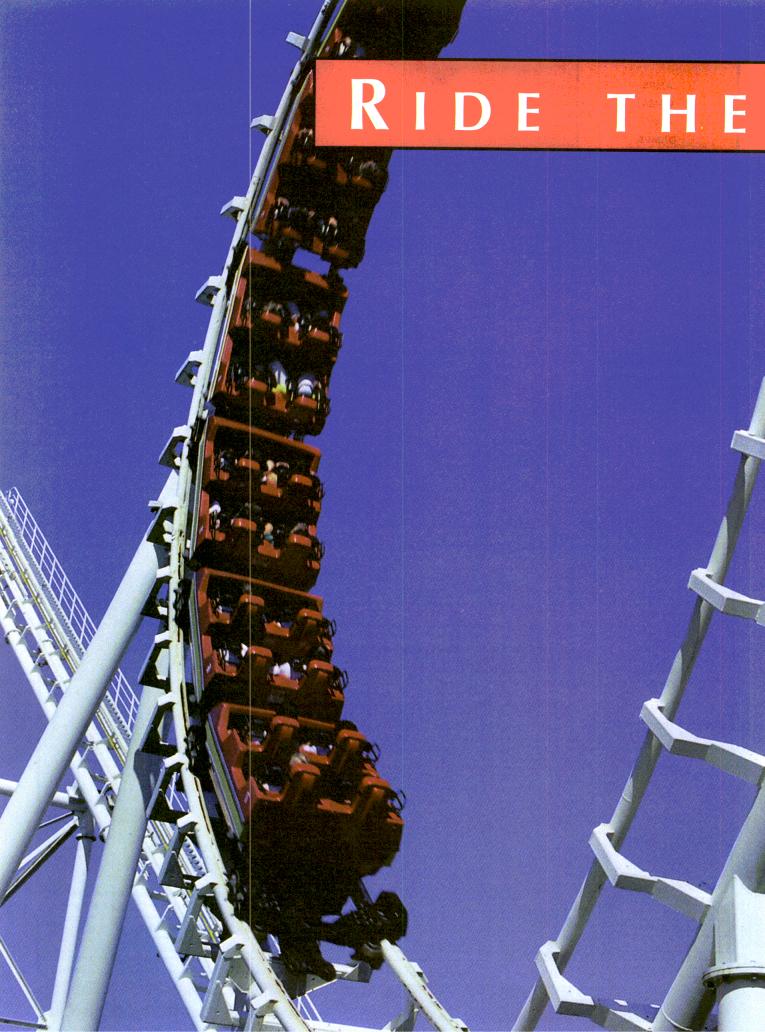
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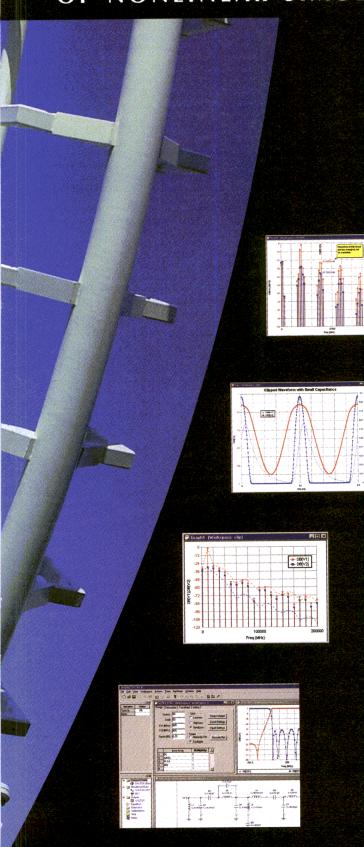
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BRIEFS

• Melcor Corporation has announced plans to add 12,000 square feet of manufacturing, engi-



neering laboratory and office space to its production

facility in Trenton, NJ. The expansion is designed to meet increased demand for the company's telecommunications and electro-optics products.

- Littlefeet Inc. has moved into a new 45,000-square-foot corporate headquarters facility in Poway, CA, that includes a new research and development center.
- Infineon Technologies has announced plans to expand its Richmond, VA, location to add production capabilities for a line of 300 mm wafers.
- Dielectric Laboratories Inc. has announced the expansion of its heaquarters location, doubling its size to 120,000 square feet. The facility will house production for the company's ceramic capacitors.
- Lucent Technologies has announced that it has opened five new Bell Labs facilities in Greece, Australia, China, India and Italy over the past eight months. The locations provide research and development activities covering broadband and mobile internet technologies including optical, data and wireless communications.
- SaRonix has launched an estore through its web site, www. saronix.com. The site offers online ordering capabilities for the company's frequency control products.

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

Report: Bluetooth certification to push technology's growth

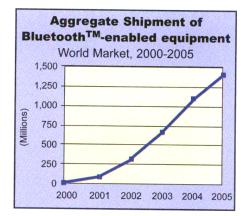
A new report released by Allied Business Intelligence (ABI) cites Motorola's recent BluetoothTM certification as "a watershed event" in the technology's development.

Motorola has received Bluetooth certification for its PC card and USB adapter, targeted at notebook and desktop PCs. According to the report, this certification may allay some concerns over the delays in getting the technology to market.

"We believe that Motorola will be joined rapidly by other vendors in getting their Bluetooth products certified, and this will allow seeding of the market to begin in the fourth quarter of this year," said Navin Sabharwal, ABI's director of residential and networking technologies.

Bluetooth product certification and shipments have been delayed by lack of production volume silicon and concerns about the robustness of the specification, the report says. However, ABI projects that annual shipments of Bluetooth-enabled devices will reach more than 1.4 billion nodes by 2005, up from just 56 million in 2001.

"We have to be careful not to



throw out the baby with bathwater simply because of some premature market hype," Sabharwal said. "While some concerns Bluetooth such as interoperability and security are valid, it does not dull the tangible cross-industry enthusiasm for an inexpensive, lowpower wireless connectivity solution. It should also be noted that wireless local area network (WLAN) solutions such as IEEE 802.11b are, for the most part, complementary technologies, and we do not expect their success to pose a competitive threat to Bluetooth prospects."

ABI is a technology research institute based in Oyster Bay, NY.

WDF, CTIA announce merger plans

The Wireless Data Forum (WDF) and the Cellular Telecommunications and Internet Association (CTIA) have announced plans to merge their operations. WDF's staff will join CTIA as the Department for Wireless Internet Development

The move will increase CTIA's emphasis on mobile data and wireless internet issues, as well as providing WDF members with expanded opportunities in these growing markets. CTIA will also create a Wireless Internet Caucus to focus on the wireless internet industry.

More information on CTIA is available on the association's web site, www.ctia.org.

CDMA group adds members

The CDMA Development Group (CDG) has announced the addition of 18 new member companies, bringing the total roster to 110 companies worldwide. Among the new members are Novatel Wireless, BellSouth International, Transcept, Shema Ltd., 3G Cellular, Tantivy Communications Inc., Ditrans Corporation, Acterna and Airvana.

The CDG is an international trade association focused on the development and implementation of code division multiple access (CDMA) wireless technology worldwide. More information is available at the association's web site, www.cdg.org.

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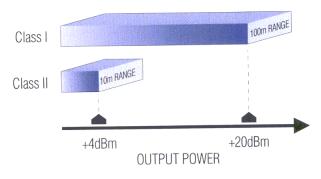
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Atmel, CES, ESA team up for next-generation ICs

Atmel Corporation has announced a three-year agreement with the European Space Agency (ESA) and the French Centre National d'Etudes Spatiales (CNES) to develop the next generation of integrated circuits dedicated to space applications.

Under the agreement, Atmel

Europe will work with the two agencies to create a system-level integrated solution for data and signal processing under space conditions. These applications require significant processing power and fast memory, as well as specialized libraries and intellectual property.

Atmel will use 0.25 µm CMOS technology to manufacture the product, at its Rousset, France, facility.

The product will be adapted to attain the radiation hardening imposed by the space environment.

Atmel, based in San Jose, CA, manufactures advanced logic, mixed-signal, non-volatile memory and RF semiconductors, as well as system-level integration semiconductor solutions.

Motorola qualifies new transistor wafer process

Motorola's Semiconductor Products Sector has completed qualification of its true enhancement-mode (E-mode) heterostructure field effect transistor wafer process.

This advanced single power supply gallium arsenide (GaAs) process is engineered to provide high-performance, cost-effective results in both linear transmitter and receiver circuits for low-voltage portable wireless applications.

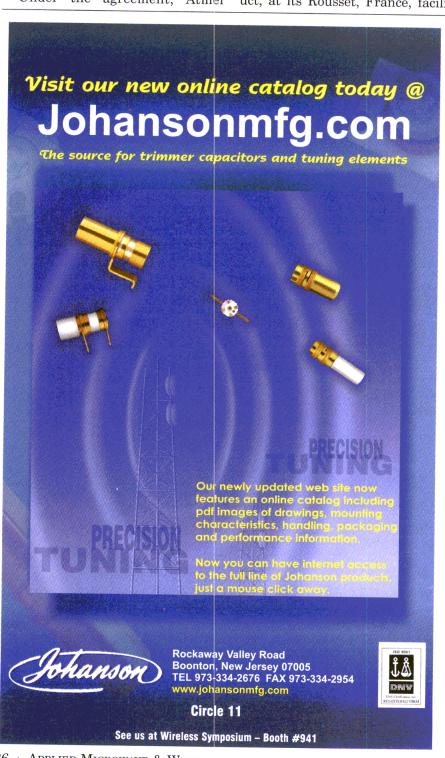
Motorola, based in Schaumburg, IL, provides semiconductors, integrated communications solutions, embedded electronic systems and components.

Honeywell, RF Integration to develop RFIC products

Honeywell Solid State Electronics Center and RF Integration have agreed to jointly develop a line of high-performance, low-cost standard radio frequency integrated circuits (RFICs). The products will be designed for use in wireless and broadband communications.

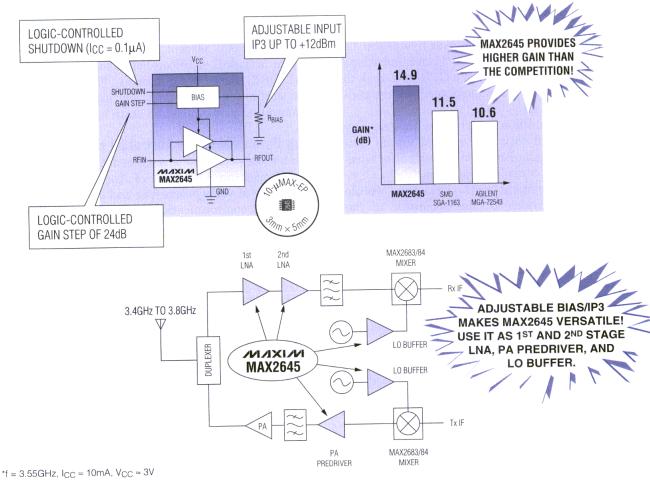
The RFICs will be developed using Honeywell SSEC's µwave CMOS SOI foundry and RF Integration's development capabilities, combining digital and RF functions into single chips. Initial products planned include digital attenuators and high-isolation switches with integral decoder drivers and logic functions.

Honeywell SSEC, based in Plymouth, MN, provides control technologies for telecommunications. RF Industries is a fabless semiconductor company based in Lowell, MA.



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BUSINESS AND FINANCE

Motorola announces new contract awards

Motorola has received a series of contract awards for products and network services in the United States, China and Pakistan.

- Under a contract with the U.S. Army, Motorola will provide Tactical Air Space Integration Systems (TAIS). Motorola provided the TAIS prototype and three production systems under previous agreements. The initial value of the contract is \$22.3 million, with a total value of up to \$150 million over five-years.
- An agreement with China Mobile Communications Corporation calls for the supply of a GPRS network to four major cities in China. Financial terms of the contract were not disclosed.
- · As part of a \$29 million contract with Zhejiang Mobile, Motorola will expand the GSM digital network in China's Zhejiang Province and will offer wireless applications and consulting services.
- A \$26 million agreement with Pakistan Mobile Communications provides for the expansion of the existing GSM digital wireless network infrastructure. Motorola, based in Schaumburg, IL, provides semiconductors, integrated communications solutions,

embedded electronic systems and components.

EMCORE receives order for solar cells

EMCORE Corporation has announced a \$12 million order from Palo Alto, CA-based Space Systems/Loral for high efficiency, triple-junction solar cells. The cells will be used to provide power in space for advanced communications satellites.

EMCORE's gallium arsenide (GaAs) offer more power without adding weight by converting more spectral energy into electrical power. Degradation after 15 years in orbit is 8 percent, as compared to the 15 percent that is typical of silicon-based solar cells.

EMCORE, based in Somerset, NJ, provides compound semiconductor products for broadband and wireless communcations and solid state lighting.

Analog Devices acquires Australian company

Analog Devices has announced the acquisition of Signal Processing Associates of Australia, a developer and supplier of voice processing and fax/data relay software for telecommunications. Financial terms of the agreement were not disclosed.

Analog, based in Norwood, MA, manufactures precision high-performance integrated circuits for analog and digital signal processing applications.



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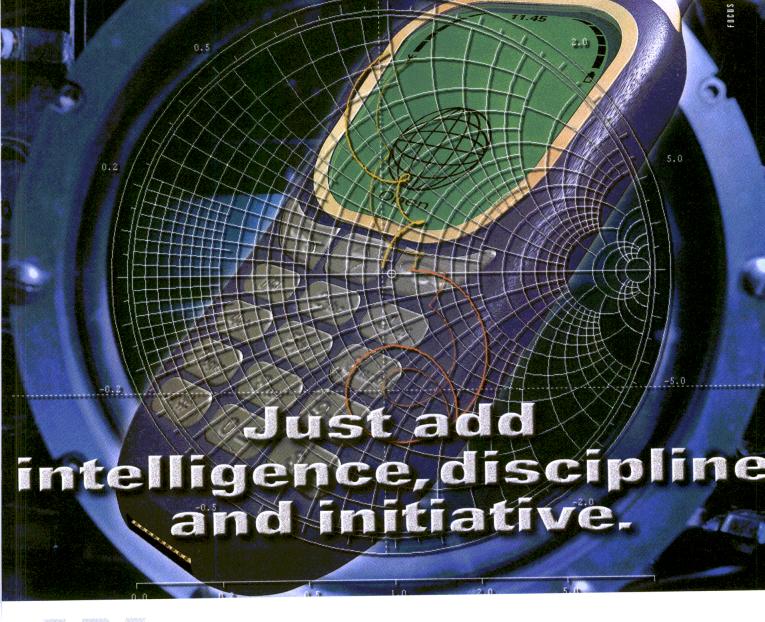
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BUSINESS AND FINANCE

Comarco acquires EDX Engineering

Comarco has announced the acquisition of Eugene, OR-based EDX Engineering, a developer of system planning tools for the wireless industry. Financial terms include \$2.1 million in cash, as well as more than 250,000 shares of Comarco stock.

Under the agreement, EDX will operate as a division of Comarco Wireless Technologies, the company's wireless subsidiary. Comarco, based in Irvine, CA, provides test and measurement equipment and engineering services for the wireless industry

RTI launches semiconductor company

Research Triangle Institute (RTI) has announced the formation of a new semiconductor company, Ziptronix. Ziptronix will offer a proprietary technology that allows integration of semiconductors through wafer bonding and backside processing.

The company is the first in a planned series of commercialization efforts for technologies developed at RTI, an independent, non-profit research organization based in Research Triangle Park, NC.

Andrew completes broadband wireless system in Peru

Andrew Corporation has announced that it has completed construction of the first broadband wireless network in South America, providing high-speed wireless data and internet connections in Lima and Callao. The network was completed under a contract with World Wide Wireless Communications, part of a systems integrator agreement worth a potential \$50 million.

Andrew, based in Orland Park, IL, supplies communications systems equipment and services for communications markets.

Ericsson to provide GSM/GPRS network in Argentina

Ericsson has signed an agreement to provide GSM/GPRS core and radio access infrastructure equipment for Telecom Personal SA in Argentina. Financial terms were not disclosed.

Ericsson, based in Stockholm, Sweden, supplies systems, applications, mobile phones and other wireless products and services worldwide.

Herley announces two new contracts

Herley Industries has announced two new military contracts. The first, a three-year, \$1.1 million agreement, calls for the supply of beacon transponders for use in a new European missle program. The second, worth \$1.4 million, is with the U.S. Air Force and provides for radar transmit enhancements to F-16 aircraft.

Herley, based in Lancaster, PA, manufactures microwave products and systems for defense and commercial wireless applications.

Frequency Electronics to provide R/T modules

Frequency Electronics has received its first contract for the production of receive/transmit (R/T) modules, designed to increase throughput in advanced optical transport (fiber optic) systems. The intial contract is worth approximately \$2 million.

Frequency Electronics, based in New York, NY, develops frequency, timing and synchronization products for telecommunications.

inSilicon announces acquisition of Xentec

in Silicon Corporation has announced the acquisition of Xentec, a provider of high-speed mixed-signal analog and wireless technologies. Financial terms include \$2.9 million in cash, as well as stock considerations.

in Silicon, based in San Jose, CA, provides communications platforms used by semiconductor and systems companies to design systems-on-chip products.

Lucent spinoff named Agere Systems

Lucent Technologies' microelectronics spinoff company has selected Agere Systems as its name. The name was taken from an Austin, TX-based network processing company Lucent acquired in 2000.

Agere, formerly the Microelectronics Group of Lucent, is based in Allentown, PA, and comprises two divisions, Integrated Circuits and Optoelectronics.

Mimix Broadband acquires Taridan subsidiary

Mimix Broadband, formerly Shason Microwave Corporation, has announced the acquisition of Taridan Microwave Network's Australian Design subsidiary. Financial terms were not disclosed.

The acquisition significantly expands Mimix's development capabilities for gallium arsenide (GaAs) MMICs and modules for broadband wireless applications. Mimix is based in Webster, TX.

Applied Epi receives MBE system order

Applied Epi has received an order for a GEN200T MBE system from Agilent Technologies. Agilent will use the system in support of its testing and measurement equipment for RF and IR wireless communications devices.

Applied Epi supplies epitaxy equipment and services for the manufacture of compound semiconductors.

Mitel to sell business division

Mitel Semiconductor has announced plans to sell its Communications Systems division, including the name Mitel, to Dr. Terence H. Matthews. The transaction is valued at approximately \$350 million.

Mitel is a provider of semiconductor and communication systems for voice and data networks.



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MBA-18L MBA-25L MBA-35L MBA-9	+4 +4 +4 +7	1.6-3.2 2.0-3.0 3.0-4.0 0.8-1.0	6.95 6.95 6.95 5.95	MBA-9MH MBA-12MH MBA-15MH MBA-18MH	+13 +13 +13 +13	0.8-1.0 0.8-2.5 1.4-2.4 1.6-3.2	7.95 7.95 7.95 7.95
MBA-12 MBA-26 MBA-591	+7 +7 +7	0.8-2.5 2.2-2.7 2.8-5.9	5.95 5.95 6.95	MBA-25MH MBA-35MH MBA-9H	+13 +13 +17	2.0-3.0 3.0-4.0 0.8-1.0 0.8-2.5	7.95 7.95 9.95 9.95
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Enhancing the MMDS Transport Layer

MMDS uses different frequency reuse plans than cellular phone systems

By Dr. J.R. Sanford and Joel Raymond REMEC Broadband

ecent investments by major telecom operators in the UMMDS and MDS spectrum spurred research related to system planning and hardware design. The envisioned application is high data rate communications. In this article, we compare the properties of an MMDS site to those of a cellular phone site.

Like the cellular systems of the 1980s, initial MMDS deployments will be noise limited. However, as the deployments increase, the system will become interference limited. This capacity limitation is thor-

oughly discussed in this article. After noting the difference between MMDS and cellular, the known limitations of a capacity limited cellular network are used to predict what will happen with MMDS deployments. Site planning and transport configurations that maximize capacity are then suggested.

An analysis of a number of different link scenarios shows that filtering and antenna sidelobe rejection are key to maximizing data throughput. The vast increase in data that the MMDS systems will support in comparison to cellular systems is also an apparent criterion. Finally, from the RF transport quality viewpoint, the hub receiver will likely be the limiting factor. Either interference robust coding schemes or lower order modulation may be appropriate for the uplink.

MMDS relative and cellular

We begin by pointing out the main differences between a cellular phone site and an

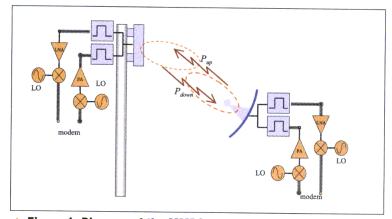


Figure 1. Diagram of the MMDS transport layer.

MMDS site. Cellular systems are well understood. In order to better understand the issues related to multipoint distribution systems, we compare the cellular environment to that of MMDS. Below are the defining differences between the two systems.

Antenna Directivity

Cellular phones employ antennas that are omni-directional, and while MMDS customer premise equipment (CPE) employ antennas that direct power in a desired fashion. This results in less interference between CPEs and between adjacent cells.

Line of Sight (LoS)

Most MMDS proposals suggest antennas that can communicate directly with the hub without going through building wall or dense foliage. This condition is rare in cellular phone systems and hence a significant margin must be added to the cellular link budgets.

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SWITCH TYPE	SPDT				
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Insertion Loss (Max.)	0.2	0.3	0.4	0.7	
VSWR (Max.)	1.3	1.4	1.5	1.7	
Isolation (Min.)	70	60	50	40	

Power Rating, RF Cold Switching:

10 Watts Impedance: 50 ohms 25° C (ma nominal)

Operating Power: (Failsafe):

12 Vdc at 130 ma

Connectors, RF

and Power:

.018 DIA. Pins

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Life:

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Operating Mode:

Switching Sequence:

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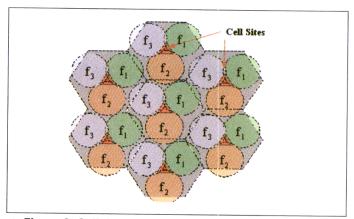


Figure 2. Cellular phone frequency reuse.

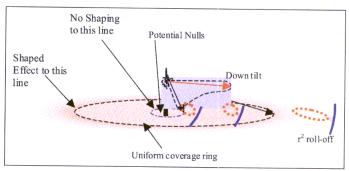


Figure 3. Effect of antenna directivity.

Diversity

In order to combat the effect of fading due to multipath, the cellular base station receivers normally employ two antennas. The statistical improvement in performance is sometimes referred to as diversity gain. For the downlink, the power is simply increased to a level that is adequate to overcome the fade. For LoS MMDS systems, the fading will be relatively small, so a single receive antenna is sufficient.

Batteries

One of the biggest obstacles for cell phone designers is designing energy efficient radios. This dictates that the amplifiers must operate in saturation, which limits the types of modulations that can be effectively employed. Consequently, although more spectral efficient modulations are well known, the most popular modulation for cellular is PSK. MMDS systems typically reside in locations where power is not an issue and hence higher order modulation schemes can be used.

For the purposes of this paper, noise and interference are differentiated as follows: interference is unwanted signals generated by the MMDS system; noise is everything that is not interference or the desired signal. For example, the image signal from a PCS site or internally generated harmonics will both be considered noise. Interference can be further subdivided into co-channel

and cross-channel. Co-channel interference resides at the same frequency as the desired signal, and crosschannel interference is due to signal on nearby frequency bands.

Figure 1 shows a simplified diagram of the MMDS transport layer. The antennas and filters provide noise and interference rejection to the front end amplifier. The aggregate performance of these devices can be compared by using both up and down links. The hub antenna will typically cover a sector ranging from 45 to 120 degrees in azimuth. The CPE antenna will have a gain ranging from about 7 to 25 dBi. Higher gain CPE antennas tend to be larger and more expensive.

The spatial filtering of the CPE antenna provides a degree of interference rejection not available in a cellular system. The cost constraints on the hub are not as stringent as those on the CPE. Therefore, higher Q filters can be employed at the hub end. Because power is readily available at both the CPE and hub, both the hub and CPE amplifiers can operate in a linear region. Therefore, spectrally efficient modulations, such as versions of OFDM or QAM can be used. The level of the modulations (i.e., QPSK through 1024 QAM) will be determined by the acceptable bit error rate (BER) and the signal to noise ratio (SNR) or carrier to interference (C/I): whichever is the limiting factor. For simplicity, we will assume that we can increase the M-QAM level by a factor of 4 for every 7 dB improvement in SNR. This corresponds to a doubling of the data rate with the same 7 dB improvement. Improving C/I results in more modulation and error correction dependency, but similar trends hold. Hence, reducing interference increases data capacity.

In their most basic configuration, cellular phone systems are sectorized into three-cell configurations. The motivation for this is frequency reuse. In a single cell, the frequency band may be broken into three equal subbands with one sub-band per sector. This in itself does not provide any frequency reuse over an omni configuration. However, when the same scheme is used in a multiple cell configuration, it results in a reuse of three, as indicated by Figure 2. The cost of the additional hub equipment required for the sectorization is small in comparison to the over all system cost. This scheme minimizes the C/I in a multiple cell cellular configuration and maximizes the capacity, which, in this case, corresponds to the number of users.

Cellular phones have omni direction antennas that provide no isolation between cell site locations. The isolation is purely due to the frequency filtering and the propagation characteristics. In contrast, the MMDS CPE antennas can consistently provide between 25 and 40 dB of isolation between cells. Therefore, there is little motivation to follow the cellular phone scheme of sectorization for MMDS. To better understand the MMDS limitations, two scenarios are examined.

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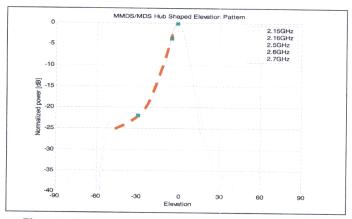


Figure 4. Elevation pattern of a shaped beam hub antenna.

Range effects

Let us first look at a system with a hub and three CPEs. The CPEs are at various distances from the hub (i.e., 100 m, 1 km and 5 km). Perhaps the biggest advantage MMDS has over cellular is the antenna directivity of the CPE unit. Besides adding link margin, this reduces interference into adjacent cells. Higher gain antennas can be used towards the cell periphery for link margin balancing. Normally, higher gain antennas can provide a higher front-to-back ratio than lower gain antennas. The systems at the cell edge employ the better front to back ratio with respect to reducing interference into and from the adjacent cells. The combination of the shaped beam hub antenna together with the use of CPE antennas with various gains allows the majority of the CPE receiver dynamic range to be used by the modem rather than for power control and link balancing. Further, it also adds to the dynamic range in the CPE transmitter. The same argument applies to the hub receiver and transmitter. This virtual dynamic range increase corresponds to higher data capacity.

Hub antennas with shaped elevation patterns are readily available. The shape of the pattern follows a csc0 electric field distribution from the antenna's 3 dB point to approximately –45 degrees in elevation. An example is shown in Figure 4.

Let us assume the hub is mounted 50 meters above the CPEs and covers a cell that is 10 kilometers in diameter. The CPE at 100 meters resides at the 30 degree point in the elevation pattern, while the CPE at 1 kilometer resides at the 3-degree point in the elevation pattern. The antenna has a very small electrical down tilt such that the CPE at 10 kilometers is at the main beam peak. The energy available at the locations of the inner two CPEs is approximately the same because of the shape of the pattern. We will assume that physically small 11 dBi antennas are used at these locations. The CPE at 5 kilometer has at least 14 dB more path attenuation than the unit at 1 kilometer, and the hub has 3 dB more gain in this direction. Here we make up the 11

dB difference by using a 22 dBi gain antenna. Now, at both the hub and the CPE we have approximately the same link characteristics. The hub then receives three channels of comparable strength and demodulates each of them. Each CPE receives three channels of comparable strength but only demodulates one of the three channels. This all happens without sacrificing dynamic range on either the up or down link. Hence, the signals can be transmitted at their maximum data rates. Although this representation is somewhat of an oversimplification, it does illustrate the goal of maximizing the available dynamic range to allow the highest order modulation to be used.

In order to minimize noise at the hub, a horizontal polarized antenna is chosen. This reduces the noise generated by vertically polarized PCS base station transmitters. The MMDS hub has better than 40 dB of crosspolar rejection. However, typical base station antennas typically only have about 20 dB rejection in the sideline region. Hence, there is about a 20 dB improvement in PCS noise rejection over using a vertically polarized antenna.

Sectorization

Without sectorization, adjacent cells will interfere with one another, and the frequency reuse factor will be one. However, an overly sectorized cell will interfere with itself and will not efficiently reduce the interference into adjacent cells. The optimal sectorization from an interference standpoint is one that balances the effects of the cell's self interference with the interference from adjacent cells. The frequency reuse factor is more difficult to understand. In cellular systems, the problem is simpler because of the fixed data rate. For voice communications, there is no point in improving beyond a given threshold. However, advanced MMDS systems will employ dynamic rate allocations based on the quality of the communications channel. Adding more sectors increases the system cost. However, site acquisition and infrastructure normally outweigh the antenna and RF equipment cost.

Once again, we will look at a relatively simple example first. We will use the same equipment as in scenario one. Due to the link balancing, the proposed equipment should reduce the spectral re-growth of cross-channel interference to a level that can be neglected. For simplicity, a four sector configuration is assumed and can be extrapolated to higher orders of sectorization. Recently, antennas with a high degree of sidelobe rejection have been developed for MMDS. Figure 5 depicts the carrier and the interference power. The blue (solid) line depicts frequency set one and the red (dashed) line depicts frequency set 2. Here we see that the co-channel interference is around 34 dB while the cross-channel interference is 0 dB (the cell cross- over points).

Hence, frequency filtering is relied on for the cross-

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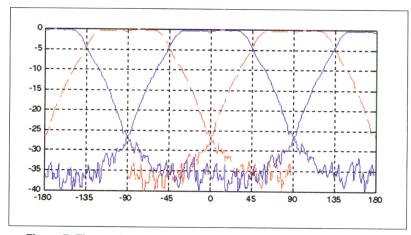


Figure 5. The carrier and interference power of an antenna.

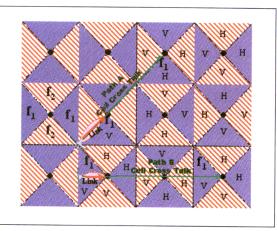


Figure 6. 90 degree sectors with a reuse of two.

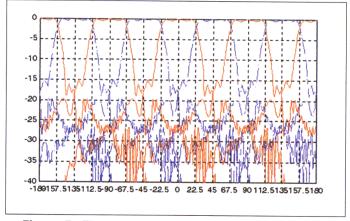
channel interference. In order to maximize the rejection in the modem, frequency set one might consist of odd channels, while frequency set two would correspond to even channels. Based on QAM threshold levels, this level of co-channel interference would allow 256 QAM with a 10^{-6} bit error rate (BER). This corresponds to nearly 8 bits/S/Hz.

The goal of the sectorization is to reduce the co-channel interference and provide frequency reuse. From Figure 6 we can see that the line of sight path to the next hub operating with the same frequency set will be about three times that of the local hub (Path A). Therefore, the line of site cell to cell interference may be as high as -9dB relative to links within the cell. This corresponds to a CPE on the cell edge interfering with the next hub along that same diagonal. CPEs in the center of the cell will not cause co-channel interference with an adjacent cell but may leap over that cell and cause interference at a level -25 dB down from the direct link (Path B). Filtering of the co-channel interference is not an option. However, since the signals are delayed by at least three times the delay of the direct signal, interference rejection coding methods can be applied to the effects of these unwanted signals to reduce the effects. Alternatively, the polarization of every other sector using a common frequency set can be rotated by 90 degrees. This is depicted by the V (vertical polarized) and H (horizontally polarized) in Figure 6. The hub antennas provide approximately 40 dB of cross-polar isolation while the CPE antennas can provide 30 dB in the main beam region. However, based on measurements done at 2 GHz, the multipath of the propagation environment typically allows only about 15 to 20 dB of cross-polar isolation to be realized. Likewise, a 10 degree rotational misalignment of the CPE will introduce a cross-polar component that is about 15 dB down from the copolar radiation. Hence, we should not count on more than about 15 dB of isolation due to cross-polar rejection, which improves the worst case cell-to-cell interference to about

-24 dB, without the use of coding techniques. This level is still not good enough for 64 QAM. Therefore, even with good cell planing, worst case conditions dictate either temporal coding or a lower order modulation (16 QAM).

We now apply the same concepts to an eight sector configuration with a frequency reuse of four. Figure 7 shows the patterns of cascaded antennas with 45 degree 3 dB beamwidths. These antennas provide approximately 25 dB of co-channel interference rejection. In the cell of interest, there are now up to three interfering signals that are assumed to have various powers and add randomly. The interference level is now approximately -25 dB + $10\log3 = -20$ dB. This is not quite good enough for 16 QAM at 10^{-6} BER (4 bits/S/Hz) and hence, QPSK or robust error correction is required under worst case conditions.

Therefore, in going from a four sector configuration to an eight sector configuration we doubled the capacity through frequency reuse but then reduced it by at least a factor of two by increasing the interference. Hence, using the defined hardware, the cost of the additional equipment and complexity did not pay any dividend.



▲ Figure 7. The patterns of cascaded antennas with 45 degree 3 dB beamwidths.

Conclusions

There are a multiplicity of techniques to approach MMDS frequency and cell planning. However, in all cases the capacity of a system is a function of the quality of the transport layer. The MMDS systems transport layer will provide much higher C/I ratios than cellular systems. Antenna directivity and adaptive modulation schemes are the defining advantages, which, in turn, will provide better spectral efficiencv. Due to cross-channel interference and noise, the hub receivers may limit the system. If these issues can be easily addressed with high-Q filtering at the hub, the same modulation can be used on both the up and downlinks. Otherwise, the slower uplinks can be employed in order to accommodate the reduced channel quality. MMDS should be able to support modulations ranging from a worst case of QPSK all the way to a best case of 256 QAM. The data capacity of the MMDS should be far more than an order of magnitude greater than that of cellular.

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A VCA Using Resistive Line Approach with Parasitic Inductance Cancellation Circuit

By Raymond W. Waugh, Agilent Technologies and Louis Fan Fei, Lucent Technologies

Power control is a crucial feature in modern communication systems. In today's spread spectrum and CDMA systems, each individual user appears as thermal noise to the others. If the user nearest to the base station produces more power than his neighbor, it will increase the neighbor's noise floor. In the worst case, this will disable the other user completely. This is the well known near-far problem. Tight power control will ensure that every user can have a quality link to the base station without causing fatal damage to other users.

In the receive chain, power control is needed for the AGC loop to ensure consistency of the SNR. Power control also will help to extend the dynamic range of the receiver chain. Power control is typically achieved using a voltage controlled attenuator (VCA).

There are many ways to implement a VCA. Implementing typically involves some variable impedance device, which can be done with a MESFET operating as a voltage variable resistor in its linear region or as a PIN diode operating as a current controlled resistor. PIN diodes offer the advantages of low distortion and low cost. In this paper, a PIN diode based VCA using the resistive line approach at 2.45 GHz will be discussed. Simplicity, low cost, high dynamic range and high power handling capability make the resistive line approach a popular microwave VCA design.

Building blocks of the parasitic cancellation scheme

The building block of the resistive line approach is a quarter wave transmission line (TL) and a shunt resistor (a PIN diode in this design). The quarter wave transformer is often

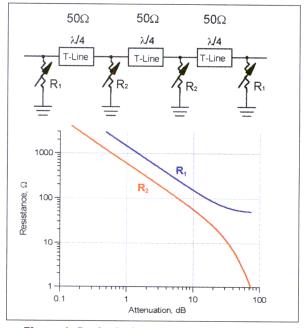


Figure 1. Basic design approach.

used to transform impedance. The design equation is very simple:

$$Z_{out} = \frac{Z_0^2}{Z_{in}} \tag{1}$$

The impedance of one end (Z_{in}) of the transformer is inversely proportional to the impedance at the other end (Z_{out}) of the transformer. For example, if $Z_{in}=1$ ohm and the TL has characteristic impedance (Z_0) of 80 ohms, Z_{out} will be 6400 ohms. This high impedance reflects back most of the incoming RF signal. The typical values of Z_0 of the TL range from 50 to 90 ohms. To obtain variable attenuation using this

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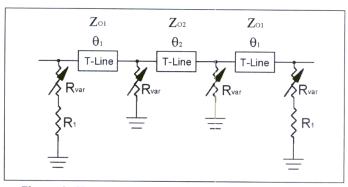


Figure 2. Modified circuit (idealized).

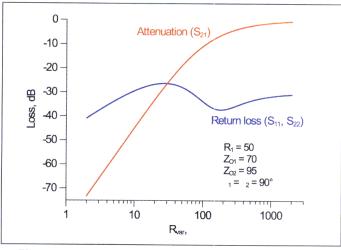


Figure 3. ADS simulation of the modified circuit.

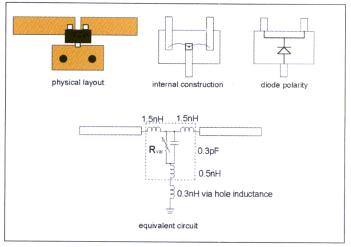


Figure 4. PIN diode construction and equivalent circuit.

approach, the fixed value Z_{in} is replaced with a variable resistance PIN diode. A typical shunt configured PIN diode can achieve a maximum attenuation of about 20 to 30 dB at 2.45 GHz. In this particular design, a dynamic range of 50 dB is desired, and consequently, four shunt diodes are used, as shown in Figure 1. Any number of

variable resistors can be used, depending upon the desired range of attenuation.

The middle two shunt diodes provide the bulk of the attenuation by reflecting the incoming RF signal. However, a reflective VCA is not desirable in most applications, especially in high power transmitter application. The reflected RF energy must be absorbed inside the VCA to provide low return loss. This will require R_1 to be different from R_2 . The required values of R_1 and R_2 necessary to maintain a constant 50-ohm input and output impedance are shown in Figure 1. A complex driver circuit is necessary to produce the two curves of resistance using PIN diodes as current controlled resistors.

A close approximation to this design can be achieved using a modified circuit, as shown in Figure 2. Four identical variable resistors (R_{var}) simplify the PIN diode bias network, and fixed resistors (R_1) are added to the outer variable resistors. The values of R_1 , Z_{01} , Z_{02} , θ_1 and θ_2 trade-off size, dynamic range and input/output return loss.

In the design the variables we are discussing are:

- $R_1 = 50 \text{ ohms}$
- $Z_{O1} = 70 \text{ ohms}$
- $Z_{O2} = 95 \text{ ohms}$
- $\theta_1 = \theta_2 = 90$ degrees

The use of a fixed resistor in series with a PIN diode at the input and output of the network results in lowered distortion at maximum attenuation, since the incoming RF signal is dissipated in a passive device rather than a diode.

The attenuation and return loss of this ideal circuit, in which diode parasitics have been neglected, are shown in Figure 3. This simplified approach offers good return loss over the entire range of attenuation.

The key part of this design is the PIN diode. The PIN diode consists of a highly resistive intrinsic I-layer between highly doped P- and N-layers. For the PIN diode, we can define a cutoff frequency, f_c , as follows:

$$f_c = \frac{1}{2\pi\tau} \tag{2}$$

where τ = minority carrier lifetime.

At frequencies above $10\,f_c$, where f_c is the cutoff frequency, the diode's resistance is controlled by the forward bias current though the diode. The PIN diode can be designed with different doping profiles and I-layer thickness for different applications. Some PIN diodes are optimized for fast switching at low current, whereas other diodes might be optimized for low distortion and low cut-off frequency. The PIN vendor can determine which series of the PIN is better for your specific application. The diode chosen for this design features a highly resistive I-layer of $125~\mu$ thickness for low f_c and low distortion.

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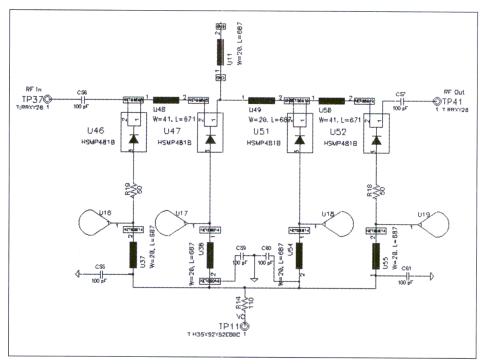




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🔺 Figure 5. VCA block diagram.

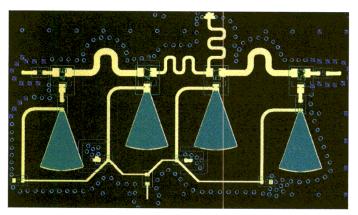


Figure 6. VCA layout.



Figure 7. Photograph of the VCA.

Part	Vendor	Number
PIN	Agilent	HSMP481B x 4
Res	KOA	50 W x 2
Res	KOA	110 W x 1
Сар	AVX 10 pF x 2	
Cap	AVX	100 pF x 4

▲ Table 1. Materials for the test board of the VCA.

The circuit shown in Figure 2 is idealized in that parasitic diode elements (package inductance and capacitance, junction capacitance) are neglected. At 2.45 GHz, these elements must be taken into account. The diode chosen for this project is a low cost SOT-323 part designed for shunt applications, as shown in Figure 4.

Reducing the effects of package parasitic inductance can turn an ordinary design into a high performance circuit. The parasitic inductance cancellation scheme does not need to be complicated. The main contributions are package lead, bondwire and via hole inductance. Each package lead produces 0.5 nH of parasitic inductance, and each bondwire is 1.0 nH (see Figure 4). Mounting the diode as shown moves the lead and bondwire inductances of leads 1 and 2 into the series circuit, where they

cannot reduce the isolation of the diode.

Lead 3 (the GND pin) has 0.5 nH, and via holes (if used) would contribute another 0.3 nH. This inductance can be cancelled by simply using a shortened radial microstrip stub (capacitive impedance), in place of the via holes, to resonate out the parasitic inductance of lead 3. A rectangular stub can also be used for this design. The dimension of the radial stub is determined during simulation. The simulation can be used to optimize the TL and radial stub elements. The PIN diode is modeled in Figure 4.

Actual test board

Having examined the basic building blocks of the parasitic cancellation scheme, we will now look at the actual test board. The circuit is built as a FR-4 microstrip, 0.042 inches thick, for lowest cost. The block diagram is given in Figure 5. The 4 shunt configured PIN diodes U46, U47, U51, U52, as well as TL U48, U49 and U50 form the skeleton of this design. The radial stubs U16 to U19 are parts of the compensation circuit. U37, U38, U54 and U55 are the RF choke high impedance TL, and R14 is a bias resistor. The rest are the capacitors for DC blocking or for bypassing. The circuit has a low component count since free microstrip elements are used as much as possible. The bill of material is listed in Table 1.

Performance of the VCA

The major testing parameters for the VCA are dynamic range and impedance matching at each attenu-

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S3W2	S3W5	N3W5	3	±0.40	
S4W2	S4W5	N4W5	4	±0.40	
S5W2	S5W5	N5W5	5	±0.40	
S6W2	S6W5	N6W5	6	±0.40	
\$7W2	S7W5	N7W5	7	±0.60	
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\$20W2	S20W5	N20W5	20	±0.60	
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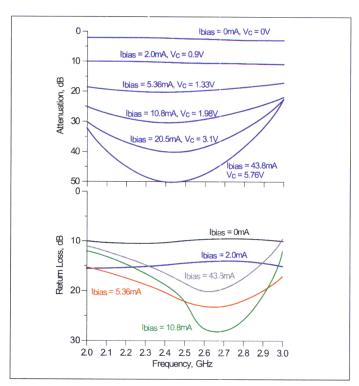


Figure 8. Summary of measured data.

ation state. The prototype demonstrated about a 50 dB dynamic range. The input and output impedance match was better than -10 dB in all attenuation states. The current consumption was only 43.8 mA for maximum attenuation. The test results are summarized in Figure 8. Detailed plots of insertion loss and return loss can be found in Figures 9 through 26, which follow in the Appendix on pages 48 and 50.

Conclusion

This article has presented a discrete PIN design for a voltage-controlled attenuator, using resistive line approach. The design is low cost and features a high dynamic range, excellent input/output matching, low current consumption, low component count and high power handling capability. The design approach, PIN

diode and parasitic cancellation were also discussed.

Acknowledgements

The authors would like to thank Maureen Bennett of Agilent Technologies for her assistance.

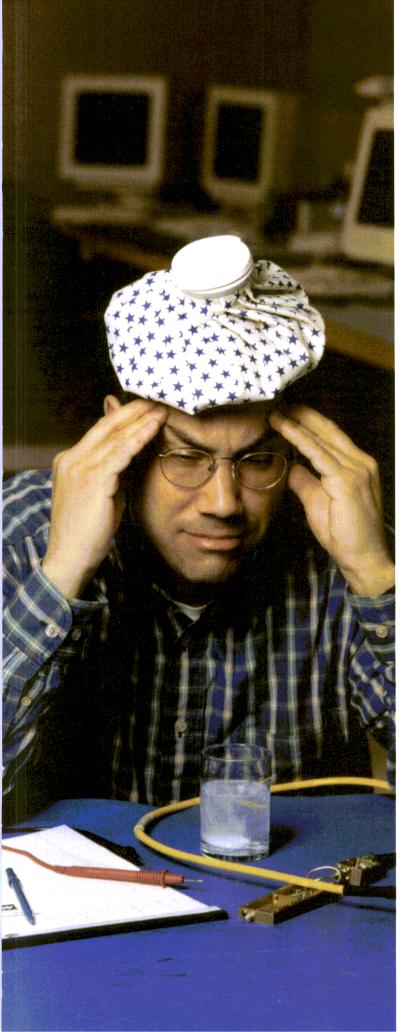
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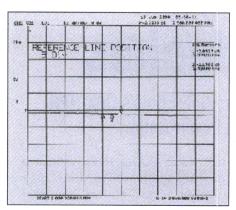
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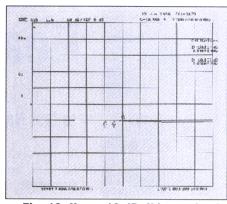


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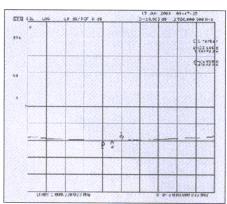
Appendix



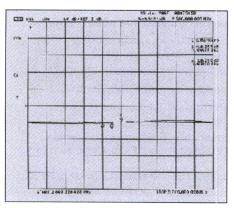
▲ Figure 9. Minimum IL = -2 dB, Ibias = 0 mA, Vc = 0.



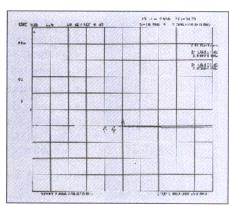
▲ Fig. 12. IL = −10 dB, Ibias = 2 mA, Vc = 0.9 V.



▲ Fig. 15. IL = -20 dB, Ibias = 5.36 mA, Vc = 1.33 V.



▲ Figure 10. Input matching with IL = -2 dB.



▲ Fig. 13. Input matching with IL = -10 dB.

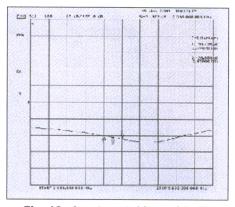
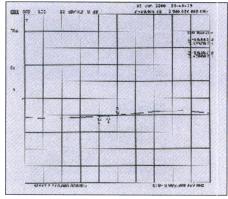
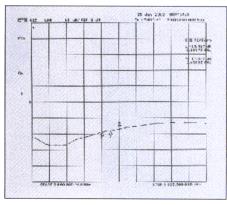


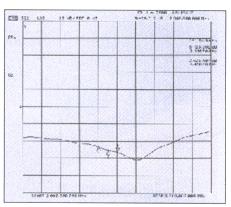
Fig 16. Input matching with IL = −20 dB.



▲ Figure 11. Output matching with $\|L\|$ = -2 dB.



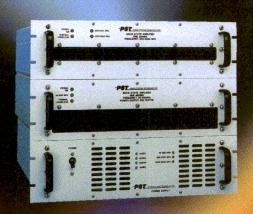
▲ Fig. 14. Output matching with IL = -10 dB.

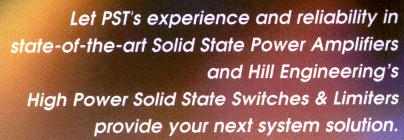


▲ Fig. 17. Output matching with IL = -20 dB.



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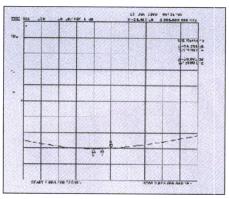


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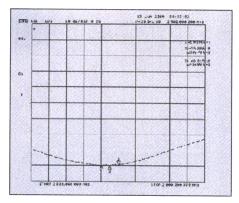
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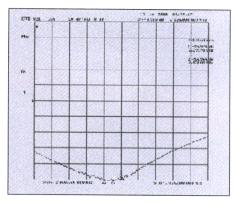
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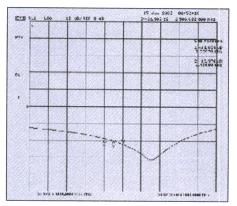
▲ Figure 18. IL = -30 dB, Ibias = 10.8 mA, Vc = 1.98 V.



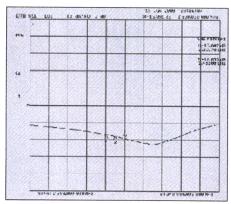
▲ Figure 21. IL = -40 dB, Ibias = 20.5 mA, Vc = 3.1 V.



▲ Figure 24. IL = -50 dB, Ibias = 43.8 mA, Vc = 5.76 V.



▲ Figure 19. Input matching with IL ≔ -30 dB.



▲ Figure 22. Input matching with IL = -40 dB.

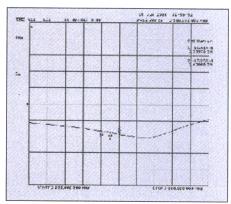
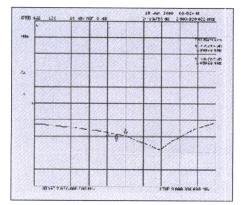
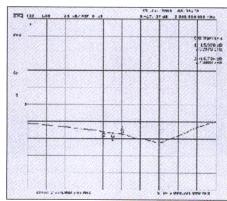


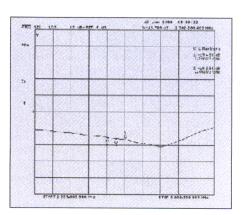
Figure 25. Input matching with IL = -50 dB.



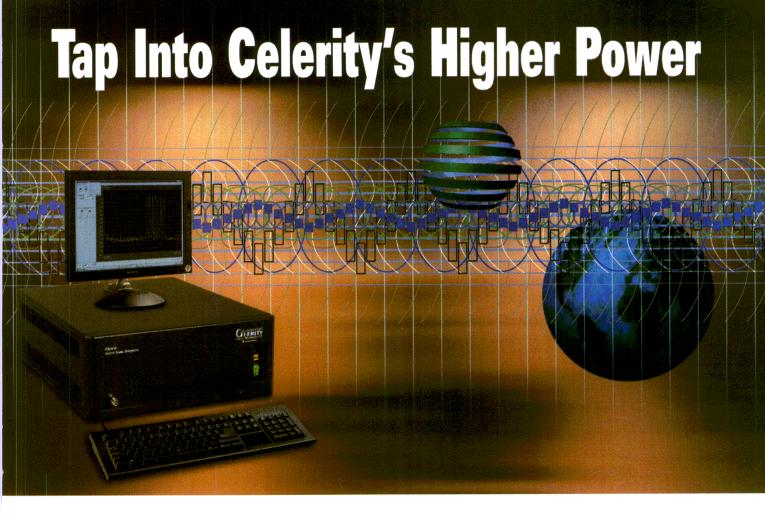
▲ Figure 20. Output matching with IL = -30 dB.



Arr Figure 23. Output matching with IL = -40 dB.



▲ Figure 26. Output matching with IL = -50 dB.



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A VCA Using the Constant Impedance Approach

This design technique maintains accurate matching between system stages

By Raymond W. Waugh, Agilent Technologies and Louis Fan Fei, Lucent Technologies

he voltage-controlled attenuator (VCA) is a crucial building block in a communication system. In the modern transmitter, it is typically used in a digital control loop to deliver constant maximum power to the antenna port. The VCA is also used to compensate temperature and device-to-device variations. On the receiver side, it is used to adjust the input RF power with the help of DSP to maintain sufficient SNR for the receiver.

A 2.45 GHz VCA PIN diode-based design

A VCA requires a current or voltage-controlled variable impedance in the form of a MESFET or a PIN diode used as a linear resistor. In this article, we discuss an experimental 2.45 GHz VCA PIN diode design. The basic design approach is shown in Figure 1. As described in Addendum 1, a quadrature (90 degree) coupler and two variable resistors can be used to form a low-cost variable attenuator of moderate dynamic range with a better input and output impedance match than the Pi [1] or resistive line attenuator [2]. An RF signal is applied to port 1 of the coupler and two matched variable resistors on ports 2 and 3 are varied in magnitude. The result is a variable attenuation between ports 1 and 4. The input impedance at port 1 and the output impedance at port 4 remain constant at 50 ohms over the entire range of attenuation — this characteristic is assured by the fundamental operation of a quadrature hybrid. (See the S-parameter matrix in Addendum 1.)

The variable resistors on ports 2 and 3 are realized using PIN diodes. The PIN diode consists of two distinct parts: die and package [3]. The die can be modeled as a current controlled-

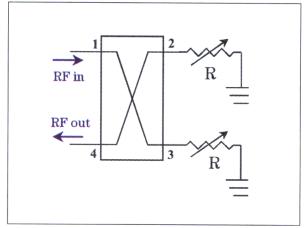


Figure 1. Design approach for the 2.45 GHz VCA PIN diode design.

variable resistor and a shunt parasitic junction capacitance. It consists of a lightly doped I-region sandwiched between heavily doped P-type and N-type regions. The PIN diode behaves as a pure resistor at frequencies ten times higher than its cutoff frequency f_c , where

$$f_c = \frac{1}{2\pi\tau} \tag{1}$$

and τ = minority carrier lifetime.

The resistor value is controlled by a DC forward bias current, which injects carriers into the I-region, lowering its resistance. The PIN diode's resistor value can range from a few ohms up to several thousand ohms. I-layer thickness, doping density and diameter can be adjusted to tailor the diode's characteristics to the specific application. These useful features make the PIN diode an excellent choice for VCA design.

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881.5	25	Rx	U.S. Cellular	855782
942.5	35	Rx	EGSM	855810
942.5	35	Rx	EGSM	855820
947.5	25	Rx	GSM	855794
1842.5	75	Rx	DCS	855860
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1880.0	60	Tx	U.S. PCS	855833
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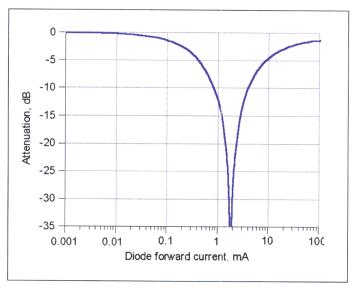




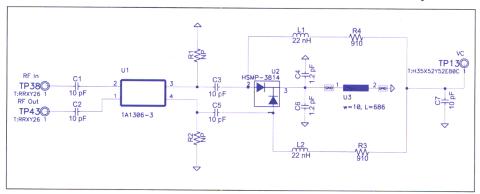
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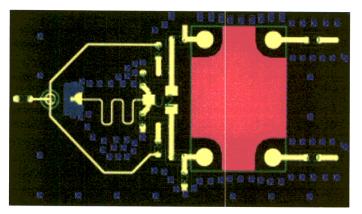
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▲ Figure 2. Attenuation vs. diode current (HSMP-3810).



▲ Figure 3. Schematic of the 2.45 GHz PIN diode-based VCA design.



▲ Figure 4. Layout of the 2.45 GHz PIN diode-based VCA design.

The package that contains the chip adds parasitic inductance and capacitance to the diode's impedance, and the low-cost leaded plastic package has particularly large parasitics [4]. In the real world of design, we no

longer have the simple variable resistors shown in Figure 1. However, a simple compensation circuit can be used to tune out the package and chip parasitics at the frequency of interest. For example, a diode package lead and bondwire inductance of 0.7 nH will contribute an inductive reactance of approximately 10 ohms to the diode's resistance. This would degrade the dynamic range of the attenuator, making the compensation circuit important. The simplest cancellation scheme is to use a shunt capacitor as the RF ground. The shunt capacitor is also used to tune out the parasitic inductance. The value of the shunt capacitor is determined experimentally.

Consider the circuit shown in Figure 1. When the PIN diode current is very high (> 10 mA), diode resistance is low and the RF signal applied at port 1 is reflected back into the hybrid at ports 2 and 3, emerging at port 4 with little loss. As current is reduced, diode resistance rises to a value of 50 ohms (thanks to the compensation circuit), at which point the diodes absorb the incident RF signal

and attenuation is highest. Further reduction in current causes diode resistance to be much higher than 50 ohms, which results in reflections at ports 2 and 3 and a reduction in attenuation. For a typical PIN diode with a thick I-layer, this result can be plotted as shown in Figure 2. The designer has two options: to use the current range of 0 to 1.7 mA, or 1.7 to 100 mA. Each choice has its tradeoffs. If the range of current $I \geq 1.7$ mA is used, some circuit simplification may be possible, but minimum attenuation is

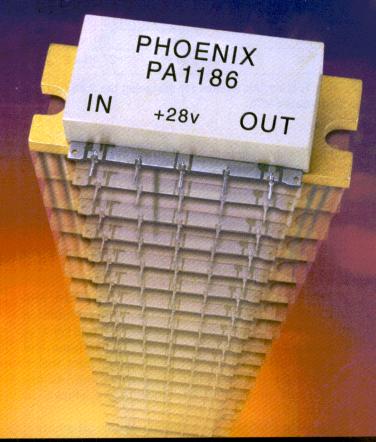
high (2 dB or more) because the PIN diode resistance is not zero at high currents. If the range of current I \leq 1.7 mA is used, circuit insertion loss (minimum attenuation) will be lower. This article discusses the latter approach to the design.

The schematic for the attenuator is shown in Figure 3, and the microstrip board layout is given in Figure 4. The circuit was realized on a 0.014-inches thick FR4 microstrip with a half ounce copper conductor and ground plane.

The choice of quadrature hybrid and PIN diodes, and the design of the parasitic cancellation circuit are three important aspects of the constant impedance VCA. The hybrid chosen was the 1A1306-3 from Anaren. The HSMP3814 is from Agilent Technologies. Good matching between the two diodes can be expected since the two dice came from adjacent sites on the wafer. C1, C2, C3 and C5 are DC block caps. Ll and L2 are RF choke inductors. R3 and R4 are resistors to set the bias current of the PIN diodes. C6 and C4 are used to cancel the parasitic inductance associated with the PIN diode. The

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Pout @ 1 dB. comp. (dBm.)	38.0	38.0	37.5	37.5	37.5
Noise Figure (dB.)	2.4	2.7	3.0	3.0	3.0
ACPR (30kHz BW)*	-50.0	-54.0	-47.0	-47.0	-47.0
VSWR (Input/Output)	1.5:1/2:1	1.5:1/2:1	1.5:1/2:1	1.5:1/2:1	1.5:1/2:1
IP3 (two tone)**	+56.0	+54.0	51.0	51.0	51.0
Supply Required	+28/1000	+28/1000	+28/1000	+28/1000	+28/1000

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- ** IP3 measured with 2 tones @ +25dBm. per tone

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Vendor	Number
Anaren	1A1306-3
Agilent	HSMP3814
AVX	10pF x 5
AVX	1.2 pF x 2
KOA	910 x 2
Coilcraft	27 nH x 2
	Anaren Agilent AVX AVX KOA

▲ Table 1. Materials needed for designing the 2.45 GHz PIN diode-based VCA.

components count is very low. The bill of material is listed in Table 1.

A few simple experiments were performed on the hybrid evaluation board to verify the concept at the two extremes of diode resistance. In the first case, ports 2 and 3 were left open-circuited (no diode), resulting in a 1.5 dB IL from port 1 to port 4. In the second case, ports 2 and 3 were terminated with a 50-ohm load (chip resistor). The resulting value of S41 was more than 30 dB.

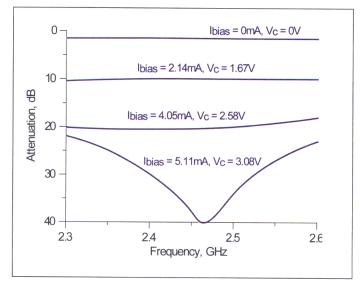
A prototype 2.45 GHz VCA was built and tested, providing excellent results on the first try. The attenuation ranged from -1.5 to -32 dB, and bandwidth was good, as shown in Figures 5 and 6. The return loss at input and output was better than -10 dB in all attenuation states. Detailed test results at minimum attenuation, -10 dB, -20 dB and maximum attenuation are shown in Addendum 2.

There is a deep notch at the maximum attenuation because of the parasitic compensation circuit. At the series resonant frequency, the parasitic inductor and compensation capacitor cancel each other out. The Q of the resonant frequency is high, which causes the deep notch. The VCA is designed to have 30 dB dynamic range, which is achieved with more control range near the center of the frequency band.

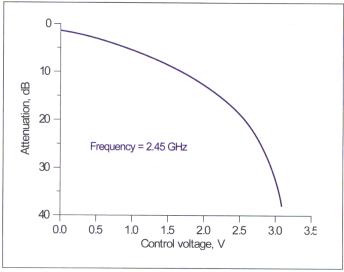
Further improvement or modification can be made to make the design more compact or to lower production costs. In this design, an off-the-shelf surface mount hybrid coupler was used. A hybrid based on another technology, such as lumped elements, will yield a smaller size. If size is not an issue, a transmission line coupler design, such as the popular, high performance branchline coupler, can be used. In this case, the coupler is "free," since it is part of an etched microstrip board, which must be manufactured in any event. The RF choke inductor can also be replaced with high impedance transmission lines to further reduce the cost if there is enough board space.

Conclusion

This article presented a VCA using the constant impedance approach. The VCA had more than 30 dB dynamic control range, excellent input/output matching,



▲ Figure 5. Attenuation vs. frequency.



▲ Figure 6. Attenuation vs. control voltage.

and a very low insertion loss of 1.5 dB, at the minimum attenuation state. It is also very compact, has a low component count and a low cost.

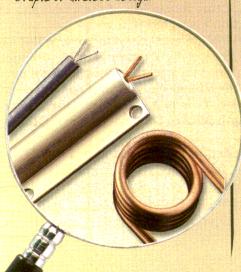
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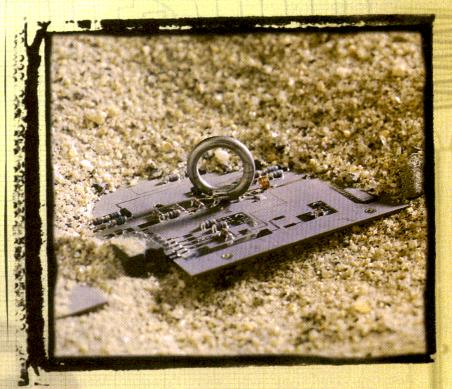
The authors thank Mauren Bennett of Agilent Technologies; Peter Shveshkeye, Gerald Hiller and Todd Brown of Alpha Industries; and Chad Blitz of Anaren for their time, assistance and generous discussions about the technical issues.

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 - 2. Louis Fan Fei and Raymond W. Waugh, "A VCA

oard layout issues, insertion loss optimizing and power handling challenges were as real in 1973 as they are today. That's when Sage patented Wireline technology. Originally created to provide jumper style board design flexibility. engineers found the balanced, twin conductor technique offered many other design, performance and cost advantages. Its popularity flourished in the 1970's with many important programs employing it. The advent of surface mount technology and the push for automated assembly in the 80's tempered its use, as companies sacrificed performance for production speed. But next generation cellular and PCS applications are creating new design challenges. And today's professional is finding surface mount devices still can't match the insertion loss, power handling and flexibility of this proven technology. Packaging variations and enhanced automation capabilities are making it a born again staple of wireless design.





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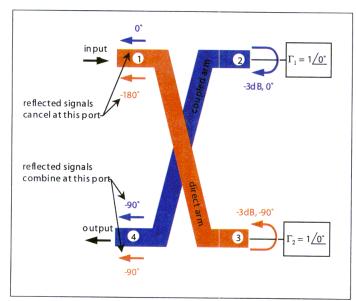


Figure 7. 3 dB quadrature coupler.

Using Resistive Line Approach with Parasitic Inductance Cancellation Circuit," *Applied Microwave & Wireless*, January 2001.

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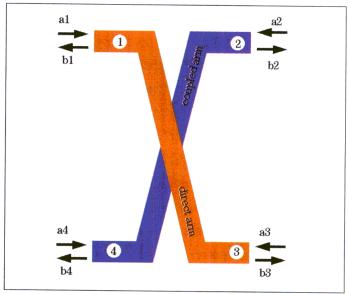


Figure 8. Four port S-parameter definitions.

Addendum 1: the 3 dB quadrature coupler

The 3 dB quadrature coupler can be realized in a variety of ways: as a distributed transmission line backward wave coupler of one or more sections (as illustrated in Figure 7), as a transmission line branchline coupler, or as a lumped element device. All realizations share some common characteristics that make this RF component particularly useful. If an RF signal is applied to port 1 (the "input"), one half of the power will come out of port 3 ("direct") and one half will come out of port 2 ("coupled"), and the equal amplitude RF voltages at these two ports will differ in their phase angles by 90 degrees. In the ideal coupler, nothing will come out of port 4("isolated").

However, if one places mismatches of equal magnitude and phase angle on outputs 2 and 3, some of the RF energy will be reflected back into the quadrature coupler. In the simple case shown in Figure 7 ($\Gamma_1 = \Gamma_2 = 1.0$ /0 degrees), the RF energy will recombine at the "isolated" port (minus two times the insertion loss of the coupler). If $\Gamma_1 = \Gamma_2$ with a magnitude of less than 1.0, the attenuation between the "input" and "isolated" ports will be $20 \log_{10} \Gamma$ (the return loss of the loads) plus two times the insertion loss of the coupler.

If one can realize a current or voltage-controlled variable mismatch $(0 \ge \Gamma \ge 1)$, a simple variable attenuator can be created. When the package parastics and junction capacitance of the PIN diode are tuned out with a simple single capacitor or inductor, the diode's junction can be made to vary from 2 to 3000 ohms, passing through 50 ohms.

The forgoing heuristic analysis may not satisfy some of those looking for a more rigorous analysis. Refer to Figure 8 in which four port S-parameters are defined. The familiar S-parameter definitions, such as

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	HMC314	0.7 - 4.0	5.0	185	18.0	29.5
200	HMC315	DC - 7.0 DC - 7.0	5.0 7.0	31 50	12.0 16.5	26.8 31.0
~	HMC323 & HMC324	DC - 3.0	7.5	57	16.8	30.0
	HMC326MS8G	3.4 - 3.6	5	125	24	36.0

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$$S_{11} = \frac{b1}{a1}$$

$$S_{32} = \frac{b3}{a2}$$
 (2)

apply. The equation for the operation of the quadrature coupler can be written as

For the ideal (zero loss, infinite isolation) 3 dB quadrature coupler, the S-parameters are

$$S11 = S22 = S23 = S32 = S33 = S44 = 0$$

$$S12 = S21 = S34 = S43 = 1 + j0$$

$$S13 = S24 = S31 = S42 = 0 + j1$$

If a1 = 1 and a2 = a3 = a4 = 0, multiplying the matrices will result in

$$\left[0\,\frac{-1}{\sqrt{2}}\,\frac{-j}{\sqrt{2}}\,0\right]$$

The magnitude of b2 and b3 is 0.707 and b2 and b3 differ in phase by 90 degrees.

Now, consider a mismatch on ports 2 and 3 of $\Gamma_2 = \Gamma_3 = \rho / 0$ degrees, where ρ is the magnitude of the reflection coefficient. Referring to Figure 8,

$$a2 = \rho \frac{-1}{\sqrt{2}}$$

$$a3 = \rho \frac{-j}{\sqrt{2}}$$

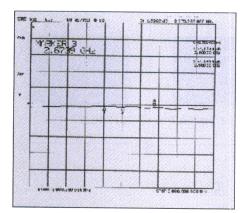
Substituting these values into the equation for the quadrature coupler, we obtain

$$[0 \ 0 \ 0 \ \rho]$$

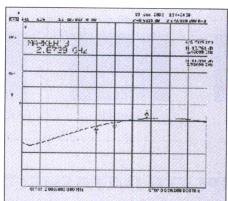
or S_{41} for the entire network is ρ , resulting in an insertion loss of 20 $\log_{10} \rho$. This is the same result as that obtained in our intuitive explanation.

The discussion assumes that the coupler has infinite isolation (loss from "input" to "isolated" with perfect 50-ohm terminations on "coupled" and "direct" outputs). In practice, no coupler has perfect isolation, and the designer must choose his coupler carefully to insure that it offers greater isolation than the dynamic range demanded of the attenuator.

Appendix



▲ Figure 9. IL = -1.5 dB, $I_{bias} = 0$ mA, Vc = 0.



▲ Figure 10. Input Matching with IL = -1.5 dB.

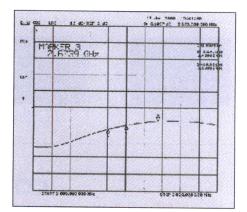
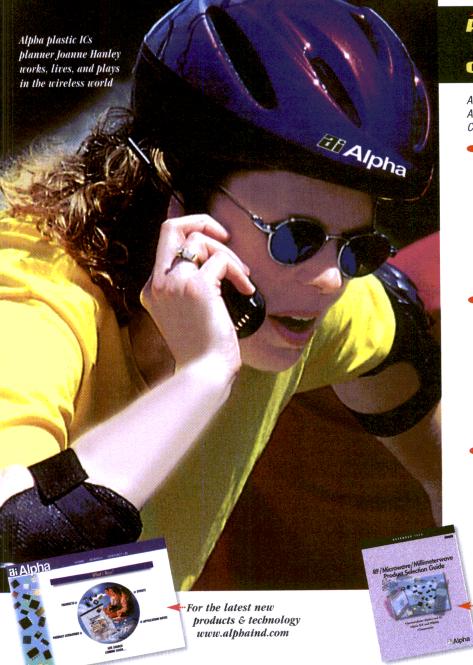


Figure 11. Output Matching with IL = −1.5 dB.

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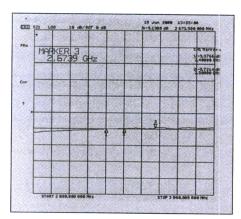
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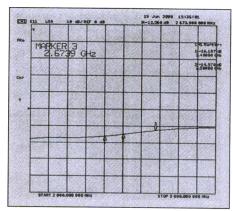
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 \blacktriangle Figure 12. IL = -10 dB, I_{bias} = 2.14 mA, Vc = 1.67 V.



▲ Figure 13. Input Matching with IL = -10 dB.

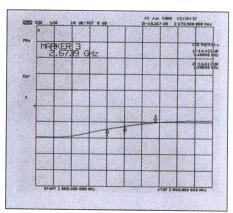
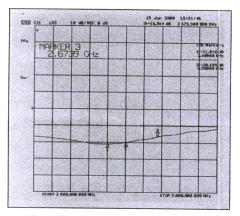


Figure 14. Output Matching with IL = -10 dB.



 \blacktriangle Figure 15. IL = -20 dB, $I_{bias} = 4.05$ mA, V = 2.58 V.

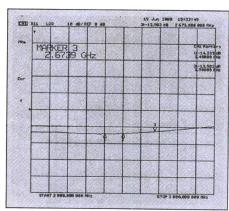


Figure 16. Input matching with IL = -20 dB.

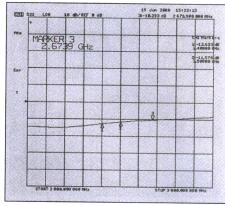
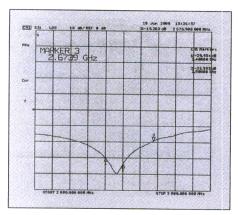
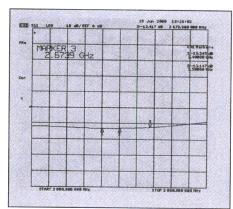


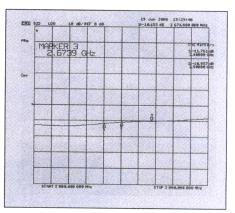
Figure 17. Output matching with IL = -20 dB.



▲ Figure 18. IL = -30 dB, $I_{\text{bias}} = 5.11$ mA, Vc = 3.08 V.

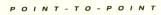


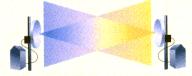
▲ Figure 19. Input matching with IL = - 30 dB.



▲ Figure 20. Output matching with IL = -30 dB.

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High Power Transmitter Uses TE₁₁ Mode Suppressor

To prevent unwanted radition, a transmitter requires additional harmonic rejection

By Richard M. Kurzrok, PE RMK Consultants

tropo scatter communications transmitter in the 755 to 985 MHz frequency range uses a high power amplifier (HPA) containing a 10 kilowatt klystron. To handle this average power level, 3-1/8-inch rigid coaxial transmission lines [1] are employed. This coaxial line size can propagate the TE₁₁ mode above a cutoff frequency of approximately 1.713 GHz. This falls within the second harmonic band of the HPA with levels greater than -20 dBc (referred to carrier fundamental). These second harmonic emissions are not substantially reduced by an absorptive low pass filter or a high power duplexer that were designed for only TEM operation. To provide adequate second harmonic reduction, a longitudinal TE₁₁ mode suppressor was needed.

3-1/8-inch rigid coaxial transmission line

To realize a 50-ohm characteristic impedance, the rigid transmission line uses thin wall copper tubing as an outer conductor with outer diameter of 3.25 inches and inner diameter of 3.027 inches. The center conductor outer diameter is 1.315 inches. The impedance (air line) is checked with the following equation [2]:

$$Z = 60 \ln \left(\frac{b}{d}\right) \tag{1}$$

where b = inner diameter of outer conductor = 3.027 inches; and d = outer diameter of inner conductor = 1.315 inches. The calculated impedance equals 50.02 ohms.

The cutoff frequency for the TE_{11} mode is obtained as follows [2]:

Fundamental Frequency in MHz	Second Harmonic Frequency in MHz
755	1,510
870	1,740
985	1,970

Table 1. Transmit frequency bands.

$$F = \frac{7.51}{(b+d)} \tag{2}$$

where F = cutoff frequency in GHz. The calculated cutoff frequency equals 1.731 GHz, which is equal to 1731 MHz.

Sections of the 3-1/8-inch-inch rigid coaxial line are mechanically supported at periodic intervals by commercially available teflon anchors. With unity VSWR, ambient temperature of 40 degrees C and one atmosphere absolute dry air pressure, the 3-1/8-inch-inch coaxial line can handle an average power level of 14 kilowatts [1].

The transmit frequency bands are shown in Table 1. More than half of the transmit second harmonic band is greater than the 1,731 MHz TE_{11} mode cutoff frequency.

TE₁₁ mode suppressor details

The TE₁₁ mode suppressor uses nominal 1/4-inch square lossy rods installed in longitudinal slots cut into the center conductor of the 3-1/8-inch-inch rigid coax line. The lossy rods attenuate the longitudinal current of the TE11 mode

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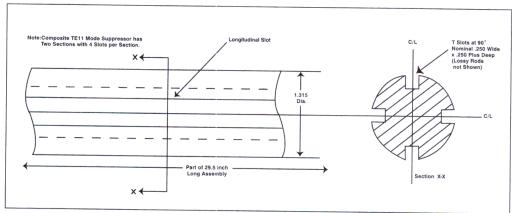


Figure 1. A simplified view of the coaxial center conductor.

without significantly affecting transmission of the dominant TEM mode.

The overall assembly is 29-1/2 inches long with Teflon® anchors at the ends and midpoint. The composite mode suppressor uses two cascaded sections of lossy rods that are 11-1/2 inches long. Each section contains four rods that are circumferentially located at 90-degree intervals. The rod material is a refractory ceramic that is capable of handling the 10 kilowatts average power level. The composite mode suppressor uses a total of eight rods. A simplified view of the coaxial center conductor is shown in Figure 1.

A crucial design detail is the mechanical retention of the rods in the center conductor's longitudinal slots. Custom designed metallic springs of 0.032 inch beryllium copper were created [3]. Each rod uses three springs. Each section (four rods) uses 12 springs. The overall mode suppressor (eight rods) uses 24 springs. Rod retention using epoxy was not viable at 10 kilowatts average power.

TE₁₁ mode suppressor performance

Over the 755 to 985 MHz transmit band, the composite mode suppressor insertion loss was less than 0.1 dB and the return loss was greater than 21 dB. Transmitter operation was satisfactory at 10 kilowatts average power.

Conclusions

A TE₁₁ mode suppressor was developed for an L band communications transmitter. Longitudinal lossy rods in the

center conductor of 3-1/8-inch-inch rigid coaxial transmission line attenuated the transmit second harmonic with minimal degradation of the 10 kilowatt transmit TEM fundamental.

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 - 3. S. Interlandi, Private Communication, 1970.

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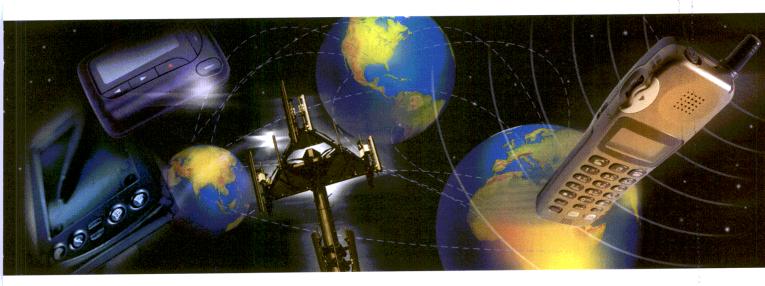
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Spurious Responses in Thickness Shear Quartz Crystals

This short tutorial explains crystal behavior to help engineers develop realistic specifications

By Louis Bradshaw

Fox Electronics

ne of the most important but least understood aspects of preparing crystal specifications involves specifying the suppression and testing of spurious frequency responses (spurs) in thickness shear quartz crystals such as the AT. Crystal units manufactured for use in most types of oscillators usually do not exhibit spurious frequency responses strong enough to be troublesome. However, for certain custom applications, the designer must determine if the suppression of frequency responses that may exist will be important to the integrity of the design. If such specifications are deemed necessary, it is helpful to have some basic knowledge about spurious frequency responses, their separation from the main mode and their amplitude.

Spurious frequency responses

In general usage, the word spurious is defined as "unreal or not genuine." However, the use of that term in reference to frequency responses is a misnomer because spurious frequency responses are regularly occurring thickness shear frequency responses found within a relatively narrow band just above the main frequency response. Despite the inaccuracy of the term, the widespread use of the terms spurious and spurs to describe these frequency responses make it unlikely they will ever be replaced.

Because spurious frequency responses occur regularly, it is possible to predict their approximate frequencies and therefore their approximate separation from the main (desired) frequency. However, the resistance (amplitude) of these responses is not easily predictable and, as a result, neither is the need for their suppression relative to the main frequency response.

Nevertheless, depending on other parameter specifications for a given crystal, some control over these spurious responses can be achieved, both in terms of separation from the main frequency response and in suppression relative to that response.

The frequency of a thickness-shear quartz crystal such as the AT is primarily a function of the thickness of the quartz plate. However, lateral dimensions (width and length or diameter) also play a role.

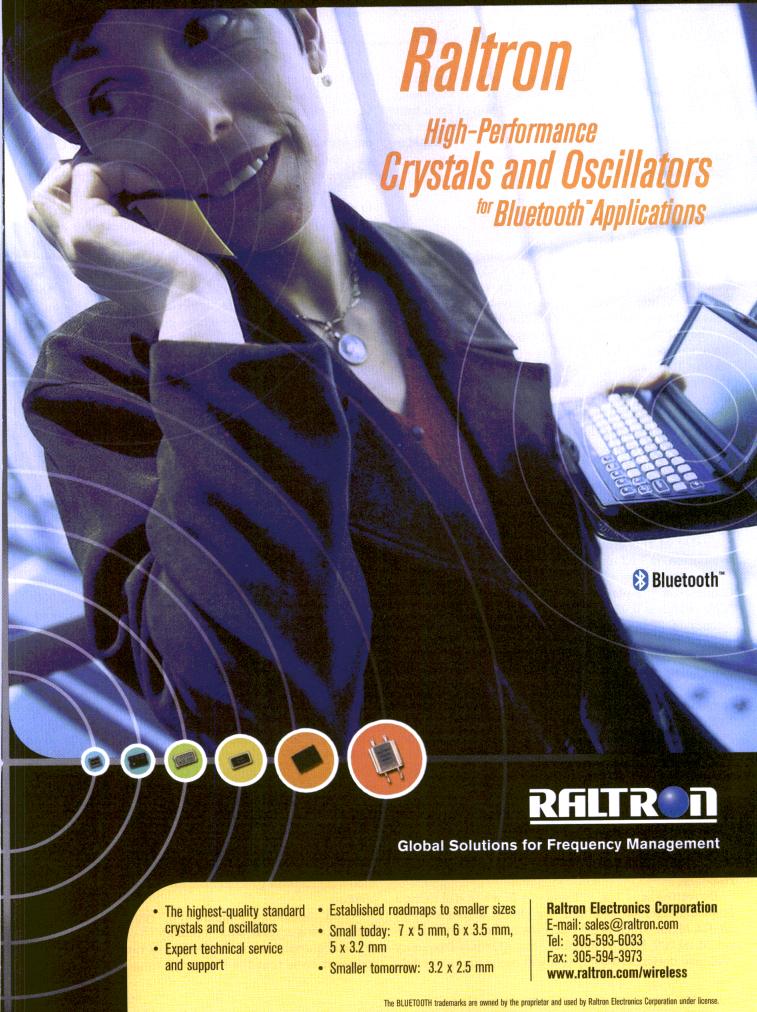
In order to examine this in more detail, we will assume that a given crystal specification includes, among other things, the order of overtone, the desired frequency and the crystal holder to be used. We will also assume a fundamental mode, AT-cut crystal, operating at a frequency of 20.000 MHz, housed in the industry standard HC-49/U holder. Knowing the order of overtone (fundamental) and the operating frequency (20.000 MHz), we can calculate the thickness of the quartz plate. Knowing the type of crystal holder allows us to estimate the lateral dimensions of the quartz plate, which in this case will almost certainly be circular.

The thickness of the quartz plate can be easily calculated by

$$t = \frac{k}{f} \tag{1}$$

where t is the thickness in mm, f is the frequency in kHz and K is a constant, which in the case of the AT-cut is 1660 kHz/mm.

Using this equation, we find the thickness of the 20.000 MHz plate to be 0.083 mm. We can now calculate the approximate frequencies of some spurious responses.



SPURIOUS RESPONSES

Equation (2) results in only approximate frequencies for a given set of physical dimensions. To our knowledge, the equation has never been precisely solved for a finite plate and probably never will be. However, it does give us an idea of the complexity of our project, and a standard by which to determine and specify suppression of spurious responses.

$$fm_{1}n_{1}\rho=0.5\sqrt{\frac{1}{\rho}}\sqrt{\frac{C_{66}m^{2}}{T^{2}}+\frac{\left(C_{11}n^{2}+C_{55}\rho^{2}\right)}{D^{2}}} \tag{2}$$

where ρ is the density of quartz (2.65); m, n, and p denote modes; C_{66} , C_{11} , and C_{55} are the elastic constants in the Y, X, and Z directions respectively; T is the thickness of the plate in cm; and D is the diameter in cm.

The elastic constants are expressed in dynes/cm² and their values are as follows: $C_{66} = 29.34 \times 1010$; $C_{11} = 86.05 \times 1010$; and $C_{55} = 69.80 \times 1010$. If m = n = p = 1, the order of overtone is the fundamental. The third overtone would be designated 3, 1, 1, and the higher orders of overtone would be similarly designated, with the first digit taking the number of the overtone. Such designations indicate a plate at a given frequency, free of spurious responses.

The HC-49/U holder will comfortably house a quartz plate on the order of 8.6 mm (0.339 inches) in diameter. It is more likely, however, that the actual diameter will be somewhere between 5.0 and 8.0 mm. A common diameter at this frequency, which we will use in this evaluation, is 7.62 mm (0.300 inches).

By setting m=n=p=1 and using 7.62 mm as the diameter of our plate, we obtain a frequency of 20.006 MHz, which is 0.03 percent greater than our target frequency of 20.000 MHz. Using a diameter of 5.0 mm without changing the other parameters results in a frequency of 20.015 MHz, 0.07 percent higher than our target. On the other hand, if we use a diameter of 10.0 mm (which will not fit in the HC-49/U holder), we obtain a frequency of 20.004 MHz, 0.019 percent higher than our target. Obviously, the larger the plate, the closer the resulting frequency will be to the nominal frequency, although it will never be 100 percent accurate.

To calculate the frequencies of two spurious responses, we will use a plate diameter of 7.62 mm and set $m=1,\,n=3$ and p=1. This combination yields a frequency of 20.034 MHz, which is 0.17 percent higher than our target frequency of 20.000 MHz. Therefore, the spurious frequency response designated as 1, 3, 1, will occur approximately 30 kHz higher than the fundamental response.

By setting m=1, n=1 and p=5, while still using a plate diameter of 7.62 mm, we obtain a frequency of 20.074 MHz, which is 0.37 percent higher than our target of 20.000 MHz. Therefore, the spurious frequency response designated as 1, 1, 5 will occur approximately

70 kHz higher than the fundamental response.

In each of these instances, changing the plate diameter will result in entirely different frequencies. To complicate matters further, the accuracy of the equation depends on the accuracy of the entered values for thickness and diameter. In real life applications, inaccuracy in the measured values tends to make the equation imprecise.

The above discussion implies that the electrodes used to energize the quartz plate are equal in diameter to the plate and of zero mass. In reality, the electrodes are of finite dimensions, smaller than the resonator plate, and their mass is greater than zero. Even so, the frequencies of the spurious responses and their separation from the main mode are approximately those yielded by the Equation (2). We may assume that the electrodes on a plate similar to the one we have been discussing usually will be in the range of 2.5 to 5.5 mm in diameter.

The complexity and approximate nature of these calculations lead one to wonder if these spurious frequency responses can be controlled. The short answer is that usually they are of such low magnitude (high resistance) in comparison to the main mode that they are not troublesome. However, there are cases where one or more spurious frequency responses become troublesome. In these cases, it is theoretically possible to use energy trapping to control the spurious frequency responses. Energy trapping depends on the existence of cut-off points that arise when a relatively sharp difference in thickness exists between the electroded area and the remainder of the plate. There are two ways to achieve this difference. One is by contouring or beveling the major faces of the plate, resulting in a constantly diminishing thickness from the center to the edges. A 20.000 MHz plate with a calculated thickness of 0.083 mm is so thin that such a process would be nearly impossible. In the second approach, the amount of metal deposited to form a finite electrode is varied, or the electrodes themselves are modified, according to the specifications of the crystal design engineer.

The best results, in terms of controlling spurious responses, are achieved when the metal electrodes are small in diameter, but thick. The worst results are achieved when the electrodes are relatively large in diameter, but thin. The use of the terms best and worst here is highly subjective, as is the use of thick and thin. Best and worst conditions are application-driven. For instance, if the crystal is to be used in a phase-locked loop application, where pullability is a major requirement, it is necessary to use large diameter electrodes. Placing a severe spurious suppression specification on such a crystal will probably render it impossible to manufacture.

When spurious suppression requirements are imposed on a crystal, it is necessary to carefully consider the requirements of the frequency range. A common specification is that the frequency range should be the **Broadband RF and Microwave**

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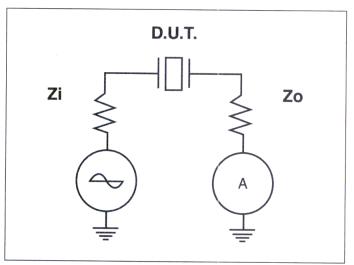
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SPURIOUS RESPONSES



▲ Figure 1. A typical test fixture for the measurement of spurious response suppression.

nominal frequency, ± 10 percent. In the case of our 20.000 MHz example, that equates to ± 2.0 MHz or from 18.0 to 22.0 MHz. If you are not certain that you need such a specification, discuss it with your crystal manufacturer, which will prevent a delay in your delivery date and an increase in cost.

Finding the right fixture

It is of paramount importance to specify clearly the fixture to be used in testing spurious response suppression, because different test fixtures yield different results. The usual method for spurious suppression is to specify the spurious response as "x" dB down from the main response. This method is completely meaningless unless the impedance of the test fixture is specified. A typical test fixture for the measurement of spurious response suppression is shown in Figure 1.

The equation for calculating the suppression in terms of dB is as follows:

$$dB = 20\log \frac{Z_i + Z_o + R_r}{Z_i + Z_o + R_s}$$
(3)

where Z_i is the input impedance, Z_o is the output imped-

ances, R_r is the crystal main mode resistance in ohms and R_s is the spurious response resistance in ohms.

The EIA pi network is a recommended test fixture for oscillator crystals because it is widely available, easy to construct and immediately recognizable by the crystal manufacturer. It has input and output impedances both equal to 12.5 ohms. Test fixtures used for testing filter crystals, in contrast, typically have input and output impedances both equal to 5000 ohms. We will assume that our 20.000 MHz crystal has main mode resistance of 30 ohms and a spurious response resistance of 120 ohms. Tested in the EIA pi network, the spur is found to be suppressed by 8.42 dB. The same spurious response, measured in a filter test fixture, is suppressed by 0.08 dB. This demonstrates the importance of selecting a test fixture that is appropriate for the intended crystal application.

Conclusion

It is not recommended that spurious suppression clauses be included in a crystal specification without strong justification. The need for spurious suppression values must be carefully weighed against other requirements of the crystal. In addition, any spurious suppression specification is essentially meaningless unless the applicable test fixture is clearly specified, as well as the frequency range over which the suppression level is to apply.

As with any crystal specification, discuss these issues with your crystal vendor as early in the design stage as possible. Do not wait until it is time to order a part with ± 300 ppm pullability and a spurious suppression of -25 dB over a frequency range of ± 20 percent centered about nominal to be told you can not have it. By asking early, it is possible to avoid specifying unnecessary and unrealistic spurious suppression values and the frustration that may result.

Author information

Louis Bradshaw is a technical support engineer with Fox Electronics. He attended Texas Technological College, Lubbock, TX, for two years and has more than 30 years of experience in the quartz crystal industry. He can be reached via e-mail at louisb@foxonline.com.

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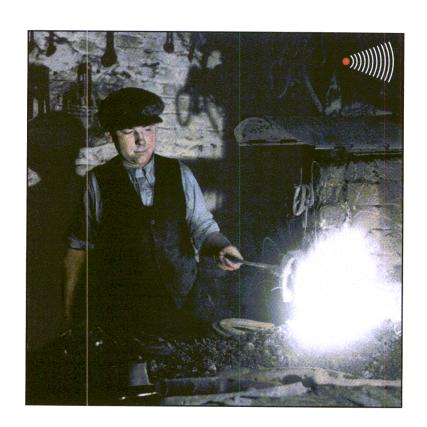
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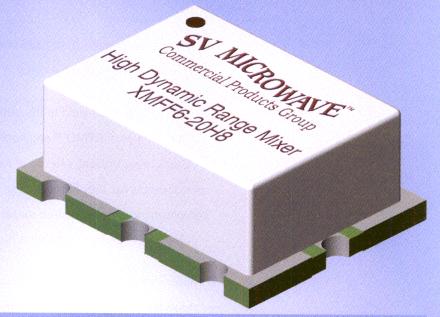
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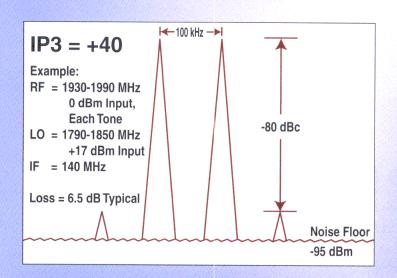
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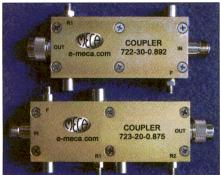


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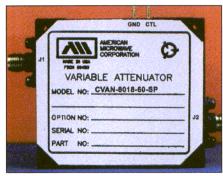
operates over the frequency range of 1 to 18 GHz, has a coupling of 3 dB, an amplitude imbalance of ± 0.6 dB maximum, a phase imbalance of ± 12 degrees maximum, an isolation of 15 dB minimum, a maximum VSWR of 1.7 to 1 and an insertion

loss of 2.9 dB maximum. Typical applications include splitting and combining signals in amplifiers, switching circuits and antenna beam forming networks.

Krytar Circle #161

Current controlled analog, absorptive attenuator

American Microwave Corporation announces the release of a 60 dB, current-controlled, nonlinearized, absorptive, analog attenuator that



operates over the octave band of 8.0 to 18.0 GHz. Other features include a VSWR of 2.0 to 1, an RF operating input power of 20 dBm and a survival rating of 30 dBm. This attenuator's rise time is 100 ns maximum, and its fall time is 20 ns maximum.

American Microwave Corp. Circle #162

Weather resistant 2-way divider/combiner

Bird Component Products has released a weather-tight, 2-way divider/combiner that is designed for harsh environments. This unit operates over a frequency range of 460 to 960 MHz. Features include insertion loss of less than 0.4 dB, an isolation of 20 dB minimum, a phase balance of 2 degrees maxi-



mum and an amplitude balance of 0.2 dB maximum. The price for 1 to 10 pieces is \$450 each.

Bird Component Products Circle #163

Low-loss coupler/detector

Planar Monolithics Industries has developed a high-speed, adjustable, low-loss coupler/detec-



tor with output optimized to operate over 2.4 to 2.5 GHz with a VSWR of 1.5 to 1. This unit has SMA connectors on the RF and TTL output and solder pins for the DC power and control.

Planar Monolithics Industries, Inc. Circle #164

Compact diplexers

Wireless Technologies Corporation has introduced a new line of highperformance compact diplexers for use in the SMR, cellular B and GSM



bands. These diplexers offer low loss, good termperature stability, high port to port and TX/RX isolation. A 70 dB isolation between TX/RX, a mid-band insertion loss of less than 0.8 dB and a return loss of greater than -20 dB are other features of the diplexer.

Wireless Technologies Corp. Circle #165

T-switch for space applications

Dow-Key Microwave has introduced a new high-power T-switch

Products

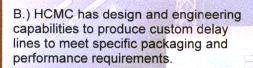


designed to offer low distortion in space-based transmit applications. Operating in the frequency band ranging from 2.5 to 4.8 GHz, this switch moves high-power signals from one port to another and has peak RF power levels as high as 560 watts, with an average power level of 140 watts.

Dow-Key Microwave Corp. Circle #166

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A.) HCMC manufactures and stocks fully tested standard straight semi-rigid and flexible assemblies which can be hand formed. We also provide cable assemblies to customer specification.



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Circle 40

CABLES & CONNECTORS

UHF male connector

Times Microwave Systems has announced the availability of its nonsolder UHF male connector. This connector eliminates the need



to solder the center conductor and braid which can cause overheating and melting of the cable dielectric. The new connector is available for most LMR cable sizes and includes UHF, N, 7-16 DIN, TNC and reverse polarity TNC interfaces.

Times Microwave Systems Circle #167

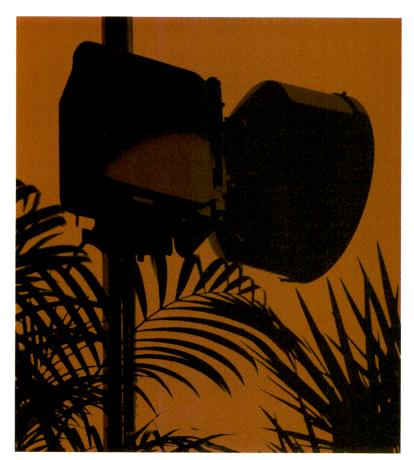
7-16 panel receptacle

Tru-Connector offers a 7-16 panel receptacle featuring a safety interlock switch that prevents human contact with live, highpower, high-current RF contacts. By defaulting to the off position,



this panel receptacle avoids the cumbersome use of safety covers and other devices to achieve its safety goal. It operates on 4 to 24 VDC and is constructed with either gold or silver center conductors, beryllium-copper contacts, Teflon® insulators, and brass bodies. The 7-167 interlock switch panel receptacle is priced at approximately \$89 each, depending on quantity.

Tru-Connector Corp. Circle #168



Low Power, Low Noise YIG-Based Synthesizers for Digital Radios



Micro Lambda, Inc. a leader in the development of next-generation YIG devices now offers YIG-Based Frequency Synthesizers covering the 2-12 GHz frequency range. Designed specifically for Digital Radio ODU's and harsh commercial environments, these synthesizers offer excellent integrated phase noise characteristics over carrier offset frequencies from 10 kHz to

Tunable bandwidths of either 2 GHz or 3 GHz are available as standard products. This results in fewer numbers of synthesized sources required for a variety of Digital Radio frequency plans. Millimeter-Wave frequencies can easily be obtained using frequency multipliers to obtain output frequencies between 24 GHz through 44 GHz.

Applications include QAM and QPSK modulated Digital Radio's and a multitude of general purpose applications.

FEATURES

- 2 12 GHz Frequency Coverage
- Excellent Integrated Phase Noise Characteristics
- Compact Size
- 3-Line Serial Interface
- Low Prime Power
- 500 kHz Step Size
- Internal Memory (last frequency programmed - recall)

MLSL-SERIES SYNTHESIZERS

This series of synthesizers utilize an external 1 to 50 MHz crystal reference oscillator to generate tunable frequencies covering the 2 - 12 GHz range. Output power levels of +12 dBm to +15 dBm are offered depending on frequency, with a standard tuning step size of 500 kHz. Input tuning commands are via 3-Line Serial interface. The size of these compact units is 2.5" x 2.5" x 1.0" without mounting plate and consume less than 6 watts of prime power. The units have an internal memory capability which "recalls" the last frequency programmed when the prime power is removed and reapplied. Standard models include 2-4 GHz, 4-6 GHz, 5-7 GHz, 7-9 GHz and 9-11 GHz. Specialized frequency ranges are easily implemented utilizing the versatile synthesizer architecture.







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Circle 46



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Circle 78

Products

Hybrid connectors

Harting has launched a series of hybrid connectors designed to fill the need for signal security in bus sys-

tems that feature decentralized control of field components. Accommodating fibre optic or copper twisted pair data transmission, these connectors include a



power supply of 24V/10A in one connector. These connectors are compatible with many standard hoods and housings, including enclosures offering IP65 and IP68 protection.

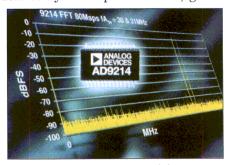
Harting, Inc. Circle #169

SEMICONDUCTORS

Analog-to-digital converter

Analog Devices introduces three versions of a new high-speed, 10-bit supply analog-to-digital converter that offers a range of sampling rates and performance options. All three deliver dynamic performance, guar-

antee no missing codes and dissipate low amounts of power. Typical dissipapower tions for the three models. with a 10.3 MHz input frequency, are 190 mW, 265



mW or 285 mW. Prices in 1,000 piece quantities range between \$80 and \$30, depending on the model.

Analog Devices, Inc.

Circle #170

Digitally programmable potentiometers

Xicor has released a series of single, 1024 tap, nonvolatile digitally programmable potentiometers. These devices offer the highest resolution available in the industry and are ideal replacements for high-precision, multi-turn, mechanical potentiometers in appications requiring highly accurate adjustments or calibration. The units are available in 14-pin TSSOP packages with a total end-to-end resistance of 100 k Ω . Pricing starts at \$2.97 each in quantities of 1,000 pieces.

Xicor, Inc. Circle #171

Three-zone thermal supervisor IC

Micrel Semiconductor has developed a three-zone thermal supervisor IC for thermal management



using embedded thermal diodes. Available in 8-pin MSOP and SOIC packaging, the IC features one local and two remote temperature measurement zones, a programmable interrupt output and an address selection input.

Micrel Semiconductor, Inc. Circle #172

Transmit modulator and IF-AGC amplifier

RF Micro Devices has made available an integrated quadrature modulator and IF-AGC amplifier designed for the transmit section of wideband CDMA applications. The unit has an operating range of 2.7 to 3.3 volts. Other features include digitally controlled power down modes, adjustable current consumption and AGC linearity, IF frequencies of 380 to 570 MHz, and balanced input/output for LO I&Q and IF signals.

RF Micro Devices, Inc. Circle #173

Digital direct conversion receiver

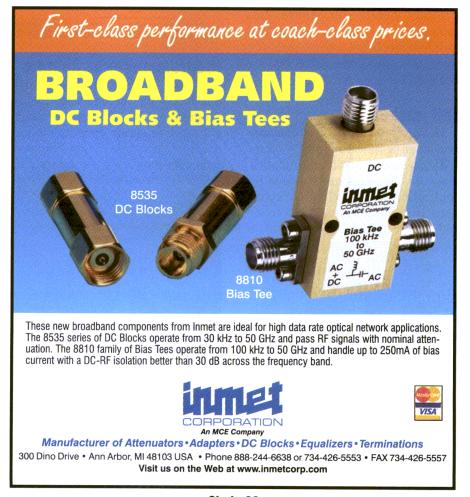
TDK Semiconductor has released a new low cost, high performance direct conversion receiver integrated circuit for digital wireless applications. The 5504 DCR is designed to operate over an input



frequency range of 950 to 2150 MHz. The device accepts an input signal in this frequency range and down-converts directly to baseband. The local oscillator signal is generated by a completely integrated phase-lock loop that is fully programmable through a standard serial port interface.

TDK Semiconductor Corp. Circle #174

Does your company have a new product? Let us know about it, so we can tell our readers! Send your new product releases, with a color photograph if available, to: Applied MICROWAVE & WIRELESS 630 Pinnacle Court Norcross, GA 30071 Or e-mail to: amw@amwireless.com



MATERIALS & MANUFACTURING

Alumina ceramics

GBC Materials offers miniature, dry-pressed alumina. Ideal for electronic, appliance and automotive applications, these alumina ceramics provide a cost-effective solution for demanding applications in the medical, telecommunications, semiconductor and aerospace markets. The parts can be manufactured in sizes as small as 0.007 inches in diameter, 0.010 inches wall thickness and 0.008 inches long.

GBC Materials
Circle #175

Standard and custom etched lids

Photofabrication Engineering has released a full line of standard and custom lids for seam-sealed microcircuit packages produced by the photo chemical etching process. Typical metals for these lids include Kovar, Alloy 42, nickel and stainless steel.

Photofabrication Engineering, Inc. Circle #176

EMI gasket

Holland Shielding Systems has developed a new range of V-shape EMI gaskets for difficult applications. The gaskets are suitable for application in existing constructions that do not have to be modified to accommodate the gasket. If

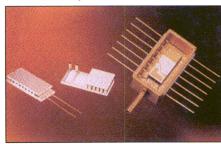


mounting space is not available, gaskets with a thickness of less than 0.2 mm can be applied. The gaskets' self-adhesive strip makes mounting easy.

Holland Shielding Systems BV Circle #177

Telecom cooling solutions

Melcor Corporation introduces complete telecom cooling solutions, including new thermoelectric coolers and expanded packaging and testing capabilities. This line of thermoelectrics includes a new class of thermoelectrics built with tin-antimony solder that melts at



232 degrees C. Other options available in the product line include wire-bondable posts or pads, aluminum nitride ceramics, and custom metallization patterns on the ceramic.

Melcor Corporation Circle #178

FREQUENCY CONTROL

Programmable oscillators

C-MAC MicroTechnology introduces a range of one-time factory programmable oscillators housed in a 7×5 mm ceramic surface-mount package. Available in any frequency



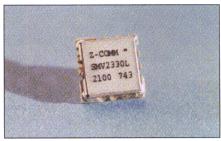
between 1 and 133 MHz, the oscillators are ideal for quick prototyp-

ing. Devices are priced from \$4.10 each, depending on quantity and specification.

C-MAC MicroTechnology Circle #179

Surface mount VCO

Z-Communications announces the release of a surface mount low profile package VCO for W-CDMA base station systems. Engineered to



lend itself to quick integration into PLLs, this device generates frequencies ranging from 2300 to 2360 MHz within a control voltage range of 0.5 to 2.5 VDC. Energy is preserved because the device draws only 8 mA of current from a 2.7 VDC supply.

Z-Communications, Inc. Circle #180

Communication crystals

Rakon has miniaturized the RSX-3 and RSX-5. These crystals



offer excellent shock and vibration performance. Other product features include short-term stability and low aging.

Rakon Ltd. Circle #181

PLL modules

Champion has released a series of PLL modules with a stable low reference frequency that can be generated into a stable high fre-

RF/IF MICROWAVE COMPONENTS



13dB "DO-IT-YOURSELF" COUPLER DELIVERS COST SAVINGS

The TCD-13-4-75 from Mini-Circuits needs only a commercially available 75 ohm external chip resistor, and a complete 5 to 1000MHz directional coupler is realized. Designed to lower costs through automated manufacturing, this rugged 75 ohm coupler provides 13.0dB±0.5 nominal coupling (±0.9dB max. flatness) with 0.8dB mainline loss and 15dB directivity typical midband. The 50/75 ohm "do-it-yourself" TCD family contains 9 units with 9 to 20dB coupling for 5 to 1000MHz.



BROAD BAND 970 TO 2150MHz VCO HAS 5V OPERATION

Mini-Circuits low cost ROS-2150VW voltage controlled oscillator performs in the broad 970 to 2150MHz band with low -96dBc/Hz SSB phase noise at 10kHz offset, 0.5 to 25V tuning voltage (min. to max.), and operates from a 5V power supply drawing up to 25mA current. The unit is housed in a miniature 0.5"x0.5"x0.18" industry standard SM package and is suitable for integration with monolithic PLL chips and commercial synthesizers. Power output is 4dBm (typ).



+10dBm (LO) I&O MODULATOR SERVES 1800 TO 2000MHz.

IQBG-2000 is a patented Blue Cell™ in-phase and quadrature (I&Q) modulator for feed forward amplifier and PCS applications 1800 to 2000MHz. The unit typically exhibits -30dBc carrier and -34dBc sideband rejection, 7.5dB conversion loss, and low noise floor for good performance in poor signal to noise conditions. State-of-the-art automated manufacturing using multilayer thick film ceramic construction delivers superb temperature stability, high repeatability, and low cost.

2WAY SPLITTER/COMBINER IDEAL FOR 75 OHM CATV APPLICATIONS

Mini-Circuits has introduced the 5MHz to 1000MHz broad band ADP-2-10W-75 to accommodate demand for a 2way-0° power splitter/combiner with low insertion loss (0.3dB typ), very good input VSWR (1.08:1 typ), and excellent amplitude (.05dB typ) and phase (1.2 degrees typ) unbalance. The unit handles up to 1 watt power input as a splitter. Available off-the-shelf.





BROAD BAND 40 TO 2500MHz MIXER IS ULTRA LOW COST

Mini-Circuits broad band SYM-25DLHW frequency mixer operates over 40 to 2500MHz with low 6.3dB conversion loss, high 40dB L-R, 33dB L-I isolation, and 22dBm IP3 typical at midband. This level 10 (LO power) mixer is housed in a miniature 0.375"x0.500"x0.23" low cost plastic package with solder plated terminations and targets cellular, PCN, and ISM applications. Operating temperature range is -20°C to +85°C. A 5 year Ultra-Rel® guarantee is included.



700 TO 2100MHz 2WAY COMBINER HANDLES HIGH POWER

The ZAPD-2-21-3W is a high power 700 to 2100MHz broad band combiner from Mini-Circuits with typically low 0.4dB insertion loss, excellent 25dB isolation, and excellent 0.05dB amplitude, 0.7 degree phase unbalance. As a combiner of noncoherent signals, maximum power input per port is 1.25W. As a splitter, maximum input is 10W. Housed in a rugged coaxial metal case equipped with N-Type connectors, applications include LMDS and VSAT. 50 ohm operation.



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- Microcircuit Packaging Mixers Oscillators Power Dividers Terminations RF Transformers
 - Splitters Switches Waveguide Adapters Bends Loads Straights Twists Flexible

quency output. Output frequencies are available from 1.544 MHz to



2.488 GHz. Each portion of the module can be customized to specific designer objectives.

Champion Circle #182

S-band synthesizer

ITT Industries, Microwave Systems, introduces a high performance, single-channel S-band synthesizer. The device combines

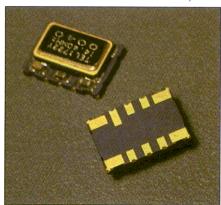


direct digital synthesis with microwave mix/divide circuits to accomplish performance specifications, such as a frequency resolution of 0.7 Hz, a switching speed of 150 ns and high spectral purity. Standard models operate from 1.6 to 2.8 GHz. The internal oscillator is free running or phase locks to an external 10 MHz reference.

ITT Industries, Microwave Systems Circle #183

Temperature compensated oscillator

Tellurian Technologies has released a new line of miniature, low-



profile, surface mount, voltage-controlled, temperature compensated oscillators. They are ideal for applications, such as telecommunications, wireless, networking, cellu-

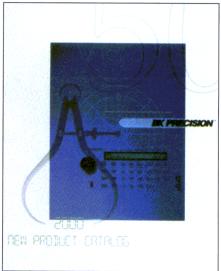
lar, remote meter reading, PLLs and other systems that require a stable frequency in a space efficient SMD configuration. The oscillators are priced at \$4.98 each in 10,000-piece quantities.

Tellurian Technologies Circle #184

LITERATURE

Test and measurement products catalog

B&K Precision Corporation has made available a new product line



catalog for 2001. The new catalog features more than 50 new products, including IC testers, program-



EYOND THE EXPECTED

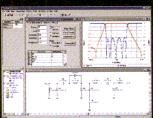
IN FILTER SYNTHESIS PERFORMANCE











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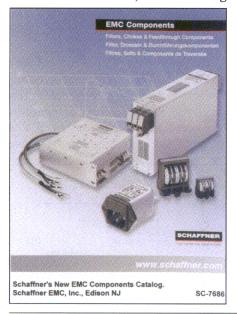
Products

mable power supplies, cable testers, environmental instruments, video monitor testers and a full line of accessories.

B&K Precision Corp. Circle #185

EMC components catalog

A new EMC components catalog from Schaffner EMC provides detailed technical data on a broad range of filters, chokes and feedthrough components. The catalog covers noise-suppression circuits, current-compensated chokes, rod-cored chokes, saturating

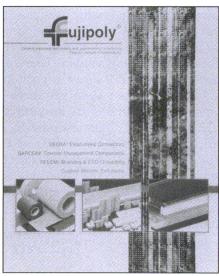


chokes, PCB filters, IEC-inlet filters, single-phase filters, three-phase filters, output filters, feedthrough capacitators and filter input-output connections.

Schaffner EMC, Inc. Circle #186

Electronic packaging products catalog

Fujipoly America Corporation has published a catalog for design engineers offering components for



electronic products that need to dissipate heat or make many connections in a small space. The catalog includes detailed specifications and performance characteristics of hun-

dreds of silicon electronic packaging components.

Fujipoly America Corp. Circle #187

Engineering reference guide

IFR Sytems has made available the *Microwave Datamate*, a compilation of reference data that is often



used by microwave and RF engineers. The reference guide includes charts, tables, data and practical information, such as steps that can be taken to improve microwave power measurement uncertainties.

IFR Systems, Inc. Circle #188



Transmission Zeros in Filter Design

By Randall W. Rhea Eagleware Corporation

ore economic and effective bandpass filters can be designed by controlling the location of transmission zeros. What do we mean by transmission zeros? Consider the fifth-order lowpass filter in Figure 1(a). There is little attenuation at low frequencies and increasing attenuation above the cutoff. Only at infinite frequency is there no transmission. In fact, at infinite frequency, each inductor becomes an open and each capacitor becomes a short. This filter has five transmission zeros (TZs) at infinite frequency. The fifth order highpass filter in Figure 1(b) has five TZs at DC.

It is essential that the inductors and capacitors alternate. If we were to attempt to build a fifth-order lowpass with five series inductors, we would essentially have only one inductor whose inductance is the total of the five series inductors: this is only a first order filter. A similar effect occurs if all elements are shunt capacitors. The discovery by Cambell in the U.S. and Wegner in

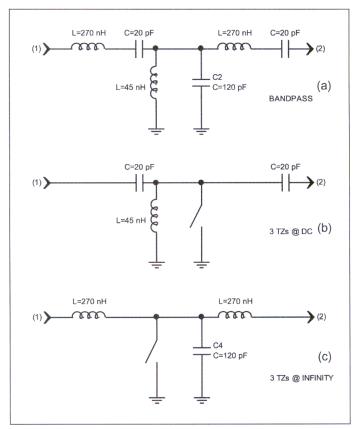
(1) L=1000 nH L=2000 nH L=1000 nH (2) C4 C=680 pF C=680 pF (a) C=680 pF C=750 pF (b) C=750 pF C=1000 nH C=1000 nH C=1000 nH C=1000 nH (b)

▲ Figure 1. Fifth-order lowpass (a) with five TZs at infinity, and highpass (b) with five TZs at DC.

Germany in 1915, that elements or resonators must alternate, was the beginning of filter theory.

Recognizing the number of TZs is more interesting with bandpass filters. Consider the conventional third-order bandpass in Figure 2(a). At DC (B), the series inductors and the shunt capacitor have no effect — they vanish. There are three TZs at DC. At infinity (C), the series capacitors and the shunt inductor vanish, and there are three TZs.

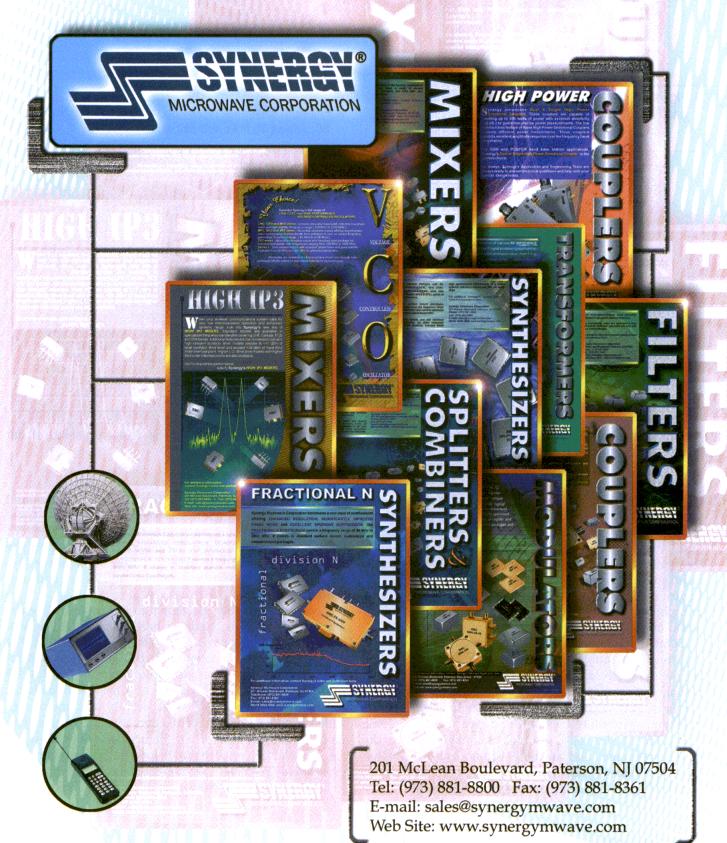
In lowpass filters, the quantity of TZs at infinity determines the selectivity. In bandpass filters, the quantity of TZs at DC determines the selectivity below the passband, and the quantity of TZs at infinity determines the selectivity above the passband. If the number of TZs at DC and infinity is equal, the transmission response



▲ Figure 2. Third-order bandpass filter (a) as seen at DC (b) and infinite frequency (c).

High Performance

RF & Microwave Signal Processors



DESIGN IDEAS

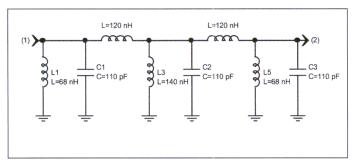


Figure 3. Top-L coupled bandpass filter with one TZ at DC and five at infinity.

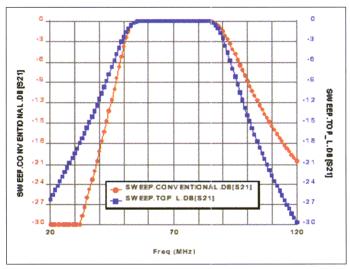
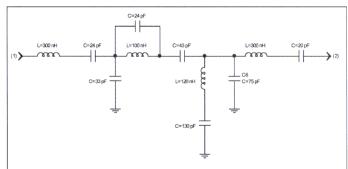


Figure 4. Amplitude responses of a conventional bandpass with three TZs at DC and three at infinity (circular markers) and a top-L coupled bandpass (square markers).

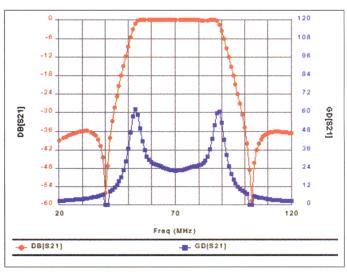
plotted on a logarithmic frequency scale has equal slope above and below the passband. The quantity of TZs at DC and infinity are not required to be equal. In fact, if more attenuation is required above the passband, then the bandpass may be designed with more of the TZs at infinity. Consider the third order bandpass shown in Figure 3. This filter has three resonators with top coupling inductors. It also has a total of six TZs but one is at DC and five are at infinity.

Compare the responses of the conventional bandpass and the top-L coupled bandpass shown in Figure 4. The red trace with circular markers is the amplitude response of the conventional bandpass. Plotted on a linear frequency scale, it has more selectivity below the passband. The blue trace with square markers is the amplitude of the top-L coupled bandpass. Notice the similar passbands and the increase selectivity of the top-L above the passband.

Selecting the quantity of TZs at DC and infinity pro-



▲ Figure 5. Bandpass filter with three TZs at infinity, one at DC, one at 40 MHz and one at 103 MHz.



▲ Figure 6. Amplitude and group-delay responses of the symmetric bandpass.

vides independent control of the selectivity above and below the passband. How can we achieve a symmetrical response? Carassa [1] proved that if the quantity of TZs at infinity is three times the quantity at DC, then the bandpass is symmetric when plotted on a linear frequency scale. This can be true even if TZs are added at finite frequency.

Consider the bandpass shown in Figure 5. Unlike the previous filters, this bandpass has TZs at finite frequencies, that is, frequencies other than DC or infinity. For example, C3 and L2 resonate at 103 MHz which causes a notch (TZ) above the passband. Likewise, L3 and C5 resonate at 40 MHz, which causes a TZ below the passband.

This filter has three TZs at infinity and one at DC, which satisfies Carassa's rule, and thus provides a symmetric response, as shown in Figure 6. Notice that it has similar selectivity above and below the passband and the group-delay response is symmetric.

The design of the conventional bandpass and capaci-

FILTERS

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tor or inductor coupled resonator filters is accomplished using predefined lowpass to bandpass transforms [3]. These filters are restricted to specific ratios of DC and infinite TZs. The design of filters with arbitrary placement of finite, DC and infinite TZs, such as the symmetric filter shown in Figure 5, requires direct synthesis techniques [2].

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Author information

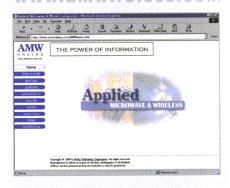
Randy Rhea is the founder of Eagleware Corporation and Noble

Publishing. He received his BSEE from the University of Illinois and his MSEE from Arizona State University. He has been an RF and microwave



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Sampling Probe for Microwave Frequencies

Here is a simple design to acquire a signal for microwave measurements

By Richard M. Kurzrok, PE RMK Consultants

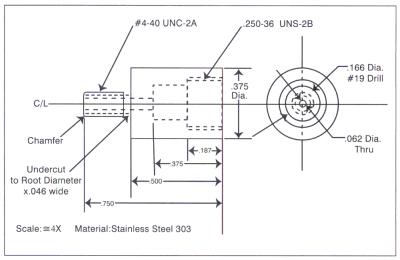
odal voltages are used in the design, development, alignment and test of bandpass filters at microwave frequencies [1, 2, 3, 4]. To implement the measurement of nodal voltages for individual filter resonators, sampling probes are used.

These probes are constructed using a coaxial connector (or adapter), an insulated wire probe and a machined housing. Mechanical details for a typical sampling probe housing have been previously provided [4]. This housing, which uses a BNC panel jack, is viable at frequencies up to 4 GHz. This article discusses a sampling probe

design for a microwave frequency range of up to 12 GHz that uses an SMA connector.

Sampling probe details

A mechanical sketch of a sampling probe housing compatible with SMA connectors is shown in Figure 1. A jack to jack SMA adapter (such as M/A-COM part number 2080-1900-02 with mechanically captivated contacts and passivated stainless steel finish) is screwed into the 0.250-36 internal threads of the housing. A piece of partially insulated bus wire is passed through the 0.062 inch diameter hole of the housing and inserted into the interior center conductor of the SMA adapter. Number nineteen AWG bus wire (nominal 0.036 mil diameter) will simulate an SMA male center pin. Number twenty AWG bus wire can also be used



▲ Figure 1. Sampling probe housing that is compatible with SMA connectors.

by crimping it in a vise prior to insertion. Scotch tape can be used to insulate the bus wire from the metallic housing. The housing number 4-40 thread is screwed into threaded test ports at appropriate filter locations. For sampling probes that are frequently used with known probe length, the coaxial adapter can be staked to the housing with glyptol.

Conclusions

Mechanical details have been provided for an SMA compatible sampling probe that can be used for microwave bandpass filter nodal voltage measurements up to 12 GHz. These measurements are particularly useful for microwave bandpass filter structures that are not readily amenable to analytical or computer aided design techniques. [3]



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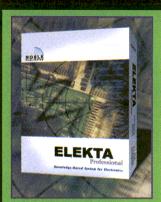
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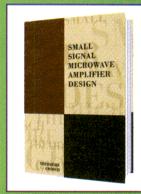
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Surface Mount Components Reduce Broadband Equipment Costs

By John Kennedy Alpha Industries

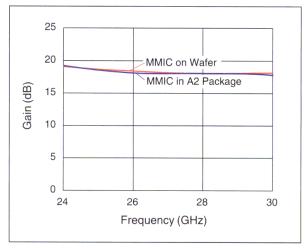
anufacturing throughput and costs are becoming critical as microwave radio manufacturers ramp up production to meet the growing demand for high-frequency, high-speed broadband communications. Alpha's DC to 43 GHz surface mount components simplify production processes while improving manufacturing yields.

Manufacturers of point-to-point microwave and high-speed optical communications systems are scaling up production because of the growing demand for metropolitan networks, first/last mile access, ring closure and cellular base station interconnection. At the same time, they are looking for ways to reduce manufacturing costs. In addition, market demand is outstripping the production capacity of many microwave and fiber optic equipment manufacturers, which opens the door to increased competition from T1, DSL and other low-frequency data delivery systems.

Microwave and fiber optic equipment manufacturers can no longer rely on traditional production systems and methods to maintain market share and keep pace with growing demand. Many manufacturers are finding it difficult to ramp up production using conventional "chipand-wire" component assembly, a process that requires vacuum pickups and other expensive capital equipment, as well as highly-trained and skilled assembly technicians, who are currently in short supply. The Alpha-2TM program helps manufacturers address these problems.

The Alpha solution

Alpha's design objective is to allow high-frequency, high-speed broadband communications manufacturers to reduce their production costs



▲ Figure 1. Electrical characteristics of Alpha-2TM packaged components maintain the performance of bare MMICs.

while addressing the interface, grounding and quality control problems often encountered when incorporating high-frequency MMICs into microwave transceivers and fiber optic equipment.

Alpha's proprietary surface mount technology is now implemented in an extendable multichip module family of low-noise amplifiers, driver amplifiers, variable attenuators and mixers designed to operate at frequencies of up to 43 GHz. These multi-chip, ceramic packages significantly reduce the manufacturing cost of LMDS and fiber optic networking equipment.

The Alpha-2 program provides the necessary, single-step solution. It addresses the manufacturing and quality control problems facing microwave and fiber optic equipment manufacturers and meets industry demands for highly





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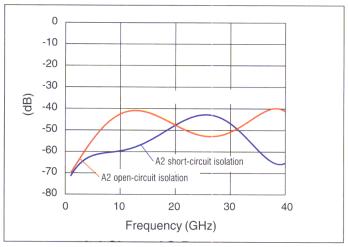
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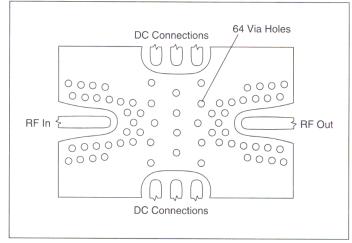
PRODUCTS & TECHNOLOGIES



▲ Figure 2. The Alpha-2 package maintains high isolation through 43 GHz, eliminating feedback-induced ripple.

reliable components operating at frequencies up to 43 GHz. Alpha-2 is the first surface-mounted package specifically designed for high-frequency, high-speed ICs used to implement point-to-point microwave links, Local Multipoint Distribution Systems (LMDS) and OC-192/OC-768 fiber optic systems. The Alpha-2 family currently includes low-noise amplifiers, driver amplifiers, single- and double-balanced mixers and variable attenuators, and an SPDT switch will be released shortly.

Electrical signals operating at millimeterwave frequencies, if not constrained, radiate in all directions, causing a loss proportional to the wavelength of the signal. Plastic packaging can not control this loss and can not control radiated feedback that can distort the original signal. Alpha has addressed this problem with ceramic packaging. The Alpha-2 package encloses the microwave circuit in such a way that the electromagnetic signal can propagate within the package in a controlled manner. The Alpha-2 package also provides a method for transferring a signal from the microwave circuit to the printed circuit board. The base of the package is made from a dielectric ceramic material over which a conductive layer is placed to form a transmission line with carefully controlled impedance. This transmission line forms an electromagnetic wave guide that, combined with the desirable electrical properties of the ceramic package, minimizes signal loss. As a result, the electrical characteristics of Alpha-2 packaged components are virtually identical to MMICs, as shown in Figure 1. They provide >40 dB isolation (Figure 2) with only a few tenths of a dB loss. Alpha-2 ceramic components also have good mechanical properties because they can be formed with the precise, smooth surface needed for high-definition patterns. At the same time, ceramics tolerate temperature extremes and exhibit a thermal coefficient of expansion nearly matching that of the gallium arsenide commonly used for MMICs.



▲ Figure 3. The Alpha-2 footprint, patterned on a printed circuit board, facilitates either microstrip or coplanar wavequide connections.

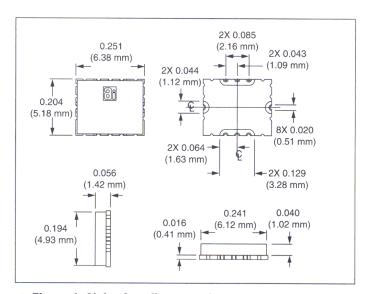
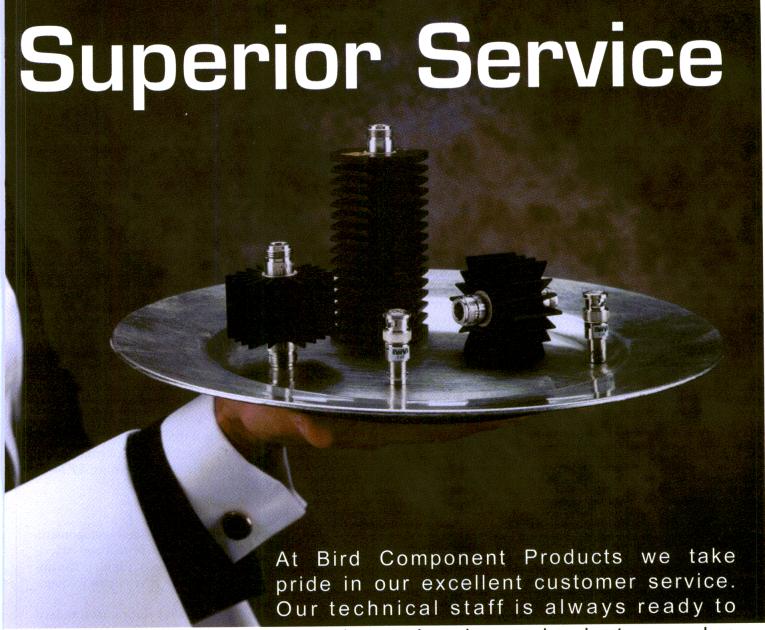


Figure 4. Alpha-2 outline occupies only 0.05 square inches of board space and is just 0.06 inches tall.

Environmental and mechanical dependability

Alpha-2 products have outstanding mechanical specifications and are designed for standard, inexpensive, reflow solder, surface mounting and are compatible with standard tape and reel equipment. In essence, Alpha-2 components are handled and are assembled like low-frequency, baseband components.

Ceramic packaging is ideal for transceivers and other components that must operate on open rooftops and other exposed environments where they may be subjected to high humidity and extreme temperatures. Building on its experience with ceramics, Alpha was able to develop a family of high-frequency surface mount components capable of operating in military temperature ranges of –55 degrees to +90 degrees C with sealed components that pass standard moisture intrusion tests (85)



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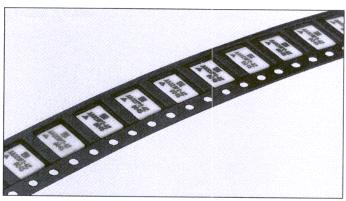
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▲ Figure 5. Alpha-2 components are delivered on tape-andreel for direct insertion in high-volume manufacturing lines.

percent relative humidity for 1,000 hours).

Figure 4 shows the Alpha-2 footprint with numerous via holes to provide positive grounding. Each via is filled with a conductive material and the vias both direct the signal from the package to the microwave circuit and block propagation of the signal to prevent feedback to the microwave circuit.

Eliminating reworks

MMICs are small, fragile, difficult to handle and easy to damage. Components that passed quality control tests at the wafer level may no longer operate properly after they have been sawed and handled. As a result, transceivers often have to be reworked, adding substantially to manufacturing costs. Such existing transceiver manufacturing processes present inherent quality control problems. As manufacturers of cellular phones and PCs have shown, the elimination of "bare" chips is a prerequisite in the development of high-volume manufacturing

G = 15 dBG = 12 dB $P_{1 dB} = +16 dBm$ $P_{1 dB} = +25 dBm$ $C_L=6 dB$ AM02852-A2 AA028P2-A2 ► T_X Out AA032P1-A2 Filter G = 15 dBAA028P2-A2 $P_{1 dB} = +16 dBm$ AA028P2-A2 G = 15 dBAA028P2-A2 G = 15 dB $P_{1 dB} = +16 dBm$ $P_{1 dB} = +16 dBm$ Filter G = 17 dBG = 15 dB $_{1 \text{ dB}} = +9 \text{ dBm}$ $P_{1 dB} = +16 dBm$ NF = 3 dBFilter AM028D1-A2 AA028P2-A2 AV850M2-A2 AA028N1-A2 - R_x In $C_i = 7 dB$ Att Range = 30 dB $P_{1 dB} = +10 dBm$

▲ Figure 6. A high frequency wireless broadband transceiver consists of ten Alpha-2 components that can be mounted to a printed circuit board in a single operation. The total semiconductor cost is less than \$100.

systems and the elimination of expensive reworks.

Unlike MMICs that are tested on the wafer, Alpha-2 products are tested after packaging when they are immune to damage in handling. This method saves costly reworks that can slow production and increase the manufacturer's total cost of ownership.

Lowering manufacturing costs

Integrated circuits for microwave and millimeterwave applications have traditionally been wired together in large, expensive, hard to assemble packages. The cost of this packaging is often many times the cost of the chips themselves. Alpha-2 packaging solves this problem. By eliminating the need for tuning and the slow, expensive process of wire bonding by hand, Alpha-2 technology enables manufacturers of high-frequency broadband equipment to replace labor and capital intensive microelectronics assembly with standard, fast, inexpensive surface-mount manufacturing. This is particularly important to manufacturers attempting to ramp up production in the face of a growing shortage of highly skilled wire-bond technicians.

Alpha has made available a number of different components in low-cost Alpha-2 packages. For example, the AA028P2-A2, a 25 to 31 GHz driver, is only \$7.74 in quantities of 100,000.

Solution example

Alpha's offering of different Alpha-2 components allows implementation of complete broadband transceivers in a single assembly technology. Alpha is continuing to expand our product line to cover more frequencies and more functions.

Alpha has developed designs that show how standard Alpha-2 components fit into common broadband applications to help manufacturers to transition to the use of

Alpha-2 components. One such design, a 28 GHz wireless broadband transceiver, is shown in Figure 6. This design, which has been successfully prototyped, represents one of the first all-surface-mount broadband transceiver designs at this frequency.

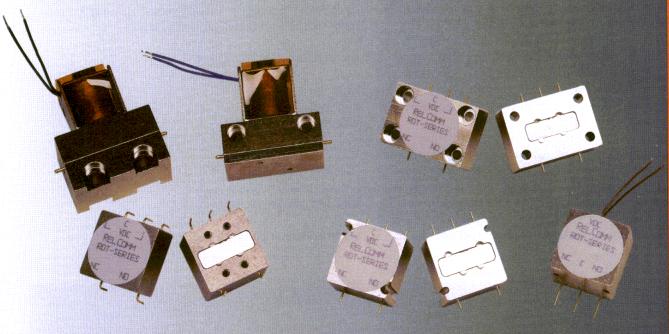
The next generation

The current generation of high-frequency communications transceivers will likely be obsolete in a year or two as manufacturers develop new high frequency, high data rate broadband communication systems operating up to 60 GHz and data rates up to 40 Gbps.

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At the same time, the growing demand for broadband communication devices will force manufacturers to streamline manufacturing processes. Alpha is developing the products needed to support the next generation of microwave and fiber optic systems while reducing manufacturing costs.

The Alpha-2 family joins Alpha's line of RF, microwave and millimeterwave GaAs ICs, discrete semi-conductor devices and passive components engineered for wireless telephony and satellite, instrumentation, defense and other communications markets.

Manufacturers today are not just buying new parts, they are looking to work with a company that will work with them to develop new and better products and processes that will allow them to capitalize on the growing demand for high-speed, high-capacity voice and data transmission.

Working with leading microwave and fiber optic equipment manufacturers, Alpha is creating the innovative new products needed to support the ever-growing volume of broadband traffic. Alpha has demonstrated its ability to integrate multiple components in ever-smaller packages. And, with its proven high-volume, low-cost production capabilities, Alpha is providing its customers

with the innovative products they need to meet the growing demand for ultra-high speed, high-capacity data and voice wireless communications.

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John Kennedy is an engineering manager at Alpha Industries. He received his BSEE and MSEE from the University of Massachusetts and his MBA from Syracuse University. He has been working in high-frequency packaging for fifteen years. He may be reached by e-mail at jkennedy@alphaind.com

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2001 Wireless Symposium Brings the Industry to San Jose

he Wireless/Portable Symposium & Exhibition will be held in San Jose, CA, with the conference and workshops on February 12-16 and the exhibition open February 13-15, 2001. This event draws engineers and businesses involved in wireless communications into one venue for an update on the technology of wireless and the products that make it work. Following is a preview of the technical program schedule.

Monday, February 12, 2001

Workshops 9:00 AM - 4:30 PM

WKS01 - 3G Made Simple

WKS02 - Balanced Circuit Design and

Measurement for Wireless Applications

WKS03 – Antennas & Propogation for Wireless Communications

WKS04 - Behavioral Modeling

WKS05 - Wireless Internet Made Simple

WKS06 - PLL Design

WKS07 – RF Systems Fundamentals

WKS08 – Fundamentals of Short Range Wireless

Tuesday, February 13, 2001

8:30 AM Keynote Breakfast

Wireless Meets the Internet Economy: The Role of Wireless in the E-business Revolution

Michael Karasick, CTO of IBM's Pervasive Computing Division

10:30 AM - Noon

IP02 – Indoor Propagation

FL02 – The Latest Developments in Filter Technology

UL02 - Ultra-broadband Market Outlook

DC02 - Modules and Components for Digital

Communications

SR02 – Current Issues in Software Radio Design

W102 – Enabling the Wireless Internet

IR02 - IrDA, A New Era of Promised Wireless

1:30 PM - 3:00 PM

IPO3 – Propagation Models and Measurement Techniques

FL03 – Extending Filter Design Methods to Other Passive Devices

UL03 - Radio Subsystems for Ultra-broadband

DC03 – Digital Communication Hardware Measurement and Optimization

SR03 – Designing with High Speed ADCs

WI03 – M-Commerce: Reaching the Mobile

Customer through the Wireless Internet

IR03 - Irda: The Smart Wireless

3:30 PM - 4:30 PM

IP04 – Antennas and RF Equipment for Indoor Coverage

FL04 – New Approaches to Filter Design

UL04 – Ultra-broadband Network Radio Systems

DC04 – Hardware Testing Routines

SR04 – Enabling Software Radio via Direct Modulation Based Synthesis

W104 – Security from the Wireless Customer to the Web

IR04 – IrDA: Simply Wireless

Wednesday, February 14, 2001

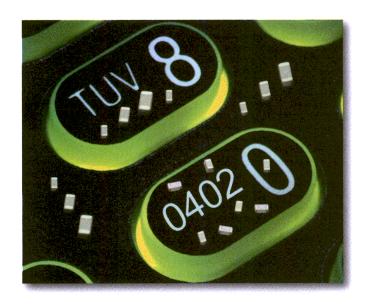
9:00 AM - 10:00 AM

BS05 – Architecture Concerns in Base Station Design

WP05 – LTCC Technology: Designing for Wireless Applications with Green Tape LTCC Ceramic Technology

BB05 – Fixed Wireless Access

Johanson high frequency multilayer ceramic capacitors

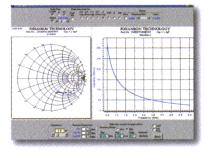


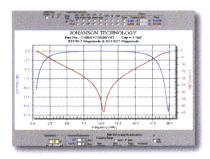
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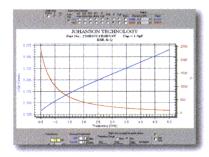


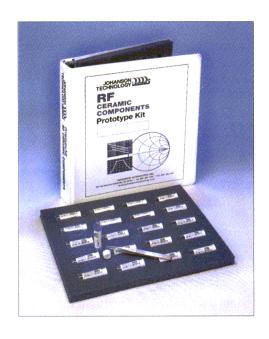
Prove it to yourself! Just surf over to our web site at www.johansontechnology.com and download your free copy of MLCSoft®, an industry leading RF modeling and evaluation software. Using MLCSoft® you'll be able to chart critical performance parameters such as Quality Factor, Equivalent Series Resistance and S-parameters for Johansons entire range of high frequency multilayer ceramic chip capacitors from 1MHz through 20 GHz. After you've found the high frequency capacitor that's right for your design, order an engineering kit for in-circuit evaluation.













PRODUCTS & TECHNOLOGIES

WLA05 - High Performance Wireless LANs

3G05 - Spread Spectrum Fundamentals

WE05 – Mobilizing Internet Content

PB05 – Memory Components for Wireless Applications

11:00 AM - Noon

BS06 3G Challenges to Base Station Systems Design

WP06 - Trends in Wireless Packaging and LTCC Design

BB06 - Broadband Wireless Access Systems

WLA06 - WLAN and Bluetooth Co-existience Issues

3G06 – Code Domain Measurements

WE06 - Mobilizing Enterprize Data

PB06 – Filterless Class-D Audio Amplifiers for Wireless Phones

1:30 PM - 3:00 PM

BS07 – High Power Amplifiers for Base Station Applications

WP07 - LTCC Materials and Applications

BB07 Fixed Wireless Access Solutions

WLA07 - Wireless Networking Fundamentals

3G07 - Components for 3G

WE07 - Enterprise Solutions to the Wireless Web

PB07 - Enabling Low Cost Chargers for Portable Systems

3:30 PM - 4:30

BS08 - Base Station Devices and Modules

WP08 – Plated and Bonded Cu and Interactive Discussion

BB08 - Technology Update

WLA08 – Real World Experiences WLAN Systems

3G08 3G Outlook: Evolving Standards and Alternatives

WE08 – Personalizing, Transcoding, and Repurposing Content for the Wireless Web

PB08 – Rotating-Wheel Braille Display Provides Accessibility for Compact Portable Devices

Thursday, February 15, 2001

Workshops 9:00 - 4:30

WKS09 - Oscillators

WKS10 - CDMA Fundamentals

Information about the Wireless Symposium

Conference: Monday-Friday, February 12-16, 2001 Conference Hours: 9:00 a.m. - 4:30 p.m.

Exhibition Dates and Hours:

Tuesday, February 13: 10:00 a.m. - 6:00 p.m. Wednesday, February 14: 10:00 a.m. - 5:00 p.m. Thursday, February 15: 10:00 a.m. - 2:00 p.m.

For additional conference information and to register, visit the show web site:

http://www.wirelessportable.com

WKS11 - RF & Wireless Made Simple, Part I

WKS12 – RF Fundamentals, Part 1

WKS13 - DSP Made Simple for Engineers, Part 1

WKS14 - Amplifier Linearization

9:00 AM -10:00 AM

TM09 - Real World Measurements

AN09 - Active Integrated Antennas

MT09 - Identifying Modulation Error Sources

BT09 - Bluetooth Case Study

IC09 – New Developments in Wireless IC/RF IC Solutions

WC09 – Understanding, Predicting, and Measuring Wireless Capacity

BP09 - Batteries & SuperCaps

11:00 AM - Noon

TM10 – Testing for Bluetooth, Wireless LAN and Other Short-Range Wireless

AN10 – Compact Antenna Design

MT10 - Taming the Quadrature Modulator

BT10 – Bluetooth Coexistience with Other Protocols

IC10 - Is the Super-Heterodyne Radio Dead?

WC10 – Understanding, Predicting, and Measuring Wireless Capacity

BP10 - Rechargeable Batteries and Battery Recycling

1:30 PM - 3:00 PM

TM11 - Wide Dynamic Range Measurements

AN11 - Practical Approaches to Antenna Design

MT11 - Improving Modulators for Specific Signals

BT11 - Bluetooth Applications and Developments

IC11 - RFIC Fundamentals, I, II, and III

WC11 – Understanding, Predicting, and Measuring Wireless Capacity

BP11 - Chargers & Battery Management

3:30 PM - 4:30 PM

TM12 - 3G Testing

AN12 – Antenna Design

MT12 – Advanced Modulation Schemes that Improve Systems Performance

BT12 - Bluetooth Access Points

IC12 – Wireless IC Issues

WC12 – Understanding, Predicting, and Measuring Wireless Capacity

BP12 - Chargers & Battery Management

Friday, February 16, 2001

Workshops - 9:00 - 4:30

WKS15 - 3G Wideband CDMA

WKS16 - Introduction to Bluetooth

WKS17 - RF & Wireless Made Simple, Part II

WKS18 - RF Fundamentals, Part II

WKS19 - DSP Made Simple for Engineers, Part II

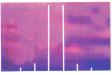
WKS20 – Practical Filter Design

HIGH IP3 MIXERS +30dBm IP3

5 to 2500MHz from \$14.95 (1-24 qty.)

The popularity of wireless communication services is soaring, but when signal overcrowding creates intermodulation distortion... Mini-Circuits has the solution! Our full range of low distortion, high IP3 SYM mixers provide the muscle it takes to **suppress noisy intermods** and unwanted signals. At the same time, these affordable surface mount solutions achieve low conversion loss and excellent L-R, L-I isolation. Developed for both analog and digital

use, applications include airphone, cellular and cordless phones, radar, satellite, FM Broadcast, ISM, PCS, and PCN. Achieve the high performance your customers expect. Specify low loss, high IP3 SYM mixers from Mini-Circuits. It's the *clear* choice!



TYPICAL SPECIF	FICATIONS: Freq. (MHz)	IP3 Midband (dBm)	Isolation (dB) L-R L-I	Conv. Loss Midband (dB)	Price \$ea. Qty. 1-24
SYM-18H	5 -1800	30	45 40	5.75	16.85
SYM-15VH	10 -1500	31	45 35	6.5	27.95
SYM-25DHW	80-2500	30	37 33	6.4	24.95*
SYM-14H	100-1370	30	36 30	6.5	14.95
SYM-10DH	800 -1000	31	45 29	7.6	17.80
SYM-22H	1500 -2200	30	33 38	5.6	18.75
SYM-20DH	1700-2000	32	35 34	6.7	14.95

All models are surface mount and available in tape and reel. LO=+17dBm except SYM-15VH LO=+23dBm



*SYM-25DHW: 1000 Quantity Price Only \$6.45 Ea.

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The Design Engineers Search Engine Provides ACTUAL Data Instantly From MINI-CIRCUITS At: http://www.minicircuits.com

Product Focus — A Look at Recent Test Product Introductions

Fast-switching dual-channel synthesizer

Programmed Test Sources has expanded its line of dual-channel synthesizers with the PTS DLx10, a unique dual-channel slot synthesizer.

The DLx10 contains two fully independent high-performance, low phase noise, fast-switching slot synthesizers, each covering a 10



MHz decade between 0.1 and 100 MHz, with 0.1 Hz resolution. The unit is housed in single rack or benchtop cabinet. Each channel is controlled via a 50-pin parallel interface. Frequency switching is 5 μ s maximum, phase noise is –132 dBc/Hz at 1 kHz offset and spurious output is –60 dBc. The DLx10 can operate from either an internal PTS-suppled frequency standard or from a customer-supplied 5 or 10 MHz external source. Domestic price of the unit is \$3,600, without an internal frequency reference.

Programmed Test Sources, Inc. Circle #189

Test cable assemblies

Semflex introduces Replaceable Head Test (RHT) cable assemblies, featuring a series of phase-matched connector heads on an armored flexible cable. The RHT 300 and RHT 400 assemblies feature a double shielded high frequency cable, covered by a stainless steel armor and a polyurethane jacket. The cables can be fitted with a variety of connectors types, 2.4 mm, 2.92 mm, 3.5 mm and SMA for the RHT 300

assembly, or SMA, Type N, TNC, ETNC and 7 mm for the RHT 400. An RHT 400 cable assem-

bly with SMA connector heads will have a VSWR of less than 1.35:1 and an insertion loss of less than



0.48 dB/ft at 26 GHz. The cable assemblies exhibit low phase change with flexure and less than 15 ppm/°C with temperature. The RHT assemblies can be purchased individually or in a complete kit of cables, connector heads and wrenches, packed in a wooden storage box.

Semflex, Inc. Circle #190

32-channel RF test station

Space Electronics has announced a new line of Shason Instruments Power Amplifier Automated Reliability Test Sets (PAARTS).

These systems are capable of performing 3-temperature life cycle tests on discrete transistors, M M I C s, hybrid microwave ICs and R F/microwave modular assemblies. The test sys-



tem includes hardware and software to initiate,

Incredibly New and Innovative Interconnect Salution



shown actual size

M

P

HANDSETS

PDAS

LAPTOPS

WIRELESS LAN ACCESS POINT

PCMCIA

AUTOMOTIVE







The **Ultra Miniature Pressure** Contact (**UMP**) from Radiall features high RF performance in the world's lowest profile (2mm mated height)! The positive locking system of the UMP is reliable and easy to use. Packaged in tape & reel, the UMP is ideal for high volume applications. The UMP can be used on board or edge applications and can be used in conjuncton with external or embedded antennas.

KEY SPECIFICATIONS

• Operating frequency: DC - 6 GHz

• Typical VSWR: Frequency Value

2GHz 1.07:1

4GHz 1.12:1

6GHz 1.20:1

Max. Insertion Loss (dB): 0.2 √F

• RF Leakage (dB): -40 at 2 GHz

• Durability: 100 matings min.

• Cable retention force (1 mm cable): 20 N

• Platings: Gold

AMERICAS - Brasil: Radiall Componentes do Brasil El. Lta 55 21 282 13 25 ASIA - China: Shanghai Radiall Electronics Co., Ltd 86 21 66 52 37 88; Hong-Kong: Radiall Electronics Ltd 852 2 959 38 33; India: Radiall Protectron 91 80 839 46 73; Japan: Nihon Radiall KK 81 3 38 66 23 90 EUROPE - France: Radiall Worldwide Headquarters: 33 1 49 35 35 35; Finland: Radiall S.F.: 358 0 934 89 356; Germany: Radiall G.m.b.H.: 49 6 074 910 70; Italy: Radiall Elettronica S.R.L.: 39 2 48 85 12 1; Netherlands: Radiall B.V.: 31 33 253 40 09; Sweden: Radiall A.B.: 46 8 444 34 10; U.K.: Radiall Limited: 44 1 819 978 880



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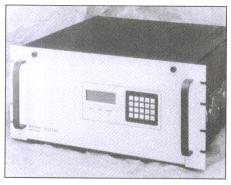
PRODUCTS & TECHNOLOGIES

supervise and record temperature, electrical and RF performance parameters automatically. The devices under test do not have to be identical circuits, since each can have independent bias, temperature and RF control. Testing with various modulation signals is supported, including CDMA and IMD testing.

Space Electronics, Inc. Circle #191

32 × 32 RF video matrix

Matrix Systems Corp. now offers Model 10693, a 32 × 32 RF video matrix that handles signals from DC to 100 MHz. Front panel keyboard control can be used, or remote programming via an RS-232/IEEE-488 interface. 40 configurations can be set up and recalled. The unit's bandwidth is ideal for video routing. Model 10693 is housed in a rack-



mount case measuring $8.75 \times 19.00 \times 17.00$ inches (HWD).

Matrix Systems, Inc. Circle #192

Handheld spectrum analyzer

Anritsu Company offers the MS2711A, a lightweight fully-functional handled spectrum analyzer for maximum mobility and flexibility in field applications. The MS2711A weighs four pounds and is



powered by a lightweight NiMH battery. The instrument covers $100~\mathrm{kHz}$ to $3~\mathrm{GHz}$, which includes a wide range of today's communications systems. It has $65~\mathrm{dB}$ dynamic range, $\pm 1.5~\mathrm{dB}$ amplitude accuracy, a full-span noise floor of $-97~\mathrm{dBm}$ and minimum resolution bandwidth of $10~\mathrm{kHz}$. The MS2711A is priced at \$7,000 with four to six weeks delivery.

Anritsu Company Circle #193

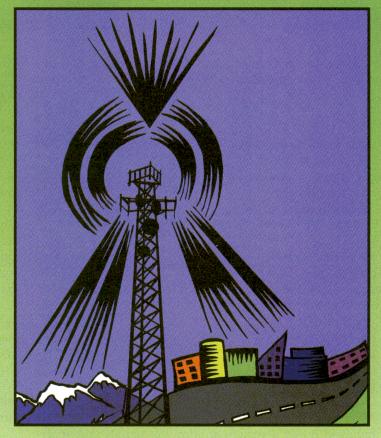
Communications analyzer gets data test software

IFR Systems now supports the move into digital wireless data by TDMA-EDGE operators, phone manufacturers and chipset developers. The new Radio Data Link test software option is available for the IFR-1900-5 CSA (cellular system analyzer) test system. The software



Base Station Repeater Radio **OEM's**

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



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

Applications include:

- Standard base station filters/duplexers
- Custom performance enhancing base station assemblies
- Delay filters for feed-forward amplifiers

- Cosite interference solutions
- Diplexers for 2.4-5.8GHz radios
- Custom products up to 40GHz

PCS/Cellular Duplexers



Integrated Assemblies



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Transmit Receive Filters



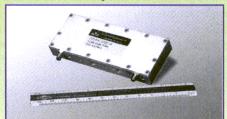
2.4/5.8 Duplexers





technologies, inc.

Delay Filter



Waveguide/Duplexers



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

PRODUCTS & TECHNOLOGIES

reduces development time and increases design confidence by testing circuit switched data radio link protocol

1, as defined in ANSI-136.310. The IFR-1900-5 CSA is an established test tool for operators and designers bringing TDMA systems to market. It tests multiband and 800/1900 MHz mobile and base



station products. The Radio Data Link test option (AC1068) is priced at \$3,995. The IFR-1900-5 system is priced at \$64,995.

IFR Systems, Inc. Circle #194

60 GHz microwave communications analyzer

LeCroy Corporation has released the model MCA1060 Microwave Communications Analyzer, featuring 60 GHz bandwidth and a variety of stimulus signals and analy-

sis capabilities. The unit provides a fully integrated test system for .01 to 40 Gbit communications signals. The noise floor is -80 dBm and the instrument comes standard with two



60 GHz input channels, a 6.24 to 200 MHz TTL output, 6.25 MHz to 1.6 GHz ECL output and an impulse output with frequency content from 6.25 MHz to 60 GHz. There are also GPIB, VGA and Centronics ports, plus connections for 10 MHz reference in/out. Applications include broadband TDR measurements, phase and group delay measurement and frequency domain transmission and return loss measurements in microwave radio and many optical communications systems.

LeCroy Corporation
Circle #195

Performance monitoring and analysis

Spirent Communications (formerly Telecom Analysis Systems), announced the release of InfoDM v2.0, part of the recently-acquired InfoSOFT Technologies product line. InfoDM is a high-speed over-the-air diagnostic monitoring tool used by developers, test engineers and field engineers to analyze and certify CDMA terminal and network performance.

Spirent Communications Circle #196

2001 measurement products catalog

Tektronix, Inc. has a new catalog, the *Tektronix 2001 Test*, *Measurement and Monitoring Products Catalog*.

Available in paper and CD-ROM, the catalog includes a broad offering of more than 1,400 products used in the design, manufacture, deployment and maintenance of global communications systems. Tektron-



ix solutions range from low-cost instruments and handheld products to conventional measurement products and advanced mixed-signal test solutions. New products include the TDS700 Series Digital Phosphor Oscilloscopes, OTS9000 Optical Test System, NetTek OTDR and the Net-7 network monitoring system.

Tektronix, Inc. Circle #197

Auto-latching doors for shielded enclosures

Lindgren RF Enclosures has introduced its Auto-Latching Door System, providing superior sealing quali-

ties and shielding performance. The new door system is an easy-to-use pneumatically-operated latching device that eliminates the need for excessive force to operate the latch. The system main-



tains a controlled positive seal of the perimeter door contact fingers. The new door system can be included with new shielded rooms or existing installations.

Lindgren RF Enclosures Circle #198

ISN testing unit for telecom testing

Schaffner EMC has introduced the ISN System 22, designed to comply with new CISPR 2 standards. These standards require that all telecommunications ports on information technology (IT) equipment be tested for RF emissions in the frequency range of 150 kHz to 30 MHz. Placed on a line, the ISN System 22 measures emissions coming out of the devices, and stabilizes the impedance at 50 ohms. With RF coupling in or out, the unit can also perform conducted immunity testing.

Schaffner EMC, Inc. Circle #199



INNOVATIVE MIXERS

.smaller size .better performance .lower cost

Searching high and low for a better frequency mixer? Then take a closer look at the innovative Innovative Technology built into Mini-Circuits technology ADE mixers. Smaller size is achieved using

an ultra-slim, patent pending package with a profile as low as 0.080 inches (2mm) in height. Electrically, ADE mixers deliver better performance than previous generation mixers through all welded connections and unique assembly construction which reduces parasitic inductance. The result is dramatically improved high frequency and IP2-IP3 performance. Plus, ADE's innovative package

design allows water wash to drain and eliminates the possibility of residue entrapment. Another ADE high point is the *lower cost*...priced from only \$1.99 each (qty.10-49). So, if you've been searching high and low for a mixer to exceed expectations...ADE is it"



ADE Mixers...Innovations Without Traditional Limitations!

50kHz to 4200MHz



		PECIFICATIO		Conv. Loss	L-R Isol.		
	leight (mm)	Freq. (MHz)	LO (dBm)	Midband (dB)	Bandwide (dB)	IP3 (dBm) @ Midband	Price (\$ea.) Qty. 10-49
ADE-1L ADE-3L ADE-1 ADE-1ASK ADE-2ASK ADE-6 ADE-12	3 4 4 3 5 2	2-500 0.2-400 0.5-500 2-600 1-1000 0.05-250 50-1000	+3 +7 +7 +7 +7 +7	5.2 5.3 5.0 5.3 5.4 4.6 7.0	55** 47** 55** 50** 45** 40	16 10 15 16 12 10	3.95 4.25 1.99 3.95 4.25 4.95 2.95
ADE-4 ADE-14 ADE-901 ADE-5 ADE-13 ADE-20 ADE-18	3 2 3 3 2 3 3	200-1000 800-1000 800-1000 5-1500 50-1600 1500-2000 1700-2500	+7 +7 +7 +7 +7 +7 +7	6.8 7.4 5.9 6.6 8.1 5.4 4.9	53** 32 32 40** 40** 31 27	15 17 13 15 11 14	4.25 3.25 2.95 3.45 3.10 4.95 3.45
ADE-3GL ADE-3G ADE-28 ADE-30 ADE-32 ADE-35 ADE-18W	2 3 3 3 3 3 3	2100-2600 2300-2700 1500-2800 200-3000 2500-3200 1600-3500 1750-3500	+7 +7 +7 +7 +7 +7	6.0 5.6 5.1 4.5 5.4 6.3 5.4	34 36 30 35 29 25 33	17 13 8 14 15 11	4.95 3.45 5.95 6.95 6.95 4.95 3.95
ADE-30W ADE-1LH ADE-1LHW ADE-1MH ADE-1MHW ADE-12MH ADE-25MH	3 4 3 4 3 4 3	300-4000 0.5-500 2-750 2-500 0.5-600 10-1200 5-2500	+7 +10 +10 +13 +13 +13	6.8 5.0 5.3 5.2 5.2 6.3 6.9	35 55** 52** 50** 53** 45** 34**	12 15 15 17 17 17 22 18	8.95 2.99 4.95 5.95 6.45 6.45 6.95
ADE-35MH ADE-42MH ADE-11H ADE-10H ADE-12H ADE-17H ADE-20H	3 4 3 3 3 3	5-3500 5-4200 0.5-500 400-1000 500-1200 100-1700 1500-2000	+13 +13 +17 +17 +17 +17	6.9 7.5 5.3 7.0 6.7 7.2 5.2	33** 29** 52** 39 34 36 29	18 17 23 30 28 25 24	9.95 14.95 4.95 7.95 8.95 8.95 8.95

ni-Circui^t

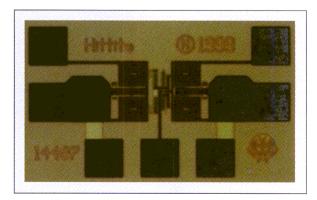
P.O.Box 350166, Brooklyn, New York 11235-0003 (718) 934-4500 Fax (718) 332-4661 For quick access to product information see MINI-CIRCUITS CATALOG & WEB SITE The Design Engineers Search Engine Provides ACTUAL Data Instantly From MINI-CIRCUITS At: http://www.minicircuits.com

Three New MMIC Frequency Converters Reduce Cost and Complexity of mm-Wave Radios

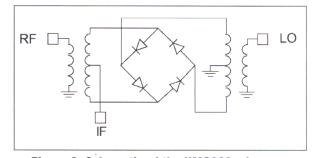
ittite Microwave Corporation is taking a lead position in offering high performance, low cost millimeter wave frequency converters to the market. During the "make vs. buy" analysis, the items listed on the bill of material are given careful scrutiny. Knowing this, Hittite has focused on producing small, high performance microwave and millimeter wave MMIC frequency converters in the lowest cost technology possible. The new HMC329 (25 to 40 GHz) fundamental mixer, HMC330 (25 to 40 GHz) subharmonic mixer. and HMC331 (24 to 36GHz) frequency doubler can reduce the end users component count, lower the materials cost, and simplify the manufacturing assembly and test processes. To satisfy all frequency plans, Hittites offers subharmonic mixers, fundamental mixers and frequencv doublers.

The HMC329, HMC330 and HMC331 were specifically designed to address the cost targets defined by LMDS radio designers. These products use a low cost MESFET technology on a four-inch wafer process and do not require additional external components or matching. Comparing the price of a Hittite MMIC converter to a discrete diode beam lead solution reveals that the MMIC solution is favorable. Total manufacturing costs of implementing a discrete solution include the costs of beam lead diodes, balun structures, assembly and tuning time of the discrete components and associated yields, as well as the costs of acquiring and maintaining multiple items. This approach is less desirable than manufacturing with a fully-tested single MMIC mixer chip.

The HMC329 fundamental mixer provides excellent LO to RF and LO to IF isolations due to the monolithic balun that provides an almost perfect voltage split across the diode ring, which then creates extremely high LO suppression and low spurious generation. Hittite's designers



▲ Figure 1. Photograph of the HMC329 mixer.



▲ Figure 2. Schematic of the HMC329 mixer.

focus on this key performance parameter and optimize designs for the best LO suppression based on customers' requirements and frequency plans. The HMC329 offers greater than 37 dB LO to RF isolation across the entire 25 to 40GHz band, and a conversion gain of better than -9 dB with LO drive levels above +12 dBm. Figures 1 and 2 show a photograph and schematic of the HMC329. Figures 3 and 4 show RF performance. The HMC329 mixer price meets the targets of LMDS customers, selling at \$5 to \$7 in volume production.

To assist in the LO multiplier chain, Hittite has expanded its MMIC doubler product line by adding a new low cost HMC331 24 GHz to 36



Demand for high linearity in communication systems is accelerating.

Cross the finish line first with the new **SPA** GaAs HBT MMIC amplifiers with exceptional linearity, long life and on-chip active bias circuitry keeping performance flat over process and temperature variation. Operating at 850 MHz, 1950 MHz and 2150 MHz, the SPAs are perfect for driving power amplifiers in cellular, PCS, WLL, UMTS, CDMA and W-CDMA infrastructure equipment.

The SPAs, powered with a single positive supply voltage to reduce part count, offer typical output third-order intercept points of +48 dBm. These integrated circuits provide intermodulation performance previously achieved only through costly discrete assemblies.

Part Number	Freq (MHz)	Gain (dB, typ.)	P1dB (dBm, typ.)	IP3 (dBm, typ.)	Voltage (VDC)	Current (ImA)
SPA-1108	810-960	17.0	29.5	+48.0	+5.0	320
SPA-1208	1930-1990	12.0	29.5	+48.0	+5.0	320
SPA-1308	2110-2170	11.0	29.5	+48.0	+5.0	320



New SPA series is available in plastic SO-8 packages with backside metallization for improved thermal path.

Drive your design performance to higher levels with the new high linearity SPA amplifiers from Stanford Microdevices. For more information, call our toll free number or Email us at info@stanfordmicro.com

Stanford Microdevices Inc. (SMDI), with design centers throughout the U.S. and Canada, is a leading supplier of RF components for the communication equipment industry.



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See us at Wireless Symnosium - Rooth #1319

PRODUCTS & TECHNOLOGIES

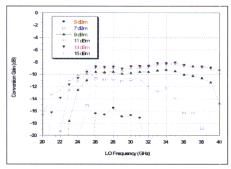


Figure 3. HMC329 conversion loss vs. LO drive.

GHz (output frequency) doubler. This doubler can be used in conjuntion with the HMC329 fundamental mixer. The doubler contains a full wave rectifier circuit and input and output transformers. The two port MMIC is fully matched to 50 ohms requiring no external matching. The HMC331 provides 15 dB conversion loss with +13 dBm drive level and greater than 40 dB F₀ isolation. Figures 5, 6 and 7 show a chip photograph, schematic, conversion loss and harmonic isolations of the HMC331.

Generating a millimeter wave LO

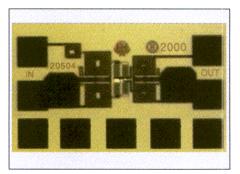


Figure 5. Photograph of the HMC331 frequency doubler.

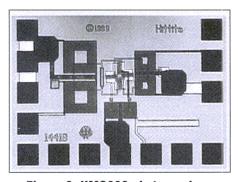
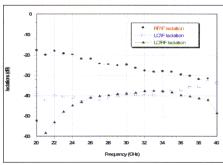


Figure 8. HMC330 photograph.



▲ Figure 4. Plot of HMC329 RF/IF, LO/IF and LO/RF isolations.

can be eliminated if the HMC330 subharmonic mixer is implemented. This mixer shows improved conversion loss, IIP3 and LO to RF isolations compared to previous Hittite sub-harmonic mixers. designers have implemented novel double-balanced sub-harmonic topologies and balun structures in the HMC330. Figures 8 and 9 present the HMC330 photograph and schematic. Conversion loss is 15 dB at LO drive levels of +12 dBm across the 25 to 40 GHz band. The double balanced topology also yields

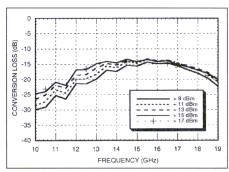


Figure 6. HMC331 2F₀ Loss as a function of input frequency.

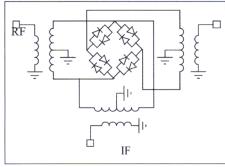


Figure 9. HMC330 subharmonic mixer schematic.

improved LO suppression at the IF and RF ports, as seen in Figure 10. The HMC330 will provide greater than +16 dBm IIP₃ across the 25 to 40 GHz frequency spectrum.

Hittite Microwave Corporation frequency converter products continue to evolve, as seen by the improved performance of the HMC329, HMC330 and HMC331. All three products are available standard products and data sheets are available at on the company's website. All products will be 100 percent RF tested prior to shipment, which enables Hittite to guarantee MMIC performance over the -55° C to +85° C temperature range.

For more information, contact:

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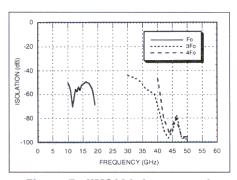
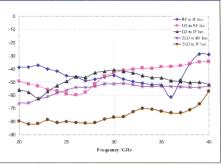
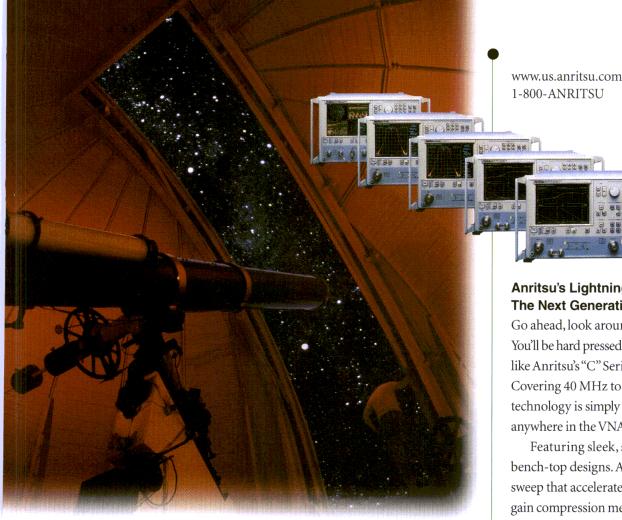


Figure 7. HMC331 frequency doubler isolation at F₀, 3F₀ and 4F₀.



▲ Figure 10. Plot of HMC330 isolation performance.



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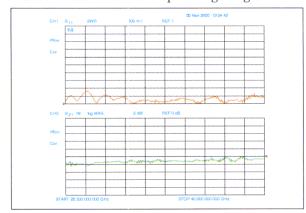
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WG-28 Waveguide Relay Offers High Performance in a Small Size

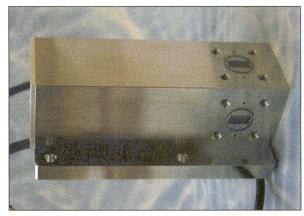
oaxial relays have long been the choice for switching transmission paths with minimal loss, high isolation and the ability to handle high power levels. But, at frequencies of 26 GHz and higher, power is at a premium. System engineers cringe when adding up the losses in typical coaxial structures. As an alternative, waveguide can greatly reduce these losses and dramatically increase system performance. Unfortunately, the higher cost, weight and size of waveguide components often convince engineers to avoid them and sacrifice system performance.

RelComm Technologies, a leading supplier of coaxial relays, has introduced a high performance, reduced size 1P2T WR-28 Waveguide Relay. The relay operates over the frequency range of 26.5 to 40 GHz. Insertion loss is less than 0.25 dB, isolation is better than -50 dB and VSWR is less than 1.30:1.

The relay's switching action is a latching type with self de-energized circuits that cut power to the relay after changing position. Auxiliary contacts are also supplied to indicate the selected state. Operating voltage is 12 ± 2 VDC over the temperature range of -40° to $+80^{\circ}$ C. Maximum actuating current is 500 mA at 12 VDC and 25° C (other voltages available). Switching time is less than 50 ms over its operating range.



▲ Isolation and loss plots show relay performance.



RelComm's new WR-28 waveguide relay saves weight and space in 26 to 40 GHz applications.

The unique switching mechanism permits this relay's slender profile, greatly reducing the bulk size typically found with these types of devices. The waveguide shuttle and actuator assembly is incorporated into a precision one piece, nickel-plated, aluminum housing. The waveguide openings are designed with external choke flange-type couplings. Mounting is accommodated by an integral base plate flange. The relay weighs in at less than 8 ounces.

Applications include transmit/receive switching, test equipment and microwave radios with high performance requirements.

For more information, contact:

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axim Integrated Products announces the MAX2750/2751/2752 series of fully self-contained 2.4 GHz VCOs. These RFICs integrate the inductor and varactor tuning elements on a single chip with the oscillator, buffer and voltage regulator circuitry. The new integrated VCO simplifies the design and manufacture of 802.11 11 Mbps WLAN, Home RF, Bluetooth and other 2.4 GHz wireless communications products.

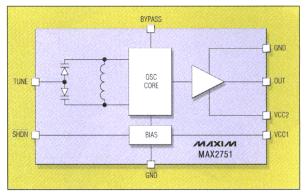
Multiple models developed or planned

Three products have been developed in the MAX275x series. The MAX2750 tunes 2400 to 2500 MHz for zero-IF or transmit-only applications. The MAX2751 tunes 2120 to 2260 MHz for applications with low-side LO injection using a 240 to 280 MHz IF. Model MAX2752 tunes 2025 to 2165 MHz for low-side LO injection using an IF of 335 to 375 MHz. Phase noise performance is typically –125 dBc/Hz at 4 MHz offset.

All three models have single-ended outputs and operate from a supply voltage of 2.7 to 5.5 VDC, drawing 10 mA of current. A digitally controlled shutdown reduces the supply current to less than 1 μ A. Internal voltage regulation eliminates the need for an external low-dropout regulator (LDO).

Model	Tuning Range	Application
MAX2750	2400-2599 MHz	Zero-IF
MAX2751	2120-2260 MHz	240-280 MHz IF
MAX2752	2025-2165 MHz	335-375 MHz IF
MAX2753*	2400-2500 MHz	Differential Output
MAX2754*	1145-1250 MHz	Direct Frequency Modulation Uses Frequency Doubler
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Models included in the new VCO product line.



Maxim introduces a fully-integrated voltage controlled oscillator that can save as much as 60 percent or more of board space, compared to other 2.4 GHz VCO implementations.

Two additional models are planned for future release. The MAX2753 will provide 2400 to 2500 MHz tuning with differential outputs, while the MAX2754 is designed for 1145 to 1250 MHz tuning for either zero-IF or up to 110 MHz IF, using a frequency doubler. The MAX2754 will also feature a linear modulation input for direct frequency modulation.

Pricing starts at \$1.78 each in quantities of 1,000 pieces. A fully-assembled evaluation kit is available to reduce design time.

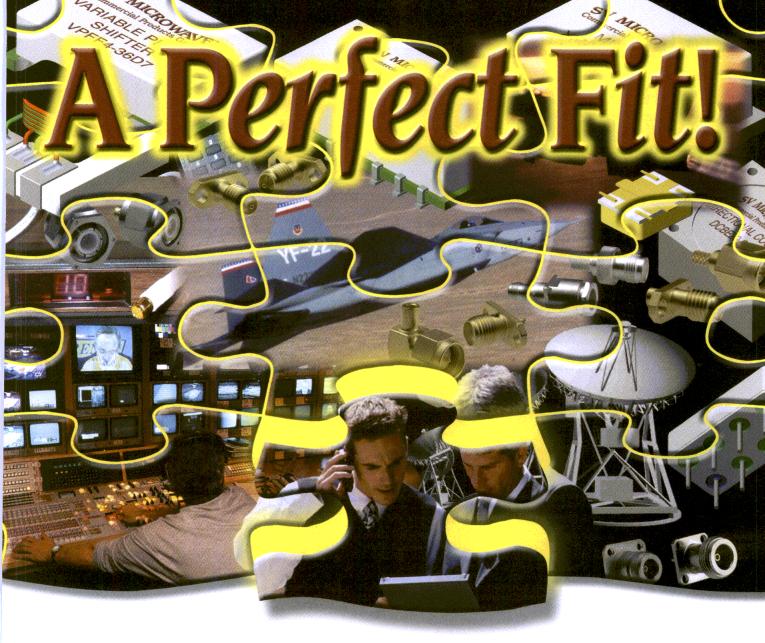
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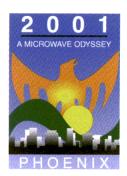
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Wireless Suppliers Have Mixed Views on the Economic Slowdown

he present weakness in the stock market and modest slowdown in consumer spending have analysts working overtime to explain what is happening and where it is leading. Opinions and predictions vary widely concerning the depth and length that this downturn is likely to have.

The most optimistic comments are that this is simply a correction to an overheated economy and unrealistically high stock prices. Much evidence supports this as a plausible scenario. Inflated-value "dot.com" stocks have led the stock market decline, while the uncertainty caused by both a transition in the Presidency and the delayed election results has created an extra emotional burden on investors and the public.

At the pessimistic end of the spectrum are analysts who claim that natural business cycles guarantee that a recession must follow an extended period of prosperity. They have good historical evidence for their position, as well. Some of them also note that the absence of a major social or political crisis has brought our collective mind-set to a point of malaise, and that some sort of "spark" will be needed for recovery to occur.

Views inside the wireless industry

As one would expect, the exact response to the present economic condition varies among participants in this industry. A few suppliers that have been struggling to meet delivery schedules have expressed some relief that orders have diminished enough to catch up with the backlog. They will also be quick to say that a short slowdown is enough, and they will be ready to resume a faster pace in the near future.

The supply difficulties are also cited as one cause for the slowdown, since it is evidence of an overheated economy. A related problem is the inability to hire all the people needed to sustain the rate of growth established over the past two to three years. The classic effect of low unemployment is inflation, with a slowdown of business growth the result if inflation does not occur.

A pessimistic attitude has been adopted by a relatively small number of people in the wireless industry. Chief among their concerns is the ability to maintain high growth rates. They cite saturation of certain market segments and too many choices for consumers, which dilute the available dollars for any one market segment.

Also high on the list of concerns is the overwhelming dominance of the U.S. market in the world economy. While many other regional economies are sound, few are booming, and some are still worrisome, including Japan, Indonesia, Russia and Argentina. Trade issues are also a matter for concern but generally are not viewed as having as large an effect on wireless communications as they do in other industries, such as automobiles, textiles or toys.

The most optimistic viewpoint is that the wireless industry will help the economy recover from its slowdown. Proponents of this view point out that there is a long list of developing applications that will bring convenience and power to both mobile and fixed communications. 3G voice-and-data and 4G high-speed data will propel the wireless phone portion of the market. LMDS, MMDS and digital cable will be major players in the market to meet consumer (and business) demand for high-speed Internet access. Added to this list are the efforts by component makers to lower costs through high-level integration and advanced manufacturing techniques, which will help keep consumer prices low.

Although these positive arguments are powerful, technology alone does not guarantee market success (remember those failing dot.com companies). New technologies require investment in their development and consumers must both see the need and have the money to spend to obtain those products. It seems, then, that all factors are interrelated.

A balanced-view prediction for 2001

A prediction of the wireless communications market in 2001 is risky, but a middle-ground position can be characterized as follows:

- An emotional lift will follow President-elect Bush's inauguration, with business returning to normal in Washington. This will initiate a rebound in the stock market.
- If there are no major armed conflicts in the world, and
 if there is no economic wild card such as a new oil crisis, consumers will return to their confidence in the
 future and resume spending.
- The Federal Reserve policies of Alan Greenspan appear to be effective. Assuming they continue, the overall economy will recover after the much-touted "smooth landing" that has been the Fed's goal.
- Creative technology solutions will play a strong role in providing new capabilities and controlling costs, which will contribute to economic recovery and future wireless market growth.

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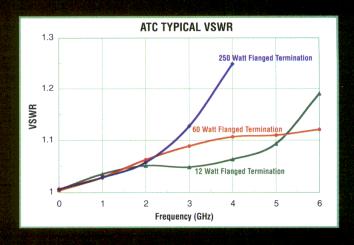
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