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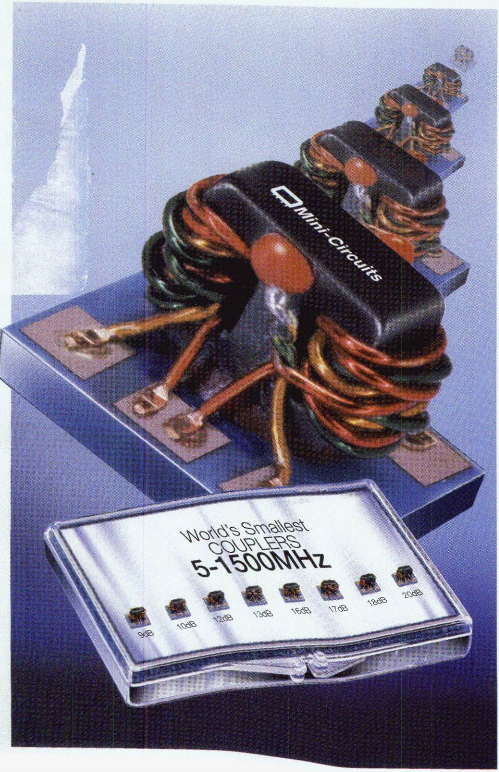

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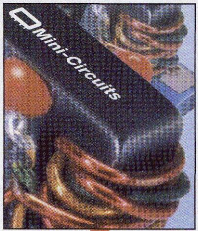

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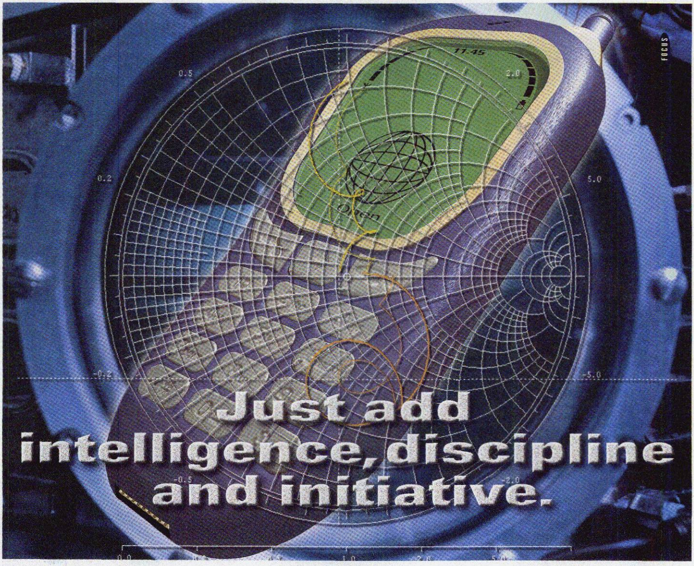
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2001 IEEE Radio and Wireless Conference (RAWCON2001)
August 19–22, 2001
Boston, MA

Sponsor: IEEE Microwave Theory and Techniques Society (MTT-S). Topics: Third-generation (3G) and fourth-generation (4G) cellular, wireless LAN, broadband fixed wireless, Bluetooth/Home RF/personal area networks, ultra-wideband communications, modeling and simulation, active and passive device technology, antennas, propagation and channel modeling, system performance and signal processing, and system architecture. For additional information visit http://rawcon.org. Contact: Michael S. Heutmaker, general chair, Lucent Technologies, Princeton, NJ (609) 639-3116 or e-mail: heutmaker@lucent.com.

2001 IEEE Emerging Technologies Symposium on Broadband Communications for the Internet Era
September 10–11, 2001
Dallas, TX

Sponsor: IEEE, Dallas Section. Topics: Third-generation cellular, LMDS, network planning and management, Internet standards and protocols, wireless infrastructure, fiber optics, WDM, optical CDMA, WLL, WLANs, Bluetooth, software radio, systems-on-a-chip, embedded processors, embedded ASICs, MMICs, optoelectronics, MEMS, smart antennas, digital signal processing, PDAs, Ad-hoc networks, secure networks, mobile satellite broadband-GEO, MEO and LEO, low power integrated circuits, coding and modulation schemes, digital subscriber loop, wireless digital subscriber loop, metro access networks, optical ethernet, cable modems, streaming audio and video services, wireless Internet, location based services, IP over WDM, new services, network architectures, business models and other broadband access technologies. Contact: Donald Butler, symposium chair, Southern Methodist University (214) 768-3081 or e-mail: dpb@engr.smu.edu.

4th European Microwave Week
September 24–28, 2001
London, UK

Sponsors: Electronics Group of CMP Europe on behalf of the European Microwave Association, the GAAS Association and IEEE MTT. The European Microwave Week will feature three conferences, an exhibition and a host of related workshops and short courses. GAAS 2001, the 31st European Microwave Conference and the 2001 European Conference on Wireless Technologies will all form components of the event.

34th IICIT Symposium
October 1–3, 2001
Anaheim, CA

Sponsor: International Institute of Connector and Interconnection Technology Inc. (IICIT).

Topics: RF/microwave interconnections, fiber optics, high speed connectors, automotive, surface-mount technology, space and hi-rel applications, materials and test equipment. Four technical tutorials focusing on interconnection products and technology, and a marketing seminar are included as part of the symposium. For more information visit www.iicit.org. Contact: Suzanne Romeo, IICIT managing director, (800) 854-4248.

34th International Symposium on Microelectronics
October 9–11, 2001
Baltimore, MD

Sponsor: International Microelectronics and Packaging Society (IMAPS). Topics: ball grid arrays, chip scale packaging, flip chip technology, fine pitch soldering, chip-on-board design process and characterization technology, lead-free developments, conductive adhesives and new inorganic materials developments, quality and reliability, thick film technology, MEMS, design for manufacturability, economics and marketing, market and market trends, and technology roadmaps and trends for electronic assembly. For more information visit www.imaps.org/imaps2001. Contact: IMAPS, 611 2nd Street, NE, Washington DC 20002 (703) 758-1060, fax (703) 758-1066 or e-mail: IMAPS@imaps.org.

GHz Interconnect Workshop
October 21–24, 2001
Chandler, AZ

Topics: Innovative applications and designs, design and implementation considerations and issues, software tools for design and simulation, interdependence of high frequency packaging requirements, MMIC and hybrid circuits, new packaging techniques and structures, advancement in high frequency-compatible materials, materials testing and characterization, circuit fabrication and assembly considerations, system and component reliability, and high volume manufacturing. Contact, David Light, program chairman, Tessera, 3099 Orchard Drive, San Jose, CA 95134 (408) 383-3671, fax (408) 894-0768 or e-mail: davidl@tessera.com.

2001 IEEE GaAs IC Symposium
October 21–24, 2001
Baltimore, MD

Topics: innovative RFIC device and circuit concepts, circuit design and fabrication, manufacturing technology and cost issues, CAD/CAM/CAT tools and techniques, IC testing and methodology, packaging technology, reliability, advanced device applications, system applications (commercial and military), and optoelectronic and OEIC applications. For more information, contact: 2001 IEEE GaAs IC Symoposium c/o IEEE, Attn: Mary Clemente, 445 Hoes Lane, Piscataway, NJ 08855 (732) 562-5350, fax (732) 981-1203 or e-mail: m.e.clemente@ieee.org.

23rd Antenna Measurement Techniques Association (AMTA) Symposium
October 21–26, 2001
Denver, CO

Sponsors: National Institute of Standards and Technology, Ball Aerospace and *Antenna Systems Technology Magazine*. This annual event is intended for people in the antenna and radar cross section industries. The symposium consists of a four-day technical program plus over 25 specialty vendors with exhibits. Contact: Mike Francis, 2001 AMTA Symposium c/o NIST, Mailstop 813.02, 325 Broadway, Boulder, CO 80305 (303) 497-3321, fax (303) 497-6665 or email: francis@boulder.nist.gov, or Paul Kolesnikoff, 2001 AMTA Symposium c/o Ball Aerospace & Technology Corp., MS AMC, PO Box 1538, Broomfield, CO 80038 (303) 533-7225, fax (303) 533-7379 or e-mail: pkolesni@Ball.com.

WORKSHOPS & COURSES

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■ **Topics:** The latest information on MEMS technology and applications in communications, with specific information on CoventorWare™ software products and intellectual property available from the company for rapid development and integration of MEMS into products.
■ **Site:** Schaumburg, IL
■ **Date:** July 12, 2001
■ **Contact:** Gail Massari, senior manager, marketing communications, Coventor Inc., 4001 Weston Parkway, Cary, NC 27513 (919) 854-7500 ext. 102, fax (919) 854-7501.

Connector Testing

■ **Topics:** New testing strategies to determine the performance levels now evolving including new procedures and how to establish efficient and cost-effective test programs including the dos, don'ts and cautions.
■ **Site:** Detroit, MI
■ **Date:** July 18, 2001
■ **Contact:** Suzanne Romeo, executive manager, IICIT (800) 854-4248 or e-mail: sromeo@iicit.org.

Satellite Communications Payload and System Design

■ **Topics:** Understanding design and assembly of modern satellite payloads and systems to meet the most demanding service requirements of the private and government sectors. Fee: $1295.
■ **Site:** Los Angeles, CA
■ **Dates:** July 18–20, 2001
■ **Contact:** UCLA Extension's Department of Engineering, Information Systems and Technical Management, Short Courses (310) 825-1047, fax (310) 206-2815.

RF & Microwave Fundamentals

■ **Topics:** Understand the principles of RF/microwave engineering, undertake RF measurements using power meters, spectrum analyzers, network analyzers. Introduction to noise figure and phase noise.
■ **Site:** Winnersh, UK
■ **Dates:** August 29–31, 2001
■ **Contact:** Tracey Bull, Agilent Technologies +44 118 927 6741, fax +44 118 927 6862.

RF Power Amplifiers, Classes A through S

■ **Topics:** A detailed explanation of the various classes of RF power amplifiers and where each class is used in today's wireless designs. Classes A through S are defined and clearly explained. Fee: $800.
■ **Site:** Lake George, NY
■ **Dates:** September 27–28, 2001
■ **Contact:** R.A. Wood Associates, 1001 Broad St., Suite 450, Utica, NY 13501 (315) 735-4217, fax (315) 735-4328 or e-mail: RAWood@rawood.com.

Optoelectronics Advanced Technology Workshop

■ **Topics:** Optoelectonics packaging, alignment, bonding and interconnect issues, signal routing and integration, optoelectronics case studies and applications, standardization issues and needs.
■ **Site:** Bethlehem, PA
■ **Dates:** October 11–14, 2001
■ **Contact:** IMAPS, 611 2nd St., NE, Washington, DC 20002 (703) 758-1060 or e-mail: IMAPS@imaps.org.

W-CDMA and UMTS Systems Operation and Technology

■ **Topics:** A clear, comprehensive presentation from the system introduction through to W-CDMA and UMTS standards, emphasizing the system issues.
■ **Site:** Research Triangle Park, NC
■ **Dates:** October 17–19, 2001
■ **Contact:** Anita Hellstrom, Organizational Effectiveness Institute (800) 683-7267, fax (301) 871-4942 or e-mail: Anita.Hellstrom@oei-edu.com. Additional information is available at www.oei-edu.com.

Spectrum Analysis Measurements

■ **Topics:** Theory of operation, understanding specifications, dynamic range, intermodulation, modulation measurements (AM, FM, pulsed RF). Includes practical lab sessions.
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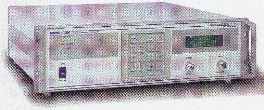

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A Long Range View of Short Range Wireless Systems

The development of short range wireless systems, particularly Bluetooth and wireless local area networks (WLAN) has captured the industry's imagination, if not the market that was initially predicted. Bluetooth technology originated in Europe, with early research and development driven by European-based companies. In this special supplement *Microwave Journal* reviews current European activity, worldwide expansion and globally competing technologies to discover whether going wireless comes with strings attached.

No wires — what an attractive proposition! Consider the savings in cabling costs and flexibility offered if an office's computers were served by a WLAN. Just imagine being able to eliminate the tangled mass of wires currently necessary to connect a PC, not just to the network, but also to its peripherals such as the keyboard, mouse and printer. Meanwhile, the mobility of cellular and cordless technology has promoted ideas for a generic short range wireless access solution for various devices.

These are all desirable aims but the interest in and development of short range wireless data networking has not just been prompted by the need to disentangle office chairs from trailing wires. The real impetus has come from the desire and expectation of individuals and companies to be able to access data and information almost anytime, anywhere, any place. Laptop-based users and broadband access in homes are more of the elements converging to drive ideas of a short range wireless access solution as well. Ally that with the prospect of vast numbers of cell phones becoming Internet enabled with users wanting to link up to laptops, headsets, hands-free kits and LAN access points, and a lucrative market is assured provided that the technology is available to implement it.

With such a large and untapped market there has been no shortage of contenders vying to provide that technology. This article looks at two of the leading contenders, Bluetooth and WLANs. Issues covered include how Bluetooth has built on its European origins and early development to capitalize on Europe's Global System for Mobile Communications (GSM) to enable it and synergize with it, together with the opportunities that 3G could offer. By mapping WLAN development and global deployment it is considered as both a competing technology and growth market in its own right.

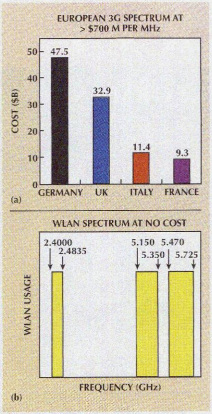
Bluetooth: An Overview

Since Ericsson originally devised the technology in 1994 Bluetooth has grabbed the

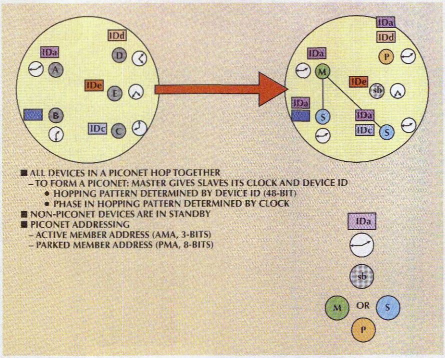
[Continued on page 24]

Richard Mumford
Microwave Journal *European Editor*

RIDE THE

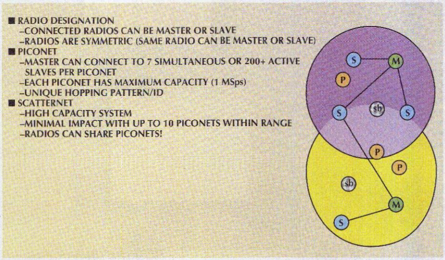


▲ *Fig. 1 The (a) European 3G spectrum cost per country and (b) WLAN spectrum at no cost.*



▲ *Fig. 2 The piconet.*

▼ *Fig. 3 Bluetooth network topology.*



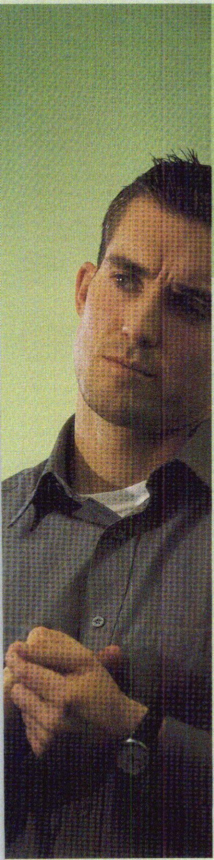
imagination and most of the headlines. The company continued working on the project alone until February 1998, when it shared its research with Nokia, Intel, IBM and Toshiba to found the Bluetooth Special Interest Group (SIG). The main purpose of the SIG is to protect the integrity of the technology and control its development. It is responsible for the certification process that all devices must complete before they can be acknowledged as having a Bluetooth compliant product. Without certification, a product cannot claim to be Bluetooth-enabled or use the Bluetooth trademark. The certification process ensures that developers keep to the standard and ensure interoperability.

The commercial specification, Bluetooth 1.0, was issued in July 1999 and ratified in February of this year. The growth of activity in the technology is illustrated by the fact that there are currently some 2000 companies working on or developing products based on this specification. From its European origins — it is named after a 10th century Norwegian King — Bluetooth has inevitably become of global interest to both manufacturers and potential users.

The attraction is that Bluetooth can offer low cost, small physical size (single chip) and low power consumption over throughput and range. Allied to its capability to function in noisy radio environments and offer high transmission rates. These features, together with support for real-time traffic of both voice and data, make it an attractive wireless networking technology for personal digital assistants (PDA), cell phones and laptops.

Licensed spectrum is expensive, particularly in Europe (> $100 billion paid for 140 MHz). A major appeal of Bluetooth is that it operates at the internationally available unlicensed industrial, scientific and medical (ISM) 2.4 GHz frequency band, enabling worldwide compatibility. ***Figure 1*** shows the European 3G spectrum cost vs. the WLAN spectrum (83.5 MHz in the 2.4 GHz band and 455 MHz in the 5 GHz band) at no cost. Bluetooth wireless technology operates in a multiple piconet topology (see ***Figure 2***) that supports point-to-point and point-to-multipoint connections. With the current specification, up to seven slave devices can be set to communicate with a master radio in one device. As ***Figure 3*** illustrates, several of these piconets can be established and linked together in ad hoc scatternets to allow communication among continual-

[Continued on page 28]



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ly flexible configurations. All devices in the same piconet have priority synchronization, but other devices can be set to enter.

Bluetooth's baseband technology supports both synchronous connection orientated (SCO) links for voice and asynchronous connectionless (AC) links for packet data. Both utilize time division duplex (TDD) as the access technique for full duplex transmission. Voice coding is accomplished using a continuously variable slope delta (CVSD) modulation technique, under which voice packets are never retransmitted. The master unit controls the link bandwidth and decides how much bandwidth to give to each slave and slaves must be polled before transmission.

An asynchronous channel that transmits data can support an asymmetric link of 721 kbps in either direction and permit 57.6 kbps in return. For a symmetric link the channel can support 432.6 kbps. Since Bluetooth devices can support three voice channels operating at 64 kbps, or one data channel, they can achieve data rates of up to 1Mbps. The Bluetooth 1.0 specification calls for 1 mW transmitters with a nominal antenna power of 0 dBm to operate up to 10 m (line of sight). A higher power transmitter of 100 mW (+20 dBm) included in the specification will increase the range to 100 m, although this will require a separate PA antenna driver. The compromise is increased costs and power consumption.

Bluetooth utilizes frequency hopping spread spectrum (FHSS) technology, where the system will frequency hop 1,600 times a second, delivering short time division multiplexed packets with each hop. With spread spectrum hopping, the sequence is random and the receiver must hunt down the chosen transmission frequency after each hop. Before any connections in a piconet are created, all devices are in standby mode which allows for the device to listen on 32 hop frequencies defined for each unit, for messages every 1.28 seconds. The connection begins when one device initiates a connection and becomes the master of the piconet. A connection is made by a page message if the address is known, and if it is not then an inquiry message followed by a page message is sent. The devices synchronize and then connect. At the point of connection each device assumes a media access control (MAC) address to distinguish them.

ROLL-OUT

The Bluetooth technical specification may be clear, product roll-out less so. The marketing machines did their job in creating awareness but in the process raised expectations that have yet to be fulfilled. All too quickly allegations, particularly in the media, of over hype and over elaborate market forecasts were hitting the headlines. However, last year saw a significant number of product launches together with the initial shipments of products bearing the Bluetooth logo. There has been consolidation for the first half of this year with the end of 2001 seeing significant predictions.

Frost & Sullivan forecasts global shipments of Bluetooth-enabled products to reach over 11 million units in 2001, equaling \$2.5 billion in revenues, while Micrologic Research is more conservative with its estimation that the market will reach five million devices in 2001 and 1.2 billion in 2005. Such variations in figures tend to muddy the waters and emphasize the unpredictability of the market, but in such an embryonic technology this is perhaps understandable.

This is a point made by Michael Wall, research analyst at Frost & Sullivan, who has stated: "Although the delays in the development of Bluetooth are beginning to prompt a backlash from certain sections of the media, industry observers have to take the infancy of Bluetooth as an industry standard technology into consideration when assessing the status of this marketplace. Apart from Ericsson, the original pioneers, even the most progressive developers were not attracted to the project until 1998. Other mobile communications technologies such as the GSM took longer to develop than is being allowed for Bluetooth."

Semiconductor chipset development is a key element in the technology's progress, with a range of development models emerging within the Bluetooth semiconductor industry. Two distinct manufacturing routes are being taken. There are either those offering complete integrated solutions from the silicon wafer level to the consumer product level or those providing part of the sum of a chipset, that is, baseband, radio and software.

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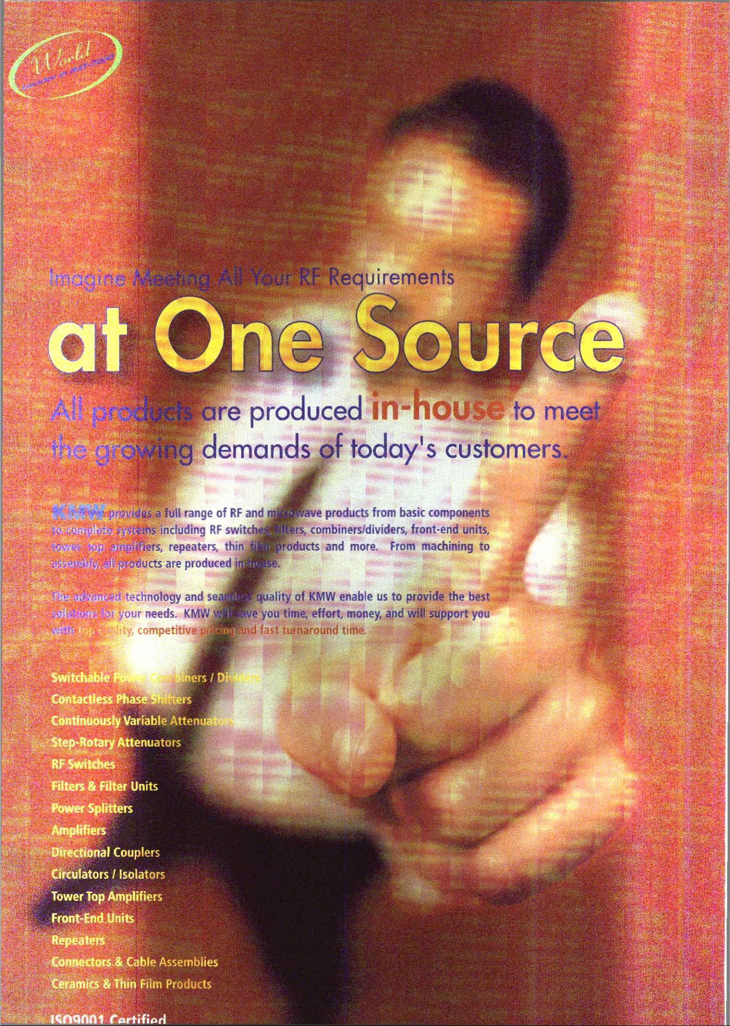
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SILICON CHOICES

Debate continues over the most effective choice of silicon technology for Bluetooth. The diversity of silicon technologies and solutions architectures being used has emphasized the software protocol stack. It has become one of the most crucial elements of the solution, especially with regards to achieving interoperability and will become increasingly important as semiconductor companies come closer to launching their products onto the market.

Alongside some of the big names a number of smaller design services companies have entered the Bluetooth software market offering complete or partial protocol stacks to semiconductor developers. In the same vein Bluetooth has offered a number of smaller, highly innovative fabless semiconductor developers, such as Cambridge Silicon Radio and Silicon Wave, an opportunity to build early market share with fast time-to-market solutions. Amongst the larger integrated Bluetooth developers, Philips Semiconductors has been the main player to offer solutions in volume. It is expected that a large number of solutions will be on offer by the end of 2001.

Market success may be determined by a chicken and egg combination of chipset supply. Observers have warned that restrictions in the supply of chipsets to smaller product developers may cause delays in the time-to-market of new innovative applications that will provide future revenue streams for chipset suppliers. Despite such words of caution Frost & Sullivan forecasts that the total shipments of Bluetooth chipsets will be over 956 million in 2006, and the total market for these chipsets is predicted to be over $2.3 billion in 2006. Further up the value chain from chipsets the early Bluetooth offerings are fairly generic wireless network access products, such as PC cards and other add-on devices, together with access points (AP).

Also, in Europe, a significant number of Bluetooth mobile phones were launched at the CeBIT exhibition in Germany in March 2001 with many more expected over the summer. However, the market cocktail has become more intriguing because of 3G market developments. At a time when the huge cost of 3G licenses is impacting on the telecoms stock market and the equipment required to roll-out Universal Mobile Telecommunication System (UMTS) networks has not yet come to fruition, many of the services planned for 3G mobile could be delivered by currently available technologies which operate in unlicensed (free) frequency bands.

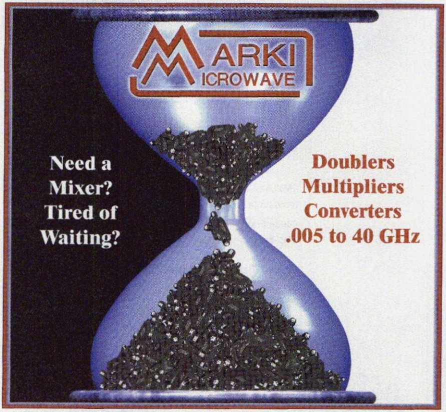
Mobile operators who have 3G license debts to service are under pressure to maximize revenue of existing data services, and demonstrate that the market has the appetite for 2.5G and 3G services. Bluetooth mobile phones could be one solution by allowing users access to the Internet on their PDA using the phone as a wireless gateway. Ericsson, for instance, is promoting the Bluetooth Local Information Point (BLIP), which provides Bluetooth access to the Internet, within range of a BLIP access point. Such developments will continue to keep Bluetooth in the headlines and the public eye.

WLAN

WLANs are emerging from the wings as a strong contender to rival Bluetooth. WLANs enable the Ethernet cable from the wall outlet to a device (such as a PC) to be replaced by a wireless link between an access point and a wireless interface card that is either part of the wireless device or plugged into it. The technology is in no way a newcomer, however. In fact, it was back in 1990 when, in the US, the IEEE 802.11 Wireless Local Area Networks Standards Working Group was formed with the task of developing a global standard for radio equipment and networks operating in the 2.4GHz unlicensed frequency band for data rates of 1 and 2 Mbps.

Over a decade ago what the original 802.11 standard did, to a degree, was to help unify a confused WLAN marketplace, which was crowded with proprietary solutions. Although the original specification supported three different transmission media – frequency hopping spread spectrum (FHSS), direct sequence spread spectrum (DSSS) and infrared (IR) – the major area of development has been for DSSS. DSSS spreads the signal over several frequencies, can switch

[Continued on page 36]



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VARIETY

channels to avoid interference and also makes the signal harder to intercept than standard wired Ethernet.

The IEEE 802.11 standard was adopted in 1997. The modulation scheme used when operating at the 1 Mbps rate is binary phase shift keying (BPSK) where each symbol carries one bit and one million symbols per second (1 Msps) are transmitted. Thus, with each symbol storing one bit, the bit-rate achieved is 1 Mbps. Quadrature phase shift keying (QPSK) is the modulation scheme used to yield 2 Mbps. With this technique the system is able to transmit two channels simultaneously, and although the symbol rate is still 1 Msps with QPSK mapping two bits per symbol, the result yields 2 Mbps. However, these data rates of 1 Mbps and 2 Mbps are significantly slower than the wired LAN equivalents. This aligned with questions over interoperability and price, limited take up and acceptance of the standard as a viable option.

IEEE 802.11B

That all changed in September 1999 when the IEEE ratified a new high rate standard for WLANs – IEEE 802.11b, which also goes under the various guises of WiFi (Wireless Fidelity) and high rate wireless Ethernet. It is significant because it offers a top-end data rate of 11 Mbps. Each access point can support dozens of connections, although they all must share 11 Mbps of capacity. There can be three access points working in the same area, and each typically has an indoor range of 90 m at 1 Mbps and 25 m at 11 Mbps. To achieve this higher data rate the IEEE 802.11b specifies complementary code keying (CCK) as the modulation scheme. The technique maps four bits per symbol to achieve 8 Mbps, which allied to an increased rate of 1.375 Msps yields a bit rate of 11 Mbps. Therefore, while the number of symbols sent per second hardly varies from the symbol rate used for IEEE 802.11 LANs, more bits per second are sent. Also, as CCK is a DSSS technique, 802.11b is backward-compatible with products that meet the original 802.11 specification, enabling 802.11b standard products to interoperate with 802.11 compliant DSSS products by falling back to 1 Mbps or 2 Mbps operation.

With an industry body to verify interoperability and the interoperability of 802.11b cards being assured, due to there being just two silicon manufacturers worldwide using a similar MAC layer specification, that deficiency in the WLAN offering has been addressed. The increased bit rate of 11 Mbps has also dealt with the performance issue with 802.11b being able to match standard Ethernet for speed. This has resulted in a renewed interest in, and perhaps more importantly, investment in the development of 802.11b products by large players who did not view any involvement in 1 to 2 Mbps products as a viable option.

Now, the benefits that WLANs offer in terms of mobility and flexibility, allied to increased speed and the falling costs of PC cards, has made it an attractive option for the home market where broadband access is growing for small businesses and particu-

[Continued on page 38]

larly for the enterprise customer. Typical applications include the creation of ad hoc LANs, the linking of portables into a wired infrastructure, WLAN bridging and in peer-to-peer networks where PCs with wireless cards can exchange data directly. Alternatively, an access point allows PCs to communicate with fixed Ethernet topologies via an Ethernet hub or switch port. Although WLAN cards are still far more expensive than ordinary cable-based Ethernet cards, having a standard means that all manufacturers move to the same technology and prices come down. Today there are cards at around the $200 mark.

WIFI DEPLOYMENT

The key to the progress of WiFi is its wide and global deployment, and without any hype it has begun. Airports as far afield as Europe, Japan, Hong Kong and the US have installed 802.11b networks, with hotels and conference centers also being prime areas of development. Additionally, with the increased use of laptops, the natural synergy between their mobility and the mobility offered by WLANs is propelling the growth of 802.11b. Offering mobility is going to be the key to success of WiFi. For instance, when users have a notebook, they want to be able to use it in the office, at home and on their travels without having to swap cards. Only a wide deployment of 802.11b will facilitate that.

Mobile operators also see WLANs as a cheap and easy way to provide high speed access to densely populated areas. Because they rely on very short-range transmissions, users see improved battery life, and with health risks being a concern there is the added advantage of lower power usage. Again, at CeBit there were a large number of equipment suppliers showing WiFi components in the form of PC cards, universal serial bus (USB) devices, access points and home gateways. However, at present the Wireless Ethernet Compatibility Alliance (WECA) only recognizes one test house in the US for certification of WiFi products with plans for a European test house to be recognized soon. Such expansion is vital for the technology to be viewed as truly global in terms of development.

The key factor in the growth and development of the WLAN market has been the increased data rate of 11 Mbps being afforded by the 802.11b standard. However, in October last year the IEEE Standards Board approved P802.11g, a new project within the IEEE 802.11 WLAN Working Group to enhance the data rate of WLANs operating in the 2.4GHz frequency band. The expectation is that the data rates will be increased to greater than 20 Mbps and the mission of the task group is to review proposals. Areas of development currently being undertaken which could afford this 'doubled' data rate include a new modulation technology that improves the robustness of RF data transmissions. It not only overcomes much of the background RF noise and other sources of interference but also provides better performance against multipath interference.

On the receiver side, advanced equalizer technology used in concert with these new modulation algorithms will act to reduce the need to retransmit data packets. This is important because when interference in WLANs causes unrecoverable corruption of a reflected data stream or noisy signals are discarded and are retransmitted which slows the data rate and interrupts the data flow, the system is less reliable for real time transmission. With advanced equalizer technologies, reflected or noisy signals are not simply discarded or filtered out. Forward error correction (FEC) algorithms can take corrupted signals and reconstruct them, significantly reducing retransmits.

Data rates of over 20 Mbps will open up new applications for the industry to exploit. As might be expected, interest will most likely be led by leisure applications. Faster transmission speeds will enable streaming video for high definition television and graphics for interactive gaming while also providing the headroom to accommodate new applications when they come on stream. Businesses and enterprises are always screaming out for the means to transmit large amounts of data quickly. Home automation will be another avenue by facilitating the interaction of heating,

[Continued on page 40]

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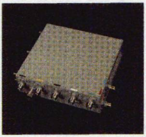

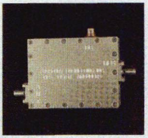

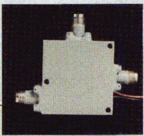

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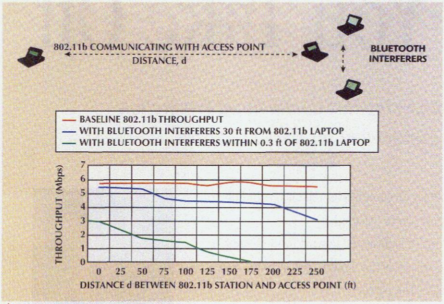
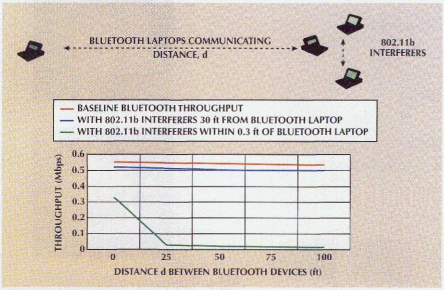


▲ *Fig. 4 Empirical testing of Bluetooth on 802.11b interference. (Source: Texas Instruments/IEEE 802.15.2 group)*

Fig. 5 Empirical testing of 802.11b on Bluetooth interference. (Source: Texas Instruments/IEEE 802.15.2 group) ▼



lighting, air conditioning and security systems.

THE WLAN MARKET

Such applications may be some way off but the WLAN is a growing market as the statistics show. According to the latest figures from IDC worldwide WLAN equipment revenue jumped 80% in 2000, breaking the \$1 billion mark. IDC predicts that by the end of 2005 the market will be approaching \$3.2 billion. Demand, especially in the US, has been particularly strong in vertical industries such as education, retail and health care. In the coming years, the market will see increased use of WLANs in the home and small- to medium-sized business (SMB) segments together with the growth of broadband. Despite the optimistic outlook for the overall market, particularly in the US, Western Europe and Japan, IDC believes vendors will have to overcome several obstacles, including resolving standardization issues, educating their partners, improving security and reducing prices so that WLANs are affordable for mainstream segments.

INTERFERENCE

The chipset market for 2.4 GHz WLAN products is set to continue to expand, although growth will not be as high as for Bluetooth chipsets. Frost & Sullivan anticipates direct sequence 802.11b chipsets to be in great demand, predicting that the market for them will be worth over \$1.3 billion in 2006. This demand will be driven by the growth in mobile computing and by falling product costs.

Bluetooth and WLANs may have differing profiles in terms of marketing and publicity but it is clear from the market statistics and investment in technical development that both are technologies that are becoming established and set to grow. However, can they coexist technically? Interference has been a topic of debate and concern since the early stages of Bluetooth development and to a certain extent it has become a fear of the unknown. What is known is that interference between 802.11b and Bluetooth devices can occur. In the US the Federal Communications Commission (FCC) requires every device operating in unlicensed bands to have a label stating that it can cause interference. However, what is not known is the potential of the problem. The fact that the devices operate in an unlicensed band and projections of mushrooming market growth for Bluetooth and 802.11b is fueling concerns.

Although the level of concern may turn out to be unwarranted, it has at least grabbed the attention of wireless standards groups, regulatory bodies and wireless industry participants. They are all well aware that if users do experience interference problems it will damage user confidence in the technology. With so much investment it is a risk that manufacturers, in particular, cannot take. Global technical development work is being carried out and standards are being addressed to limit interference. In the US the IEEE 802.15.2 Task Group is coordinating efforts, and the FCC has also put together a set of rules that allow multiple devices to share the spectrum, providing room for considerable innovation in building radios that can resist interference.

Consequently, extensive research to monitor the effect that WiFi and Bluetooth devices operating in the same vicinity have on one another is under way. Results do vary and ***Figures 4*** and ***5*** are examples of a particular study to illustrate the effect. However, what is generally accepted is that if the anten-

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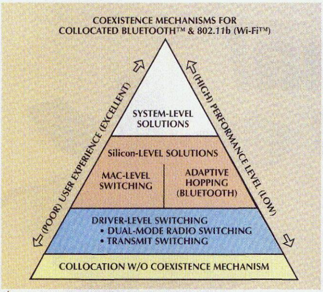

▲ *Fig. 6 Performance hierarchy. (Source: Mobilian Corporation)*

nas of the Bluetooth and WiFi devices are kept over 2m apart, then there will be graceful degradation of the two protocols, which will only be noticed by very sensitive users. Move the two antennas within a meter, however, and there can be significant interference.

Interference really becomes a serious issue when both radios are integrated into the same device with the antennas close together. Examples of when the two devices are collocated (that is, separated by less than 10cm) are in a combination PC card and laptops or Internet appliances enabled with both technologies. Also, it is believed that collocated products will play an important role in devices such as notebook PCs. An example is a notebook that has a Bluetooth radio integrated for connection to a PDA or cell phone and at the same time has a WiFi radio integrated for LAN access.

COLLOCATION

Coexistence is a major issue for such applications and one which the industry is striving to address with standards bodies and wireless companies starting to develop and lobby for a variety of coexistence approaches. These vary from regulatory intervention and special standards task forces such as IEEE 802.15.2 to various technical approaches ranging from simple device 'collocation without any coexistence mechanisms' to integrated silicon solutions covering the entire wireless sub-system.

Mobilian Corporation, together with industry partners, is a company working on developing a solution and has categorized these various technical approaches into a performance and user experience hierarchy, as shown in ***Figure 6***, with each having their strengths and limitations. 'Collocation without a coexistence mechanism' is relatively controversial. It does have the advantage of being a rapid time-to-market approach which provides a single-card reference design only. The close proximity of the two radios with no coexistence mechanism will likely produce worst-case scenarios, and can consequently result in significant degradation to both radios' performance.

Dual-mode radio switching does not require changes to the silicon, and could be relatively quick to market. It incorporates a coexistence mechanism that requires that while one radio is operational, the other is completely suspended. The operation can be implemented primarily in two ways. In the first, the system simply shuts the non-operating radio off with no signaling to other nodes in its network. This can result in difficulties for the network and can drop performance levels below that of simple 'collocation without a coexistence mechanism.' The second method does signal other network nodes that it is suspending one of its radios. Performance will still be 60 percent lower than that of unhindered radios because of its modal nature (one on/one off), but is better than simply shutting the radios off. Neither method supports switching while Bluetooth voice (SCO) links are in operation.

Driver-level transmit switching generally describes an approach in which application transmit requests are mediated at the driver level, thereby avoiding simultaneous transmission. Intuitively, this approach degrades throughput by some measure simply due to its modal transmit structure. More important, though, are its limitations in avoiding collisions with incoming packets. The resulting transmission of one protocol during reception of the other causes loss of received packets, interference and potential user difficulties. This is caused by the technique's dependence on the host operating system, which is generally non-deterministic in its response time (non-real-time). Again, this approach does not switch quickly enough to support Bluetooth SCO links, and will also have difficulties mitigating the interference from Bluetooth piconet master/slave polling activities.

While Bluetooth adaptive hopping certainly improves simultaneous performance under limited penetration scenarios, its widespread adoption will likely require intervention from regulatory organizations and standards bodies. Even under a fast-track program, this can be a time-consuming process. This time-delay exacerbates the problem that the technique's effectiveness is compromised with higher penetrations of WiFi systems and unmodified Bluetooth devices. Adaptive hopping will likely be initiated as an optional Bluetooth profile, indicating that modified devices will not use the functionality in piconets with unmodified devices. Further, in the presence of more than one Bluetooth piconet or WiFi network, adaptive hopping can be counter productive to coexistence.

MAC-level switching is the most effective of the modal/switching style approaches, and provides performance levels approaching those in no-interference scenarios. It is a collaborative technique accomplished by exchanging information between the two protocols at the MAC level and managing transmit/receive operations accordingly. Because MAC-level switching is performed in the baseband, it is able to switch between protocols at a much faster rate than driver-level approaches. Consequently, it is able to mitigate many of the problems that driver-level switching cannot. MAC-level switching does not suffer from transmitting signals into incoming receptions, Bluetooth polling or operating system latency. However, it is susceptible to adjacent-channel interference and does suffer noticeable degradation. Also, because it is located in the baseband, it has a longer development cycle than driver-level approaches.

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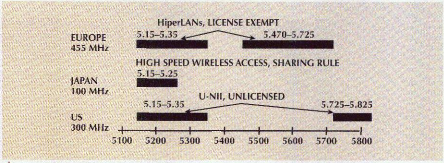

▲ *Fig. 7 Spectrum allocation at 5 GHz.*

Simultaneous operation provides the ability to automatically detect all available wireless networks, select the ones needed and connect to them seamlessly. By providing coexistence in a highly integrated two-chip solution – an analog front-end chip and a digital baseband chip – it allows simultaneous operation of the two protocols while eliminating interference and maintaining reliability and performance. Interference is a genuine concern and, as has been illustrated, there are measures that can be taken and innovative initiatives under development to provide coexistence particularly for collocated devices. The potential market is too large and too lucrative for every effort not to be made to ensure smooth operation.

BLUETOOTH vs. WLAN APPLICATIONS

Bluetooth and WLAN may be competing in the same frequency band but are they competing for the same applications? Due to its simplicity in not having to be configured, low power, short range and low cost Bluetooth will be focused on small devices such as PDAs and cell phones. To provide access and synchronization of those personal devices there will also be the need for Bluetooth radios to be incorporated in access points and notebooks.

Another possibility that Bluetooth affords is the deconstruction of devices into individual components, allowing for new form factors and device types. For instance, by having a separate headset there is no longer the need to include one in a cell phone, which simply becomes a cellular receiver/transmitter interacting with the cellular network, PDAs and laptops. More long-term, a so-called killer application for Bluetooth could well be public access. It is all very well to have synchronization between the notebook, PDA or cell phone but, when in an airport or shopping mall, access to the Internet or information about the local area would be valuable. For that to happen, though, there is the chicken and egg situation where a company is not going to deploy Bluetooth enabled access points unless there are significant numbers of devices in the marketplace to use them and vice versa. The same goes for the providers of the information that users will be seeking. Nevertheless, this is an area actively being developed.

Public access is a definite application for WLAN and, as has been mentioned, systems are already being globally deployed in airports. Their high data rate being comparable to the wired Ethernet makes them particularly suitable for the enterprise sector for computer networking between PCs and to take advantage of the trend towards laptop mobility. Simplicity, low cost and the facility for expansion also make WLAN suitable for small office home office (SoHo) implementation and the expansion of the home broadband access market, particularly in the US, also opens up opportunities.

THE 5 GHZ FREQUENCY BAND

Even if just a fraction of these applications for Bluetooth and WLAN come to fruition, the narrow (80 GHz) 2.4 GHz band will soon become congested. In anticipation of this, spectrum will play a crucial role in the deployment of next-generation, high speed WLANs and has prompted licensing authorities globally to allocate large blocks of license free spectrum in the 5 GHz band. As ***Figure 7*** shows, in Europe, a total of 455 MHz is available in the two blocks from 5.15 to 5.35 GHz and from 5.470 to 5.725 GHz. Similarly, the US has allocated a total of 300 MHz in the two blocks of

[Continued on page 46]

spectrum at 5.15 to 5.35 GHz and 5.725 to 5.825 GHz. In Japan, one 100 MHz block at 5.15 to 5.25 GHz is being considered.

Again two different 5 GHz standards are being developed on either side of the Atlantic with both specifications offering data rates of up to 54 Mbps, and therefore well placed to provide high speed communication services. Originating in the US the IEEE 802.11a standard was ratified in 1999. The physical layer (PHY) is based on orthogonal frequency division multiplexing (OFDM) and shares a common MAC layer with all IEEE 802.11 standards including 802.11b.

Alternatively the European Telecommunications Standards Institute (ETSI) is developing high performance radio LAN (HIPERLAN) standards as part of its Broadband Radio Access Network (BRAN) initiative. Under its remit is the development of four standards — HIPERLAN1, HIPERLAN2, HIPERLink (designed for indoor radio backbones) and HIPERAccess (intended for fixed outdoor use to provide access to a wired infrastructure).

The HIPERLAN1 standard, which is based on the well-established technique of Gaussian minimum shift keying (GMSK) modulation, is complete and was ratified in 1997. HIPERLink and HIPERAccess, on the other hand, are at the early stages of development. It is HIPERLAN2 where current activity is focused.

The physical layers of both 802.11a and HIPERLAN2 use OFDM modulation to achieve high speed transmission rates. This multichannel spread spectrum modulation technique allows individual channels to maintain their distance (or orthogonality) to adjacent channels, enabling data symbols to be reliably extracted and multiple subchannels to overlap in the frequency domain for increased spectral efficiency. For instance, in the spectrum allocation for Europe, HIPERLAN2 channels will be spaced 20 MHz apart for a total of 19 channels.

Both IEEE 802.11a and HIPERLAN2 specify an OFDM physical layer that splits the information signal across 52 separate sub-carriers. 48 provide separate wireless pathways for parallel data transfer, while the remaining four are used as a reference to disregard frequency or phase shifts of the signal during transmission and provide synchronization. Synchronization enables coherent (in-phase) demodulation. The two standards may have this similarity but differ above the physical layer with 802.11a generally viewed as simpler and less complex, while HIPERLAN2 is more sophisticated (or complicated depending on your viewpoint) with wider scope.

HIPERLAN2

For HIPERLAN2, mobile terminals such as a laptop or handheld devices communicate with access points. To provide continuous coverage, these access points must have overlapping coverage areas. Coverage typically extends 30 m indoors and 150 m in unobstructed environments. By utilizing automatic frequency allocation (AFA) access points monitor the HIPERLAN radio channels around them and automatically select an unused channel. A mobile terminal, after association, will only communicate with one AP at each point in time, but if it receives a better signal strength it can request to be connected to another. When a mobile terminal roams from the coverage area of one access point to another, it automatically initiates a handoff to the new access point. The APs involved in the handover ensure that established connections over the air interface as well as security associations are transparently shifted from the old to the new. Security support includes both key negotiation, authentication (conventions such as the network access identifier (NAI) and X.509 can be used), as well as encryption using DES or 3-DES.

OFDM modulation can supply transmission rates of 54 Mbps but this can be dynamically adjusted to a lower rate by using different modulation schemes depending on the prevalent radio conditions. All traffic is transmitted on connections, bi-directional for unicast traffic and uni-directional towards the mobile terminals for multicast and broadcast traffic. This approach makes support for quality of service (QoS), implemented through time slots, straightforward. QoS parameters include bandwidth, bit error rate, latency and jitter. The original request by a mobile terminal to send data uses specific time slots that are allocated for random access. The access point grants access by allocating specific time slots for a specific duration in transport channels. The mobile terminal then sends data without interruption from other mobile terminals operating on that frequency. A control channel provides feedback to the sender, indicating whether data was received in error and whether it must be retransmitted. The QoS delivered depends on how the HIPERLAN2 network interoperates with the fixed network; for example, if it is via packet-based Ethernet, cell-based ATM or IP.

HIPERLAN2 operates as a seamless extension of other networks, so wired network nodes see HIPERLAN2 nodes as other network nodes. All common networking protocols at layer 3 (IP and IPX, for example) will operate over HIPERLAN2, permitting all common network-based applications to operate, making the technology both network and application independent. Interoperation with Ethernet networks is supported from the beginning, but easy extensions also provide support for ATM, PPP, IP and UMTS. The standard has been specified with the clear objective of achieving interoperability and the industry consortium, HIPERLAN2 Global Forum (H2GF), aims to run tests to verify interoperability among products from member companies.

The most obvious application for HIPERLAN2 will be in the enterprise LAN environment but networks can also be deployed at 'hot spot' areas such as airports and hotels, supplying remote access and Internet services to business people. Its ability to act as an alternative access technology to 3G cellular networks is also a key application. As the high throughput and QoS features of HIPERLAN2 support the transmission of video streams in conjunction with datacom applications, HiperLAN2 has potential applications in the home by creating a wireless infrastructure for home devices (for connecting home PCs, VCRs, cameras and printers, for example).

HIPERLAN2 almost sounds too good to be true and price-to-market is a concern. For instance, the higher cost of silicon for OFDM operation could stall reasonably priced implementation. At present, costs remain relatively high for 5 GHz OFDM systems, mainly due to the high linearity demands that it places on the power amplifier in the

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transmitter and the low noise amplifier in the receiver. Consequently, HIPERLAN2 products will likely cost more than lower speed alternatives. Also, some view the fact that HIPERLAN2 is sophisticated and able to support a wide range of applications not necessarily as a selling point but as overkill that comes at a price.

IEEE 802.11a

On the other hand, IEEE 802.11a, due to its simplicity and maturity, represents lower costs and a faster time-to-market. However, although 802.11a and HIPERLAN2 have a near identical physical layer, they differ in the MAC layer. Deficiencies include built-in quality of service, guaranteeing performance in work environments and when streaming home video. Therefore, efforts to close the MAC gap are a priority. Moreover, whereas the IEEE 802.11a and HIPERLAN2 both meet US regulatory spectrum requirements, HIPERLAN2 is currently the only 5 GHz WLAN that meets European interference avoidance restrictions. Conversely, HIPERLAN2 must restrict the frequency range and power for the US to comply with FCC rules.

The danger is obvious with the possibility that the US and Europe will embrace two different standards. The consequence that the corporates' inability to use one standard and benefit from lower acquisition and support costs could delay deployment of 5GHz wireless LANs significantly. It is a serious issue for global development because they are two incompatible WLAN standards. Thus, if 802.11a and HIPERLAN2 wireless terminals were operating in the same area, there would be interference, no coexistence and no interworking. Also, no roaming would be possible if different access points were deployed in different public areas. The end user will be forced to make a standards choice and the 5 GHz WLAN market is in danger of being fragmented if different industry players adopt different standards.

To avoid this several industry partners have started a 5 GHz industry advisory group. In the HIPERLAN2 ETSI BRAN group and 802.11a Forum there are sub groups specifically looking at what is required to get to one standard. At present, there is much work to be done.

CONCLUSION

Over the last few years the short range wireless data networking headlines have been dominated by Bluetooth, resulting in unreasonably high expectations. What tends to be forgotten is that, in relation to the development of similar technologies, Bluetooth is still embryonic. It is also a victim of its own potential. Articles on the subject wax lyrical about the possibility of consumer appliances being Bluetooth-enabled to have the capacity to 'talk' to each other and the merits of so-called 'hidden computing' applications. These will allow synchronization of laptops, PDAs and mobile phones to automatically update calendars, appointments and e-mail when within range. Envisaged industrial applications include the wireless monitoring of transported goods and chemical processes.

However, most of the early applications are essentially cable replacement or connection substitutes primarily aimed at the cell phone and PDA markets. The industry needs to walk before it can run so it should be, and to a great extent is, concentrating on steady development and addressing ways of ensuring interoperability, standardization and coexistence issues. Bluetooth has its origins in Europe with its initial development concentrated in Scandinavia, and although it is truly a global technology, that is where its early deployment will be greatest. Bluetooth has attracted all the key players, investment is considerable and perhaps some of the hype is justified.

On the other side of the coin and the Atlantic, but in the same 2.4 GHz unlicensed frequency band, the IEEE 802.11b (WiFi) WLAN standard has been developed steadily without any razzmatazz. Its high data rate, together with the falling costs of PC cards, allied to the mobility and flexibility it offers has seen significant market growth. It is well placed to benefit from the rise in the use of laptops and growth in home broadband access. Globally, 802.11b networks are making inroads in 'hot spot' applications at airports, conference centers and hotels, and WiFi products are hitting the market. Again, issues of interoperability, coexistence and standardization are being addressed. However, although the establishment of a registered test house in Europe will aid acceptance, certification needs to be more widespread.

With the inevitability that the unlicensed 2.4 GHz band will become congested, the development of the 5 GHz band for next generation high speed WLANs is vital. However, the possibility of fragmentation, with separate standards being adopted in the US and Europe is a real threat to global development and could delay deployment significantly. A standards war will benefit nobody, possibly undermining confidence and making manufacturers wary of significant investment.

Going wireless has come with some strings attached but short range wireless systems have a long term future. Its ability to satisfy the industry's desire for seamless connectivity will ensure continued market growth and development.

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- Frost & Sullivan, www.frost.com
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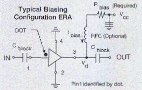
Model	* Freq. (MHz)	Gain (dB)	Max. Power Out (dBm, @1dB Comp.)	Dynamic Range NF(dB)	Dynamic Range IP3(dBm)	@Device Current (mA)	① Price $ea. (30 Qty.)
ERA-1SM	DC-8000	11.8	12.0	4.3	26.0	40	1.42
ERA-21SM	DC-8000	13.2	12.6	4.7	26.0	40	1.57
ERA-2SM	DC-6000	15.2	13.0	4.0	26.0	40	1.57
ERA-33SM	DC-3000	17.4	13.5	3.9	28.5	40	1.72
ERA-3SM	DC-3000	18.7	12.5	3.5	25.0	35	1.72
ERA-6SM	DC-4000	12.2	▲17.9	▲4.5	▲36.0	70	3.90
ERA-4SM	DC-4000	13.4	▲17.3	▲4.2	▲34.0	65	3.90
ERA-51SM	DC-4000	16.1	▲18.1	▲4.1	▲33.0	65	3.90
ERA-5SM	DC-4000	18.5	▲18.4	▲4.3	▲32.5	65	3.90
ERA-50SM	DC-1500	•18.3	▲17.2	▲3.5	▲32.5	60	2.95

Notes:
Specs are Typ. at 2GHz, 25°C except: ▲ indicates at 1GHz and • at 1.5GHz.
* Low freq. cutoff determined by external coupling capacitors.
① Price (ea.) Qty.1000: ERA-1SM $1.19, -2SM or -21SM $1.33, -3SM or -33SM $1.48, -4SM, -5SM,-6SM or -51SM $2.95, -50SM $2.00.

Typical Biasing Configuration ERA



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US Army Lets Long Range Advanced Surveillance Systems Contract

DRS Technologies has received a contract to provide Long Range Advance Scout Surveillance Systems (LRAS3) for the US Army's High Mobility Multipurpose Wheeled Vehicles. The $8.7 M contract was awarded by Raytheon System Company's Electronic Systems operation in McKinney, TX and provides additional funding and added scope to the LRAS3 program. Work for the contract will be done at the company's DRS Optronics unit in Palm Bay, FL.

The long range multi-sensor LRS3 provides real-time detection, recognition, identification and pinpointing of distant target locations for the US Army's Scout vehicles. It bridges the gap between systems now in the field and the Future Scout and Cavalry System, and enables heavy battalion and regimental scouts to conduct 24-hour reconnaissance and surveillance missions while remaining outside the acquisition and engagement range of threats. Usually deployed on the M1114 HMMWV in a mounted configuration, it can also be used on tripodes during dismounted missions. The system provides precise target location by employing Second Generation Forward Looking Infrared (FLIR), a global positioning system interferometer, a laser range finder and a television camera.

The M1114 HMMWV Scouts are frequently deployed to assist heavy battalion missions in remote areas with rough terrain and difficult conditions where agility is a primary requirement for supporting multi-pronged strategies during ground conflicts. The vehicles provide light, tactical, mobile platforms for command and control, special purpose shelter carriers and special purpose weapons.

US Firms Face European Challenge as Fighter Market Enters Transitional Period

A new report from Forecast International/DMS, "The World Market for Fighter/Attack/Jet Trainer Aircraft — 2001-2010," finds, that while the next generation of combat aircraft is moving into production, timetable slippages have afforded manufacturers of current designs opportunities to lobby for attrition buys from their own governments and to offer their products on the international market.

The Boeing F-15 is cited as the most obvious beneficiary of these developments. The report notes that although the program appeared to be in its final stages a year ago, the US Air Force has ordered 10 more with FY00-01 funds, Saudi Arabia wants another 24 and Korea's airforce would like to use the F-15 to fill its F-X new fighter requirement. Another small USAF F-15 buy is expected since the F-22, its intended replacement, failed to achieve all the milestones required for a Low Rate Initial Production decision in December 2000.

Forecast International expects the market to gain momentum during the next 10 years and forecasts a total production of 3,500 aircraft in the class valued at $124 B in the 2001-2010 period. Boeing is expected to lead the field with deliveries of 600+ aircraft worth $27.6 B. The Eurofighter consortium is expected to take second place with sales of $21 B and the Lockheed/Boeing's F-22 is expected to account for sales of $16.5 B.

At this time, the US Air Force is still buying small numbers of F-16s from Lockheed Martin, the company is promoting the aircraft in international competitions and its current backlog stands at more than 230 units. The selection of the final contractor (or contractors) for the Joint Strike Fighter is due in late 2001. The Eurofighter Typhoon is in production and Greece has committed to up to 90 aircraft. Dassault Aviation has delivered the first Rafale Ms to France, it reports interest from several other nations and will deliver the initial Rafale Bs to France in mid-decade. Saab has a 28-unit order from South Africa for its JAS Grippen and is selling it aggressively to some eastern European and Latin American prospects. The T/A-50 advanced trainer designed by Samsung in collaboration with Lockheed Fort Worth is scheduled to fly in 2002.

The report expects that Boeing and Lockheed will face very stiff competition from a European industry offering its Eurofighters, Rafales and Grippens. It also expects that if its cost and performance targets can be met, the Joint Strike Fighter will be very difficult to beat. For additional information, contact: Bill Dane, Forecast International (203) 426-0800, ext. 146.

Next Decade US Defense Electronics Market to Rank With the Best

Another new report from Forecast international/DMS, "Overview of the US Defense Electronics Market," forecasts that the next 10 years will be the decade of production and procurement in that market. Considering current production alone, defense electronics is predicted to generate nearly $128 B in sales during the coming 10 years.

The study notes that ships, aircraft and vehicles are becoming too expensive to simply replace and increased emphasis will be placed on upgrading existing systems to extend their operational lives. The concept is much like when a PC starts to get outdated, it is usually quicker and cheaper to upgrade key components than go out and buy a new system. The study finds that many of the "next-generation" defense electronics systems developed in the 1990s are now being built and deployed. With their production runs expected to continue until at least 2015, the US defense electronics segment will be the healthiest and most profitable of the entire US defense market.

Procurement is forecast to rise to $13.5 B in 2005 as the newest versions of military electronics equipment begin their deployments. The market is forecast to peak in 2006 and 2007 and decline thereafter to a level of approximately $10.9 B in 2010. After 2010, emphasis and funds will shift from production to the research and development required for "future technology" systems. For additional information, contact: Richard Sterk, Forecast International (203) 426-0800.

Tactical Air Control Party Equipment Modernized

Technology acquired by the US Air Force Electronics Systems Center, Hanscom AFB has the potential for increasing the effectiveness of the Air Force's Tactical Air Control Parties (TACP).

The TACP, typically a two-man airman team, works in an Army ground unit directing close air support firepower toward enemy targets on the ground. The TACP modernization program involves four main products, a dismounted multi-band radio, a laser range finder, a computer software suite and a vehicle-mounted package radio.

The dismounted radio, the Manpack, is a multi-band, multimode radio covering VHF, UHF and UHF SATCOM communications bands. The unit is also compatible with the single Channel Ground and Airborne Radio System used by the Army. The Manpack takes the current three radios and combines those into one. Last year, 221 Harris PRC-117F Manpack Radios were delivered to TACP units. A contract for an additional 561 radios has been let and the first 230 units are scheduled for delivery by July 2001. The radio upgrade has cost a bit more than $10 M. The new Mark VII Eyesafe Laser Range Finder, which looks like a regular pair of binoculars, also enhances TACP capability by replacing previous range estimates with precision coordinate information. When someone looks through the range finder, it emits a laser beam onto the target, which bounces back and provides the exact coordinates. Litton Laser Systems will build 184 units at a cost of $9 M and deliver the first of these in March 2002. Paper maps will be replaced with continuously-updated computer generated displays that will indicate the user's location, will display enemy coordinates using data from the range finder and will track incoming aircraft. A prototype hand-held computer will be evaluated for the application. The entire dismounted systems package, computer, radio and range finder will fit into a single rucksack. Systems are scheduled to be fully deployed by December of next year. ■

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The Force Behind The Field.

R & S Claims New Standards in High End Spectrum Analyzers

German contractor Rohde & Schwarz (R & S) is claiming that its newly launched FSU3 and FSU8 spectrum analysers set 'new standards' in dynamic range, measurement accuracy and speed within high end equipments of their type. In backing up its claim, the company notes an average displayed noise level of –158 dB (at 1 Hz bandwidth and with 1 dB compression of the input mixer at 13 dBm) and a typical third-order intercept point of 25 dBm for the equipments, together with the ability to simultaneously process signals with widely different levels without mutual corruption. Again, the use of fast data transfers using either an IEC/IEEE bus or an Ethernet local area network, together with 'optimised' test routines, are claimed to offer extremely high measurement speeds. Here, the equipments are noted as being capable of 30 measurements per second in manual mode and as having minimum sweep time and zero span values of 2.5 ms and 1 μs, respectively. In addition to all common test routines, R & S notes that the FSU family also provides adjacent channel power measurement as standard and resolution bandwidths of up to 50 MHz. At resolution bandwidths of up to 30 kHz, fast Fourier transform is available as an option, facilitating, it is claimed, the ability to take measurements at speeds of up to 300 times those of equipments using digital filters. The FS-K3, FS-K4 and FS-K5 software packages support the FSU family (covering the 20 Hz to 3.6 GHz band in its FSU3 model and the 20 Hz to 8 GHz range with the FSU8 device). Of these, the FS-K3 tool addresses noise figure, noise temperature and gain measurement while the FS-K4 package automates phase noise measurement over a complete offset frequency range and determines residual frequency modulation. The FS-K5 application firmware is designed for radio frequency and modulation measurements.

Slovenian Provider Picks Siemens for DSL Technology

Slovenian telecommunications provider Telecom Slovenije has awarded German supplier Siemens Information and Communication Networks (SICN) a contract covering the supply of Digital Subscriber Line (DSL) technology. Working with in-country partner company Iskratel, SICN will install and commission 20,000 asynchronous DSL ports at 100 locations throughout Slovenia during the course of 2001. Based on Siemens' Attane XpressLink DSL accesses multiplexer, the system will increase the capacity of Slovenije's existing copper wire infrastructure in order to facilitate broadband data transport.

Chinese Radar Insight

In the wake of the EP-3E Hainan incident, 'International Report' has received insight into current mainland Chinese radar technology in the form of details of the Type 2405 shipborne surveillance radar. Developed by the Nanjing Marine Radar Institute (NMRI), the Type 2405 sensor is described as being a C-band (4 to 8 GHz) multifunction equipment that is designed for shipboard air and surface surveillance, target indication and anti-shipping missile defence. The radar is equipped with a cosecant^2 lightweight stabilised antenna that provides 50° coverage and a sidelobe value of –30 dB. Stabilisation is in both pitch and roll, and the equipment makes use of a 'wideband, high power, transistor-travelling wave tube' transmitter chain that incorporates solid-state modulators and a wideband linear receiver. The Type 2405 is further noted as making use of stable frequency synthesis, frequency agility, digital moving target indication, constant false alarm rate, sidelobe suppression and variable polarisation (horizontal and vertical). Data display is by means of a colour raster terminal and the sensor's antenna assembly incorporates an integral identification friend or foe array. At the –3 dB point, Type 2405 has an azimuth beamwidth of 1.5° and the sensor is described as having azimuth and range accuracy values of 0.3° RMS and 50 m RMS, respectively. The type's resolution values are given as being 2° in azimuth and 150 m in range and its antenna scans at the rate of either 15 or 30 rpm, depending operator selection. NMRI further notes that the Type 2405's antenna assembly (including its stabilisation platform) weighs less than 520 kg and that its free space coverage extends to an altitude and range of plus 9 km and plus 96 km, respectively.

French Air Force Orders Giraffe Radars

The French Air Force has ordered a small quantity (thought to be four) of Giraffe AMB radars for use in an air defence application. Produced by Swedish contractor Ericsson Microwave, Giraffe AMB is a G/H-band (4 to 8 GHz) 3-D active phased array sensor that was originally developed for use in Sweden's RBS 23 BAMSE and RBS 97 air defence missile systems. System features include the ability to detect targets from ground level up to an altitude of more than 20 km, and automatic helicopter detection mode, threat evaluation and automatic combat control functions, and identification friend-or-foe Mk XII compatibility. Alongside France, the Giraffe AMB radar is known to have been procured by the Swedish Army (under the designation UndE 23) and Coastal Artillery arm. In this latter con-text, the radar is a 2-D sensor, is mounted on a MOWAG armoured command and control vehicle, and is designated as the KAPRIS system.

Europe Creates Super Missile Entity

After a protracted round of negotiations, European contractor's BAE Systems, the European Aeronautic, Defence and Space (EADS) Company and Finmeccanica have agreed to the establishment of the pan-European MBDA missile group. To create MBDA, the missile activities of Matra BAe Dynamics, EADS Aerospatiale Matra Missiles and the missile sector of Alenia Marconi Systems are being amalgamated, with BAE Systems and EADS each owning 37.5 percent of the business and Finmeccanica holding the remaining 25 percent. At the point of its creation, MBDA is understood to have an orderbook valued at Euro 13 billion (US$10.9 B), making it the world's second largest missile contractor after Raytheon Systems. The new company is to be headed up by Matra BAe Dynamics' current chief executive officer Fabrice Brégier, with BAE Systems' Alan Garwood and Finmeccanica's Mario Di Donato being appointed chief operating officers.

Looking to the future, EADS Deutschland is reported as being extremely keen to see German contractor LFK merge its missile business into the new entity. As currently configured, EADS owns 70 percent of LFK and the company would like to consolidate it with Germany's other major airborne weapons manufacturer BGT. Dhiel (BGT's parent company) does not favour this and EADS is taking the attitude that if no LFK/BGT deal can be struck by the third quarter of this year, it will go ahead with rolling LFK into the MBDA group on its own.

The creation of MBDA has also impacted the BAE Systems/Finmeccanica Alenia Marconi Systems (AMS) joint venture. Here, AMS loses its missile business to MBDA but gains BAE Systems' Combat and Radar Systems subsidiary and will continue operating with a business portfolio that encompasses radar, command and control systems, simulation and training systems, and air traffic management systems. Balancing the two companies' 50 percent holdings in AMS is understood to have involved Finmeccanica in further investment in the Euro 1.3 billion turnover organisation. Britain's David Singleton has been appointed chief executive officer of the revised AMS with Antonio Bontempi as his deputy. ■

New All-silicon Chips for Wireless Base Stations

Newsedge reports that Lucent Technologies has announced the development of an all-silicon chipset for wireless base stations. The announcement was made at the recent Solid State Circuits Conference in San Francisco. These new chips will be used in base stations that receive signals from mobile devices, such as cell phones and handheld computers. The receivers in use now typically have 10 to 20 GaAs chips compared to only three of the new silicon chips. Lucent claims the new system is 100 times smaller at a cost savings of 10 to 100 times and will have the effect of improving quality and lessening the cost of wireless networks. The breakthrough is expected to be deployed over the next four or five years.

Semiconductor Foundries Bounce Back to Lead the Industry

Despite having played a limited role during the last semiconductor boom of 1993 to 1995, the foundry business has become a primary industry driver as IDMs and OEMs become increasingly dependent on outsourcing manufacturing. The Cahners In-Stat Group finds that while the industry grew by 36.8 percent in 2000, leading foundries grew even faster with the largest achieving growth rates in the 60 to 125 percent range.

Satisfying the approximately 500 to 600 fabless chip start-ups that have emerged in the past decade will require foundries to produce more of the world's chips over the coming decade. "While the semiconductor industry braces for much slower growth in 2001, the foundry segment is expected to outperform the industry as a whole with foundry revenues expected to rise from $7.6 B in 1999 to $35.4 B in 2004," said Steve Cullen, director of In-Stat's semiconductor service. They also find that both Integrated Device Manufactures such as Motorola and system OEMs are shifting more of their manufacturing to third party foundries. Some IDMs are even converting older fab plants into foundries. "With several fables chip makers leaping into manufacturing, the industry's well defined functional segmentation lines are becoming blurred," said Curren. "Foundries will have a mojor impact on the new hybrid semiconductor development strategy." In-Stat also projects that the foundry business will become more geographically diversified over the next few years, extending its reach into other parts of Asia as well as the United States and Europe.

A report "Foundries: Outsourcing the Semiconductor Future" can be purchased from In-Stat at: www.instat.com/catalog/cat-si.htm#0101sf.

Latin America's Cellular/PCS Subscribers to Pass 150 Million by 2006

The Yankee Group reports via Newsedge that Latin America's wireless mobile markets continued their remarkable growth trend over the course of the last year, reaching a regional average growth rate of 58.6 percent during 2000. Wireless penetration increased from a regional average of 10 percent at the end of 1999 to 15.6 percent by the end of 2000.

"Following such impressive growth rates in the past years, the Yankee Group expects that growth will begin to slow down in this sector. Our total cellular/PCS subscriber forecast will reach an aggregate 2000-2006 compound annual growth rate of 17.9 percent for the entire region, and total wireless subscribers will more than double from 60 million at year-end 2000 to 162 million at the end of 2006," said Cristiane Mahler of the Yankee Group's Wireless/Mobile Latin America Practice. "In such a capital-intensive industry, scalability and critical mass are paramount for wireless operators to maintain profitability in increasingly competitive environments. As such, there is a major push by regional players to consolidate their regional positions with nation- and region-wide expansions, as well as to streamline operations. This is illustrated through Telephonica's persistent attempts to gain a nationwide footprint in Mexico's wireless market and Telecon Italia Mobile's pursuit to consolidate nationwide coverage in Brazil and Venezuela." Operators across the region are currently making important decisions with respect to 2.5 and 3G network deployments. In the fourth quarter of 2000, following NTT DoCoMo's investment in AT&T Wireless, the American company announced a contract to deploy a GSM/GPRS network alongside its TDMA infrastructure that will enable the rollout of advanced mobile data services to its customers. Following this lead, several TDMA operators have announced contracts to do the same. CDMA vendors expect that 1xRTT infrastructure will be available by mid-2001, with commercial deployment soon after. For more information, e-mail: hroach@yankeegroup.com.

Ericsson Signs GSM, Multiservice, IP Backbone Contracts in China

Ericsson has been awarded a series of contracts in China for GSM and multiservice network projects including IP backbone construction in Beijing and the provinces of Shandong, Hebei and Yunnan. With a combined value of more than USD 400 Million, the contracts further strengthen Ericsson's market leadership in China.

Beijing Ericsson Mobile Communications Company Limited and Nanjing Ericsson Panda Communications

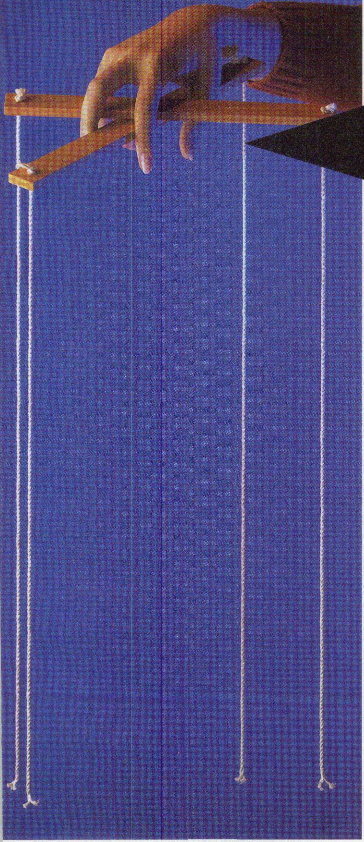
Company Limited, Ericsson's two major joint venture companies in China, will deliver all related systems and equipment. All contracts are being carried out with Chinese partners.

Ericsson will supply Shandong Telecom with IP backbone routers for their inter-city broadband IP Networks. This is a follow-up to a similar contract last year. Under an agreement with China Telecom, Ericsson will also supply routers for all nodes of China Telecom's second data communications expansion project. In a third agreement, Ericsson will also supply similar equipment to Jiangsu Mobile in addition to switches and ADSL equipment for Liaoning Telecom.

In a GSM expansion contract with Shandong Mobile, Ericsson will supply radio and switching infrastructure elements, prepaid systems, network planning and operational support services as well as customer and project support services. Ericsson is the sole supplier in the fast growing GSM market in Shandong Province, which has a population of over 90 million. A similar expansion contract will supply switching and radio equipment, adding GPRS and Mobile N services for Hebei Mobile. A fifth GSM expansion project for Yunnan Unicom is scheduled for completion in June of this year and a similar expansion project for Hubei Mobile is scheduled for completion in September. Additional contracts with Chongging Mobile, Jiangsu Mobile and Xinjiang Mobile are also in place. Additional information is available on the Web at: www.ericsson.com/press.

ETSI Completes First Specifications for Satellite-based PCS Systems

The European Telecommunications Standards Institute (ETSI) has published the first release of a complete set of specifications for a mobile satellite radio interface, known as "GEO-Mobile Radio Interface specifications (GMR)." There are two variants of the GMR standards in this first release: GMR-1, led by HNS Hughes and adopted by the Thuraya system, and GMR-2, led by Lockheed Martin Global Telecommunications, developed for the ASIA Cellular Satellite System (AceS). The Thuraya system provides services in 99 countries spanning Europe, North and Central Africa, Middle East, Central Asia and the Indian Subcontinent. The AseS system provides services over an area covering India, China, Indonesia, as well as most of South East Asia. More detail is available on the ETSI Web site at: www.etsi.org. ■



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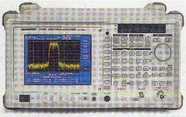

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For almost any 3G mobile telephony format!

The R3267/3273 spectrum analyzers feature a frequency span accuracy within ±1% in the 8GHz/26.5 GHz band, and a dynamic range of -154dBc/Hz (typ.) in the 2GHz band. They are designed to be configurable with virtually any 3G mobile telephony format. The unique Digital Modulation Analysis option can measure Bluetooth, W-CDMA, 3GPP, cdma2000, GSM/DECT/EDGE, PDC/PHS/IS-136, cdmaOne, AMPS/JTACS/NTACS, and others.

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INDUSTRY NEWS

■ **Endwave Corp.** acquired **M/A-COM's Broadband Wireless Business Unit (BBU)**, initiating a strategic relationship with Tyco Electronics and making Endwave the most complete RF subsystem supplier for millimeter-wave radio OEMs.

■ **Aeroflex Inc.** has acquired **TriLink Communications Corp.** for approximately 1.2 million shares of Aeroflex common stock. This acquisition adds key optical components to Aeroflex's growing portfolio of proprietary fiber optic modules.

■ **Plexus Corp.** has signed a definitive agreement to acquire **Qtron Inc.** The acquisition will expand Plexus' presence, establishing a manufacturing base in Southern California's fast-growing market.

■ **Alamosa Holdings Inc.** has completed its merger with **Southwest PCS Holdings Inc.** The acquisition increases Alamosa's licensed population by 2.8 million. Concurrent with the acquisition of Southwest, Alamosa has also gained the right to service additional territory from Sprint PCS totaling approximately 115,000 residents.

■ **TRW** has formed **Velocium**, a new company that will provide very high speed InP and GaAs components and other products for fiber optic and wireless telecommunications systems.

■ **Advanced Hardware Architectures (AHA)** opened a new design center in Portland, OR. The new center will develop broadband wireless products based on the company's patented Turbo Product Code (TPC) technology.

■ **Corning Cable Systems** opened a new production facility dedicated to optical manufacturing services. The facility, approximately 20,000 square feet, is located in Hickory, NC.

■ **First Source Inc.** has opened a new Southern California sales office to provide additional local sales support for the San Diego and Los Angeles areas.

■ **RIFOCS Corp.** has relocated its **Harsh Environments Division**, formerly known as Mil/Aero, into a new 8000 square-foot facility. The move to a larger manufacturing space provides plenty of room for the division to expand.

■ As part of a high volume production agreement, **Raytheon's RF Components division** will supply the **Hyundai Corp.** with the RMPA 1951 GaAs HBT power amplifier for the handset manufacturer's TX-20B PCS platform. Hyundai has earmarked the dualband tri-mode TX-20B for the US CDMA market.

■ **StratEdge** has contracted to assemble and test **TriQuint Semiconductor**'s OC-192 broadband amplifiers using patented, high performance StratEdge packages.

■ **Tektronix Inc.** has partnered with **Telogy Inc.** to provide a unique instrumentation trade-in program allowing Tektronix customers to trade-in used test instrumentation when purchasing new products from Tektronix. In related news, **RSoft Inc.** has entered into an exclusive distribution agreement with **Sony/Tektronix** for sales and services of its software products in Japan. Sony/Tektronix will handle RSoft's full line of software products for CAD and simulation of both photonic devices and optical communication systems.

■ **GSI Lumonics** and **Melles Griot** have agreed to work together to mutually enhance their ability to supply manufacturing solutions to fiber optic telecommunication component manufacturers.

■ **University College London (UCL)** and **Agilent Technologies** marked their partnership with the opening of the Agilent Broadband Communications Laboratory. The new lab will also play an integral part in UCL's Master's program.

■ **Zentrix Technologies** and the electrical and computer engineering department of the **University of Florida** have announced a collaborative partnership on circuit packages. With this partnership, the University of Florida will use Zentrix Technologies low ground inductance, high performance CuPack® Circuit Packages to develop RF and microwave circuits.

■ **Sprague-Goodman Electronics Inc.** added **Mouser Electronics**, Mansfield, TX, to its franchised dealer network. Sprague-Goodman's products are included in Mouser's on-line and nationally distributed print catalogs.

■ **Ansoft Corp.** and **Agilent Technologies Inc.** have signed an agreement in which Agilent has agreed to license its high frequency structure simulator (HFSS) software product line to Ansoft. Under the agreement, Agilent may also purchase up to 60 licenses of Ansoft HFSS.

■ **Taiyo Yuden Co. Ltd.** announced that its Bluetooth™ Module is the first full module in the world to earn certification for compliance with the requirements of Bluetooth Specification Version 1.1. The company has certified two variations of its Class 2 module, one with a USB interface and one with a UART interface.

■ **Merrimac Industries Inc.** announced that its subsidiary, **Filtran Microcircuits Inc.**, has been awarded the ISO 9002 certification from Factory Mutual Research. The certification completes the company's fourth and final phase of its ISO certification initiative, with all of the company's facilities certified.

■ **dBm LLC** has successfully completed its first year of operations. During that year, the New Jersey-based test equipment manufacturer purchased the Satellite Link

[Continued on page 64]

Emulator product line, and is now delivering an enhanced version of the product as well as supporting existing customers. The company also recently announced a Carrier to Noise Generator product line.

■ **Labtech**, a member of the Intelek group of companies, has won the Queen's Award for Enterprise, the highest honor which can be bestowed upon a UK company.

FINANCIAL NEWS

■ **Motorola Inc.** reports sales of $7.8 B for the first quarter of 2001, compared to $8.8 B for the same period last year. Net loss was $206 M (9¢/share) compared to a net income of $481 M (21¢/share) for the first quarter of 2000.

■ **Andrew Corp.** reports sales of $251.5 M for the second quarter ended March 31, compared to $220.0 M for the same period last year. Net income was $8.2 M (10¢/share) compared to $17.3 M (21¢/share) for the second quarter of 2000.

■ **Powerwave Technologies Inc.** reports sales of $73.0 M for the first quarter ended April 1, compared to $103.9 M for the same period last year. Net loss was $9.5 M (15¢/share) compared to a net income of $10.3 M (16¢/share) for the first quarter of 2000.

■ **TESSCO Technologies Inc.** reports sales of $60.0 M for the fourth quarter ended April 1, compared to $56.3 M for the same period last year. Net income was $220 K (5¢/share) compared to $1.4 M (31¢/share) for the fourth quarter of 2000.

■ **Cree Inc.** reports sales of $53.37 M for the third quarter ended March 25, compared to $29.53 for the same period last year. Net income was $13.72 M (18¢/diluted share) compared to $8.96 M (12¢/diluted share) for the third quarter of 2000.

■ **Advanced Power Technology** reports sales of $13.2 M for the first quarter ended March 31, compared to $9.6 M for the same period last year. Net income was $1.8 M (19¢/diluted share) compared to $244 K (4¢/diluted share) for the first quarter of 2000.

■ **Superconductor Technologies Inc.** reports sales of $2.5 M for the first quarter ended March 31, compared to $1.0 M for the same period last year. Net loss was $4.6 M (26¢/common share) compared to $5.3 M (47¢/common share) for the first quarter of 2000.

■ **Raytheon Co.**'s Secure Mobile Anti-jam Reliable Tactical Terminal (SMART-T) satellite communications (SATCOM) program has received a three-year $49 M award to develop, test and validate an advanced extremely high frequency retrofit kit for installation on approximately 330 SATCOM ground terminals.

[Continued on page 66]

AROUND THE CIRCUIT

■ **Zeevo Inc.** has closed a third round of funding with $25.5 M in equity financing. The round is led by **Dell Ventures**. Zeevo expects to use the money to expand sales, marketing and operations talent for ramping its product line, a Bluetooth SoC solution to production.

■ **Antenova** has secured £3.4 M of venture capital to fund its smart directional antenna technology for mobile communications, from a consortium led by **Cambridge Gateway Fund**. The funding round will allow Antenova to develop prototypes of its product ideas.

CONTRACTS

■ **LCC International Inc.** has won a contract from Click Vodafone to perform deployment and overall project management services for phase three of the nationwide Egyptian network. The $16 M, one-year contract extension is in addition to the Operations and Maintenance contract awarded to LCC in October of 2000.

■ **M/A-COM SIGINT Products** received the highest single order for its Model 388 IF-to-Tape/Baseband converter from **Raytheon Systems Co.** The models are expected to be delivered later this year.

■ **Microwave Data Systems (MDS) Inc.** received a follow-on purchase order to supply additional LEDR point-to-point radios for installation in the network of the Brazilian telephone company, Telemar. This order is in addition to the $7 M order received by MDS in February for LEDR radios.

PERSONNEL

■ Palomar Technologies Inc. promoted **Kevin Conlon** to chief operating officer. Conlon joined the company in 1997 as VP, sales and marketing.

■ Advanced Hardware Architectures (AHA) appointed **Eric Kinneberg** chief financial officer. Kinneberg comes to AHA from Southern Era Resources, where he served as VP of finance and chief financial officer.

■ The Board of Directors at Mimix Broadband has elected **Charles Lee** as chairman of the board. The election represents a new position created by the Board. Lee founded Charles Lee Enterprise in 1990 to facilitate strategic alliances between America and Asia.

■ **Denis P. Ritchie** has joined Microwave Device Technology Corp. as president. Most recently, Ritchie served as director of marketing and sales for Analogic Corp.

■ Aptix Corp. appointed **Fuad Musa** president; Amr Mohsen continues as the company's CEO and chairman. Most recently, Musa was president and CEO at Moscape, a Magma company.

■ Everett Charles Technologies (ECT) promoted **Patrick T. Flynn** to president of the recently realigned ECT equipment and services group. Flynn joined ECT last year as group VP. In related news, the company appointed **Joseph Baalman** regional sales manager for the northwest region. Baalman will be responsible for ECT Test Fixture Group sales including TTI product and In-Circuit Pogos. **Ryan McClusky** also joined the company, and will be responsible for in-circuit and functional fixture sales in the north central region. Before joining ECT, McClusky worked for Mahar Tool Co. as an account manager for Daimler Chrysler.

▲ *Pushp Kumar Sharma*

■ TriPoint Global Communications promoted **Pushp Kumar Sharma** to VP and chief information officer. Previously, Sharma was VP, information systems at the company.

■ TDK Semiconductor Corp. promoted **Barry Thompson** from a director of engineering to VP of engineering. Thompson will be responsible for leading the company's engineering teams in new product development and product enhancements.

■ Comtech Telecommunications Corp.'s New York subsidiary, Comtech PST Corp., named **Larry Konopelko** to the position of executive VP and general manager. Most recently, Konopelko was VP and general manager of MPD Technologies Inc.

■ GHz Technology Inc. appointed **Michael Yam** VP of engineering. In this position, Yam will be focusing on application support activities. Most recently, Yam has held management posts at Globalstar LP, a consortium of international telecommunication companies.

■ **Wolfgang Schmittseifer** will become Rohde & Schwarz's managing director for marketing and sales in North America, as of July 1. Schmittseifer will be responsible for all corporate sales activities in the US and Canada and for the cooperation with sales partners.

▲ *Todd Brown*

■ Alpha Industries named **Todd Brown** director of European sales. Prior to joining Alpha, Brown held a variety of sales and marketing management positions at MuRata, AMP and RF Monolithics.

■ **Andy Janes** has been named the sales manager of the Tensolite Precision Coaxial and Multi-conductor Harnesses and Assemblies group in Vancouver, Washington. Janes has been at the Vancouver facility for over 10 years supporting product sales and application engineering.

[Continued on page 68]

CIRCLE 140 ON READER SERVICE CARD

AROUND THE CIRCUIT

▲ Carlos E. Pedraza

■ **Carlos E. Pedraza** joined Times Microwave Systems as regional sales manager for Latin America including Mexico. Previously, Pedraza was part of the management team at Marped Corp., a manufacturer of antennas and distributor of Times cables in Colombia.

■ First Source Inc. has named **Debi Luce** Southwest regional sales manager. Luce comes to the company from Arrow/RF Vision.

▲ Nick Trickett-Bell

■ National Semiconductor Corp. appointed **Nick Trickett-Bell** regional sales manager for the UK and Ireland. Most recently, Trickett-Bell has been responsible for the development and management of the company's major account group in the region as well as strategic business development.

■ Sea-Port Technical Sales added **Steve Pennock** to its Northwest sales representation team. Formerly, Pennock was VP of sales for Analysis Plus and prior to that sold software for Ansoft Corp. and performed research for 12 years at Lawrence Livermore National Lab.

▲ Roy Wang

■ ITT Industries, Cannon appointed **Roy Wang** director of operations for Cannon connector products in Asia. Wang will be responsible for directing the region's operational activities and lead employees in the areas of engineering, materials, production and quality control.

■ Excellon Automation Co. promoted **Bob Bell** to general manager mechanical business unit. Most recently, Bell served as Excellon's general manager of customer engineering. The company promoted **George Schmeltzer** to general manager customer engineering business unit to replace Bell. Previously, Schmeltzer was director of information technology for the company.

▲ Patricia Stubban

■ Melles Griot named **Patricia Stubban** general manager for the Photonics Components division in Irvine, CA. Stubban brings with her 19 years experience in operations and general management with an emphasis in production and material control.

■ BTC Electronic Components appointed **Scott Korenstein** account executive in its Raleigh, NC office. Korenstein will manage strategic commercial accounts with an emphasis on currently acquired product lines.

■ **Gregory G. Finn** has joined Antenna Specialists, an Allen Telecom company, as a senior RF/antenna design engineer. Finn will be responsible for the design and development of antennas and antenna interface electronics including prototyping, testing, documentation and coordination of release to production.

WEB SITES

■ Version 2 of **www.testdesignonline.com** has just been launched. Users can now configure a complete test station by selection from hundreds of products from leading manufacturers, and obtain an Excel spreadsheet complete with prices, product descriptions, rack heights, links to the data sheets of products selected and more. The site is an ideal starting point for costing and configuring a test system, and also provides technical notes that provide information on products, applications and test ideas.

■ **Jensen Tools** has recently made a number of improvements to its Web site, www.jensentools.com. The site now offers secure online ordering, an improved search function, instant order processing, online order processing for international customers, a stock status feature, detailed order acknowledgements, express order shipping options, online technical documents and free technical support. Registered customers will also be able to save shipping addresses and order history under a password-protected login name for added convenience.

■ **Comsearch** officially launched Datazone,™ a repository of standardized reports, studies and data products for the telecommunications industry. Marketing, business development, engineering or sales professionals can order market intelligence reports, spectrum usage studies, and technical and GIS data directly from the company's Web site, www.comsearch.com, to help them make informed business decisions.

REP APPOINTMENTS

■ **CMC Wireless Components**, Phoenix, AZ, has made a series of rep appointments. **Stewart Technology**, Danville, CA, will handle Southern California and **Innovative Marketing and Sales**, Coppell, TX, will cover Texas, while **Micrel Associates**, Rock Tavern, NY, will be responsible for New York, New Jersey and Pennsylvania and **O & S Associates**, New Bedford, MA, will handle New England. **BWS Microwave Marketing Inc.** will cover Atlanta, Florida, Georgia, North and South Carolina, and Tennessee.

■ **Tyco Electronics' M/A-COM** has named **First Source Inc.** as its national distributor for the full line of M/A-COM components, including those manufactured by its recent acquisition, the former Stellex Electronics.

■ **Sprague-Goodman Electronics Inc.** appointed two new sales representatives. **Tekmar Sales**, Rye Brook, NY, will represent southern New York and northern New Jersey, while **Feller Associates**, Highland Park, IL, will be responsible for sales in northern Illinois and southern Wisconsin.

POWER EFFICIENT MMIC FREQUENCY TRIPLERS

The design of an efficient frequency tripler for an S-/X-band communications receiver is described. An approach for optimizing the tripler for best power efficiency is presented. The tripler topology consists of the harmonic generator circuit, a bandpass filter and an amplifier. A novel tunable filter to increase the bandwidth of the tripler was fabricated and tested. Measured performance of an X-band GaAs MMIC frequency tripler is shown versus simulations.

Spacecraft in deep space missions, or even terrestrial satellites, have a limited amount of power available. It is very expensive to accelerate each pound of the spacecraft to 17,600 mph or greater. Compared to terrestrial communications equipment, space communication systems place a higher priority on small, lightweight and low power circuitry. In cases where commercially available components do not fit well with space communication designs, custom designed MMICs can often fit the small, lightweight and low power circuitry requirements for space communications. A small low power S-/X-band receiver was being developed under NASA Advanced Technology Development (ATD) funds at Johns Hopkins Applied Physics Laboratory. An early prototype of the receiver included a commercial frequency tripler module of several cubic inches that consumed 1.4 W of DC power. It was replaced with a custom GaAs MMIC frequency tripler 54 by 54 mils square dissipating 0.15 W resulting in an order of magnitude improvement in weight, size and power consumption. Using this custom GaAs frequency tripler MMIC saved size, weight and power consumption in an S-/X-band receiver module requiring a total 1.3 W of DC power — less than the commercial tripler module alone.

An approach to optimize the power efficiency of an MMIC tripler is presented. It is based on a topology suggested previously.[1] There are three basic sections of the frequency multiplier: the harmonic generation section, a filter section and an amplifier for the third harmonic.

[Continued on page 72]

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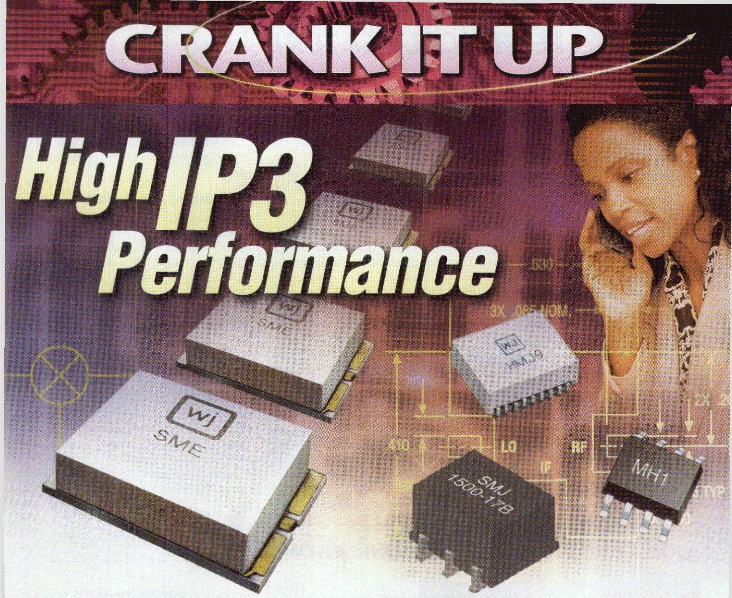

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SME 1900-17	1600-2400	1400-2390	10-250	+17	+29	7.4	26	S-PAK-3
SME 1400B-17	1-2200	1-2200	1-2000	+17	+27	6.5	30	S-PAK-3
SME 1400B-13	1-2200	1-2200	1-2000	+13	+22	6.5	30	S-PAK-3
SME 1400B-10	1-2200	1-2200	1-2000	+10	+19	6.2	35	S-PAK-3
SMJ 500-17A	2-500	2-500	DC-500	+17	+21	6.0	44	J-PAK-6A
SMJ 500-13A	2-500	2-500	DC-500	+13	+20	6.0	44	J-PAK-6A
SMJ 1500-17B	10-1500	10-1500	DC-1000	+17	+20	6.0	30	J-PAK-6B
SMJ 1500-13B	10-1500	10-1500	DC-1000	+13	+17	6.0	40	J-PAK-6B
SMJ 1003-17C	800-1000	700-980	20-100	+17	+26	7.0	32	J-PAK-6C

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Figure 1 illustrates the relative spectrum of the signal in each of the three sections of the tripler. In the harmonic generation section, multiple harmonics are produced with a nonlinear device (GaAs MESFET). A filter section greatly attenuates the strong fundamental and second harmonics. Higher order harmonics could be filtered in a bandpass section, but the on-chip filter is required only to filter out the first and second harmonics such that the third harmonic dominates the final amplifier stage. This topology works well for a frequency tripler and could be used for an efficient frequency doubler. This topology of a harmonic generator (MESFET at pinchoff) and filter section was used previously to produce an S-band to C-band frequency doubler.[3]

For this MMIC design, the harmonic generation section uses a 300 µm FET (MESFET) in TriQuint's TQTRX GaAs process. The bias of the device is near pinchoff to maximize the nonlinear characteristics for the third harmonic. This harmonic generator also produces a very strong first and second harmonic, which require filtering.

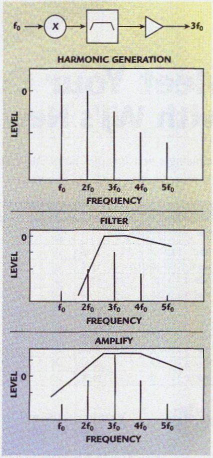
A high pass or bandpass filter is used to attenuate the unwanted harmonic components. The goal is to attenuate the second harmonic enough to keep it from saturating the output amplifier. Additional off-chip filtering can be added; however, on-chip filtering is necessary to attenuate the second harmonic by at least 20 dB. The requirement to attenuate the second harmonic while passing the third harmonic makes this topology inherently narrowband. Using a higher order filter section or a tunable filter could improve the bandwidth. A tunable high pass filter to double the practical bandwidth is described later.

The amplifier section is designed to increase the third harmonic level. A narrowband amplifier could be designed to provide additional filtering of the undesired harmonics, or the amplifier could be designed wideband with attenuation provided by on-chip or external filter sections. For these triplers, broadband efficient one-stage and two-stage amplifiers were designed to amplify the desired third harmonic (6.6 to 7.5 GHz). The two-stage amplifier was also fabricated as a separate 5.5 to 8.5 GHz efficient general-purpose amplifier.

HARMONIC GENERATION

A nonlinear device is required to generate harmonics of the input signal. For this design, a 300 µm FET in TriQuint's TQTRX process is used. The device is biased around pinchoff to enhance the nonlinear characteristics. The device was designed for a drain voltage of +5V but could also operate at +3.3V. A +3.3V supply tends to enhance the nonlinear characteristics while lowering power consumption. Bias near pinchoff is supplied to the MESFET gate through a resistor divider network decoupled from the RF matching circuit through a large inductor and large decoupling capacitor. The input matching network (IMN) to the 300 µm FET is centered around the fun-

Fig. 1 Relative spectrum of tripler sections.



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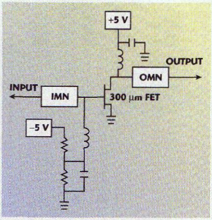
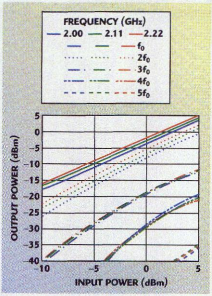


▲ *Fig. 2 Biasing of the harmonic generator.*

damental frequency (2.2 to 2.5 GHz), while the output matching network (OMN) is optimized for the third harmonic (6.6 to 7.5 GHz). ***Figure 2*** shows a simplified schematic of the harmonic generator. To reduce risk, the harmonic generation section used the same proven, but narrowband, design[1] retuned to a higher fundamental frequency of 2.2 to 2.5 GHz. While the overall tripler is inherently narrowband, it may be desirable to design a broadband harmonic generator section. Flexibility could be gained by broadbanding the harmonic generator and output amplifier while using the filter roll-off characteristics to set the operating band of the tripler. This would allow fabrication of tripler MMICs to cover a large range of frequencies by only



▲ *Fig. 3 Harmonic generation (1 to 5).*

modifying, or tuning, the filter section for each operating band.

The FET biased near pinchoff generates very strong fundamental and second harmonic signals. Setting the gate bias voltage has an effect on the gain (or loss) of each harmonic generated in the FET. A typical response (simulated) of the harmonic generator section is shown in ***Figure 3***. Note the strong first and second harmonics followed by a reasonable third harmonic and progressively weaker higher harmonics. The output of the harmonic generator feeds into the filter section.

THIRD HARMONIC FILTER

The filter section is very important to the characteristics of the tripler design and its bandwidth. This topology could also be used for a doubler by re-designing the filter to take advantage of the very strong second harmonic. As a tripler, an ideal infinite roll-off high pass filter would still only allow for a 50 percent bandwidth. The high pass roll-off of the filter must be designed to pass the third harmonic of the lowest frequency of operation but have sufficient attenuation at the second harmonic of the highest frequency of operation. Additional filtering of undesirable harmonics could be achieved in the filter design, but the primary concern is to ensure that only the third harmonic saturates the final amplifier stage. A high pass filter could be used in place of the bandpass since the harmonic generator already attenuates higher order harmonics. The size of the filter stage is important. Higher order filters could theoretically improve bandwidth but the addition of "non-ideal" elements increases loss, size and complexity.

The current bandpass filter design provides a tripler bandwidth of approximately 15 to 20 percent. External filtering could be added to the MMIC tripler to improve attenuation of unwanted harmonics. Tuning the passband frequency by replacing some of the capacitor elements with varactors can increase the bandwidth of the tripler design provided that the amplifier and harmonic generator are sufficiently broadband. The schematic of the bandpass filter is shown in

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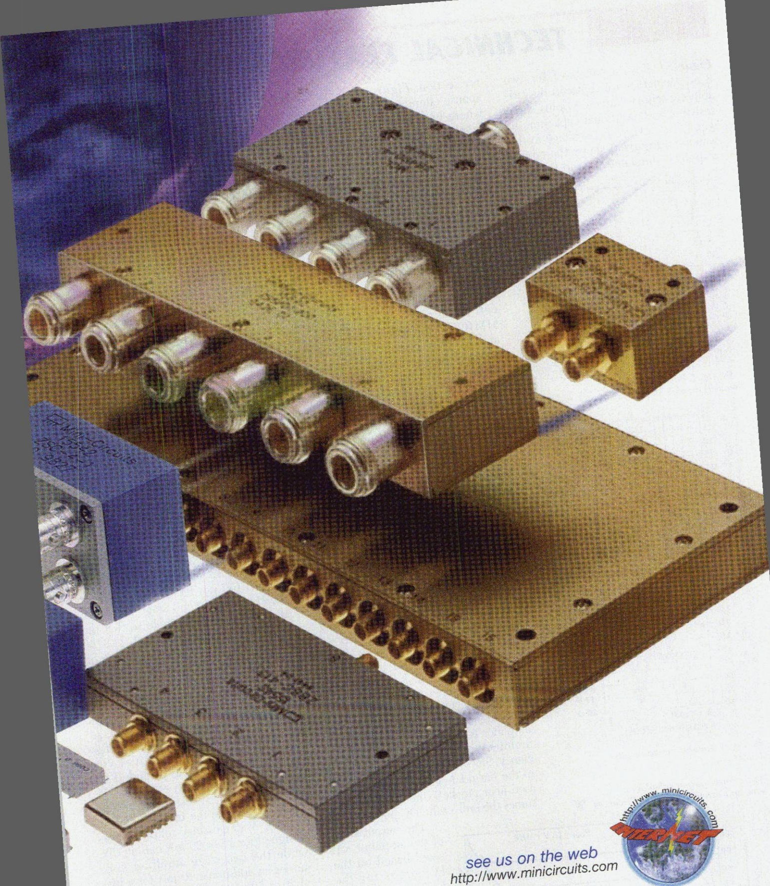
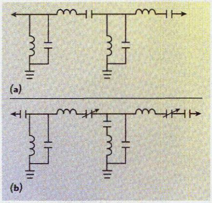
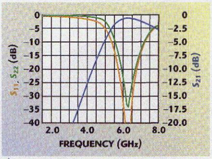


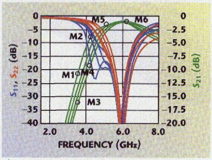
Figure 4. For the tunable filter, two fixed capacitors are replaced by variable capacitors (varactors) plus some resistors and additional capacitors to supply the reverse bias voltage to the varactors. ***Figure 5*** shows the typical response (simulated) of the fixed filter section. ***Figure 6*** shows the response (simulated) of a tunable filter where two of the four capacitor elements are replaced by reverse biased diodes acting as varactors. The tuning range of the variable filter is approximately 15 percent, which would double the current tripler bandwidth.



▲ *Fig. 4 Bandpass (a) fixed and (b) tunable filter schematics.*



▲ *Fig. 5 Fixed bandpass filter simulation.*



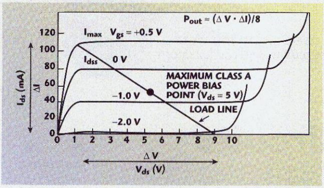
▲ *Fig. 6 Tunable bandpass filter simulation.*

EFFICIENT AMPLIFIER DESIGN

For space applications, size, weight and power consumption are key criteria for the communications design. Given the limited availability of commercial triplers, this was an excellent application for a custom MMIC optimized for the frequency and RF power requirements of the system. The input signal level was assumed to be 0 to +10 dBm, and the output third harmonic level was expected to be as high as +10 or +13 dBm. The amplifier MESFETs were sized to be power efficient, capable of delivering +12 to +15 dBm. A two-stage and a one-stage amplifier were designed for the MMIC tripler. The additional gain of the two-stage amplifier was desirable, but it is riskier and more difficult to design a stable two-stage amplifier than a single stage one.

A successful MMIC tripler operating from 1.55 to 1.75 GHz was designed previously.[1] One of the tradeoffs in the original design was to operate a single stage amplifier at saturation to maximize the gain ($I_{DSS} \approx$ 80 mA for a 300 μm FET at +7V). That design only had enough room for a single stage amplifier on the 54 × 54 mil GaAs die, so DC power was sacrificed for a higher output signal level. The amplifier is the key component in this architecture that affects power efficiency. Since little power is consumed in the harmonic generator section biased near pinchoff, the amplifier consumes the bulk of the DC power.

Fig. 7 Power output calculation using approximate MESFET IV curves. ▼



The output stage of the amplifier was sized based on the IV curves for the FET device with ±5V power supplies, plus a 2 dB margin. Estimating the maximum RF output power (P_{out}) available in Class A from the device I-V curves is illustrated in ***Figure 7***. Given a fixed supply voltage (V_s = +5V) and assuming a knee voltage of 1V, the maximum voltage swing is $\Delta V = 2 \times (V_s - 1)$, in this case ΔV = 8V. The maximum current swing ($\Delta I = I_{max}$) is proportional to the device size. Assuming a fixed voltage supply, and a sufficient device breakdown voltage, the output power is determined by the maximum current swing, that is, device size.

$$V_{rms} = \frac{\Delta V}{\left(2\sqrt{2}\right)}$$

$$I_{rms} = \frac{\Delta I}{\left(2\sqrt{2}\right)}$$

$$P_{out} = V_{rms} \times I_{rms}$$

For an I_{max} greater than 100 mA, P_{out} is approximately +20 dBm for a 300 μm FET for a +5V supply. That would yield approximately +17 dBm for a 150 μm FET. Hence a 150 μm FET is chosen to provide 2 dB margin for a +15 dBm output requirement.

A 150 μm FET operating at approximately $I_{DSS}/2$ could provide about +15 dBm, while reducing the bias to $I_{DSS}/4$ could provide at least +12 dBm. To simplify the matching design, 150 μm FETs were used for the first and second stage amplifier. Bias was made selectable so that the final stage could operate at $I_{DSS}/2$ (20 mA) or $I_{DSS}/4$ (10 mA) depending on the output power required, while the first stage is operated at the lower $I_{DSS}/4$ bias. S-parameters for the 150 μm device were not expected to vary much between $I_{DSS}/2$ and $I_{DSS}/4$, so the amplifier could be custom configured for either bias point. Even though the design was intended for ±5V, it works well with +3.3 and –5V supplies. External resistors could be used to optimize the bias for a ±3.3V system. A single stage amplifier was designed for 10 or 20 mA bias at +5V, while the two-stage amplifier consumes an additional 10 mA for a bias of 20 or 30 mA at +5V.

While the power efficiency of the tripler is dominated by the power consumption in the amplifier section, optimizing the size of the FET in the harmonic generator is necessary for best overall efficiency. If the output power requirement were reduced,

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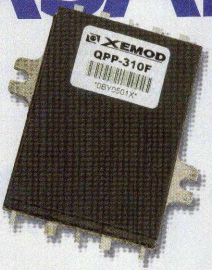
3G ASAP.



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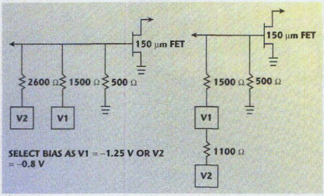

▲ *Fig. 8 Bond pad selectable bias examples.*

then not only should the FETs in the amplifier be made smaller, but the FET in the harmonic generator would need to be made smaller to match the levels required by the amplifier. At some point, a compromise must be made in customizing the design to a specific requirement. It is important to build-in design margins at the cost of extra DC power in order to provide for changing specifications during development, or to make the design flexible enough that it could be used for other systems. Adding extra bond pads to make the bias selectable is one way to optimize a single MMIC design for multiple requirements. ***Figure 8*** shows an example of modifying the gate bias by connecting to one bond pad or another. Attaching to the bond pad V1 provides a gate bias voltage of –1.25 V for a lower drain current, while attaching to V2 selects a gate bias voltage of –0.8 V for a higher drain current. Note, the 500 Ω resistor also provides RF stability for the MESFET.

AMPLIFIER DESIGN RESULTS

As mentioned, the amplifier has a strong impact on the efficiency of the overall tripler. MESFETs are sized according to the design's output power requirement plus some additional margin. Ideally, a multi-stage amplifier would have the MESFET size optimized for each stage. To simplify the matching circuit design, the same device (150 μm FET) was used for both stages in a two-stage amplifier. The first stage is run at a lower current level ($\sim I_{DSS}/4$), while the output stage is biased for maximum class A output power ($\sim I_{DSS}/2$). Matching circuits are designed to be sufficiently broadband. Generally, one desires the band of the amplifier to exceed the requirements for the tripler operating range so that any processing variations in the GaAs fabrication will still allow the amplifier to meet specifications. For this design, additional bias points were included that can be selected by bonding to different pads when packaged. Off-chip resistors could be added to optimize the bias points for a design that requires less output power. Each stage of the amplifier could be operated from a low of about 15 to 20 percent I_{DSS} up to 55 to 60 percent I_{DSS} for maximum output power. At some point, it is preferable to redesign the tripler with smaller MESFETs optimized for a lower output power requirement than to use an existing design and operate the MESFETs at too low a current bias. Given the many available papers on amplifier design and matching circuit design, a thorough step-by-step explanation of this amplifier design will not be given. Suffice it to say that the design strives to trade-off gain, stability, bandwidth, efficiency and proper de-coupling of the DC bias lines in the matching circuit design of an amplifier.

LAYOUT

Since this was a development or "proof of concept" project, multiple variations of the tripler and amplifier circuits were combined on a single large die to maximize the knowledge gained from a single fabrication cycle. For a production run, the two-stage tripler could be produced as a single 60 × 60 mil die. A single die of 120 × 120 mils using the Prototype Chip Option (PCO) for TriQuint's TQTRX GaAs process was used. Four separate designs were fabricated on one prototype die. A single stage amplifier/tripler (2.2 to 2.5 GHz) occupied one quadrant, a two-stage amplifier/tripler (2.2 to 2.5 GHz) occupied another quadrant, a two-stage broadband efficient amplifier (5.5 to 8.5 GHz) occupied one-eighth of the die and the remaining three-eighths con-

[Continued on page 83]


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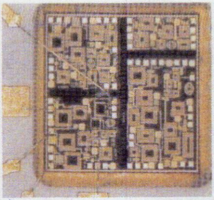
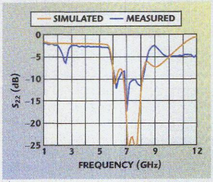
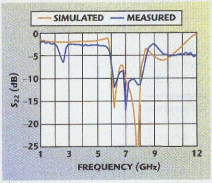


▲ *Fig. 9 GaAs MMIC tripler die layout (120 × 120 mils).*



▲ *Fig. 10 One-stage tripler's measured vs. linear simulated output match.*

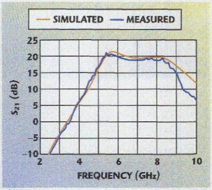


▲ *Fig. 11 One-stage tripler's measured vs. nonlinear simulated output match.*

tained a frequency tripler (1.7 to 2.1 GHz) with a tunable filter section. ICED (IC Editors Inc.) was used for the layout and design rule checking. ***Figure 9*** shows the actual chip with one tripler (quadrant) wire bonded into a test package.

MEASURED RESULTS

Simulated results agree well with the measured results. Agilent EEsof's Libra program was used for simulations using linear models from the TQTRX foundry manual[2] and TriQuint's Own Model (TOM2 and TOM3) for nonlinear simulations. For the harmonic generator FET, the



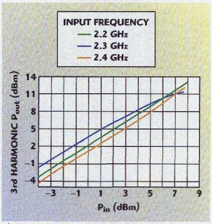
▲ *Fig. 12 Two-stage amplifier's measured vs. nonlinear simulated gain.*

linear model with the lowest available current bias (14 percent I_{DSS}) was used for simulations. For the one-stage tripler, both the linear model and the nonlinear model simulations agree well with the output match, as shown in ***Figures 10*** and ***11***.

Linear and nonlinear simulations for the two-stage amplifier vary a little depending on whether the output stage bias uses the $I_{DSS}/2$ bias or the $I_{DSS}/4$ bias. For the input match, the linear model at low bias (14 percent I_{DSS}) for the 300 µm FET matched the measured result very well. At the higher third harmonic frequencies, the actual amplifier rolls off a little lower in frequency than expected. Still, the two-stage amplifier has about 20 dB gain from 5.5 to 8.5 GHz and greater than +13 dBm output power at 21 mA from the +5V supply. Gain for the simulation and measurement agrees well, though the gain roll-off occurs slightly lower in frequency than predicted, as seen in ***Figure 12***. The power output (> +13 dBm) agreed well with estimates from the DC I-V curves and from nonlinear simulations.

Nonlinear simulations of the overall tripler predicted a third harmonic output approximately 6 dB higher than measured results. This corresponds to the same difference as in the original design.[1] Besides blaming an overoptimistic nonlinear model, the 6 dB error could also be due to the narrowband match on the input of the harmonic generator circuit. The nonlinear model predicted a better input match at the optimal frequency for the tripler than the measurements indicate. Possibly broadbanding the harmonic generator in a future design would create better

[Continued on page 84]



▲ *Fig. 13 Two-stage tripler's measured output power vs. input power.*

agreement with the nonlinear models. ***Figure 13*** shows the third harmonic power out versus power in at 2.2 to 2.4 GHz for the two-stage tripler. ***Tables 1*** and ***2*** list measured performance for the single stage amplifier/tripler and the two-stage amplifier tripler operating at +3.3V with a 2.3 GHz input signal. The MMICs were packaged on a small aluminum block with SMA connectors attached. The measurements are calibrated at the SMA connectors.

The tunable filter produced a tuning range on the order of 250 MHz from 1.75 to 2.00 GHz. While the tunable filter worked well, the current harmonic generator design needs to be broadbanded to fully utilize the extended tuning range. The tunable harmonic generator and filter section were tested with the 5.5 to 8.5 GHz two-stage amplifier circuit while varying the control voltage. As shown in ***Table 3***, the peak performance of the band shifts by modifying the control voltage. Bandwidth at each control voltage setting is approximately 250 MHz around the "peak" performance point. This MMIC is also tested as a packaged component.

The schematic of the variable filter was shown previously. The tuning element is a reverse biased diode formed from a MESFET with source and drain shorted together. Changing the voltage of the reverse bias on the diode modifies the capacitance from gate anode to source/drain cathode. While the relative tuning range is determined by the varactor GaAs processing, the designer chooses the nominal value of the variable capacitance by specifying the MESFET diode size. Two of the four capacitors on the fixed filter were replaced with varactors to achieve a 15 percent change in the roll-off frequency. Three additional large capacitors were added to supply the reverse bias control voltage to the varactors. The two capacitors on the input and output of the filter isolate the varactor bias from the harmonic generator and amplifier.

TABLE I

ONE-STAGE TRIPLER IN PACKAGE (2.1 to 2.5 GHz)

P_{in} (dBm)	–5 V (mA)	+3.3 V (mA)	DC (mW)	P_{out} (dBm)	Loss/Gain (dB)
+4	5	15.0	75	–11 (6.9 GHz)	–15.0
+7	5	17.5	83	–5.5 (6.9 GHz)	–11.5
+10	5	21.0	94	+1.3 (6.9 GHz)	–8.7

TABLE II

TWO-STAGE TRIPLER IN PACKAGE (2.2 to 2.5 GHz)

P_{in} (dBm)	–5 V (mA)	+3.3 V (mA)	DC (mW)	P_{out} (dBm)	Loss/Gain (dB)
+4	6.5	25	115	+0.5 (6.9 GHz)	–3.5
+6	6.5	27	122	+4.6 (6.9 GHz)	–1.4
+8	6.5	29	128	+7.3 (6.9 GHz)	–0.7

TABLE III

TUNABLE TRIPLER IN PACKAGE (1.7 to 2.0 GHz)

P_{in} (dBm)	Control Voltage (V)	Peak P_{out} (dBm)	Loss/Gain (dB)
+8	0.5	6.7 (5.4 GHz)	–1.3 (5.4 GHz)
+8	1.5	7.1 (5.7 GHz)	–0.9 (5.7 GHz)
+8	2.0	4.3 (6.0 GHz)	–3.7 (6.0 GHz)

CONCLUSION

An architecture for frequency triplers (or doublers) in GaAs MMICs has been described and fabricated. Customization of the circuit can allow for low power efficient operation in a particular system. For space applications, size, weight and power consumption are critical. Certainly, customized MMICs with selectable bias points can provide extremely small, lightweight, low power solutions when off-the-shelf components are not available, or not suitable.

ACKNOWLEDGMENT

The author wishes to acknowledge Craig Moore, his co-teacher in Johns Hopkins University's MMIC Design Course EE787 since 1989. He would also like to acknowledge Carson Murray, who implemented a successful MMIC tripler design during the Fall 1997 semester of the MMIC Design course that proved the architecture for this tripler design. Funding for the creation of this MMIC was part of APL's Advanced Technology Development (ATD) for NASA. ■

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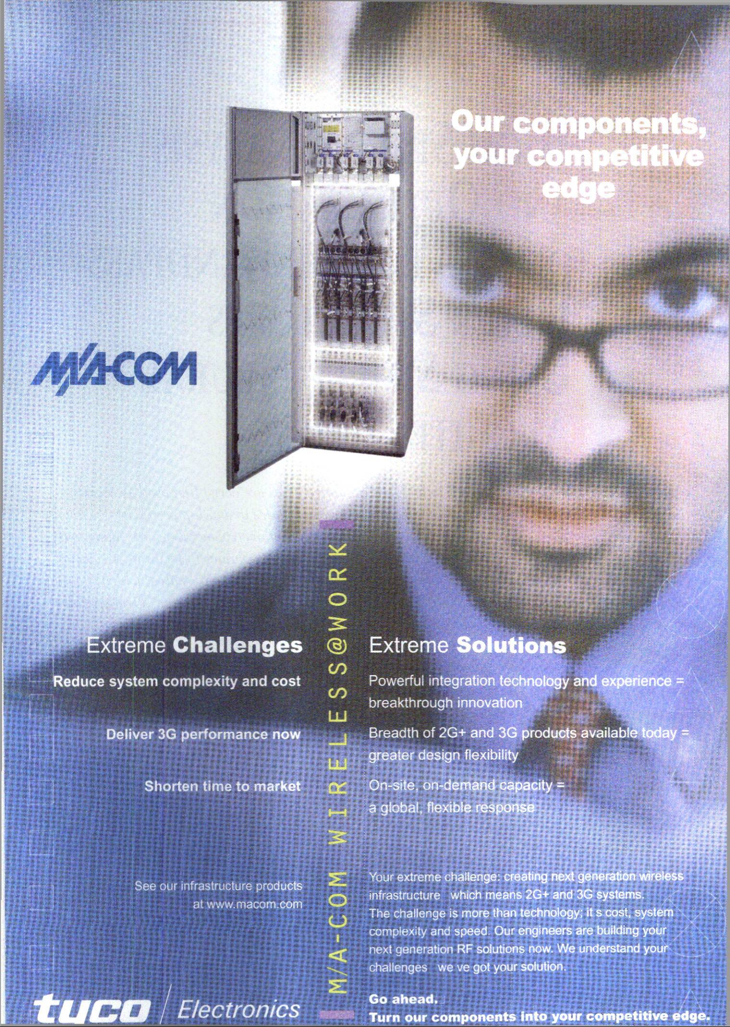
1. C. Murray, "Frequency Tripler," Student Reports, JHU EE787 MMIC Design Course, Fall 1997.
2. TriQuint Semiconductor, *GaAs IC Deisgn Manual*, TriQuint TQTRX Process, V2.0, 1997.
3. M. Reece, "Design of a S/C-band Frequency Doubler," Student Reports, JHU EE787 MMIC Design Course, Fall 2000.

John E. Penn *received his BEE from the Georgia Institute of Technology in 1980, and his MS degrees in electrical engineering and computer science from the Johns Hopkins University in 1982 and 1988, respectively. His work has involved custom integrated circuit design, silicon compilers, digital design, microwave design and microwave integrated circuits (MMICs). Mr. Penn is employed in the space department of the applied physics laboratory and co-teaches a MMIC design course with Mr. Craig Moore at the Johns Hopkins University (EE787).*



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TECHNICAL FEATURE

HIGH SPEED ANALYSIS AND OPTIMIZATION OF WAVEGUIDE BANDPASS FILTER STRUCTURES USING SIMPLE NEURAL ARCHITECTURES

At microwave frequencies, from about 7 to 60 GHz, inductive irises are very often used as coupling networks between half-wavelength cavities in rectangular waveguides to develop very selective low loss bandpass filters. This is due to the fact that symmetric and asymmetric metal inserts, along with small tuning posts, are very easy to manufacture in large production volume. To facilitate the design and optimization process, a simple and very accurate neural architecture is presented, which is easily translated to a standard electrical equivalent circuit that reproduces in a wide range of iris aperture, thickness and frequency. The proposed new models, although they can be embedded into any commercial microwave software, have been easily implemented into MMICAD® Comparisons have been made for high order high frequency waveguide half-wave filters, showing an excellent agreement with full three-dimensional (3D) electromagnetic HP-HFSS® simulations along with computation speeds thousands of times faster.

To the authors' knowledge, none of the current commercial microwave aided design (CAD) programs incorporate models for useful discontinuities in rectangular waveguide, while they have models for the standard TE10 waveguide transmission line. This means that, for a microwave designer, the waveguide world belongs to other kinds of simulators based on hard numerical methods — mode matching and finite elements where the design and optimization cycles are still very long.

In the case of planar structures (microstrip, strip and coplanar lines), the microwave designer has a wide range of electrical models available (sometimes based on electromagnetic simulations) for almost any discontinuity in such transmission media, and the designer can verify or fine-tune his or her final design through the use of accurate 2D and 2.5D planar electromagnetic simulators. The same concept can be extended to the waveguide world for some useful

[Continued on page 88]

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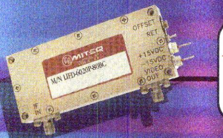
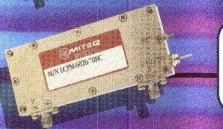


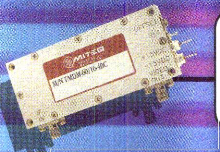
MODEL NUMBER	CENTER FREQUENCY (MHz)	DYNAMIC RANGE (dBm, Min.)	LINEARITY (dB, Max.)	RISE TIME (ns, Max.)	LOGGING SLOPE INTO 93 OHMS (mV/dB, Typ.)
LIFD-3010P-80BC	30	-80 to 0	±0.5	100	25
LIFD-6020P-80BC	60	-80 to 0	±0.5	50	25
LIFD-7030P-80BC	70	-80 to 0	±0.5	30	25
LIFD-16040-80BC	160	-80 to 0	±1.0	30	25
LIFD-300100-70BC	300	-70 to 0	±1.0	20	15

CONSTANT PHASE LIMITING AMPLIFIERS



MODEL NUMBER	CENTER FREQUENCY (MHz)	DYNAMIC RANGE (dB, Min.)	OUTPUT POWER (dBm, Min.)	POWER VARIATION (dB, Max.)	PHASE VARIATION (Max.)
LCPM-3010-70BC	30	-70 to 0	10	±0.5	±3°
LCPM-6020-70BC	60	-70 to 0	10	±0.5	±3°
LCPM-7030-70AC	70	-65 to 5	10	±0.5	±5°
LCPM-16040-70BC	160	-65 to 5	10	±1.0	±3°

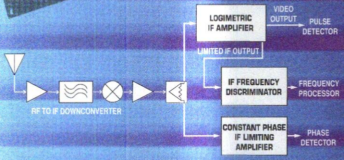
FREQUENCY DISCRIMINATORS



MODEL NUMBER	CENTER FREQUENCY (MHz)	LINEAR BANDWIDTH (MHz, Min.)	SENSITIVITY (mV/MHz, Typ.)	LINEARITY (%, Max.)	RISE TIME (ns, Max.)
FMDM-30/6-3BC	30	6	1000	±3	120
FMDM-60/16-4BC	60	16	250	±3	90
FMDM-70/36-10AC	70	36	50	±2	50
FMDM-160/35-15BC	160	35	100	±2	30
FMDM-160/50-15AC	160	50	40	±2	25
FMDM-750/150-20BC	750	150	20	±3	20
FMDM-1000/300-50AC	1000	300	10	±5	7

AUTOMATIC GAIN CONTROL LINEAR AMPLIFIERS

MODEL NUMBER	CENTER FREQUENCY (MHz)	BANDWIDTH (-3 dB) (MHz, Min.)	DYNAMIC RANGE (dBm, Min.)	OUTPUT POWER (dBm, Min.)	POWER VARIATION (dB, Max.)
AGC-7-10.7/4AC	10.7	4	-70 to 0	10	±0.5
AGC-7-21.4/10AC	21.4	10	-70 to 0	10	±0.5
AGC-5-70/30AC	70	30	-50 to 0	-4	±0.5
AGC-7-160/30AC	160	30	-70 to 0	8	±1.5
AGC-7-300/400AC	300	400	-65 to 0	3	±1.0



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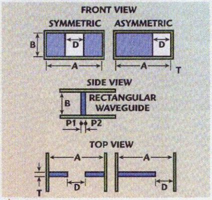
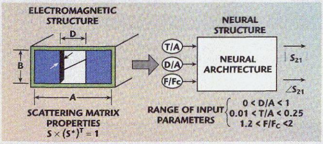
well-known discontinuities such as symmetric and asymmetric irises for microwave bandpass filter design shown in ***Figure 1***.



▲ *Fig. 1 Symmetrical and asymmetrical rectangular waveguide inductive iris.*

The existing circuit models for waveguide inductive irises, starting from Marcuwitz's work,[1] are published elsewhere; however, most of them are developed in terms of recursive closed form equations coming from electromagnetic pseudo quasi-static and full-wave approaches. Due to the multimode dispersive nature of these electromagnetic discontinuities, the equations are not easily implemented into commercially available circuit simulators. Furthermore, they are rather tedious and computation intensive, thus preventing an easy filter analysis and optimization process. Their frequency accuracy for a single iris is perhaps sufficient, but when using a high order filter structure, the propagation of the individual errors through the filter gives poor results (for example, bandwidth shift and in band attenuation). The second available solution, the use of full 3D electromagnetic simulators such as HP-HFSS®,[2] is accurate, but unacceptable in computation time (several hours/days) when used for filter design and optimization.



▲ *Fig. 2 Proposed equivalence between electromagnetic and neural structures.*

Instead of searching for more precise, and therefore more complicated closed form equations, the idea proposed here is to use simple and accurate neural architectures to fit the scattering parameters obtained by using a precise full 3D simulator for single and double inductive irises in rectangular waveguides. Since the electromagnetic discontinuity of a single or double inductive iris of aperture D and thickness T in a TE10 propagating rectangular waveguide behaves like a lossless symmetrical two port reciprocal network at the reference planes P1 and P2, it is enough to adjust a single two port parameter at the output of the neural network. For microwave filter applications, it is convenient to control the forward scattering parameter S_{21} (easily related to the traditional Z or Y parameters), and furthermore to use the well-known properties of the scattering matrix to derive the other Sij parameters as

$$S \times (S^*)^T = I \qquad (1)$$

At this point, it is evident that the input parameters for a possible neural structure should be the physical dimensions of the inductive iris, that is, D and T, along with the waveguide dimensions (A and B) and the frequency of operation. This primary strategy exhibits some important disadvantages because the standard waveguide dimensions are defined for precise frequency bands where the TE10 is the dominant propagating mode, and in a first approach a neural topology should be derived for each waveguide band (which is not a general approach). However, if the scaling properties of the waveguide structures are considered, the normalised iris dimensions D/A and T/A can be used as input parameters, as well as the normalised frequency F/Fc, where Fc is the cut-off frequency of the TE10 mode, as shown in ***Figure 2***.

Furthermore, the range of the input parameters should have some constraints regarding the usual wave-

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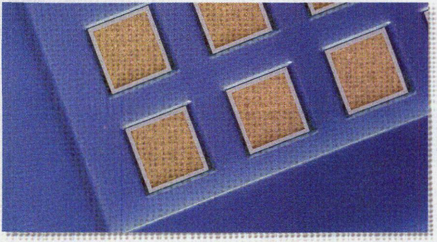
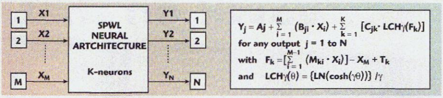




$$Y_j = A_j + \sum_{i=1}^{M}(B_{ji}\cdot X_i) + \sum_{k=1}^{K}[C_{jk}\cdot \mathrm{LCH}\gamma(F_k)]$$

for any output $j = 1$ to N

with $F_k = [\sum_{i=1}^{M-1}(M_{ki}\cdot X_i)] - X_M + T_k$

and $\mathrm{LCH}\gamma(\theta) = \{\mathrm{LN}(\cosh(\gamma\theta))\}/\gamma$

▲ *Fig. 3 General SPWL neural architecture.*

guide filter utilisation. The iris aperture could vary from 0 to the maximum aperture A, that is, $0<D/A<1$, while a reasonable range for the iris thickness T should be given by $0.01<T/A<0.25$. Finally, the normalised frequency band should be $1.2<F/F_c<2$ in order to avoid unwanted propagation modes. In conclusion, this general strategy uses a single neural architecture for the S_{21} parameter, and three normalised parameters as input data. It should be enough for any given frequency band where this kind of filter is applicable.

THE NEURAL ARCHITECTURE

From an intuitive point of view, a neural network[3] can be viewed as a parallel distributed processor that exhibits a natural ability for storing experimental knowledge and making it available for ulterior use. This knowledge is acquired through dedicated learning algorithms, along with a weighty interneuron connection. The typical neural networks, MLP and RBF families, normally require a relatively large number of neurons for a close fit to the experimental data. Because the objective is to be highly competitive against the pure electromagnetic simulation, a new SPWL[4] has been chosen for this particular problem.

The proposed SPWL model is an extension of the well-known canonical piecewise linear model (PWL) described by Chua.[5] In its basic formulation, the Canonical PWL model performs any general nonlinear mapping $F : R^M \rightarrow R^N$ (M inputs and N outputs) by means of the expression

$$Y = F(X) =$$

$$A + B\bullet X + \sum_{k=1}^{K} C_k \left| < \alpha_k, X > -\beta_k \right|$$

$$\text{(for K neurons)} \qquad (2)$$

where

$\mathbf{X}(M)$	= input vector
$\mathbf{Y}(N)$	= output vector
$\mathbf{A}(N)$, $\mathbf{B}(N\times M)$, $\alpha_k(M)$, $\mathbf{C}_k(N)$	= fitting vectors
β_k	= scalar
$<\alpha_k,\mathbf{X}>$	= inner product

This model divides the input space into different regions by means of several boundaries implemented by hyperplanes of dimension M-1. It then constructs the function approximation by means of a combination of hinging hyperplanes of dimension M. Such hinging hyperplanes are the result of joining two linear hyperplanes over the boundaries defined in the input space.

It can be seen that the expression inside the absolute value function defines the boundaries partitioning the domain space. This function controls the transition between linear regimes and, therefore, the Canonical PWL model inherits some properties from the absolute value function; it is continuous but not derivable along the boundaries. Moreover, the second and higher order derivatives are zero except at the boundaries where they are discontinuous, which is critical for circuit optimization purposes. To overcome this drawback, the substitution of the absolute value function is proposed for a derivable function in order to smooth the joint of hyperplanes at the input space boundaries. Several possibilities exist to smooth the absolute value function allowing, at the same time, a parametric control of the "sharpness" of the transition. The smoothing function is chosen as

$$\mathrm{LCH}\gamma(\tau) = \frac{\mathrm{Ln}[\cosh(\gamma\tau)]}{\gamma} \qquad (3)$$

where

γ = parameter that allows the smoothness of the transition to be controlled

The advantage is clear when one looks for the derivative of Equation 3: $d/d\tau\{\mathrm{LCH}\gamma(\tau)\} = \tanh(\gamma\tau)$ which is the activation function of a universal approximator such as the MLP. **Figure 3**

[Continued on page 92]

shows a descriptive view of the proposed SPWL model.

MODEL VALIDATION

The above description has been applied to the electromagnetic structures, that is, both symmetric and asymmetric irises. This model provides a smooth and derivable approximation that improves considerably the performance of the Canonical PWL model when it is applied to real microwave devices, mainly in the optimization process. Moreover, it requires a much smaller number of parameters and a lower computation burden than other models commonly used. Extensive full 3D electromagnetic simulations have shown that the proposed architecture, shown in ***Figure 4***, is able to reproduce the two port complex S_{21} parameter for a wide range of input data - ($0.01 < T/A < 0.25$), ($0 < D/A < 1$) and ($1.2 < F/F_c < 2.0$), thus covering most applications. In this case, a very good individual iris fit by using a seven-order SPWL is obtained; the maximum error in S_{21} for any individual iris, when compared with HFSS simulation, is less than 0.02 in module and less than 2° in phase. ***Figure 5*** shows as an example the neural fitting parameters for the symmetric iris case along with a comparison between full 3D electromagnetic simulation and the neural model for a relative large iris thickness ($T/A = 0.14$) and for various iris apertures D/A as a function of the normalised frequency.

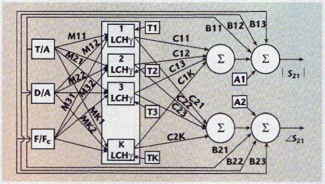
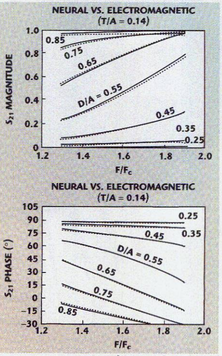


Fig. 4 Dedicated neural architecture for symmetric and asymmetric waveguide irises.

Fig. 5 Single symmetrical iris validation.

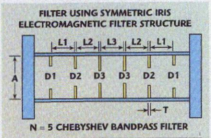
7-ORDER NEURAL PARAMETERS FOR SYMMETRIC IRIS

A1 = + 0.5313133	γ = + 6.5000
B11 = − 0.0224248	M11 = − 0.1471183
B12 = − 0.0307383	M12 = + 1.1227934
B13 = − 0.0096260	M21 = + 0.3671070
C11 = + 2.0500217	M22 = + 4.1136844
C12 = − 0.0034359	M31 = − 0.1056092
C13 = − 4.8298888	M32 = + 0.2939928
C14 = − 0.1482995	M41 = + 0.2864985
C15 = − 1.5116727	M42 = + 0.0385768
C16 = + 4.3496077	M51 = − 0.3388533
C17 = + 0.1129634	M52 = + 0.7186874
	M61 = + 0.1528574
A2 = + 72.029501	M62 = + 0.0087490
B21 = − 6.3434002	M71 = − 0.2991391
B22 = − 118.99504	M72 = + 2.2288361
B23 = − 33.658561	
C21 = − 64.315213	T1 = + 0.4822774
C22 = − 18.128299	T2 = − 0.2073612
C23 = + 289.59198	T3 = + 0.6221584
C24 = + 57.938470	T4 = + 0.0607542
C25 = + 92.329060	T5 = + 1.0709634
C26 = − 403.68554	T6 = + 0.7017891
C27 = + 47.962584	T7 = + 1.0711678



Although it is very easy to show how the proposed method accurately fits the frequency behaviour of an individual inductive iris, when designing high order microwave filters, the propagation of the individual errors could be important, especially for very narrow bandpass filters. This fact is a higher level test of the validity of the approximation. For

[Continued on page 94]

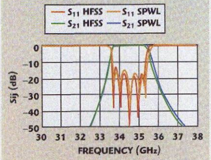


FILTER 1
PHYSICAL DIMENSIONS (mm)
WAVEGUIDE:
A = 7.11 B = 3.56 T = 0.3

FILTER

D1	D2	D3	L1	L2	L3
3.17	2.06	1.88	4.58	5.05	5.09

FREQUENCY RANGE (GHz)
F = 33.6 F2 = 35.5 BW = 1.9 (5.5%)

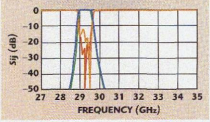


FILTER 2
PHYSICAL DIMENSIONS (mm)
WAVEGUIDE:
A = 7.11 B = 3.56 T = 0.9

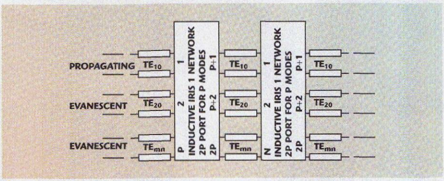
FILTER

D1	D2	D3	L1	L2	L3
3.71	2.51	2.33	6.14	6.77	6.82

FREQUENCY RANGE (GHz)
F = 28.9 F2 = 29.6 BW = 0.7 (2.4%)

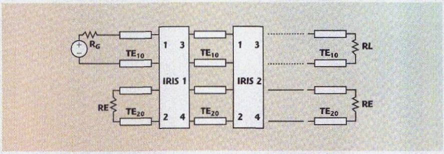


▲ *Fig. 6 Model validation through filter implementation.*



▲ *Fig. 7 Multimode structure for an iris-based waveguide filter.*

▼ *Fig. 8 TE_{10} and TE_{20} structure for an iris-based waveguide filter.*



this reason the neural architecture has been implemented easily into MMICAD[6] by using its MDL capability along with the flexibility in working with electrical model and local variables. The individual irises are joined by using fundamental TE10 waveguides (available in any simulator). At least for symmetric iris structures, and for these half-wave filters, it is not necessary to take into account high order connecting modes. Up to 21 different multi-section Chebyshev/Butterworth bandpass filters in different waveguide bands were tested, always showing very good agreement with full 3D electromagnetic simulations and having a computing simulation time more than 1000 times faster than any conventional analysis. Furthermore, the filter optimization process takes only a few seconds. This is due to the fact that the chosen algorithm is not only very fast but also continuous in its high order derivatives.

Figure 6 shows the general structure for microwave half-wave filters that use double inductive irises in a waveguide environment. For validation purposes, WR22 Ka-band waveguide (26.5 to 40.0 GHz) is chosen, where two very different N = 5 (6 iris discontinuities) Chebyshev bandpass filters have been designed and optimized. Filter 1 uses symmetrical irises having moderate (0.3 mm) thickness, with a center frequency at f_o = 34.55 GHz and having a fractional bandwidth of 5.5 percent. Conversely, Filter 2 is a very narrow band waveguide filter (2.4 percent fractional bandwidth) centered at f_o = 29.25 GHz that uses very thick (0.9 mm) irises. For both cases, all the physical dimensions are shown in the figure. In terms of analysis, HP-HFSS means full 3D electromagnetic simulation and SPWL means neural electrical equivalent circuit simulation. Note that the model implementation is extremely robust, even for very narrow filters, and it is difficult to distinguish between the two simulations.

HIGH ORDER TE10 + TE20 IRIS CONNECTION

From a general point of view, a waveguide having P modes should be considered the connecting media between successive discontinuities, that is, the discontinuity should be described as an electrical 2P-port characterised by its generalized multiport scattering matrix S(2Px2P), as shown in ***Figure 7***. Since the structure of a symmetric iris exhibits perfect symmetry, only odd modes can be excited at the discontinuity, that is, the first high order mode to be considered is the TE30. Multimode electromagnetic simulations show that for half-wave waveguide filters that use symmetric iris structures, it is enough to consider only the first connecting mode TE10, as can be seen from the results obtained for the filters using symmetric irises.

Unfortunately, this is not the case for half-wave waveguide filters that use asymmetric iris structures where the above approach is not accurate enough. Due to the non-symmetrical nature of these discontinuities, a non-negligible contribution of the TE20 mode along with an insignificant contribution of the remaining high order connecting modes can be expected. Extensive filter simulations corroborate this assertion and the final filter structure is shown in ***Figure 8***.

[Continued on page 97]

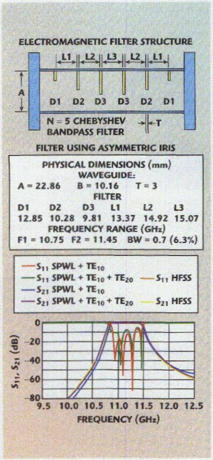
At this point it should be kept in mind that the generalized scattering matrix for the first two modes of a single iris is a 4x4 matrix having some special properties.[7] The $S_{11} = S_{33}$ and $S_{13} = S_{31}$ elements belong to the propagating mode TE10; they have the matrix properties shown in Equation 1. The terms $S_{14} = S_{41} = S_{23} = S_{32}$ and $S_{12} = S_{21} = S_{34} = S_{43}$ relates the propagating TE10 mode with the evanescent TE20 mode. After manipulation of the scattering properties they can be related in a simple manner, as shown in Equation 4.

$$S_{14} = \frac{-j\mathring{S}_{12} - \mathring{S}_{11}S_{12}}{\mathring{S}_{13}}$$

or

$$S_{12} = \frac{-j\mathring{S}_{14} - \mathring{S}_{11}S_{14}}{\mathring{S}_{13}} \qquad (4)$$

Finally, mode matching simulations show that the terms $S_{22} = S_{44}$ and $S_{24} = S_{42}$ can be made zero without any loss of accuracy because these elements relate to evanescent modes only.



▲ Fig. 9 HFSS vs. SPWL-TE_{10} and SPWL-TE_{10} + TE_{20} comparison.

In conclusion, the only need is to develop an extension of the initial neural network that has as outputs the magnitude and phase of S_{31}, along with S_{14}, for example. The remaining elements of the 4x4 scattering matrix can be deduced from the above equations. This SPWL architecture is easily converted into a standard electrical equivalent circuit and implemented into any circuit simulator and then used in the same manner as the element "bend" or "step" in microstrip, for example. The final point is to build an electrical model for the evanescent TE20 waveguide mode; however, this is not a problem because its Z matrix is well-known in the literature.

As a validation example of the aforementioned theory, **Figure 9** shows a comparison for an X-band (6 percent BW) half-wave filter that uses asymmetric iris structures. As shown, it is almost impossible to distinguish between the multimode HFSS simulation and the proposed 4-port SPWL approach. The differences are in the range of the mechanical tolerances. However, there is a 1 percent frequency shift when using the simple 2-port SPWL approach, which is unacceptable for a 6 percent filter bandwidth, thus confirming the dual mode assumption.

CONCLUSION

A very simple and extremely accurate SPWL neural architecture for inductive iris in electromagnetic structures has been presented. In order to cover the whole microwave range, normalized physical dimensions and frequency have been used as input parameters to the network. Model implementation has been accomplished through the use of standard electrical equivalent circuit structures. Model validation has been achieved for very different high order microwave filter applications, always showing excellent agreement when compared with the well-known accuracy of a full 3D electromagnetic simulator. Since the neural architecture is continuous in its high order derivatives, the filter optimization process can easily be accomplished. Finally, simulations have shown that the proposed strategy is more than 1000 times faster than any commercially available electromagnetic simulator, thus allowing the microwave engineer to really minimize the microwave filter design process without loss of accuracy. ■

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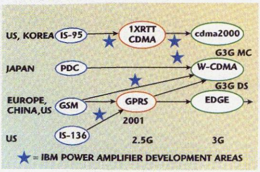
There are easier decisions
But not many

SiGe Power Amplifier ICs with SWR Protection for Handset Applications

In recent years there has been enormous growth in the wireless communications industry, placing a tremendous demand on the semiconductor industry for integrated circuits. For example, DataQuest projects the total market for semiconductors in wireless handsets alone to grow to approximately $35B by the year 2004. As wireless communication standards evolve to the next generation, the largest growth in services is projected in the area of integrated voice and data networks, which provide Internet protocol-based connectivity.

As a result of the increase in bandwidth-intensive wireless services, new demands will be placed on the semiconductors that support RF subsystems in wireless portable devices. Specifically, RF semiconductor components will require higher operating speeds, higher linearity (particularly at reduced supply voltages), better efficiency and higher levels of integration. The availability of multifunction, mixed-signal ICs with considerable RF system content will become even more critical. SiGe bipolar complementary metal-oxide semiconductor (BiCMOS) technology has recently received a lot of attention as a suitable technology for RF/analog and mixed-signal applications.[1] However, until now, SiGe has not been considered a suitable technology for power amplifier (PA) applications, primarily due to the lower breakdown voltages of SiGe NPN devices compared to their GaAs HBT counterparts.

Fig. 1 Wireless protocol road map.



This article describes how SiGe technology has been used to develop a family of five PA ICs that address all major protocols for wireless handsets as they evolve from the present to 3G requirements. The evolution to these newer protocols will occur alongside the present ones, resulting in continued demand for a wide variety of power amplifier types. The roadmap in ***Figure 1*** shows how the family of SiGe power amplifiers discussed in this article cover the evolving protocol requirements.

There are a large number of handset standards worldwide that have varying RF requirements, but they can all be placed into two categories from a transmit amplifier point of view: saturated or linear operation. The analog (AMPS) and TDMA (NADC, GSM and DCS) standards fall into the saturated PA category because they have little or no modulation envelope. For these cases, the PA can be operated near or at saturation and still meet system requirements. The CDMA and W-CDMA standards have a larger modulation envelope (peak to average ratio) and require the PA to operate in a more linear region in order to meet requirements. This higher linearity is usually obtained by running the PA

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TABLE I

SiGe BiCMOS DEVICES

Device Category	Device	Figures of Merit	
NPN SiGe HBTs	Standard	f_T/f_{max} = 47/70 GHz, BV_{cbo} = 10.5 V	
	High breakdown	f_T/f_{max} = 28/65 GHz, BV_{cbo} = 14.4 V	
FETs	NFET	L_{eff} = 0.39 mm, gm,sat = 195 mS/mm	
	PFET	L_{eff} = 0.38 mm, gm,sat = 103 mS/mm	
LPNP	Gated LPNP	gm/IC = 7.9 mS/mA	
Diodes	Schottky	V_f = 0.31 V	
	Varactor	C_J = 1.2 fF/mm^2	
	PIN	C_J = 0.25 fF/mm^2	
	ESD	2000 V protection	
Capacitors	MIM	C = 0.7 fF/mm^2	
	MIS	C = 1.5 fF/mm$_2$	
Inductor	Thick last metal	L = 1.0 nH, Q = 17 at 5 GHz	
Resistors		Rsh (Ω/sq)	TCR (ppm/°)
	Poly Si	220	–75
	Poly Si	340	–275
	Single crystal Si	25	1940
	Single crystal Si	8	2050
	Single crystal Si	1750	300

backed-off from saturation at the expense of lower power added efficiency (PAE).

For all handset standards (saturated or linear), there is a requirement that the PA survive at high load SWR conditions under full power RF drive. This is due to the varied environment that the handset must operate in and to be prepared for an antenna fault. During this test, very high voltage or current swings are created on the power transistors as the phase of the load is varied. In many cases, PAs without a protection scheme, regardless of the process technology used, will fail catastrophically under this condition due to high current, high voltage or oscillation.

The family of SiGe PA ICs described here address all major handset standards and have SWR protection circuitry on-chip that enables them to pass industry standard ruggedness tests while having competitive output power (P_{out}), PAE, gain and linearity, as well as necessary control functions.

TECHNOLOGY

The SiGe BiCMOS technology used in this work has a number of advantages in the design of radio frequency integrated circuits (RFIC). The extensive menu of devices available, including NPN, NPNHB (high breakdown), PNP, NMOS, PMOS devices, 4 types of diodes, 2 types of capacitors, 5 types of resistors and scalable inductors, permit a wide variety of RF circuits with a high level of integration to be realized. ***Table 1*** summarizes the devices offered in the 5HP/AM process.[1]

[Continued on page 104]

The resulting potential for high levels of integration is excellent in a BiCMOS process. Single-chip transmit ICs with functionality from baseband modulation to the PA output are planned in the near future. Later in time, the possibility exists for full transceiver ICs with the PA function incorporated. This is especially feasible for lower power systems such as Bluetooth.

Processing is done on 8" (200 mm) wafers. This gives a cost advantage over GaAs where processing is done on 4" (100 mm) wafers (4 times greater area per wafer for SiGe BiCMOS). Yield in Si BiCMOS is generally superior to GaAs, further adding to the cost advantages.

SiGe HBT devices offer many features that are favorable for PAs. Cutoff frequencies f_τ and f_{max} are similar to those of high breakdown GaAs HBTs[2], and therefore gain per stage is similar, while comparable PAE and linearity are observed.[3] Although the substrate electrical parasitics are higher for Si than for GaAs, the use of P-substrates combined with thick conductor and oxide layers has enabled low loss matching networks. The thermal resistance of Si is lower than for GaAs and results in lower device operating temperatures. SiGe HBTs have lower base-emitter turn on voltage (0.8 V vs. > 1 V for GaAs HBTs), which allows lower voltage operation and more transistors to be stacked between supply rails. Additionally, bias circuits in Si technologies are superior since more accurate bias reference circuits can be constructed which give constant currents over supply voltage and a flat temperature characteristic.

There are two different types of the high breakdown NPN HBTs (NPNHB) offered: V_{ceo} = 5.5 V or 8 V, depending on the process choice. A summary of high breakdown device characteristics is given in ***Table 2***.

Many PA applications require an analog efficiency/gain control voltage to adjust the current in the PA. The BiCMOS process allows for the design of control circuitry that gives a logarithmic collector current vs. linear control voltage response over a wide dynamic range, which is superior to what is attainable in competing technologies.

Prior to IC design, RF measurements were made on NPNHB transistors having emitter areas from 300 μm^2 up to 6000 μm^2 in order to determine what DC and RF current densities were appropriate for the various handset standards. Load-pull data was taken to determine power, PAE and linearity for a given emitter area. For an NPNHB device, 74 percent PAE was measured at 0.8 mW/μm^2 under

TABLE II

HIGH BREAKDOWN NPN HBTs

Process	5HP	5BO
β	100	100
BV_{cbo} (V)	14	20
BV_{ceo} (V)	5.5	8.0
peak f_τ (GHz)	28	19
peak f_{max} (GHz)	65	50

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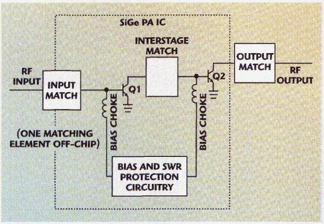

▲ *Fig. 2 Block diagram of the two-stage power amplifier.*

CW drive. With an IS-95 CDMA signal, 48 dBc adjacent channel power rejection (ACPR1) is observed at 42 percent PAE and 0.2 mW/μm^2.

PA DESIGN

Once measurements of the NPNHB PA devices were complete, it was possible to proceed with the RFIC design. Five similar designs were completed in order to cover all of the major handset standards. ***Figure 2*** shows a block diagram of the PA IC. An additional pre-driver stage (not shown) is included on personal communications services (PCS) designs.

Biasing

For a PA, it is generally desired that the circuit draw a fixed current over the temperature range so that flat output power is obtained (at the expense of gain flatness) over temperature. To achieve this, a bandgap reference circuit is created which provides a constant reference voltage over temperature that is also invariant to fluctuations in supply voltage. To start, a proportional to absolute temperature (PTAT) current is created and used to drive a diode-connected-transistor/resistor combination. If the voltage contribution from each is correct, a reference voltage equal to the bandgap of the material (1.2V for Si) is created.[4] This voltage is buffered and then placed across a current set resistor, which gives a bandgap current. If an external voltage control of current is required, that voltage is applied to this node. This results in a linear I_{cc} vs. $V_{control}$ characteristic. If a log I_{cc} vs. $V_{control}$ characteristic is required (such as for GSM and DCS), a linear-to-log converter is placed on this node along with a number of other changes. This bandgap current is then mirrored at the positive rail and then fed into an NPN current mirror for the RF device. The base-emitter voltage from this mirror is fed into an op-amp that drives an RF bias choke that is connected to the RF device's base. The op-amp is designed to provide a low impedance (< 1Ω) out to approximately 10 MHz, which reduces the regeneration of beat frequencies encountered in the modulation, resulting in good ACPR. The use of op-

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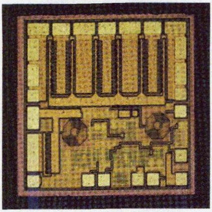
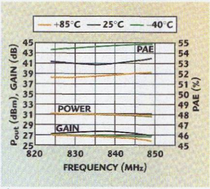


▲ *Fig. 3 Die photograph of the NADC/AMPS SiGe power amplifier.*



▲ *Fig. 4 CW frequency and temperature performance of the NADC/AMPS power amplifier.*

TABLE III

PA IC MEASURED RESULTS (V_{cc} = 3.4 V)

PA	P_{out} (dBm)	Gain (dB)	PAE (%)	ACPR1 (dBc)
NADC800	29.5	30	45	28
AMPS	31.5	28	53	n/a
CDMA800	28.5	28	37	48
AMPS	31.5	27	50	n/a
CDMA1900	29.0	28	35	47
WCDMA	27.0	28	35	38
GSM900	35.0	32	54	n/a
DCS1800	32.0	30	45	n/a

amps rather than a large capacitor on the DC side of the RF choke has the advantage of fewer components required externally on the board and keeps on/off switching times of the PA to a minimum.

RF Path

This portion of the design starts at the output match and proceeds toward the input of the amplifier. The off-chip output match has a low pass topology and utilizes 0402 type surface-mount components. The device load-pull data obtained previously was used to determine the optimum load impedance, $Z_{L,opt}$, required for a given power level. For comparison, this number was also determined using the Cripps method[5] with excellent agreement. This method involves determining $R_{L,opt}$ based on load-line analysis and lumping the device output capacitance, C_o, into the output matching network such that the current generator of the transistor drives a load which is completely real at the center of the frequency band once the network is constructed. C_o consists mostly of the large collector trace-to-substrate capacitance as well as the collector-emitter overlap capacitance from traces tying alternate collectors and emitters together in the multi-row output device. This capacitance, together with the collector bias inductor, forms a tank circuit that (ideally) yields flat real load impedance over the operating bandwidth, which in turn gives flat output power. The value of C_o can be tailored in the layout.

Optimization of C_o was also performed in concert with emitter grounding considerations. Due to the fact that the low cost SiGe process forgoes the substrate vias used in many GaAs processes, emitter downwires are required for HBT grounding. Care is taken, particularly in the PCS designs, to minimize the inductance associated with these connections in order to maximize power gain. Power cell topologies for cellular and PCS bands were independently optimized, resulting in slightly different architectures.

The interstage network designs used a high pass topology, with the final shunt-L element serving as the bias inductor for the driver (1st) stage. The driver transistor and its load impedance is determined in a manner similar to what was done previously for the output stage, but this time the gain of the output stage has to be taken into account in order to determine the amount of power required from the driver. Once this is determined, the output transistor is biased such that it is at a current in between that which it draws at quiescent and that which it draws with RF drive. The same techniques used on the output match design are then used to reach the desired interstage impedance.

Finally, the driver transistor is added to the circuit and biased in a similar manner to the output device. The input match is high pass with the first series-C element on chip. A single shunt-L is placed off chip to complete the 50 Ω match.

SWR Protection

A protection scheme for the SiGe PA is required if the amplifier is ever to encounter a non-50 Ω load on its output. At phases where a high SWR load creates a high voltage condition, the breakdown voltage of the NPNHB devices is not alone sufficient for reliable operation. The effective breakdown voltage must be enhanced for this condition. At phases where a high SWR load creates a high current condition, the devices can be damaged from too much dissipation, particularly if the duration of a high voltage signal swing approaches the C-B transit times.[6] Novel circuit techniques are used to realize the SWR protection scheme.

A die photograph of one of the PAs is shown in ***Figure 3***. The finished die size of all of the PAs is 1.4 × 1.4 mm (the only exception is the GSM PA, which is 1.6 × 1.4 mm due to the higher output power requirement for this standard).

Packaging

MLF/QFN surface-mount packaging is standard. For all PAs, the 20-lead, 4 × 4 mm package is used. Modules (non-ceramic) with 50 Ω interfaces have also been developed, which occupy less than 36 × 36 mm^2 of printed circuit board mounting area.

MEASUREMENTS

Measured results for three of the available SiGe PA IC designs to date are presented. Three additional designs showing target specs will be reported upon shortly. All PA ICs were fabricated in the standard 5HP/AM process. All measurements are corrected to the FR4 test board SMA connectors.

RF Measurements

Table 3 gives a summary of PA RF results to date. These results show extremely competitive PA RF performance for all major US/Korea handset standards. Target specs for the designs to be evaluated are shaded.

Figure 4 shows the CW performance of the NADC/AMPS PA over

[Continued on page 111]


LINK THE WORLD
1.6/5.6
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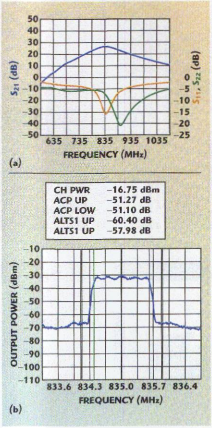
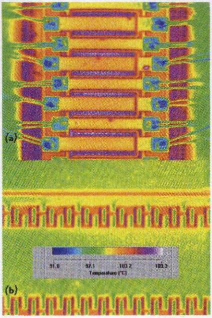


Fig. 5 CDMA power amplifier (a) S-parameters and (b) ACPR (–50 dBc) at 28.5 dBm output level.

Fig. 6 Thermal map of the (a) multi-row power cell and (b) its emitter region.



temperature and frequency at 3.6 V, while CDMA PA performance is shown in ***Figure 5***.

The bandgap-reference bias scheme gives the family of amplifiers an extremely flat P_{out} and PAE characteristic over temperature. Lowering the supply from 3.4 V to 2.9 V (minimum voltage condition) lowers the saturated output power from 31 dBm to 30 dBm.

Ruggedness (SWR) Testing

The PA ICs described here withstand industry standard load SWR tests (SWR = 10 at all phases, V_{cc} = 5 V) under RF drive sufficient to saturate the PA. Without the protection circuitry, results show the PA would fail catastrophically. These results were obtained using the standard 5HP/AM (NPNHB V_{ceo} = 5.5 V) technology along with the on-chip SWR protection circuits.

Thermal Testing

Thermal measurements were made on the output device of the SiGe PA. The results are shown in ***Figure 6*** for a

[Continued on page 113]

multirow power cell and for a close view of the emitter region. The measurements were obtained under full RF drive and a base temperature of +85° C. The Si substrate provides a higher thermal conductivity than GaAs (1.5 vs. 0.46 W/cm °C).[7] For the production SiGe IC thickness of 200um, the junction temperatures in a standard QFN package have been shown to be less than 125°C at full CDMA power. This is considerably less than what is observed for PAs in GaAs thinned to 100 µm (two times thinner, but with three times lower thermal conductivity).

CONCLUSION

SiGe PAs are a compelling alternative to GaAs HBT PAs for a variety of reasons. The NPN device RF performance is on par with other technologies, and PA IC performance is competitive. Si technology has an advantage for high volume production because wafers are larger and process yields higher, which should lead to better availability and lower cost. Bias reference and control circuitry is more accurate due to more sophisticated schemes that are possible in BiCMOS. There is a clear path to higher integration in a BiCMOS process that is not possible in GaAs due to lack of a good selection of device types and lower yields.

To these authors' knowledge, this is the first time that SiGe PAs have withstood industry standard ruggedness tests. This performance allows the PAs to be used in handset applications, which was not previously possible.

ACKNOWLEDGMENT

The authors wish to acknowledge Chris Saint for IC layout and Teddy O'Connell for technical assistance. ■

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On the Direct Conversion Receiver — A Tutorial

Increased pressure for low power, small form factor, low cost and reduced bill of materials in such radio applications as mobile communications has driven academia and industry to resurrect the direct conversion receiver. Long abandoned in favor of the mature superheterodyne receiver, direct conversion has emerged over the last decade or so thanks to improved semiconductor process technologies and astute design techniques. This article describes the characteristics of the direct conversion receiver and the issues it raises.

Very much like its well established superheterodyne receiver counterpart, first introduced in 1918 by Armstrong,[1] the origins of the direct conversion receiver (DCR) date back to the first half of last century when a single down-conversion receiver was first described by F.M. Colebrook in 1924,[2] and the term homodyne was applied. Additional developments in 1947 led to the publication of an article by D.G. Tucker,[3] which first coined the term synchrodyne, for a receiver which was designed as a precision demodulator for measurement equipment rather than a radio. Another paper by Tucker in 1954[4] reports the various single down-conversion receivers published at the time and clarifies the difference between the homodyne (sometimes referred to as coherent detector) and the synchrodyne receivers — the homodyne receiver obtains the LO directly (from the transmitter, for example), whereas the synchrodyne receiver synchronizes a free-running LO to the incoming carrier.

...direct conversion receivers, which integrated with the remaining analog and digital sections of the transceiver, have the potential to reach the "one-chip radio" goal.

Over the last decade or so, the drive of the wireless market and enabling monolithic integration technology have triggered research activities on direct conversion receivers, which integrated with the remaining analog and digital sections of the transceiver, have the potential to reach the "one-chip radio" goal. Besides, it favors multi-mode, multi-standard applications and thereby constitutes another step towards software radio.

The present article refers to several recent publications[5,6] which provide a thorough survey and insight, and display renewed interest in direct conversion receivers. Overcoming some of the problems associated with the traditional superheterodyne and being more prone to integration, DCR has nevertheless an array of inherent challenges. After a brief description of alternative and well-established receiver architectures, this article presents the direct conversion reception technique and highlights some of the system level issues associated with DCR.

[Continued on page 116]

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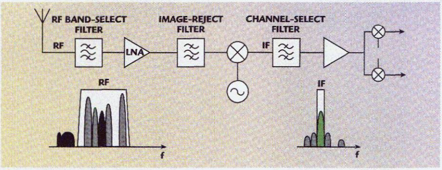

Fig. 1 The superheterodyne receiver.

TRADITIONAL RECEPTION TECHNIQUES

The Superheterodyne Receiver

The superheterodyne or heterodyne receiver is the most widely used reception technique and finds numerous applications from personal communication devices to radio and TV tuners. It has been used extensively and is well understood. It comes in a variety of combinations,[7,8,9] but essentially relies on the same principle — the RF signal is first amplified in a frequency selective low noise stage, then translated to a lower intermediate frequency (IF) with significant amplification and additional filtering, and finally down-converted to baseband with either a phase discriminator or straight mixer, depending on the modulation format. This technique is illustrated in the schematic of ***Figure 1***.

The use of a superheterodyne technique entails several trade-offs. Image rejection is a prevailing concern in this architecture. During the first down-conversion to IF, any unwanted activity at a frequency spaced at f_{IF} offset from the LO frequency (f_{LO}) on the opposite side of f_{LO} from the desired RF channel, will produce a mixing product falling right into the down-converted channel at f_{IF}. In practice, a RF bandpass filter, usually a surface acoustic wave (SAW) device, is utilized to perform band selection ahead of the low noise amplifier (LNA), while a second filter follows the LNA to perform image rejection. If these filters are identical they share the burden of the two functions. But some amount of image rejection must follow the LNA, for without it, the LNA's noise figure will effectively double due to the mixing of amplified image noise into the IF channel. Instead of the RF SAW filter, other passive filtering technologies such as dielectric or ceramic resonators can also be featured. The higher the IF, the more relaxed the requirements on the cut-off frequency of the image reject filter. Once at the IF, the presence of an interfering signal in the vicinity of the channel mandates sharp filtering around the channel; this filtering is performed after the first mixer by the channel select filter, which is also often an IF

[Continued on page 118]

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		3	165	22.5	35	18	12	2.2
SGA-9289	DC-3000	5	270	28	41	18	11	2.9
		3	315	26	39	17	11	2.6

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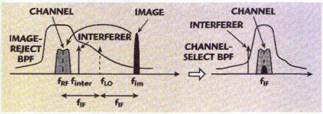

▲ *Fig. 2 Image rejection and selectivity in a superheterodyne receiver (high-side LO injection).*

SAW filter. ***Figure 2*** shows this filtering process. Essentially, the exercise is that of a carefully engineered balance among several variables, including the rejection provided by the various filters, frequency planning and linearity of the active stages. Dual IFs provide additional room to maneuver with filter selectivity, but somewhat complicate the frequency planning.

The selectivity required of the two aforementioned filters (in terms of fractional bandwidth) makes them unsuitable candidates in the foreseeable future for integration, due to the low Qs of current silicon processes, and have to be implemented by bulky off-chip components. The IF channel filter in particular requires high Q resonators for its implementation — the higher the IF, the lesser the filter's fractional bandwidth (that is, its ratio of bandwidth to center frequency), necessitating ever-higher Q. This high Q requirement is most commonly met by the use of piezoelectric SAW and crystal filters. This introduces additional constraints, as those filters often require inconvenient terminating impedances, and matching may impinge on such issues as noise, gain, linearity and power dissipation of the adjoining active stages. The narrower the fractional bandwidth, the more likely the filter's passband shape will exhibit an extreme sensitivity to variations in matching element values. Additionally, the specificity of the IF filter to the bandwidth of the signal and hence the standard used makes superheterodyne receivers unsuitable for multi-standard operation. Nonetheless, superheterodyne is known for its high selectivity and sensitivity.

Image-reject Receivers

Alternatively, by smart use of trigonometric identities, the image can be removed without the need of any post-LNA image-reject filtering. This is the principle of image-reject receivers[8,10], the first of which is the Hartley architecture, introduced in 1928[11]. It makes use of two mixers with their local oscillators in a quadrature phase relationship; this separates the IF signal into in-phase (I) and quadrature (Q) components. It then shifts the Q component by 90° before recombining the two paths, where the desired signal, present in both paths with identical polarities, is reinforced, while the image, present in both paths with opposite polarities, is cancelled out. The dual of the Hartley architecture, known as the Weaver image-reject receiver,[12] achieves the relative phase shift of one path by 90° by the use of a sec-

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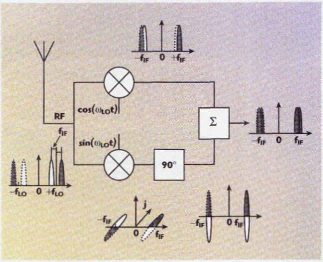
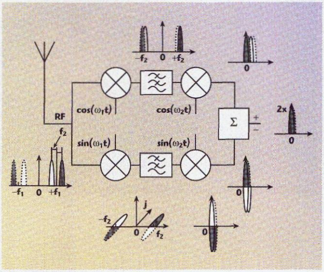


▲ *Fig. 3 The Hartley image-reject architecture.*

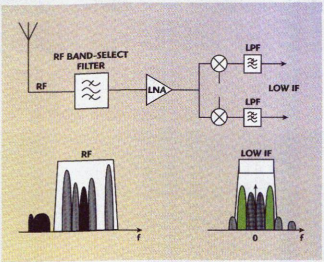


▲ *Fig. 4 The Weaver image-reject architecture.*

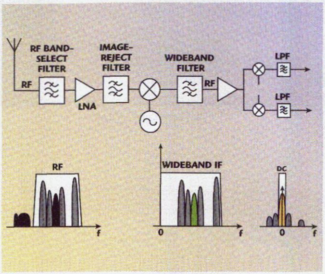
ond LO enroute to another IF or to baseband. The same result is achieved. However, the reliability of these receivers heavily depends on the accuracy of the I/Q paths, that is, the gain and phase imbalance between the two branches. ***Figures 3*** and ***4*** show diagrams of the Hartley and Weaver image-reject architectures, respectively (high frequency mixing products are removed by low-pass filtering — not shown on figures).

Low IF Single Conversion Receiver

Low IF single conversion, shown in ***Figure 5***, is an offspring of the DCR. Its main purpose is to protect the receiver from all the DC-related problems that pertain to DCR, while retaining the DCR's benefit of elimination of high Q IF filters. As its name indicates, instead of directly converting the signal to baseband, the LO is slightly offset from the RF carrier, typically one to two channels. The low IF means that the fractional bandwidth of the IF bandpass filtering is large, making it possible to implement it with low Q components. The IF SAW or crystal filter needed in the high IF case can be replaced with an active RC filter or other filter suitable for low frequency operation, that is also conducive to silicon integration.



▲ *Fig. 5 Low IF single conversion receiver.*



▲ *Fig. 6 Wideband IF with double conversion.*

The low IF signal may be translated to baseband through another mixer, or preferably, in the digital domain following analog-to-digital (A/D) conversion. Of course, this comes at the expense of faster and higher resolution A/D converters. If the IF frequency is equal to only one or two channel widths, then it is not possible to provide image rejection at RF, as the RF filter must be wide enough to pass all channels of the system. In this case, all image rejection must come from the quadrature down-conversion to the low IF, which itself resembles the Hartley architecture, once the baseband conversion is added.

Wideband IF with Double Conversion

This architecture, shown in ***Figure 6***, is very similar to the superheterodyne configuration. In this case, the first mixer utilizes an LO that is at a fixed frequency, and all channels in the RF band are translated to IF, retaining their positions relative to one another. The second mixer utilizes a tunable LO, thus selecting the desired channel to be translated to baseband. A subsequent lowpass filter suppresses adjacent channels.

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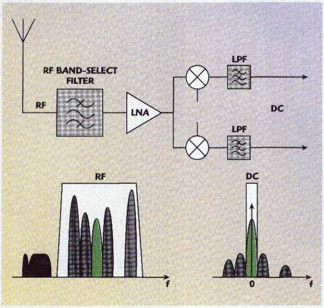

Fig. 7 The direct conversion receiver.

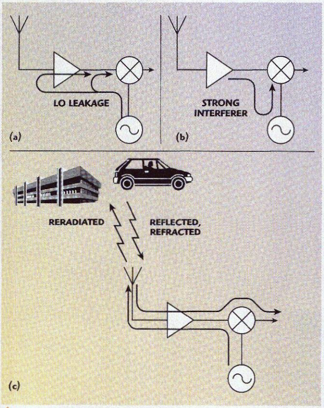

Fig. 8 DC offset mechanisms.

DIRECT CONVERSION RECEIVERS

Direct conversion reception, shown in ***Figure 7***, and also referred to as homodyne, or zero-IF, is the most natural solution to receiving information transmitted by a carrier. However, it has only been over the past decade or so that this type of reception has found applications other than pagers.[13] Direct conversion reception has several qualities which makes it very suitable for integration as well as multi-band, multi-standard operation, but there are severe inherent obstacles that have for a long time kept it in the shadow of the superheterodyne technique.

First, the problem of the image has been eliminated, since the IF is zero and the image to the desired channel (for all but single-sideband signals) is the channel itself. Then, only one local oscillator is required, which means only one phase noise contribution. The need for the bulky off-chip filters is consequently removed. Filtering now only occurs at low frequencies (baseband) with some amplification, which means less current consumption than at higher frequencies (to drive device parasitics), fewer components and lower cost. Practically, however, strong out-of-band interference or blocking signals may need to be removed prior to down-conversion in order to avoid desensitizing the receiver by saturating subsequent stages, as well as producing harmonics and intermodulation terms which will then appear in the baseband. Such a filter may be placed after the LNA for example. DCR, however, brings its own set of issues.

DC Offsets

In direct conversion, as the signal of interest is converted to baseband very early in the receive chain, without any filtering other than RF band-selection, various phenomena contribute to the creation of DC signals, which directly appear as interfering signals in the band of interest, as shown in ***Figure 8***.

The LO may be conducted or radiated through an unintended path to the mixer's RF input port, thus effectively mixing with itself, producing an unwanted DC component at the mixer output. Worse still, this LO leakage may reach the LNA input, producing an even stronger result. This effect presents a high barrier against the integration of LO, mixer and LNA on a single silicon substrate, where numerous mechanisms can contribute to poor isolation. These include substrate coupling, ground bounce, bond wire radiation, and capacitive and magnetic coupling.

Conversely, a strong in-band interference signal, once amplified by the LNA, may find a path to the LO-input port of the mixer, thus once again producing self-mixing.

Some amount of LO power will be conducted through the mixer and LNA (due to their non-ideal reverse isolation) to the antenna. The radiated power, appearing as an interferer to other receivers in the corresponding band, may violate emissions standards of the given system. It is important to note that since the LO frequency is inside the receive band, the front-end filters do nothing to suppress this LO emission. Additionally, the radiated LO signal can then be reflected by buildings or moving objects and re-captured by the antenna. This effect, however, is not of significant importance compared to the aforementioned LO self-mixing and blocking signal self-mixing.

The leakage of LO or RF signals to the opposite mixer port is not the only way in which unwanted DC can be produced. Any stage that exhibits even-order nonlinearity will also generate a DC output. This is covered in more detail later.

Whether or not the DC product will desensitize the receiver depends on the type of system. Obviously it is preferable to AC couple at the mixer output to eliminate the DC. Some modulation schemes, such as frequency shift keying (FSK) used in paging applications, show little degradation if low frequency components of the spectrum

[Continued on page 124]

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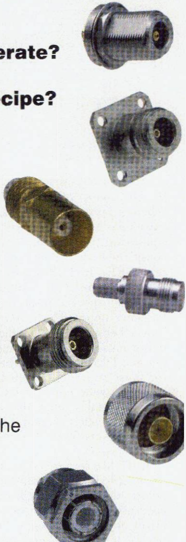

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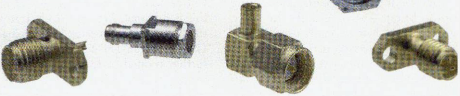

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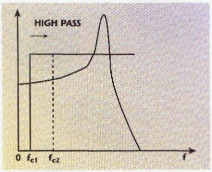
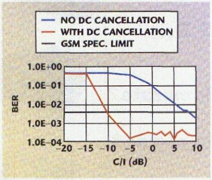
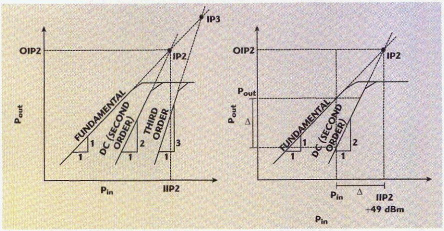


▲ *Fig. 9 High pass filtering of modulation spectrum.*



▲ *Fig. 10 BER improvement with DSP-based DC offset cancellation.*



▲ *Fig. 11 Second order intercept point (IP2).*

are filtered out, as shown in ***Figure 9***. However, other modulation schemes present a peak at DC, and capacitive AC coupling will lead to significant information loss, hence considerably degrading the bit error rate (BER). In TDMA systems such as GSM, there is no significant low frequency spectral peak, but it still becomes impossible to AC couple. This is because of the conflicting requirements on an AC coupling capacitor in a TDMA system — the capacitor must be large enough to avoid causing a wide notch at DC, but it must be small enough that all transients settle out upon power-up of the receiver (every frame) before data reception begins.

In TDMA receivers that cannot be AC coupled, the idle timeslot (just before reception) can still be put to good use by storing the value of the offset in a capacitor and then subtracting it from the signal path during the burst. This is exactly the same method that is normally used to correct DC offsets occurring at the second mix of superheterodyne TDMA receivers, where this mix goes to baseband (in that case the only problem causing DC is LO self-mixing). In this method the value of DC produced by the receiver is obtained in a pre-measurement prior to the receive burst. It is important when using this method that the signal path prior to the mixer be opened during the DC pre-measurement to prevent any large blocking signals from affecting the result. Variable or wandering offsets are most often induced by blocking signals, which can appear at any time. These offsets cannot be corrected by the measurement-and-subtraction process, because the blocking signals may appear during the measurement and not during the burst, or vice-versa. For blocking-induced DC, the most effective measures are the elimination of self-mixing paths and the maximizing of linearity to prevent the DC to begin with. Failing these, there is still the possibility of DC correction after-the-fact in the digital signal processing occurring at baseband.

Digital signal processing (DSP) techniques can be used to remove the DC offset in TDMA systems in a way that cannot be duplicated in the analog domain — a full timeslot of the received signal can be buffered, the mean of which is determined and then removed from each data point of the signal. The resulting signal has zero mean. For systems such as GSM, an unwanted result of this is that any DC that is part of the signal will be lost, but the typical effect of this is minimal. ***Figure 10*** illustrates the use of such a method for a typical GSM receiver. This technique can be further refined by tracking the mean over portions of the burst, allowing the detection of sudden interferers or blockers and cancelling their DC product only where it occurs. Careful layout can also improve isolation.

Nonlinearities

As mentioned previously, another problem for the DCR is nonlinearity. Just as with the superheterodyne receiver, the DCR exhibits spurious responses. For the superheterodyne these occur at RF input frequencies where N(RF) ± M(LO) = IF, while for the DCR they occur where N(RF) – M(LO) = 0. When a blocking signal's carrier falls on one of these spurious frequencies, the signal is translated to baseband with an attendant shift in its bandwidth, dependent on the spurious order.

More importantly, however, large blocking signals also cause DC in the direct conversion receiver, whether on a spurious frequency or not. The DC is produced at the mixer output and amplified by the baseband stages. It is due primarily to second-order nonlinearity of the mixer, characterized by the second-order intercept point (IP2) and second-order intermodulation (IM2). It can be alleviated by extremely well-balanced circuit design. However, the mixer and LNA used to require a single-ended design because the antenna and a hypothetical preselect filter were usually single-ended.

In most systems, the third-order intermodulation is of importance as it usually falls in-band, in the vicinity of the signals of interest, and is characterized by the third-order intercept point (IP3). In direct conversion, second-order nonlinearity becomes critical, as it produces baseband signals, which now appear as interfering signals in the down-converted desired signal. IM2 is measured by the IP2. IP2 is defined in the same manner as IP3, as shown in ***Figure 11***. Either a

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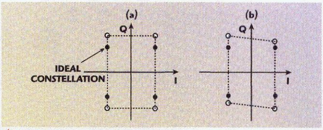

Fig. 12 IQ demodulator imperfections; (a) gain imbalance and (b) phase imbalance.

two-tone, or single tone test can be performed, and the IP2 is defined by extrapolating the low frequency beat tone in the former or the DC component in the latter, until it intercepts the fundamental curve. To illustrate the case of a single tone test, the input signal is

$$x(t) = A\cos t(\omega t).$$

Assuming a nonlinearity modeled by a polynomial

$$y(x) = a_1x + a_2x^2 + a_3x^3 + \ldots$$

$$y(x) = a_1A\cos(\omega t) + a_2A^2\left(\frac{\cos(2\omega t)+1}{2}\right) + \ldots$$

$$= \underbrace{\frac{a_2A^2}{2}}_{\text{DC}} + \underbrace{a_1A\cos(\omega t)}_{\text{fundamental}} + \frac{a_2A^2}{2}\cos(2\omega t) + \ldots$$

It can be seen that the DC component due to the second-order nonlinearity is growing with twice the slope of the fundamental on a logarithmic scale. At the intercept point,

$$\frac{a_2A^2}{2} = a_1A \Leftrightarrow A = \frac{2a_1}{a_2} = \text{IIP2}$$

Due to the doubled slope of the second-order product,

$$\text{IIP2} = \text{Pin} + \Delta \qquad \text{with } \Delta = \text{Pout} - \text{IM2}$$

Noise

Low frequency noise[14] becomes a great concern in a DCR, as significant gain is allocated to baseband stages after the mixer. Weak signal levels of a few millivolts in baseband are still very vulnerable to noise. This requires stronger RF stage gain to alleviate the poor noise figure of baseband blocks, but of course this must be traded against the linearity problems, just described, that accompany higher RF gain.

Flicker noise, or 1/f noise, is the major baseband noise contributor. Associated with a flow of direct current, it has a spectral response proportional to 1/f. In RF circuits, 1/f noise tends to be modulated onto the RF signal, and in the case of a mixer with baseband output, 1/f noise sees especially high conversion gain. In practice, flicker noise becomes an issue for MOS devices more than bipolar, and is modeled as a voltage source in series with the gate. 1/f noise complicates the use of MOS transistors for RF circuits, since the main method of reducing it in MOS is to increase the transistor's size, which increases the device capacitance, adversely affecting RF gain. For this reason it is preferable to use bipolar transistors for DCR mixer designs. In the first baseband stages after the mixer, it becomes possible to use MOS devices, as the transistor-size trade-off is feasible at low frequencies.

I/Q Mismatches

Due to the high frequency of the LO, it is not possible to implement the IQ demodulator digitally. An analog IQ demodulator exhibits gain and phase imbalances between the two branches, as well as the introduction of DC offsets. Such imperfections distort the recovered constellation. Assuming α and ϕ are the amplitude and phase mismatch, respectively, between the quadrature ports of the demodulator, and the complex signal incident upon it have in-phase and quadrature components I and Q, then

$$I_{out} = (I\cos(\omega t) + Q\sin(\omega t)) \bullet 2\cos(\omega t)$$
$$Q_{out} = (I\cos(\omega t) + Q\sin(\omega t)) \bullet 2(1+\alpha)\sin(\omega t + \phi)$$

Filtering out the high frequency terms yields

$$I_{out} = I$$
$$Q_{out} = (1+\alpha)(-I\sin\phi + Q\cos\phi)$$

Figure 12 shows how this affects a given constellation diagram. In DCR systems, however, the IQ matching is not as critical as in image-rejection architectures. Rather, it is only important insofar as the accuracy of the modulation is concerned.

Analog and digital (DSP based) calibration and adaptation methods have been described so as to correct for these imbalances.[15]

CONCLUSION

The direct conversion receiver is an attractive yet challenging receiving technique. It has been successfully applied to devices such as pagers, mobile phones, PC and internet wireless connectivity cards, and satellite receivers, etc. in a variety of process technologies and increasing integration levels. It is poised to appear in many more applications in the near future.

ACKNOWLEDGMENTS

The authors would like to thank Darioush Agahi and Morten Damgaard of Conexant Systems for their valuable input to this article. ■

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[Continued on page 128]

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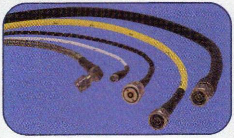

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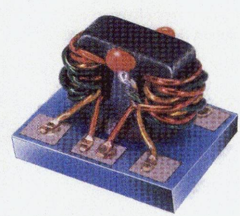


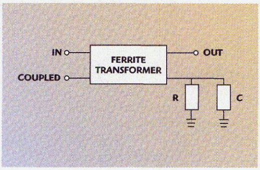
Low Cost Directional Couplers

Ever expanding applications of RF and microwaves for wireless and cable applications have revived the development efforts of components at these frequencies. There is a continuing demand to reduce size and cost, and to improve performance and quality at the same time. To satisfy these goals, a new series of directional couplers has been introduced to meet the demands of the market. These couplers measure 0.15" × 0.15" × 0.15" and are designed for assembly using automated pick and place machines.

What Constitutes a Directional Coupler

The block diagram of a directional coupler is shown in ***Figure 1***. It consists of a ferrite transformer, a resistor and a capacitor. The ferrite transformer is wound on a balun core and works as a four-port device. By proper selection of R and C, a three-port directional coupler is realized.

Fig. 1 Block diagram of a directional coupler.



Coupler Construction

Couplers working in the 5 to 2000 MHz frequency range and having multiple-decade bandwidths are traditionally constructed using ferrite cores. This provides the requisite bandwidth in a small volume. Traditional ferrite-based couplers are housed in a package measuring 0.25" × 0.31" × 0.20". The company has introduced a series of couplers[1,2] that require an external component on the user's motherboard. This reduces the cost, but the size of the device is only slightly reduced to 0.19" × 0.25". For higher frequency applications, an additional capacitor is required, and it increases the size. In the new approach, the resistor and capacitor are integrated into a multi-layer board using Blue Cell™ technology. This shrinks the overall area of the coupler to 0.15" × 0.15" and the height to less than 0.15".

The transformer is mounted on the top of the board, and all connections from the transformer to the base are made by welding. This procedure helps to ensure the preciseness of the assembly, with resulting high performance repeatability, and prevents any disconnection during reflow at the user's site. All connections from top to bottom metal layers are accomplished using filled vias. The transformer used in this series of couplers employs a patented technique[3] to obtain flat coupling over the band.

Coupler Performance

As an example, the model DBTC-13-5-75 (shown in the photograph) is a coupler designed

[Continued on page 132]

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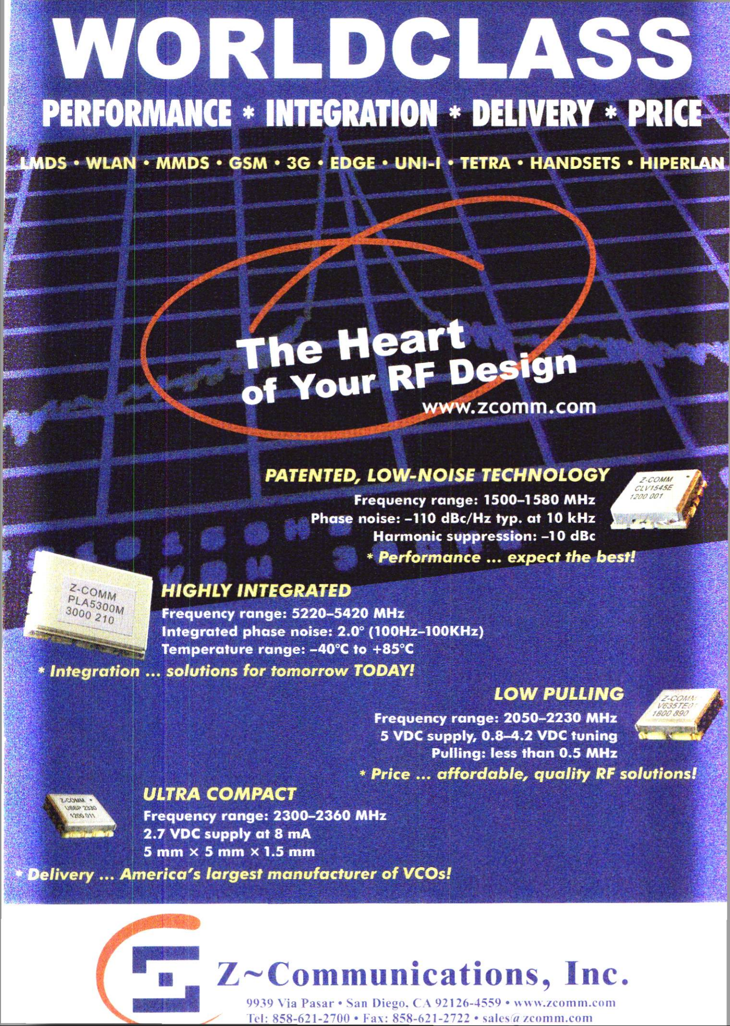
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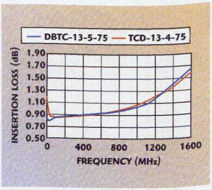
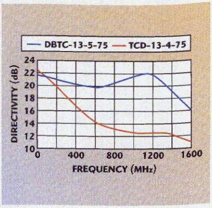
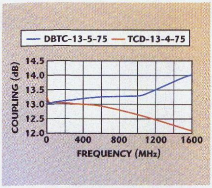


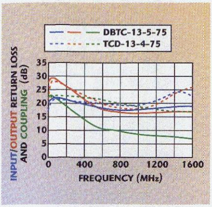
▲ *Fig. 2 The coupler's insertion loss.*



▲ *Fig. 3 Directivity.*



▲ *Fig. 4 Coupling.*



▲ *Fig. 5 Return loss.*

for 75 Ω applications using this technology. The unit operates over the 5 to 1000 MHz frequency range with a nominal coupling of 13.2 ±0.5 dB and a flatness of ±0.6 dB. The model TCD-13-4-75 is a coupler that requires external components. A comparison is made between these two couplers in the subsequent data plots to show the performance advantages of each. ***Figure 2*** shows the insertion loss of the couplers. The insertion loss is similar in both cases and is typically 1 dB. ***Figure 3*** shows the directivity vs. frequency, which is typically 20 dB over the band. Note the improvement over the TCD-13-4-75 device. ***Figure 4*** shows the coupling vs. frequency, which is typically 13.3 dB to 1000 MHz for the new coupler. ***Figure 5*** shows return loss vs. frequency at all three ports, which is typically 20 dB (1.22 SWR) for input and output. Although the coupled-port return loss is lower than that of the TCD model, for most applications this return loss performance is not important. ***Table 1*** lists the DBTC-13-5-75 directional coupler's complete electrical specifications along

TABLE I

ELECTRICAL SPECIFICATIONS

Model No. DBTC-	Freq. Range (MHz)	Coupling (dB)		Mainline Loss (dB)						Directivity (dB)						SWR[1]	Power Input (W)	
		Nominal	Max Flatness	L Typ.	L Max.	M Typ.	M Max.	U Typ.	U Max.	L Typ.	L Min.	M Typ.	M Min.	U Typ.	U Min.	Typ.	L Max.	MU Max.
9-4	5–1000	9.0±0.5	±0.5	1.2	2.0	1.2	1.8	1.5	2.0	21	17	18	13	15	–	1.30	0.5	1.0
10-4-75	5–1000	10.5±0.5	±0.7	1.5	2.2	1.4	2.0	1.5	2.0	21	16	20	13	16	–	1.30	0.5	1.0
12-4	5–1000	12.2±0.5	±0.9	0.9	1.8	0.7	1.3	1.1	1.6	33	22	21	14	15	–	1.30	0.5	1.0
13-4	5–1000	13.0±0.5	±0.6	0.7	1.3	0.7	1.3	1.1	1.6	21	17	18	13	13	–	1.30	0.5	1.0
13-5-75	5–1000	13.2±0.5	±0.6	0.9	1.4	1.0	1.5	1.1	1.6	21	17	19	14	18	–	1.30	0.5	1.0
	1000–1500	13.6±0.5	±0.8			1.4	2.2					17	–					
16-5-75	5–1000	16.3±0.5	±0.7	1.2	2.0	1.0	1.5	1.1	1.6	22	16	21	13	20	–	1.30	1.0	1.0
	1000–1500	16.5±0.5	±0.7			1.3	1.9					19	–			1.30	1.0	1.0
17-5	50–1000	17.0±0.7	±0.9			0.9	1.4					20	13			1.30	–	2.0
	1000–1500	17.7±0.9	±1.0			1.0	1.5					20	10			1.30	–	2.0
	1500–2000	18.0±1.0	±0.8			1.1	1.6					14	–			1.30	–	2.0
18-4-75	5–1000	18.2±0.5	±0.7	0.8	1.5	0.8	1.4	1.0	1.6	25	16	21	14	15	–	1.30	1.0	1.0
20-4	20–1000	20.4±0.6	±0.8	0.3	1.0	0.4	1.0	0.7	1.3	21	13	21	14	16	–	1.20	1.0	1.0

[1]For coupled port SWR above 500 MHz, 1.6 typ.

L = low range (f_L to 10 f_L) • ***M*** = mid range (10 f_L to $f_U/2$) • ***U*** = upper range ($f_U/2$ to f_U)

[Continued on page 134]

with specifications for nine additional couplers in both 50 and 75 Ω impedances.

CONCLUSION

A series of miniature couplers has been developed using Blue Cell™ technology and ferrites to realize their extremely small size. This feature will save much needed PCB area for users. These units utilize a patented technique to realize a very flat coupling response and are suitable for automated pick and place. All units are supplied in an AT790 case style and are priced at $1.99 each in 25 piece quantities.

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Circle No. 302

CHIPSETS FOR MICROWAVE AND MILLIMETER-WAVE POINT-TO-POINT RADIOS

Point-to-point, point-to-multi-point and local multi-point distribution system (LMDS) radios have emerged as cost-effective alternatives to optical fiber for high speed data transmission links serving small- and medium-size commercial properties, as well as being suitable for cellular and personal communications networks. However, a major problem facing the designers of such radio systems is that no manufacturer has been able to supply all of the high performance MMICs needed to build a complete transceiver. Recently, complete chipsets for point-to-point radios in the 23, 26 and 38 GHz bands have been developed and manufactured. All of the chipset components use Raytheon's high performance 0.25 μm PHEMT processes, and alleviate problems associated with multi-manufacturer solutions such as inconsistent operating frequencies, power levels and bias requirements. The new RRFC chipsets have been developed with the system designer in mind and the 23, 26 and 28 GHz chipsets are designed to work together with a minimum of additional components. All of the MMICs have been designed to function together as a complete system and have several features allowing rapid radio design. The operating frequency range and power level of each chip is consistent with successive chain components, which means, for example, that the low noise amplifier (LNA) can drive the mixer directly and the output frequency of the LNA matches the RF input frequency range of the mixer. Each buffer amplifier has been designed with a saturated output power performance optimized for driving the multiplier and mixer circuits over a wide range of operating conditions. All of the active components utilize the same 4 V drain bias rail, which simplifies power supply requirements and reduces overall module cost. These features mean that the module design cycle time can be significantly reduced allowing manufacturers to launch new products in the fastest possible time.

Fig. 1 A simplified millimeter-wave radio block diagram.

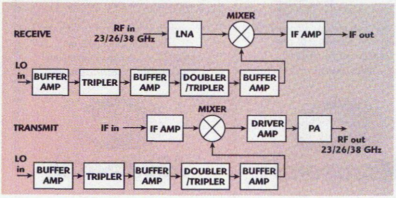

Figure 1 shows a simplified block diagram of a typical system architecture applicable to

[Continued on page 138]

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TABLE I

MICROWAVE RADIO SUBSYSTEM COMPONENTS

Part No.	Description	Frequency (GHz)	Chipset	Function
RMWL26001	LNA	21 to 26.5	23/26	Rx
RMWL38001	LNA	37 to 40	38	Rx
RMWL05001	LNA/IF amp	4.7 to 5.2	38	Rx/Tx
RMWM26001	mixer	RF – 21 to 26.5 IF – 2.5 to 4.1	23/26	Rx/Tx
RMWM38001	mixer	RF – 37 yo 40 IF – 4.7 to 5.2	38	Rx/Tx
RMWD24001	driver amp	21 to 26.5	23/26	Tx
RMWD38001	driver amp	37 to 40	38	Tx
RMWP23001	power amp	21 to 24	23	Tx
RMWP26001	power amp	24 to 26.5	26	Tx
RMWP38001	power amp	37 to 40	38	Tx
RMWT04001	multiplier (3X)	I/P – 2.8 to 4.0 O/P – 8.4 to 12	23/26/38	LO
RMWT11001	multiplier (3X)	IP – 10.5 to 11.7 O/P – 32 to 35	38	LO
RMWW12001	multiplier (2X)	I/P – 8.5 to 12 O/P – 17 to 24	23/26	LO
RMWB04001	buffer amp	3.5 to 4.0	38	LO
RMWB11001	buffer amp	10.5 to 11.7	38	LO
RMWB12001	buffer amp	8.5 to 12	23/26	LO
RMWB24001	buffer amp	17 to 24	23/26	LO
RMWB33001	buffer amp	32 to 35	38	LO

23, 26 and 38 GHz radios. ***Table 1*** lists all of the available radio components by part number and includes a brief description. The benefits of a chipset designed from the perspective of the entire system using a common technology are also presented.

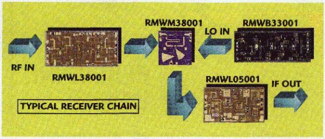
RECEIVER CHAIN COMPONENTS

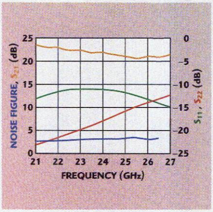
Low Noise Amplifiers

Each of the radio chipsets has a dedicated LNA designed specifically for use in point-to-point type systems. These amplifiers are manufactured using the 0.25 μm low noise PHEMT process which results in a combination of excellent small-signal performance, low noise figure and high power capability.

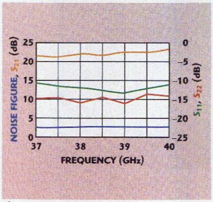
The RMWL26001 device is a single chip LNA that covers the 21 to 26.5 GHz frequency range allowing the same MMIC to be used in both the 23 and 26 GHz chipsets. Typical noise figure performance is 3.1 dB with 22 dB small-signal gain and return losses better than 10 dB. The RMWL26001 has also been designed to have a P1 dB > 10 dBm, which means that the mixer can be driven directly without the need for extra amplifier components. The RMWL38001 chip provides similar performance in the 37 to 40 GHz frequency range. Typical noise figure performance is 2.7 dB with 22.5 dB small-signal gain. The return losses are better than 10 dB with 12 dBm output power at the 1 dB gain compression point. The RMWL26001 and RMWL38001 devices both operate on $V_{DS} = 4.0$ V. ***Figure 2*** shows the MMICs in a typical receiver configuration. ***Figures 3*** and ***4*** show the small-signal and noise performance of the RMWL26001 and the RMWL38001, respectively.

▼ Fig. 2 Example of a receiver chain for a 38 GHz microwave radio.





▲ Fig. 3 The RMWL26001 LNA's on-wafer performance.



▲ Fig. 4 The RMWL38001 LNA's on-wafer performance.

Upconverter and Downconverter Components

High performance mixers are vital components in point-to-point radio systems and two mixers have been designed covering the 23/26 GHz and 38 GHz bands. Each mixer is a single-balanced FET diode mixer, offering low conversion loss and high isolation, and the same component can be used as either an upconverter or a downconverter, thus reducing the number of different ICs required. The FET diodes are fabricated using the same 0.25 mm process that is used for the amplifiers, and the mixers also offer the major benefit of requiring no DC bias. The RMWM26001 device covers the 23 and 26 GHz radio bands, and

[Continued on page 140]

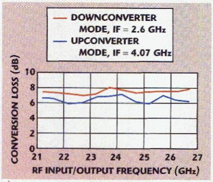
Figure 5 shows its on-wafer performance. ***Figure 6*** shows the conversion loss for the RMWM38001 mixer covering the 38 GHz band.

TRANSMITTER CHAIN COMPONENTS

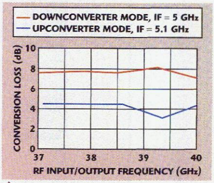
Power Amplifiers

The power amplifier is the heart of any microwave radio system and often other system components are selected based on the specification of the power amplifier. In keeping with the overall aim of producing complete radio chipsets, three power amplifiers have been designed covering popular point-to-point radio bands. Each amplifier uses the same 0.25 µm PHEMT process and the same 4 V bias voltage as the other active components thus simplifying transmitter power supply requirements.

The RMWP23001 power amplifier covers the 21 to 24 GHz frequency band, with 22.5 dB small-signal gain, a 1 dB compressed output power of 23.5 dBm and an OIP_3 of 33 dBm. The RMWP26001 amplifier covers the 24 to 26.5 GHz range with similar performance. The RMWP38001 is for the 38 GHz radio bands with a small-signal gain of 22 dB, a P1dB of 22 dBm and an OIP3 of 30 dBm (37 to 40 GHz). All of the power amplifiers include integrated power detectors that can be connected to continuously monitor output power and aid fault detection. The performance of RMWP23001 and RMWP26001 devices is shown in ***Figure 7***.

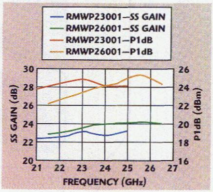


▲ *Fig. 5 The RMWM26001 mixer's on-wafer performance.*



▲ *Fig. 6 The RMWM38001 mixer's on-wafer performance.*

Fig. 7 Measured on-wafer performance of the RMWP23001 and RMWP26001 power amplifiers. ▼



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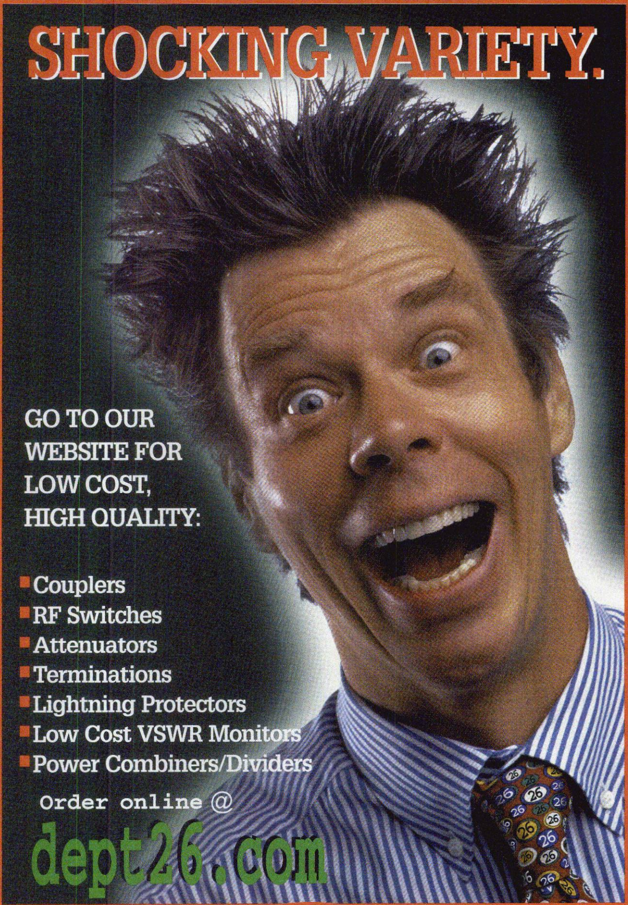

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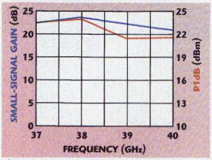
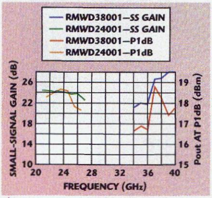
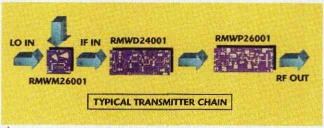
Figure 8 shows the performance of the higher frequency RMWP38001 part. Additional off-the-shelf power amplifiers can be used if higher output powers or improved linearity are required. An example is the RMPA39100 power amplifier, which is capable of 1 W over the 37 to 40 GHz frequency range.



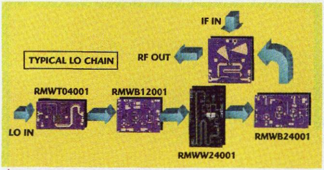
▲ *Fig. 8 Measured on-wafer performance of the RMWP38001 power amplifier.*



▲ *Fig. 9 The RMWD38001 and RMWD24001 amplifier's measured on-wafer performance.*



▲ *Fig. 10 Example of a transmitter chain for a 26 GHz microwave radio.*



▲ *Fig. 11 Example of the LO chain architecture used in the 23 GHz radio chipset.*

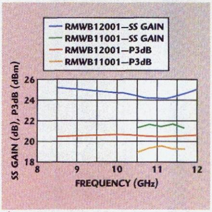
Driver Amplifiers

Two driver amplifiers have been designed for use in the radio chipsets covering the 23/26 and 38 GHz radio bands, respectively. The RMWD-24001 device has a frequency range of 21 to 26.5 GHz with greater than 21 dB of small-signal gain and a 1dB compressed output power of 17 dBm. Coverage in the 37 to 40 GHz frequency range is provided by the RMWD38001 amplifier, which has a small-signal gain of greater than 23 dB and an P1 dB output power of 18 dBm. Both of these parts have return losses better than 10 dB and also incorporate FET diode power detectors to allow continuous monitoring of the output power. This power detection feature can be used in a control loop to ensure that the optimum output power is always used. ***Figure 9*** shows the performance of both the driver amplifiers and ***Figure 10*** shows the MMICs in a typical transmitter chain using the RMWM26001 device as an upconverter.

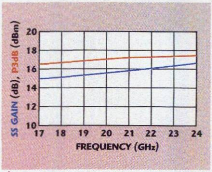
LOCAL OSCILLATOR CHAIN COMPONENTS

Buffer Amplifiers

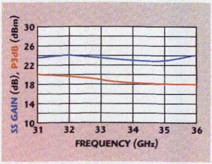
Each of the transmit and receive chains in the 23/26 GHz and 38 GHz chipsets utilize buffer amplifiers to amplify the LO signal to drive the frequency doublers/triplers and the mixers. In the 23/26 GHz chipsets the RMWB12001 and PMWB24001 buffer amplifiers cover the 8.5 to 12 and 17 to 24 GHz (RMWB24001) frequency ranges, respectively. The 38 GHz chipset uses three buffer amplifiers with the RMWB04001 device providing low frequency buffer amplification (3.5 to 4.0 GHz), the RMWB11001 amplifier covering the 10.5 to 11.7 GHz band and the RMWB33001 device covering the 32 to 35 GHz range. All of the buffer amplifiers are designed to be operating into compression, but can be operated backed off as well, allowing them to be used as linear amplifiers. Typical buffer amplifier performance is small-signal gain > 20 dB and saturated output power in the 17 to 20 dBm range. A power detection circuit is incorporated onto each amplifier MMIC allowing power monitoring or fault detection. An example of LO chain architecture is shown in ***Figure 11***. ***Figure 12*** shows the RMWB11001 and RMWB12001 performance. ***Figures 13*** and ***14*** show the performance of the RMWB24001 and RMWB33001, respectively.



▲ *Fig. 12 Measured on-wafer performance of the RMWB11001 and RMWB12001 buffer amplifiers.*



▲ *Fig. 13 The RMWB24001 amplifier's on-wafer performance.*



▲ *Fig. 14 On-wafer performance of the RMWB33001 amplifier.*

[Continued on page 144]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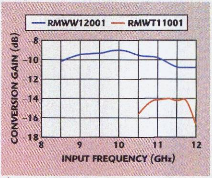
Frequency Doublers and Triplers

Frequency conversion components are used in both the 23/26 and 38 GHz radio chipsets in the LO chains. These provide multiplication, from the low frequency LO signal typically around 3 to 4 GHz up to the 17 to 24 GHz signals required in the 23/26 GHz radios and 33 GHz needed for the 38 GHz chipset.

Each of the doublers and triplers are passive components that do not require bias and all use the same PHEMT process as the amplifier circuits with the FETs configured as diodes. The RMWT04001 device is a tripler MMIC that has an input frequency range of 2.8 to 4.0 GHz and an output frequency range of 8.4 to 12 GHz. The RMWW12001 and RMWT11001 components have input frequency ranges to match the output of the RMWT04001 with output frequency ranges of 17 to 24 GHz and 32 to 35 GHz, respectively. ***Figure 15*** shows the typical performance of the RMWW12001 and RMWT11001 as measured on-wafer. The conversion gain (f_0 to $2f_0$ or $3f_0$) is plotted as a function of input frequency f_0.



▲ *Fig. 15 Measured on-wafer performance of the RMWW12001 and RMWT11001 devices.*

CONCLUSION

A complete solution for the rapidly expanding point-to-point and point-to-multi-point radio markets has been developed. In order to remain competitive designers must be able to produce new radio designs with improved performance in the shortest possible time. The chipsets described here cover several of the most important frequency bands in use and offer complete solutions for both receivers and transmitters. A complete chipset offers many advantages over the traditional approach of using many different vendors. These include identical supply rails, matched frequency and power performance, uniformity of fabrication processes, single vendor qualification, simplified design requirements and reduced module design time. These components can either be used as a stand-alone radio, or coupled with the company's successful RMPA product line, such as the RMPA39100 component that offers 1 W of output power in the 37 to 40 GHz frequency range.

All of the products discussed here are available as 100 μm thick MMIC die with 50 Ω input and output terminations in both sample and production quantities. Additional information is available at the company's Web site at www.raytheon.com/micro or contact Brian Reardon at brian_g_reardon@rrfc.raytheon.com.

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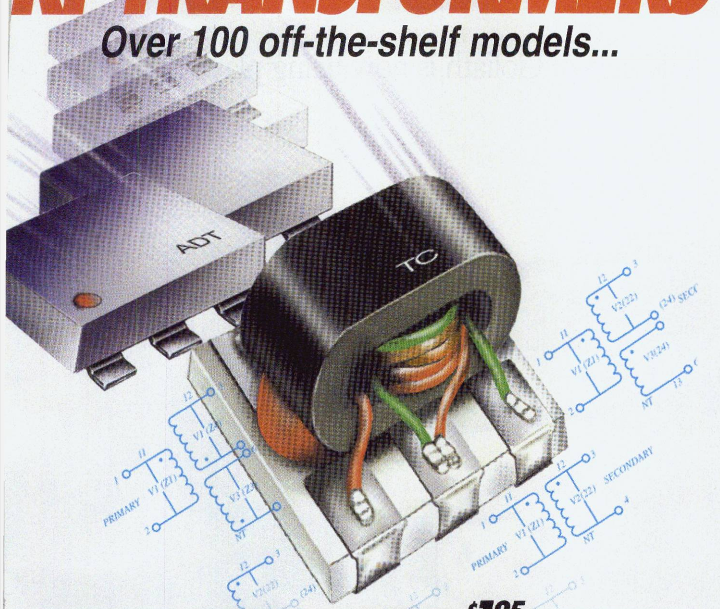

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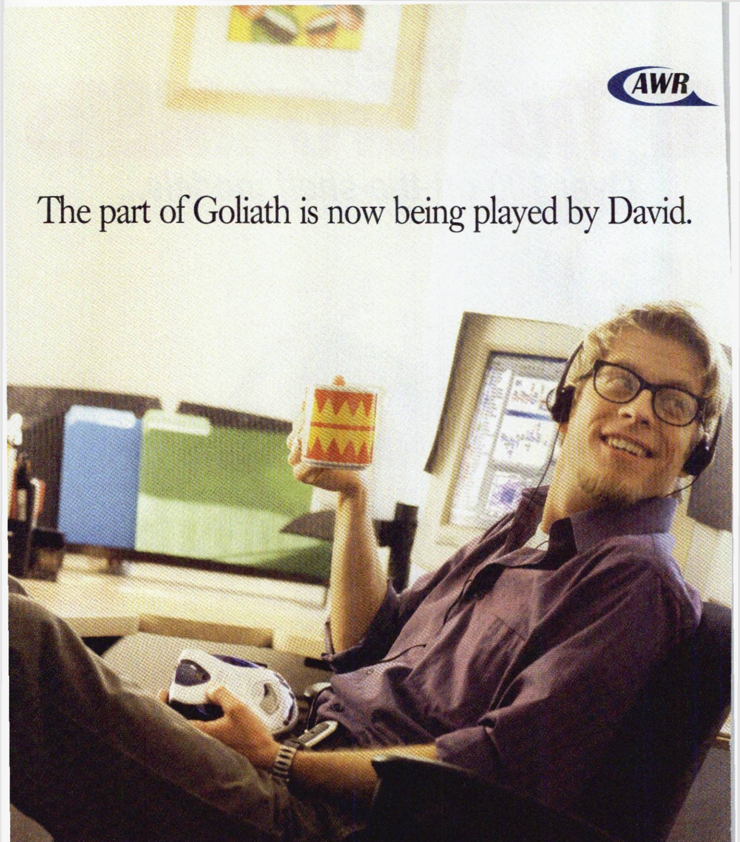

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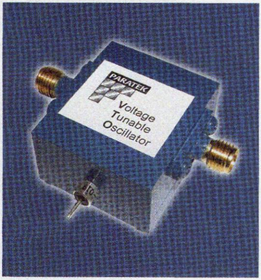
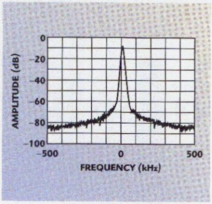


Low Phase Noise Voltage Tunable Oscillators

Driven by the VCO market's insatiable need for lower phase noise and wider tuning ranges, a new line of voltage tunable oscillators (VTO) has been introduced with superior performance in these areas. The new VTOs operate at fundamental frequencies with no inherent spurious responses or subharmonics. The oscillators feature fast tuning, low power consumption and software control.

Fig. 1 VTO phase noise at 10.5 GHz (resolution bandwidth 10 kHz).



VTO PERFORMANCE

The featured VTO operates at 11 GHz with phase noise at –106 dBc/Hz at 100 kHz offset, as illustrated in ***Figure 1***. The oscillator has a tuning range of 600 MHz (5.4 percent bandwidth), as shown in ***Figure 2***. Other performance specifications include a tuning linearity of 2.8 percent and output power of 0 dBm, with harmonics at –26 dBc and no detectable spurious outputs. In addition, its pushing factor is essentially zero. The new VTOs are packaged in a 1.0" × 1.0" × 0.375" (26 × 30 × 15 mm^3) housing with SMA connectors for RF output and control input.

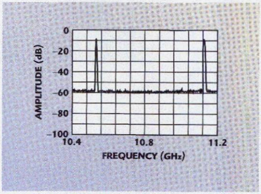


Fig. 2 VTO tuning range.

[Continued on page 154]

PARATEK
Columbia, MD

TABLE I

DESIGN CONSIDERATIONS AND INTENDED BENEFITS

Design Strategy	*Performance Parameter Affected*
Microstrip structure	Ease of manufacturing, small size, low cost
Resonator topology allowing tuning range and Q-factor to be optimized	Tuning range and linearity, phase noise and Q
Low noise active devices	Low phase noise
Optimal terminations of the active device at low frequencies	Low 1/f component of the phase noise
Optimal terminations of the active device at RF frequencies	High output power, reliable oscillation over frequency band of interest and ambient temperature range, zero spurious oscillations
Circuit topology	Low pulling factor
Integral amplifier	Low control voltage (0 to 12 V) or PLL loop amplifier included
Fundamental operation	No subharmonics
Alternative: multiplied and fundamental outputs	No prescaling required in PLL

PARASCAN MATERIALS

The VTOs are enabled by the patented Parascan™ family of materials. These are voltage tunable dielectric materials, which allow the oscillators to tune over broad frequency ranges through the application of a DC electric field. Parascan materials are ceramic and draw virtually no current (< 5 µA), and thus consume very little power. The key features of this technology in VTO applications are its high Q factors, wide tuning range and linear performance. The availability of this technology in various form factors also enables the design of different topologies. Being passive devices with no discernible noise sources, these tunable dielectric capacitors are excellent candidates for tunable oscillator applications.

The new VTOs are designed to fully exploit the properties of the Parascan materials. Some design considerations and the intended benefits are outlined in ***Table 1***.

BENEFITS

With pricing comparable to varactor-tuned oscillators, OEMs will benefit from the enhanced performance of the new VTOs. Tuning and frequency range is comparable to YIG oscillators, while spectral purity is approaching that of dielectric resonator oscillators. Switching speed is similar to varactor-tuned oscillators. Synthesizer design is made easy due to the fast linear tuning and the options of low voltage/low current control, subharmonic outputs and integral phase locked loop (PLL) amplifiers. The very best features of all competing VCO technologies are equaled or improved in these VTOs.

IN THE FUTURE

The initial VTO product results indicate that additional improvements are achievable in subsequent models. The possibilities include fundamental frequencies in the 20 to 30 GHz range, multiplied outputs up to 40 GHz, tuning ranges beyond 20 percent, better phase noise, higher spectral purity, and surface mount, drop-in and connectorized packaging.

Additional information on the new VTOs and other products including tunable filters, diplexers, delay lines and electronically scanning antennas can be obtained from the company's Web site at www.paratek.com or via e-mail at etrf@paratek.com.

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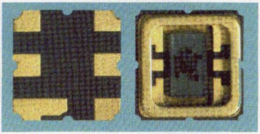


Miniature, High Performance GPS RF SAW Filters

Location-based products using Global Positioning Satellite (GPS) signals are poised to revolutionize wireless service. Implementation of federally mandated mobile subscriber location requirements is fueling the rush to market. Meanwhile, manufacturers plan to capitalize on the presence of GPS-enabled mobiles by developing new consumer-oriented software applications and next-generation hardware that will make purchasing goods and services through wireless devices commonplace.

Fig. 1 The filter's passband insertion loss.

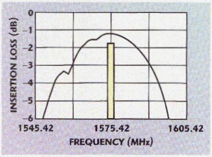
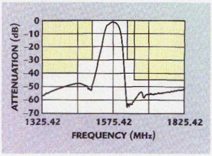


Fig. 2 Attenuation vs. frequency.



One of the most critical and essential elements of GPS receiver design is filtering at the RF stage. RF filters must be capable of providing ultra-low insertion loss to minimize signal recovery errors. Such errors can result in a loss of signal that could have dire consequences in E911 situations. Superior attenuation is also vital at key frequency ranges occupied by transmitters operating in all major voice and data protocols including AMPS, CDMA, TDMA, GSM and PCS. Size is another critical element for designers who look for a way to include the additional GPS receiver chain on already crowded PC boards.

A new GPS Rx surface acoustic wave (SAW) filter is designed to specifically address key performance specifications by providing typical insertion loss of just 1.3 dB and typical attenuation of 50 dB at the critical 824 to 869 and 1640 to 1926 frequency ranges. ***Figures 1*** and ***2*** show the filter's typical insertion loss and attenuation vs. frequency, respectively. The model 855969 SAW filter is centered at 1575.42 MHz, with a bandwidth of 2.4 MHz for top performance. In addition, its $3.0 \times 3.0 \times 1.2$ mm^3 surface-mount package is 94 percent smaller than the current ceramic alternative, making it easy to incorporate into any PCB application. The product also features a simple 50 Ω single-ended source and load configuration, and requires no impedance matching for operation at 50 Ω.

Additional information may be obtained from the company's Web site at www.sawtek.com on the "What's New" page, or phone for data sheets and full specifications. Purchase information may be obtained from Avnet Electronics Marketing at (800) 332-8638 or visit Avnet's Web site at www.em.avnet.com.

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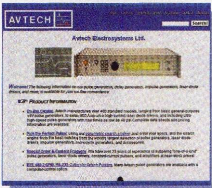

Pulse Generators & Drivers

This Web site provides data sheets and pricing for 500 models of pulse generators, laser diode drivers, impulse generators, amplifiers and delay generators, with rise times as low as 40 ps, PRF to 250 MHz and amplitudes to 3000 V. The site also includes a parametric search engine to assist the user looking for the perfect instrument.

Avtech Electrosystems Ltd.,
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www.avtechpulse.com

Filters and Filter-based Products

This Web site features the company's filter and filter-based products, including transmit, receive and delay filters as well as duplexers and multiplexers. The site also provides company news, new products, specifications, company literature, a request for quote page and contact information for sales representatives.

Clearcomm Technologies LLC,
600 Beam Street, Salisbury, MD 21801

www.clearcommtech.com

Software Tools

This Web site supports and markets the company's software tools for the simulation of electromagnetic fields in the time domain. CST MICROWAVE STUDIO,™ CST DESIGN STUDIO™ and MAFIA 4 have benefited from over 20 years experience in the area of numerical field calculation, and have established the company as a leader of CAE software houses.

CST of America Inc.,
8 Grove Street, Suite 203,
Wellesley, MA 02482

www.cst-america.com

Solid-state, Low Noise and Power Amplifiers

This Web site provides a variety of technical and corporate information, including product data sheets and technical articles (in .pdf format) for the company's comprehensive product line of ferrite isolators, circulators, solid-state low noise and power amplifiers. Other features include links to other MCE companies, a Java-script navigation bar and a keyword search.

DML Microwave Ltd.,
Chandlers Way, Temple Farm Industrial,
Est Southend on Sea, Essex, SS2 5SE UK

www.dmlmicrowave.com

On-line Marketplace for Quotes and Information

This new Web site provides a neutral marketplace that opens each potential user to the broadest range of fixture vendors that can be found in one place. The site provides a simple and logical path for selecting multiple or single vendors to match one's needs. Users can also make judgments on pricing, delivery and features based upon an objective source.

FixtureForum.com,
a service of Interconnect Devices Inc.,
5101 Richland Ave.,
Kansas City, KS (913) 342-5544.

www.FixtureForum.com

RF to Millimeter-wave Integrated Circuits

This Web site includes the full line of standard product data sheets in .pdf format, including S-parameters of selected products, a mixer spur chart calculator, as well as application notes and other topics of interest. Over 100 MMIC die, ceramic packaged die and plastic packaged die products are featured covering DC to 40 GHz.

Hittite Microwave Corp.,
12 Elizabeth Dr., Chelmsford, MA 01824

www.hittite.com

News and New Products

This Web site details the latest news and new product developments at the company, including corporate information (sales, quality and contact information), and a new and standard products section that features scroll-through tables with links to .pdf data sheets.

Inmet Corp.,
300 Dino Drive, Ann Arbor, MI 48103

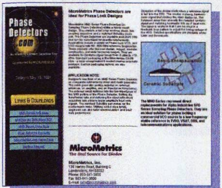
www.inmetcorp.com

Waveguide Products and Capabilities

This Web site includes information on the company's waveguide products and capabilities, including filters, diplexers, circulators, Gunn oscillators, double-ridge components and comparators. The site also provides descriptions and photographs for manufacturing processes, design capabilities and test facilities.

Microwave Development Co. (MDC),
41 Northwestern Drive,
Salem, NH 03079

www.mdc-inc.net



Sampling Phase Detectors

This new Web site was launched to complement the company's main Web site. The site allows designers to review data, outline drawings and electrical specs on sampling phase detectors, a series of resin encapsulated products ideal for phase lock VCO and DRO designs.

MicroMetrics Inc.,
136 Harvey Rd., Building C,
Londonderry, NH 03053

www.phasedetectors.com

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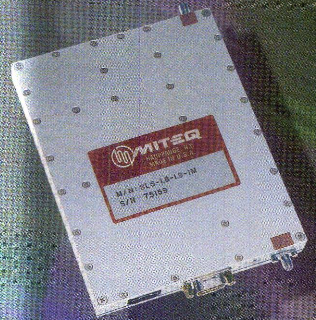

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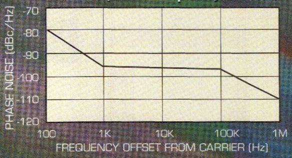

SPECIFICATIONS

MODEL	SLS SERIES
Frequency	1–15 GHz
Frequency step size	200 kHz to 10 MHz
Tuning range	Up to half octave
Switching speed	500 μs*
Output power	10 dBm min.
Output power variation	±2 dB min.
In band spurs	70 dBc min.
Harmonics	20 dBc
Phase noise	See graph
Reference	Internal or external
External reference Frequency Input power	 5/10 MHz 3 dBm ±3 dB
Frequency control	BCD or binary
DC power requirement	+15 or +12 volts, 200 mA 5.2 volts, 500 mA
Operating temperature	-10 to +60°C
Size	5" x 6.5" x 0.6"

* Acquire time depends on step size (low as 25 μs).

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RF/Microwave Components and Subsystems

This new Web site outlines the companies overall design and manufacturing capabilities of RF/microwave components and subsystems as well as a brief description and links to its five operating companies: DML Microwave, Inmet, KDI/Triangle, Metelics and Weinschel. Other features include keyword search, Java-script sitemap, new products, company news and events section that includes the latest news, technical articles and links to upcoming events.

MCE Companies Inc.,
310 Dino Drive, Ann Arbor, MI 48103

www.mcecompanies.com

Waveguide Components and Subassemblies

Visit this Web site to discover how the company became the largest independent producer of waveguide components and subassemblies in the microwave industry. In addition, learn more about waveguide bends and twists, directional couplers and monopulse comparators, rotary joints, microwave filters, rotary switches, and waveguide shutters and waveguide pressure windows.

MDL Inc.,
135 Crescent Road,
Needham Heights, MA 02494

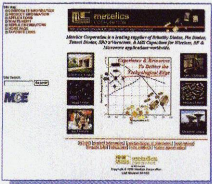
www.micro-dev-labs.com

Advanced ISM/SRF RFICs

This Web site features advanced ISM/SRD RFICs, integrated IR sensors with signal conditioning, Hall-effect sensor ICs, interface ICs and ASIC systems-on-a-chip to QS9000 standards for the automotive, industrial and consumer industries. The company's products are recognized for their innovation and have become favorites with designers worldwide because they are able to simplify RF.

Melexis,
41 Locke Road, Concord, NH 03301

www.melexis.com

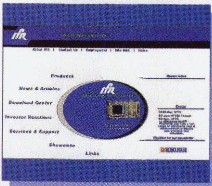


Microwave Diodes and Capacitors

This Web site delivers a variety of technical and corporate information, including product data sheets and other technical information for the company's extensive product line of microwave diodes and capacitors. Other features include product outline drawings in .pdf format, an on-line sales representative search, links to other MCE companies, a Java-script navigation bar and a keyword search.

Metelics Corp.,
975 Stewart Drive,
Sunnyvale, CA 94086

www.metelics.com



Test and Measurement Information

This Web site is updated with a new user interface and features that enable ease of access to the company's wide variety of test and measurement products and services. The new design also offers easier navigation, quick access to product and application information, news and upcoming events, and a download page that incorporates all of the company's available free software and literature in a concise download section.

IFR Systems Inc.,
10200 West York Street,
Wichita, KS 67215

www.ifrsys.com

RF and Microwave Components and Subsystems

This Web site outlines the company's custom design capabilities as well as its extensive product line of RF and microwave components and subsystems by providing a variety of technical and corporate information, including product data sheets and technical articles in .pdf format. Other features include an on-line sales representative search, links to other MCD companies, a Java-scripts navigation bar and a keyword search.

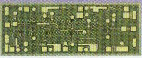
KDI/Triangle Corp.,
60 South Jefferson Road,
Whippany, NJ 07981

www.kditriangle.com

Marconi

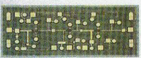
For the latest solutions - Surf to : www.caswelltechnology.com

P35-5114-000-200
20-32GHz
Low Noise Amplifier

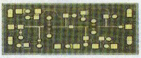


The P35-5114-000-200 is a 20-32GHz three-stage low noise amplifier. Access to all three gate ports is provided to allow application specific biasing. Manufactured using Caswell Technology's 0.2μm pHEMT technology, the circuit provides 21dB gain and a noise figure of 2.2dB @ 28GHz. It also exhibits excellent temperature performance (1dB noise figure variation -50°C to +75°C). DC power consumption is 48 mA. This circuit is available now in die form.

P35-5117-000-200
Low Noise Amplifier
3 Stage - 20dB gain



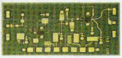
P35-5118-000-200
Low Noise Amplifier
2 Stage - 15dB gain



Increasing its range of millimetre wave amplifiers, Caswell Technology has recently launched not one but two new low noise amplifiers designed for use at 38GHz. Both designs offer a competitive noise figure of typically 3dB !!

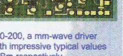
The new two-stage and three-stage LNA's are designed for point-to-point and point-to-multipoint applications and offer 15dB and 20dB of gain respectively. As part of our popular mm wave amplifier range, both designs are manufactured using Caswell's 0.2μm pHEMT process. Samples are now available in die form.

P35-5123-000-200
20-26GHz
Driver Amplifier



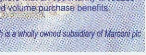
The P35-5123-000-200 is a 20-26GHz two-stage driver amplifier. Access to both gate ports is provided to allow application specific biasing. Manufactured using Caswell Technology's 0.2μm pHEMT technology, the circuit provides 12dB gain and an output power of 23dBm at the 1dB gain compression point. DC power consumption is 140 mA @ 5V. This circuit is available now in die form.

P35-5126-000-200
25-30GHz
Driver Amplifier



The P35-5126-000-200 is a 25-30GHz two-stage driver amplifier. Access to both gate ports is provided to allow application specific biasing. Manufactured using Caswell Technology's 0.2μm pHEMT technology, the circuit provides 10dB gain and an output power of 22dBm at the 1dB gain compression point. DC power consumption is 140 mA @ 5V. This circuit is available now in die form.

P35-5140-000-200
20-40GHz
Driver Amplifier



Caswell Technology has introduced the P35-5140-000-200, a mm-wave driver amplifier covering the 20-40 GHz frequency range with impressive typical values for gain and saturated output power of 20dB and 21dBm respectively.

Complementing Caswell's existing range of mm-wave amplifiers in this band, the P35-5140-000-200 die measures 1.72 x 0.76 mm and requires a modest operating current of less than 200mA at 4.5V Vdd.

This four-stage amplifier is designed with a wide range of broadband wireless applications in mind, including LMDS, point-to-point, point-to-multipoint and MVDS. The broadband performance presents RF designers with an opportunity to reduce overall component inventory bringing associated volume purchase benefits.

Caswell TECHNOLOGY

Marconi Caswell Limited,
Caswell, Towcester,
Northamptonshire, NN12 8EQ
e-mail : caswell.sales@marconi.com

WEB UPDATE

Millimeter-wave Technology and Solutions

This completely redesigned Web site is user-friendly and has special features such as on-line quote requesting, RMA returns and customer feedback, along with representative information, new product information, new product datasheets and company-wide capabilities.

Millitech LLC,
29 Industrial Drive East,
Northampton, MA 01060

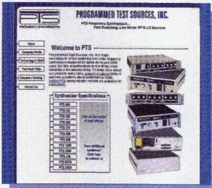
www.millitech.com

Miniature Passive Components

This new Web site presents technical specifications on a wide range of miniature passive components, including precision thick- and thin-film chip resistors, capacitors, metal/glass side wall packages, custom thick-film hybrid circuits and multichip modules for a wide variety of wireless applications.

Mini-Systems Inc.,
20 David Rd., PO Box 69,
North Attleboro, MA 02761

www.Mini-SystemsInc.com



Agile Precision Frequency Sources

This Web site provides complete technical specifications for the company's PTS frequency synthesizer line. With easy, fast and remote programming, the synthesizers are vital in advanced measurement or production systems and also serve as stand-alone test equipment.

Programmed Test Sources (PTS) Inc.,
9 Beaver Brook Road,
Littleton, MA 01460

www.programmedtest.com

Interactive Web Site Tools

This Web site has been updated to include several new interactive features intended to streamline search and design tasks. Visitors to the site now have access to instant product information, parametric and integrated search capabilities and custom design on-line. The integrated search capabilities of the site allow the user to search the company pages, on-line catalog and .pdf product pages and sales representative database with one request.

Spectrum Control Inc.,
8031 Avonia Road, Fairview, PA 16415
(814) 474-1571.

www.spectrumcontrol.com

7-16 Connectors

This satellite Web site is specifically designed for engineers looking to spec 7-16 connectors. It offers a quick reference guide to a complete selection of TRU's leading edge 7-16 plugs, jacks, receptacles, combinations and cable assemblies. A 12-page catalog can also be downloaded.

Tru-Connector Corp.,
245 Lynnfield St., Peabody, MA 01960

www.7-16connectors.com

Microwave and RF Components and Subsystems

This Web site delivers a variety of technical and corporate information, including product data sheets, instruction manuals, technical articles, an on-line sales representative search engine and links to other MCE companies' sites. A Java-applet navigation bar and a keyword site search are also included.

Weinschel Corp.,
5305 Spectrum Drive,
Frederick, MD 21703

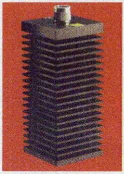
www.weinschel.com

NEW PRODUCTS

COMPONENTS

100 W AIN Termination

The model 100-NST-FN utilizes aluminum nitride as alternative to BeO substrates in an effort to remain more environmentally friendly.



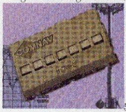
The unit has a frequency range of DC to 3 GHz and SWR at DC to 1 GHz is 1.1 (max), 1 to 3 GHz at 1.15 (max). The power rating is 100 W average and connectors available are BNC, N, TNC and 7/16.

Bird Component Products (BCP),
Largo, FL (727) 547-8826.

Circle No. 216

Chip and Wire Diplexer

This 12DLH1-900-L chip and wire diplexer is designed as a high volume, high performance,



low unit cost solution for wideband wireless local loop systems. The diplexer's specifications include 1.8 dB passband loss, 1.7 SWR and 50 dB rejection at 800 and 1000 MHz. Size: 51 × 13 × 9 mm.

ComNav Engineering,
Portland, ME (207) 797-4588.

Circle No. 218

Bandpass Filter

The model FDR10-4 small size bandpass filter is designed for clock recovery circuits in OC 192 10 gbps optical communications architectures. Operating at 10 GHz, the bandpass filter offers maximum insertion loss of 0.7 dB, SWR of 1.1 (max), frequency stability of 14 ppm/°C and power handling of 10 W (max). SMA female connectors are standard, but alternate connector or pin requirements can be satisfied upon request. Size: 2.83" × 0.67" × 0.87".

Compel Electronics Inc.,
Ashland, MA (508) 881-9293.

Circle No. 219

Semi-rigid Cables

These semi-rigid cables offer outstanding shielding and insertion loss characteristics. The

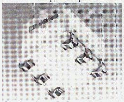
design of the cables improves system performance and increases talk time, making them extremely well suited for transmitting amplified signals across printed circuit boards used in cellular phones and other wireless devices. The cables are designed with center conductor leads formed at right angles to, or coplanar with, the bottom of the copper outer jacket. This improves installation onto thru-hole or surface-mount circuit boards. Impedance ranged from 5 to 125 Ω and cable sizes vary from 0.008" to 0.750" to meet a variety of application requirements.

MICRO-COAX,
Pottstown, PA (800) 223-2629.

Circle No. 222

20 dB Directional Coupler

The model JDC-20-5 50 Ω broadband directional coupler operates over the 50 to 1500

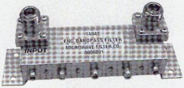


MHz frequency range with 20.5 (±0.5) dB nominal coupling value with ±0.75 dB maximum flatness. Insertion loss is low at 0.5 dB (typ) and directivity is 22 dB (typ) at midband. The all-ceramic surface-mount device is equipped with solder plated J leads for superior mechanical integrity over temperature. Applications include cellular signal sampling. Size: 0.28" × 0.31" × 0.23". Price: $17.95 (1 to 9).

Mini-Circuits,
Brooklyn, NY (718) 934-4500.

Circle No. 223

Bandpass Filter



The model 14042 bandpass filter is used to prevent PCS interference at the ENG receive site. It passes the entire ENG band (1990 to 2500 MHz) and the unit provides stopband rejection of 25 dB (min) at 1910 MHz and 2580 MHz, with a passband insertion loss of 1.0 dB (max). The impedance is 50 Ω with standard N connectors. It is designed for indoor use, but can be provided as a temperature compensated unit. Size: 6.0" × 2.0" × 2.0".

Microwave Filter Co. Inc.,
East Syracuse, NY (800) 448-1666
or (315) 438-4747.

Circle No. 224

High Performance, Lightweight Aluminum Cables

The Mini-Loss Plus™ semi-rigid cable is available with a soft, lightweight aluminum outer conductor and features low attenuation and dramatically higher thermal phase stability, ideal for critical radar and satellite applications. The cable's jacket material is made of 1100 aluminum and provides a cable that is 40 percent lighter and significantly easier to form. Mini-Loss Plus is supplied with an unplated tube, for use with crimp-on connectors or with high purity tin plating for conventional connectors.

Precision Tube,
Salisbury, MD (410) 546-3911.

Circle No. 225

High Frequency RF Chip Resistors

The RF Series of compact, lightweight resistors is ideal for use in RF and microwave applications. The components are available in 14 standard case sizes 0402 through 3838. The series is offered with single surface or wrap around terminations, and a variety of termination materials for solder mount, epoxy bound or wire bond applications. Construction material consists of either an alumina or beryllia body with a proprietary resistor element for optimum performance. The devices are optimized for 50 Ω characteristic impedance using special manufacturing techniques to reduce SWR. Power ratings for the RF Series range from 50 mW to 200 W, with a low return loss to 20 GHz. Price: $1 each in production quantities. Delivery: 12 to 14 weeks (ARO).

State of the Art Inc. (SOTA),
State College, PA (800) 458-3401.

Circle No. 226

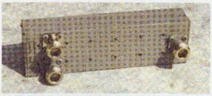
Ceramic Diplexer

The model 930073 ceramic diplexer operates in the 2.4 GHz band. Channel BW is 10 MHz, and insertion loss is 2.5 dba. The 10 dB BW is 75 MHz and TX/RX isolation is 22 dB. The diplexer offers 2 poles per channel and handles 5 W CW. SMT package is standard. Options include custom frequencies and rejection points. Size: 1.10" × 0.47" × 0.31".

Integrated Microwave Corp.,
San Diego, CA (858) 259-2600.

Circle No. 221

Miniature Diplexer



The model W2446D miniature IMD free diplexer is designed for video reception and transmission in the UMTS band. Standard +43 dBm input test signals produces < –100 dBm of IMD signals. Insertion loss is <1 dB and return loss is better than –17 dB. Tx to Rx isolation is > 65 dB. Power handling is > 100 W CW and peak power rating is > 1.5 kW. Type N connectors are standard and SMA connectors optional. The W2446D operates from –40° to +70°C. Size: 1.2" × 2.0" × 5.0". Price: < $150.

Wireless Technologies Corp.,
Springdale, AR (501) 750-1046.

Circle No. 229

[Continued on page 168]

NEW PRODUCTS

Bandreject Filter

The model EWT-41-001 bandreject filter offers a center frequency of 14250 MHz and a 3 dB (max) bandwidth of 2000 MHz. Rejection from 14000 through 14500 MHz is 50 dB (min) while insertion loss is < 1.0 dB (typ) DC to 12750 MHz and 15750 to 22000 MHz. SWR is 1.5. The EWT-41-0001 operates over a –55° to +85°C temperature range.

Eastern Wireless Telecomm Inc. (EWT), Salisbury, MD (410) 749-3800.

Circle No. 220

Solderless Connectors

These "EZ" solderless TNC and N type connectors are designed for the company's LMR-240 low loss coaxial cables. The high quality connectors (models EZ-240-TM and EZ-240-NM) have knurled coupling nuts and crimp-style outer contact attachment rings. Adding to the family of EZ solderless connectors, these connectors are well suited for use at the upper ISM frequency bands of 2.4 and 5.8 GHz because of its low loss and low SWR.

Times Microwave Systems, Wallingford, CT (203) 949-8424.

Circle No. 227

RF Coaxial Connectors

The HN-, N-, SC-, SMA- and TNC series of RF coaxial connectors can now be manufactured with Fluoroloy® H dielectrics, which allows them to operate at up to 5000 W and temperatures to 200°C, depending upon connector type. Configurations include straight, right angle and bulkhead connectors in both male and female designs for use with semi-rigid and flexible cables. Price: from $35 depending on configuration and quantity.

Tru-Connector Corp., Peabody, MA (800) 262-9878 or (978) 532-0775.

Circle No. 228

AMPLIFIERS

Broadband Amplifier

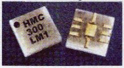
The model ABA3100 high performance balanced linear amplifier is targeted for residential gateway, set-top box and other digital interactive cable devices. It is a MMIC offering industry-leading noise and linearity performance in a cost-effective GaAs solution. The single-supply design delivers 12 dB gain across a wide 50 to 860 MHz bandwidth. Its balanced design leads to superior, reliable performance, resulting in a second order output intercept point of +60 dBm. The device also is characterized by its high linearity and low distortion while demonstrating a noise figure less than 3.2 dB across the bandwidth. The ABA3100 also serves as a low noise amplifier for use in advanced digital set-top boxes. The device compensates for the loss in signal level within the set-top box. Price: $5 (10,000).

ANADIGICS, Warren, NJ (908) 668-5000.

Circle No. 230

SMT Medium Power Amplifier

The model HMC300LM1 broadband surface-mount medium power amplifier features an SMT millimeter-wave package, a gain of > 15 dB, broadband performance, saturated output power of +24 dBm and a positive supply of 5 to 7 V. The amplifier operates from 6 V_{dd} and a –0.35 V_{gg} gate bias and requires no external RF matching components and minimal DC bypass components. A 0.25 µm power pHEMT process is used to achieve efficient gain and output power performance and requires high volume surface-mount re-flow assembly techniques, which can be used to mount the amplifier to the end user's PCB. The LM1 package eliminates the need for wire bonding or die attach mounting.



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

Circle No. 231

Low Noise Amplifiers

These modules are the first four products in a family of low noise amplifier (LNA) modules that combine high integration levels and exceptional noise figure performance. The new LNAs span the 800 MHz to 6 GHz frequency range, and are

[Continued on page 170]

NEW PRODUCTS

targeted for systems such as broadband wireless access equipment, cellular basestations and infrastructure equipment for emerging LAN, 802.11a, 802.11b and Bluetooth applications. Providing noise figure performance as low as 0.65 dB, the new modules are designed to serve as complete drop-in solutions that require no external components. The new modules replace traditional implementations. Price: $2 to $3 (10,000).
Intarsia Corp., Fremont, CA (510) 354-6301.
Circle No. 233

Multi-carrier Power Amplifier

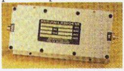
The model QBS-425 power amplifier provides 35 dB of gain for up to 4 GSM carriers. Using adaptive feedforward technology, the amplifier achieves high efficiency with low intermodulation distortion for the GSM/EDGE modulation formats. The unique design of the QBS-425 eliminates the need for external high power combining. Additionally, these amplifiers features configurable alarms (over power, over temperature and SWR) and the output port is isolator protected. The amplifiers mount in a standard 19" equipment rack.
REMEC Q-bit,
Palm Bay, FL (800) 226-1772.
Circle No. 236

Low Noise VHF Amplifier

The model 1035 LNA is designed to provide a +18 dB gain at 100 MHz with a noise floor of –175 dBc/Hz at 10 kHz. Standard supply voltage is +15 V DC with +12 V DC as an option. The model 1035 is especially suited for instrumentation applications where noise is important. Connectors are SMA female. Other frequencies are available upon request. Price: $350. Delivery: 6 weeks (ARO).
Techtrol Cyclonetics Inc.,
New Cumberland, PA (717) 774-2746.
Circle No. 237

RF Power Amplifier

The model A020 high performance 120 W RF power amplifier covers the frequency range



from 290 to 320 MHz and 35 dB of gain and high efficiency. The amplifier is also available as an AC full amplifier system. Features include automatic current limiting, forced-air cooling, current meter, over-current and thermal protection. Connectors are SMA female. The DC module features 35 dB gain (typ), 55 percent efficiency, 28 V DC power and 120 W CW (typ) output power. Size: 4.8" × 2.0" × 1.0". Weight: 1 lb.
LCF Enterprises,
Post Falls, ID (208) 457-0292.
Circle No. 234

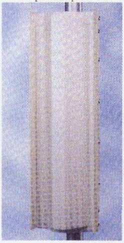
35 dB, 2800 MHz Low Noise Amplifier

The model PA-38 low noise amplifier (LNA) operates at 2800 MHz center frequency (±100 MHz), but there are many other frequency ranges also available. The amplifier has a minimum gain of 35 dB and a maximum noise figure of only 1.5 dB. This LNA uses ±15 V DC power supplies. Size: 1.85" × 0.75" × 0.40".
Planar Monolithics Industries,
Frederick, MD (301) 662-4700.
Circle No. 235

ANTENNAS

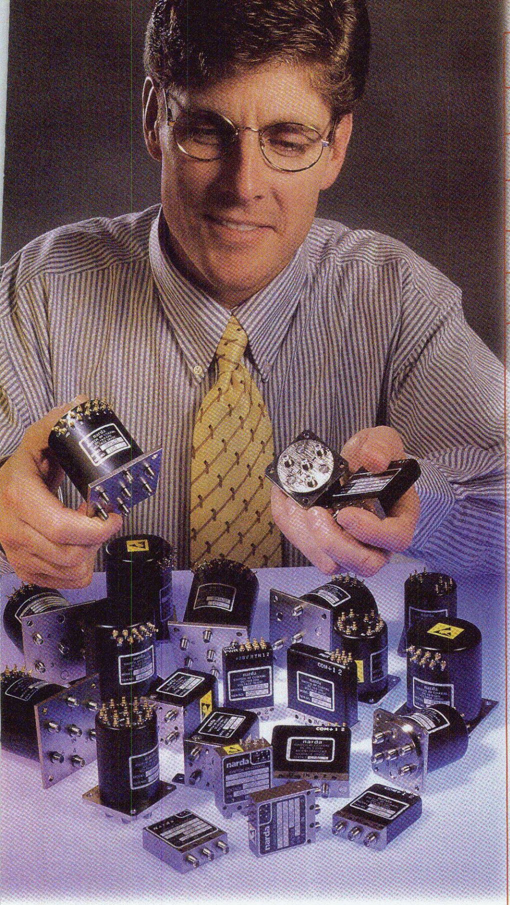
Adjustable Sector Antenna

The model MSP24013MB adjustable 2.4 GHz sector panel optimizes the performance of



wireless data networks by providing technically superior performance and a field-adjustable, multiple beamwidth design. One of these models can be field adjusted to cover horizontal beamwidths of 45°, 60°, 90° or 120° with an SWR of less than 1.5 and outstanding front-to-back ratio perfor-

[Continued on page 172]



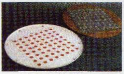
NEW PRODUCTS

mance. This antenna was especially designed for wireless broadband applications where coverage of a geographical sector is necessary.
MAXRAD,
Hanover Park, IL
(630) 372-6800.

Circle No. 238

High Gain Microstrip Antenna

The model PCA18-56C/X low profile, lightweight, flat plane antenna operates over the



5.65 to 5.95 frequency range with 23.6 dBic of gain and SWR of 2.0. The antenna has an axial ration of 2.0 dB and is designed for datalink applications.
Seavey Engineering Associates Inc.,
Pembroke, MA (781) 829-4740.

Circle No. 239

HARDWARE

Pneumatic BNC Crimper

The CTB-1 pneumatic hex die benchtop crimp tool is intended for the installation of BNC

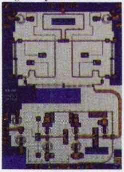
coaxial connectors. It consistently produces quality crimps while speeding installation efficiency and reducing fatigue and risk of repetitive motion injuries. The lightweight and fully portable crimper can be actuated by hand or a foot pedal, and operates at 32 cycles per minute. The CTB-1 meets MIL-C-22520/5 requirements for BNC crimp connectors. It requires a regulated, filtered and lubricated 95-120 psi air supply. Price: $2800 (includes the foot activation switch and one die-set).
Trompeter Electronics,
Westlake Village, CA (800) 982-2629.

Circle No. 240

INTEGRATED CIRCUIT

GaAs MMIC Receiver

The model XR1000 GaAs MMIC receiver is on a single chip and is a three stage low noise amplifier followed by an image reject fundamental mixer using Lange couplers to improve bandwidth. Using 0.15 micron gate length GaAs pHEMT device technology, the receiver covers the 17 to 27 GHz range. The receiver has a small signal conversion gain of 10 dB (typ) with a noise figure of 3.5 dB (typ) and 15 dB (typ) image rejection across the band. The XR1000 provides equipment designers with a highly integrated product to facilitate the design process and is well suited for wireless communications applications such as millimeter-wave point-to-point radio, LMDS, SATCOM and VSAT applications.



Mimix Broadband Inc.,
Webster, TX (281) 526-0536.

Circle No. 241

MATERIALS

Vinyl-based Weatherproof Coating for Foam Microwave Absorbers

The low cost, weatherproof coating CERSEAL coating is designed for the ECCOSORB® AN and LS foam products line. This new coating is used in high humidity environments and helps to prevent moisture uptake, which can drastically affect the performance of an unprotected absorber. The vinyl-based coating is sprayed on to seal unskinned polyurethane foams offering excellent resistance to fluids, chemicals and petroleum products. CERSEAL adds durability to foam products and imparts abrasion as well as puncture resistance.
Emerson & Cuming Microwave Products,
Randolph, MA (800) 650-5740
or (781) 961-9600.

Circle No. 242

[Continued on page 174]

NEW PRODUCTS

■ Dielectric Materials

The MICROLAM family of dielectric materials are built upon expanded PTFE structures that are impregnated with various filled resins to meet different application requirements. The MICROLAM 200 dielectric material is engineered with an extremely low loss tangent (0.0036 through 10 GHz), making it an ideal material for high frequency, laser HDI printed wiring boards or RF module applications. MICROLAM 400 is isotropically matched to copper, allowing fabrication of reliable, fine-pitch chip package substrates. MICROLAM 600 is ideal for use in build-up layers due to its outstanding reliability, increased laser drilling speeds and excellent microvia hole quality.

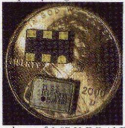
W.L. Gore & Associates Inc.,
Newark, DE (800) 445-4673.

Circle No. 243

SOURCES

■ Low Cost SMD VCXO

The SMD I605 series of oscillators covers a frequency range of 1.0 to 66.0 MHz with a fre-



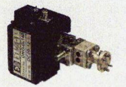
quency and temperature stability of ±50 ppm (max) over a temperature range of 0° to +70°C. Two ranges of pullability are offered as well, ±50 ppm with a control voltage of 1.65 V DC ±1/5 V DC and supply voltage of 3.3 V DC and ±100 ppm with a control voltage of 2.5 V DC ±2.0 V DC and a supply voltage of 5.0 V DC. The package height makes this oscillator ideal for ultra small peripheral application where low cost is also important. Automated mounting by pick and place machines as well as re-flow soldering are accommodated. Size: 5 × 7 mm. Price: $2.50 each (10,000). Delivery: 6 to 8 weeks (ARO).

ILSI America, Reno, NV (888) 355-4574.

Circle No. 232

■ Cavity-stabilized Millimeter-wave Oscillators

The CIDO series of cavity-stabilized millimeter-wave oscillators produce fine spectrum res-



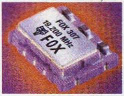
olution and low phase noise with high output power and frequency stability. The models are available in waveguide bands from 26 to 150 GHz. The solid-state, IMPATT-based design combines the extended frequency range and output power of IMPATT technology with the stability and phase noise characteristics associated with cavity-stabilized Gunn sources. The CIDO configuration consists of a waveguide cavity IMPATT oscillator coupled to a high Q, high order mode cylindrical Invar cavity. A low pass EMI filter and current stabilizer are included for trouble-free operation and an isolator is integrated into the output. The models are supplied mounted on a finned heatsink and can maintain their operating frequency within a few megahertz over the –50° to +80°C temperature range.

Gilland Electronics Inc.,
Los Gatos, CA (800) 480-3391.

Circle No. 246

■ Compact TCXO

The FOX307 series of TCXOs matches the smaller sized, industry standard footprint re-



quired for portable and wireless equipment. The oscillators are ideal for SMD applications with tight space constraints. These oscillators utilize the industry's standard pinout configuration and require a 3.0 V power supply. They have a frequency range of 12.8 to 20.0 MHz and frequency stability is ±2.5 ppm over the operating temperature range of –30° to +85°C. Storage temperature range is –40° to +85°C. The TCXOs have a current drain of less than 2 mA, and feature a low phase noise of less than –140 dBc/Hz at 100 kHz. Size: 7 × 5 mm. Price: $7 (1000). Delivery: stock.

Fox Electronics,
Fort Myers, FL (888) 438-2369.

Circle No. 245

■ VCO Modules

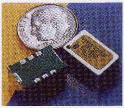
These four new VCO modules are targeted at the high growth, dual-band tri-mode CDMA/PCS cellular handset industry. The model ATXN1032A and model KXN1458A small, low cost, dual-band oscillators are designed for both low current drain to extend battery life, and industry-leading phase noise performance for improved call handling. The model ATXN1013A is a small dual-band VCO/PLL module designed to minimize phase noise and reduce lock times to less than 1 ms for improved data transmission integrity. Model ATXN1014A is a small dual-band synthesizer module that provides performance advantages similar to the ATXN1013A, but by including the company's TCXO technology, it further reduces cellular handset size, component count and total cost.

CTS Corp., Elkhart, IN (630) 924-3525.

Circle No. 244

■ 200 MHz VCXO

The model VC-8000 voltage controlled crystal oscillator (VCXO) uses an inverted-mesa



quartz crystal to combine higher frequency, lower noise, increased stability, wider pullability range and faster on/off times than is possible with an ordinary quartz crystal. The VCXO works as a signal-enhancing filter for a synchronous communication systems that imbed their own content data, clock and error correction data. The unit acts like a high Q filter, re-generating the incoming signal "from scratch." The unit's narrow bandwidth does not allow noise, jitter or other perturbations to get through, resulting in a newly re-generated signal, free of noise. The VC-8000 provides a voltage controlled output frequency up to 200 MHz with < 1 picosecond jitter, and an overall frequency stability of ±30 ppm. Units are available at any desired output frequency from 65 to 200 MHz, but specifying popular frequencies has a favorable effect on price and delivery. Price: $39 to $49 (10,000). Delivery: 8 to 10 weeks (ARO).

Raltron Electronics Corp.,
Miami, FL (305) 593-6033.

Circle No. 248

■ Programmable Oscillators

The ProTM SS002C series of surface-mount programmable oscillators features one of the industry's widest range of frequencies (1 to 125 MHz) and operating voltages (3.0, 3.3 and 5.0 V). The oscillators are designed to better serve the needs of electronics OEMs and can be programmed by local distributors to meet the immediate needs of design engineers in a matter of 24 to 48 hours. Operating at 3.0 and 3.3 V the series keeps period jitter to noise-free level of 50 ps (max) 33 to 90 MHz, 100 ps (max) 5 to 33 MHz and 167 ps (max) 1 to 5 MHz. The programmable S8002C offers precise rise and fall times, tight symmetry and frequency stability (±25, ±50 or ±100 ppm over all conditions) approaching that of conventional oscillators.

SaRonix, Menlo Park, CA (650) 470-7700.

Circle No. 249

■ Ultraminiature TCXOs

These two ultra miniature surface-mount TCXOs comprise outstanding stability performance and excellent shock and vibration performance to optimize the performance and quality of all wireless products. These products are available with ±1 ppm frequency stability, frequency range from 10 to 26 MHz, screened for perturbations and excellent temperature stability performance for low cost. Wireless applications include Bluetooth, 3G, GPRS and EDGE cellular phones, wireless modems, two way pages, microwave wireless, GPS and many wireless applications. The oscillators have footprints of 7 × 5 mm and 5 × 3 mm.

Rakon Ltd.,
Auckland, New Zealand +64 9 573 5554

Circle No. 247

■ VCO

The model CLV1540E voltage controlled oscillator (VCO) is designed for the microwave ra-

dio market. This device utilizes patented design techniques to deliver unequalled SSB phase noise performance together with superior harmonic suppression. It generates frequencies between 1520 to 1565 MHz within 0.5 to 4.5 V DC of control voltage with an average tuning sensitivity of 23 MHz/V. The VCO exhibits a remarkably clean spectral signal of –110 dBc/Hz (typ), at 10 kHz from the carrier while attenuating the second harmonic to better than –20 dBc. The CLV1540E operates off a 5 V DC source while drawing only 24 mA (typ) and is designed for the toughest outdoor applications as it is specified to operate over the commercial temperature range of –40° to +85°C. Size: 0.50" × 0.50" × 0.22".

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

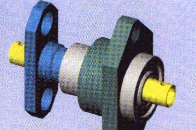
Circle No. 250

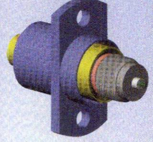
[Continued on page 176]

BLINDMATE
BMA, BMZ, BZ
Connectors & Components

Features

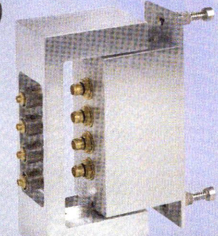
- Offers the advantage of slide-on mating while providing superior microwave performance
- Unique spring-loading mechanism allows for axial and radial misalignment
- Increased package densities
- Quick connect/disconnect
- Lower applied cost
- First QPL source for Mil PRF-31031





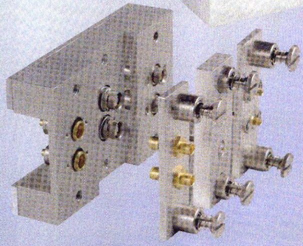
Configurations

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



Typical Applications

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



SV MICROWAVE™

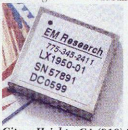
RF Connectors & Components

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

NEW PRODUCTS

Surface-mount Frequency Synthesizer

The LX series of low cost, surface-mount frequency synthesizers is custom designed for broadband mixer LO applications. This product features fixed frequency or programmable outputs in bands from 50 to 2700 MHz, with up to octave bandwidths. At 1 GHz frequency output, phase noise characteristics are –98 dBc/Hz at 10 kHz offset and –120 dBc/Hz at 100 kHz offset. Packaged in 0.75" square surface-mount housing, the LX series is ideally suited for use in broadband wireless communications systems.



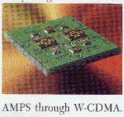
EM Research Inc.,
Citrus Heights, CA (916) 722-4266.

Circle No. 253

SUBSYSTEMS

Vector Modulators

The VM series of eight-chip, PGA packaged vector modulators can be easily integrated in- to basestation MCPA applications to increase bandwidth efficiency and support high speed data transmission for 2.5 G systems. The vector modulator offers 360° of phase control and a large linear amplitude adjustment range. With the new VM multi-chip module platform, mixed technologies can be integrated in the same package to produce high performance products that cover AMPS through W-CDMA. Typical performance characteristics include



< 15 dB insertion loss, 10 dB of phase stable amplitude adjustment range and > 40 dB of maximum attenuation.
Alpha Industries,
Woburn, MA (871) 935-5150.
Circle No. 251

Millimeter-wave Tuner

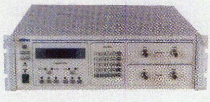
The model CS-5106C tuner is a cost-effective, high performance solution for receiving signals in millimeter-wave frequency bands. It features plug-in front-end assemblies that allow the user to simply externally remove and replace front-end modules in the field. Modules are available for any 3 or 6 GHz segment in the 18 to 40 GHz frequency range. The tuner has a tuning resolution of 10 kHz with IF outputs at either 140 MHz or 70 MHz center frequency. An FM demodulated video output is available as an option if desired. The CS-5106C can also be supplied with front panel control or with a computer GUI for RS-232 control. Both AC and DC input power versions are available.
Communications Solutions Inc.,
Baltimore, MD (410) 344-9000.
Circle No. 252

RGB Video Matrix

The model 12055 video matrix features a frequency range from DC to 120 MHz with RS-232C and IEEE-488 interfaces. The unit is non-blocking and full fanout with front panel keypad control and LCD display. It recalls 40 configurations and offers crosspoint verification. The 12055 is ideal for switching RGB video from any of eight workstations to up to eight combinations of monitors and printers. Size: 5.0" × 19.0" × 25.0".
Matrix Systems,
Calabasas, CA (818) 222-2301.
Circle No. 262

TEST EQUIPMENT

Carrier to Noise Generator



The CNG sets extremely accurate C/N rations between the user's signal and internally generated Gaussian noise. The product is offered in models for 70/140 MHz, CATV and a frequency agile version covering 1 to 6 GHz, and is compatible with all modulation formats, including pulsed spectrums. A proprietary microprocessor controlled solid-state attenuator design internally provides 0.015 dB resolution. Output power can be set between 0 and –110 dBm. The instrument is available with 1 or 2 channels and is controllable via GPIB and a user-friendly front panel. The chassis is 19" rack mountable 3U height.
dBm LLC, Wayne, NJ (973) 709-0020.
Circle No. 256

Handheld Battery Operated Spectrum Analyzer

The model 401A Personal Spectrum Analyzer™ covers 1 to 1024 MHz and is intended for both bench top and field use. It is ideal for the measurement of harmonic and spurious emissions, identification of unknown or unwanted signals, signal monitoring, field strength measurements and EMC pre-compliance testing. The unit makes EMC pre-compliance testing simple and straightforward. The 401A can monitor emissions from the very beginning of the design process, because the spec line is right on the screen. If an unwanted emission is at or above the line, the designer knows he has an issue to investigate immediately. The spectrum analyzer has a sensitivity of –95 dBm. Three frequency markers are available for signal identification. Included with the spectrum analyzer is the model P101A active e-field probe for troubleshooting and EMC measurements. Price: $2995. Delivery: stock.
Bantam Instruments,
Sunnyvale, CA (510) 610-2633.
Circle No. 255

Internet-ready Satcom Spectrum Analyzer

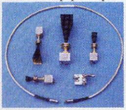
The model P9116 Satcom spectrum analyzer operates remotely from any location via Internet, LAN or modem. It includes a virtual spectrum analyzer front panel that lets you view and control your spectrum display in real time with no third party software or hardware required. The P9116 is a full-features spectrum analyzer that covers the 100 kHz to 1.6 GHz frequency range. The instrument's rugged industrial chassis includes a complete Pentium PC and Windows NT operating system. The unit has outstanding accuracy repeatability and speed.
Morrow Technologies Corp. (MTC),
Largo, FL (727) 531-4000.
Circle No. 258

RF Digitizer

The model 2319E RF digitizer for 2G, 2.5G and 3G digital cellular testing is ideal for conversion of broadband radio frequency signals into high quality, digitized data for external processing in a personal computer. When combined with an optional high power digital signal processing card and company software, the 2319E can be used as a substitute basestation receiver during early research and development phases of new mobile phones. The unit is a benchtop or rack-mounted instrument and operates across a wide frequency range and provides a generous 20 MHz digitization bandwidth sufficient to capture four UMTS radio channels. The instrument provides high quality conversion of complex modulated RF signals into digitized data. The choice of output interface is determined by the bandwidth requirements of the application, selected from low, medium or high speed options. The 2319 features a 500 MHz to 2.5 GHz frequency range, 50 W input power handling, 12 bit ADC resolution, phase noise of –121 dBc/Hz and sensitivity of –153 dBm/Hz. Price: $31,351.
IFR Systems Inc.,
Wichita, KS (800) 835-2352
or (316) 522-4981.
Circle No. 257

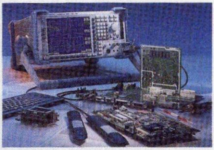
FCC Spurious and Harmonic Test Kit

This spurious and harmonic test kit is designed for use with popular spectrum analyzers. Each



kit contains four mixers providing continuing coverage from 40 to 220 GHz. Each mixer is equipped with an appropriate horn antenna for accomplishing the FCC desired radiated spurious level measurement.
Oleson Microwave Labs,
Morgan Hill, CA (408) 779-2698.
Circle No. 259

EMI Test Receiver with Spectrum Analysis



The EPSI EMI test receiver with spectrum analyzer functionality combines the precision of a test receiver and the high speed of a spectrum analyzer in a single unit. It allows precompliance and diagnostic measurements to be carried out fast and precisely in development to ensure that products are developed in line with EMC standards. The two models available operate in the frequency range from 9 kHz to 3 GHz or up to 7 GHz and are designed for commercial standards. In addition to manual measurements, the ESPI allows semi-automatic and fully automatic EMI measurements with the aid of predefined tables and EMI software. Spectrum analyzer functions can be called at a keystroke.
Rohde & Schwarz GmbH & Co. KG,
Munich, Germany +49 89 4129-13779.
Circle No. 260

[Continued on page 178]

MICRO-ADS

NEW PRODUCTS

Basestation Field Tool

The NetTek™ compact, modular basestation field tool is designed to simplify routine field installation and maintenance measurement tasks in wireless networks. It enables installation and maintenance technicians to quickly and reliably verify basestation functionality, even under adverse field conditions. The NetTek basestation field tool consists of a multi-standard measurement module, the YBT250. It addresses GSM, IS-136 and CDMAOne standards and performs the most common diagnostic tests needed for on-site basestation transmitter verification. Price: \$12,495. Delivery: 10 weeks.

Tektronix Inc.,
Beaverton, OR (800) 426-2200.

Circle No. 261

HI-THERM™ ALUMINUM NITRIDE

Literature details Carborundum Hi-Therm™ Aluminum Nitride high performance ceramic substrates and components for advanced thermal management applications such as microelectronic packages and semiconductor silicon wafer processing. Provides information on Hi-Therm™ Aluminum Nitride's excellent thermal conductivity and electrical properties. Hi-Therm™ ceramics have thermal conductivities eight times higher than alumina and approaching beryllia at higher temperatures.

Contact:
Saint-Gobain Advanced Ceramics Corp.
Microelectronics Group
2050 Cory Road
Sanborn, NY 14132
716-731-9200
www.carbo.com

NEW LITERATURE

■ Bluetooth™ CD-ROM

This Bluetooth Solutions CD-ROM provides valuable technology literature, application notes and product information to engineers developing and manufacturing ICs, modules and host devices incorporating the Bluetooth technology.
Agilent Technologies,
Berkshire, UK +44 (0) 1189 276 824.
Circle No. 200

■ New Products and Technologies Catalog

This "What's New at AVX for 2001" catalog offers valuable information on this year's new products and technologies. The catalog highlights information on the company's products, including capacitors, capacitor arrays, filters, thin film devices, ferrites, timing devices, connectors and circuit protection devices.
AVX Corp.,
Myrtle Beach, SC (843) 946-0414.
Circle No. 201

■ GaAs Semiconductor Component Catalog

This 10-page catalog features the company's line of GaAs semiconductor products for broadband wireless and fiber-optic communications. TrueTriangle™ power amplifier modules and WideFiber™ driver amplifiers are detailed. Product outline drawings, photographs, specifications, features and applications are provided.
Celeritek,
Santa Clara, CA (408) 986-5060.
Circle No. 202

■ Microwave Synthesizer Literature

This datasheet and brochure detail the low cost model 12000A microwave synthesizer. The datasheet provides detailed product specifications while the brochure covers the synthesizer's advanced digital architecture, frequency switching speed, frequency ramp sweep technique, modulation capabilities and reliability figures.
Giga-tronics Inc.,
San Ramon, CA (925) 328-4650.
Circle No. 203

■ New Product Catalog

This product catalog addresses technical specifications, design details, custom products and designer kits for the company's four major categories of inductors including surface-mount RF inductors, surface-mount power inductors, leading RF inductors and leaded power inductors.
Gowanda Electronics,
Gowanda, NY (716) 532-2234.
Circle No. 204

■ Data Sheet

This two-page data sheet features coaxial resonators made with modern, high performance ceramic dielectric materials. The coaxial TEM resonators are an ideal choice when cost, size and stability are important. Applications include dielectric resonating oscillators, VCOs, pagers, cellular and wireless communications, and bandpass/bandstop filters.
Integrated Microwave,
San Diego, CA (858) 259-2600.
Circle No. 205

■ Product Catalog

This latest edition of the company's Catalog 119 offers thousands of new products, more brand name manufacturers than ever and unique new customer services. The newly expanded product section in the catalog showcases 16,000 new products and 25 new manufacturers. In all, the company stocks 150,000+ products from more than 300 quality manufacturers.
Newark Electronics,
Chicago, IL (800) 463-9275.
Circle No. 206

■ Specialty Materials Catalog

This 16-page catalog details the company's line of specialty materials such as urethane foams, electroluminescent lamps and inverters, induflex laminates, PORON silicone materials, R/flex flexible circuit materials, RT/duroid and TMM high frequency circuit materials, RO4000 and RO3000 high frequency circuit materials, elastomer components and composite materials.
Rogers Corp., Rogers, CT (800) 774-9605.
Circle No. 207

■ RF/Microwave Products Catalog

This 72-page catalog details the RF and microwave product line including low loss flexible cable assemblies through 50 GHz, high stability flexible assemblies, VNA cable assemblies, quick-connecting test adapters, solid PTFE semi-rigid assemblies and RF coaxial cable assemblies.
Storm Products-Microwave,
Hinsdale, IL (630) 323-9121.
Circle No. 208

■ High Performance Cable and Interconnect Systems Catalog

This 10-page catalog features the company's high density cable assemblies, RF/microwave assemblies and connectors, precision coaxial and multi-connector harnesses and assemblies, and high performance wire and cable. Product photographs, descriptions, applications and features are provided.
Tensolite, a Carlisle company,
Andover, MA (800) 362-3539.
Circle No. 209

■ Technical Bulletins

This series of custom air filter product technical bulletins are intended for EOM designers, who can use the technical data when considering thermal management options in electronics and industrial equipment. The five bulletin series features air filter modules used in air cooling of electronics applications: dual EMI honeycomb, polyester, polyfold, quadrafoam and uni-foam.
Universal Air Filter Co.,
Sauget, IL (618) 271-7300.
Circle No. 210

■ Low Noise RF Modules

This 11-page catalog features Blue Tops™ RF modules, including amplifiers, frequency multipliers and dividers. Product descriptions, photographs, features, line drawings, specifications and schematics are provided.
Wenzel Associates Inc.,
Austin, TX (512) 450-1400.
Circle No. 211

Modulation and Coding for Wireless Communications

Alistair Burr

Prentice Hall/Pearson Education

352 pages; $79

ISBN: 0-201-39857-5

Wireless communications have become one of the most rapidly growing industries in the world. This book is concerned with the principles of modulation and coding as they apply to wireless systems and with actual modulation and coding schemes found in modern wireless systems. Here, the term coding refers to error control coding and in particular to forward error correcting coding. Other very important types of code, such as speech/video coding and cryptography are outside of its scope.

> *"This book is concerned with the principles of modulation and coding as they apply to wireless systems..."*

It was developed from notes used by the author to teach several university courses. It is essentially a textbook addressed to senior undergraduates and master's candidates. It will be also useful to practicing communications engineers to provide access to more advanced topics in this area and give practical guidance in developing and applying the schemes described. Each chapter, in addition to a full description of the subject concerned, offers several examples, a set of problems to check the reader's understanding and an extensive bibliography.

The book is divided in two streams. The first one consists of three chapters on advanced modulation techniques: principles of linear modulation, modulation for nonlinear systems and modem design. The other one covers forward error correction coding for another three chapters: principles of FEC coding, cyclic block codes and convolutional codes. A discussion of coded modulation techniques follows and a chapter is devoted to modulation and coding on multipath channels.

While modulation and coding are often the subject of heavy mathematical developments, the author has kept the mathematical content of the book to a minimum and makes use of graphical and verbal explanations to illustrate the concepts.

Modulation and coding in wireless systems is a rapidly evolving field and it is often difficult to keep up with advanced techniques. The book is complemented by a companion Web site hosted by Pearson Education at www.booksites.net/burr which will include a variety of materials to supplement the book.

To order this book, contact: Prentice Hall, PO Box 11073, Des Moines, IA 50336 (800) 947-7700.

Radar Systems Performance Modeling

G. Richard Curry

Artech House Inc.

336 pages; $99, £68

ISBN: 1-58053-095-8

This book addresses the need of system analysts for radar models. It provides and explains equations, computational methods and data for modeling radar performance at the system level, and provides insight on how to use the models in system analysis. The radar models described can be used by system analysts to evaluate systems that include radars, and by modelers and programmers involved in simulating the performance of radars in systems.

The book is aimed at engineers and mathematicians who are not radar specialists. While a general engineering and mathematical background is assumed, no specialized radar engineering or advanced mathematics are required. In developing and describing the models, the book gives the reader a basic understanding of radar principles. This provides useful background for analysts and programmers, and it can also serve as a reference for radar engineers. Most of the models in this book can be found in or derived from materials in standard radar texts. The radar material needed by system modelers is collected and presented in a concise format with guidance for using it in system analysis. A comprehensive bibliography is provided in each chapter for those interested in more details on any topic.

> *"This book addresses the need of system analysts for radar models."*

The book opens with a brief overview of radar operation and applications, followed by a discussion of functional radar models and their software representations. Chapters 2, 3 and 4 discuss radar configurations, radar parameters and radar waveform characteristics. The radar equation, detection, search modes and measurements are the subjects of chapters 5 to 8. Environment and mitigation techniques are covered in chapter 9, while chapter 10 discusses radar countermeasures and counter-countermeasures. Finally some radar performance modeling examples are given in chapter 11.

The custom software functions described in the book and supporting material are provided on a computer disk. The disk contains three files: the radar functions described in the book, an Excel file which contains an example of each of the custom radar functions and an Excel file which contains the spreadsheet analysis solutions to the example problems.

To order this book, contact: Artech House Inc., 685 Canton St., Norwood, MA 02062 (781) 769-9750, ext. 4002; or 46 Gillingham St., London SW1V 1HH, UK +44 (0)20 7596-8750.

Dan Massé

Dan Massé is a member of the Microwave Journal *staff.*

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3,4	Agilent Technologies Inc.	COV 2, 99	800-452-4844	415-857-5518	www.agilent.com
5	Amcom Communications Inc.	106	301-353-8400	301-353-8401	www.amcomusa.com
6	Ameramp	57	760-602-8300	760-602-8321	www.ameramp.com
7	Amitron	154	978-686-1882	978-686-0622	www.amitron.com
8	Amplifier Research	53	215-723-8181	215-723-5688	www.amplifiers.com/ampmicro.cfm
9,10	Anritsu Company	45,58	800-ANRITSU	972-671-1877	www.us.anritsu.com
11,12,13	Ansoft Corp.	25,95,165	412-261-3200	412-471-9427	www.ansoft.com
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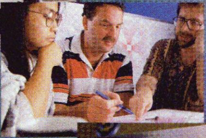

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