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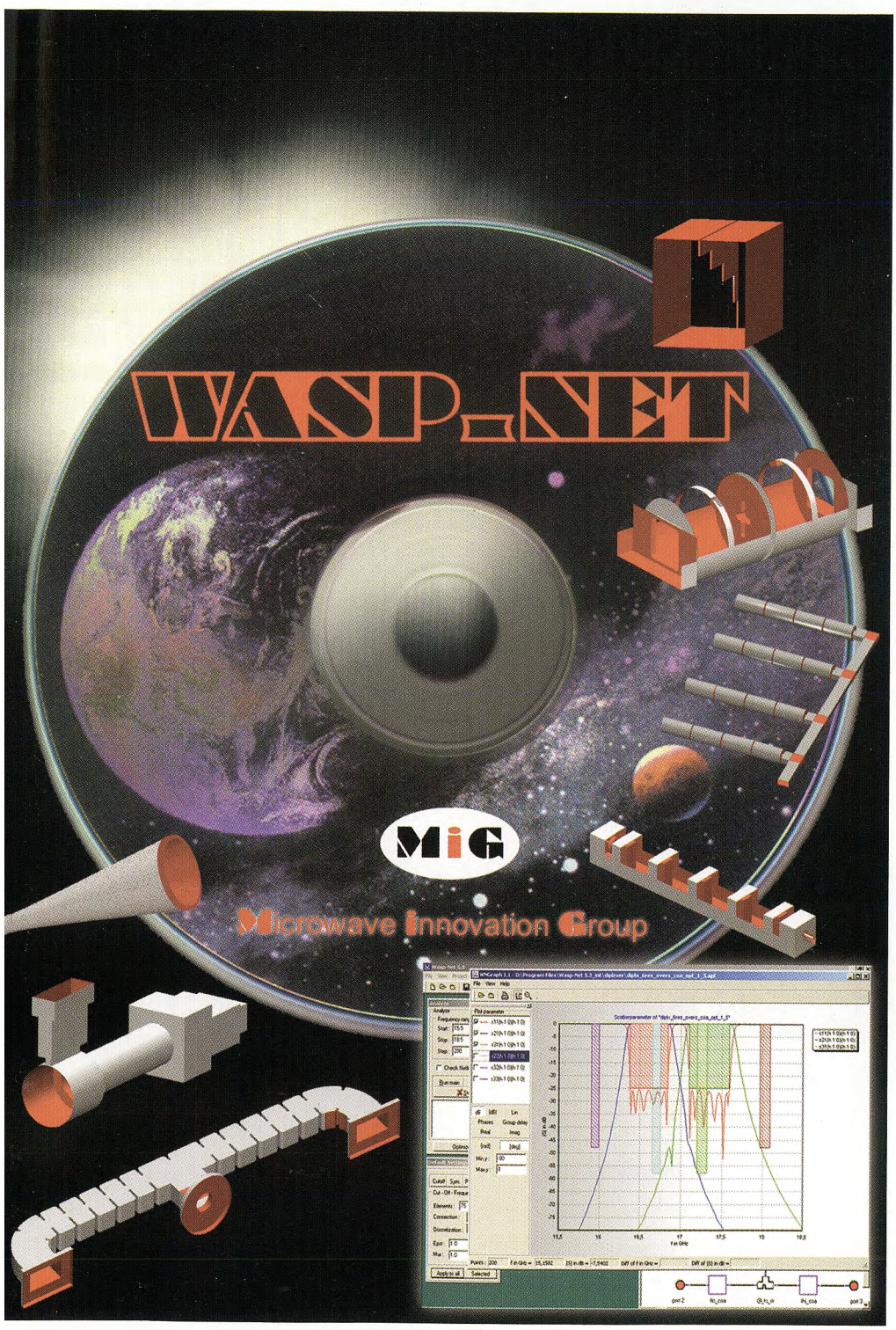

EUROPEAN SUPPLEMENT

EUROPEAN RESEARCH STATUS

OPTIMIZING LINK PERFORMANCE: PART II

MULTIMODE MULTIBAND WLANS

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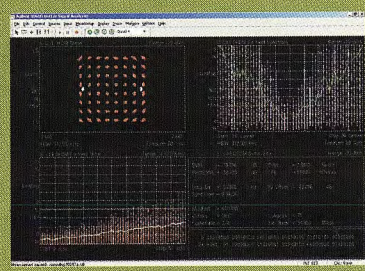
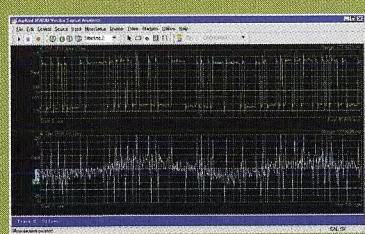


For this IEEE 802.11a signal, the overall EVM measurement is acceptable but viewing EVM versus time (lower left) and channel (upper right) shows the effect of a timing error.



The FSK error display can highlight the effects of unwanted frequency modulation, which may indicate the presence of spurious signals in the modulator.

The original idea was simple: use wireless links to give the wired generation more mobility. Of course, turning *Bluetooth* and Wi-Fi into reality—without much time for analysis—has been anything but simple. Perhaps we can help.

Enhancing interoperability. Many people attribute Wi-Fi's popularity to WECA testing that certifies device interoperability. Those who've passed tell us the roots of success often reach back to early tweaks in their transmitter or receiver designs. For transmitters, error vector magnitude (EVM) versus time or channel is a measure of modulation quality that can highlight underlying problems such as nonlinear distortion, phase noise and spurious signals. Conversely, making receivers more forgiving of nonideal transmitters can come from testing with impaired signals—in hardware, simulation or a system that links both.

Achieving certification. The Agilent Interoperability Certification Labs and Agilent's network of test partners are ready to help, too: they've tested hundreds of Wi-Fi devices and can help you clear the qualification hurdle.

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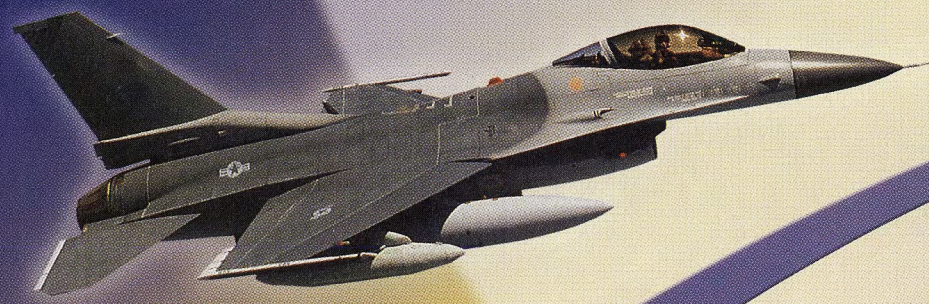

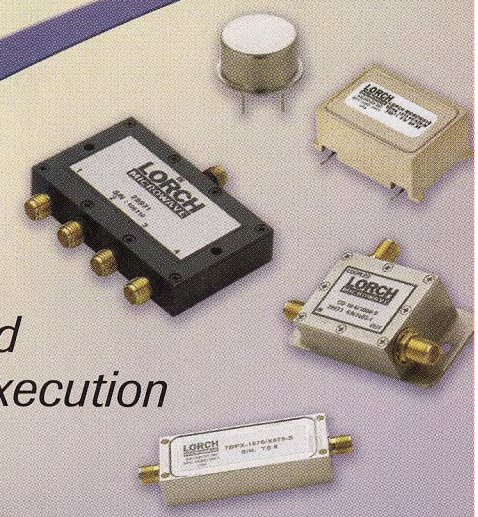

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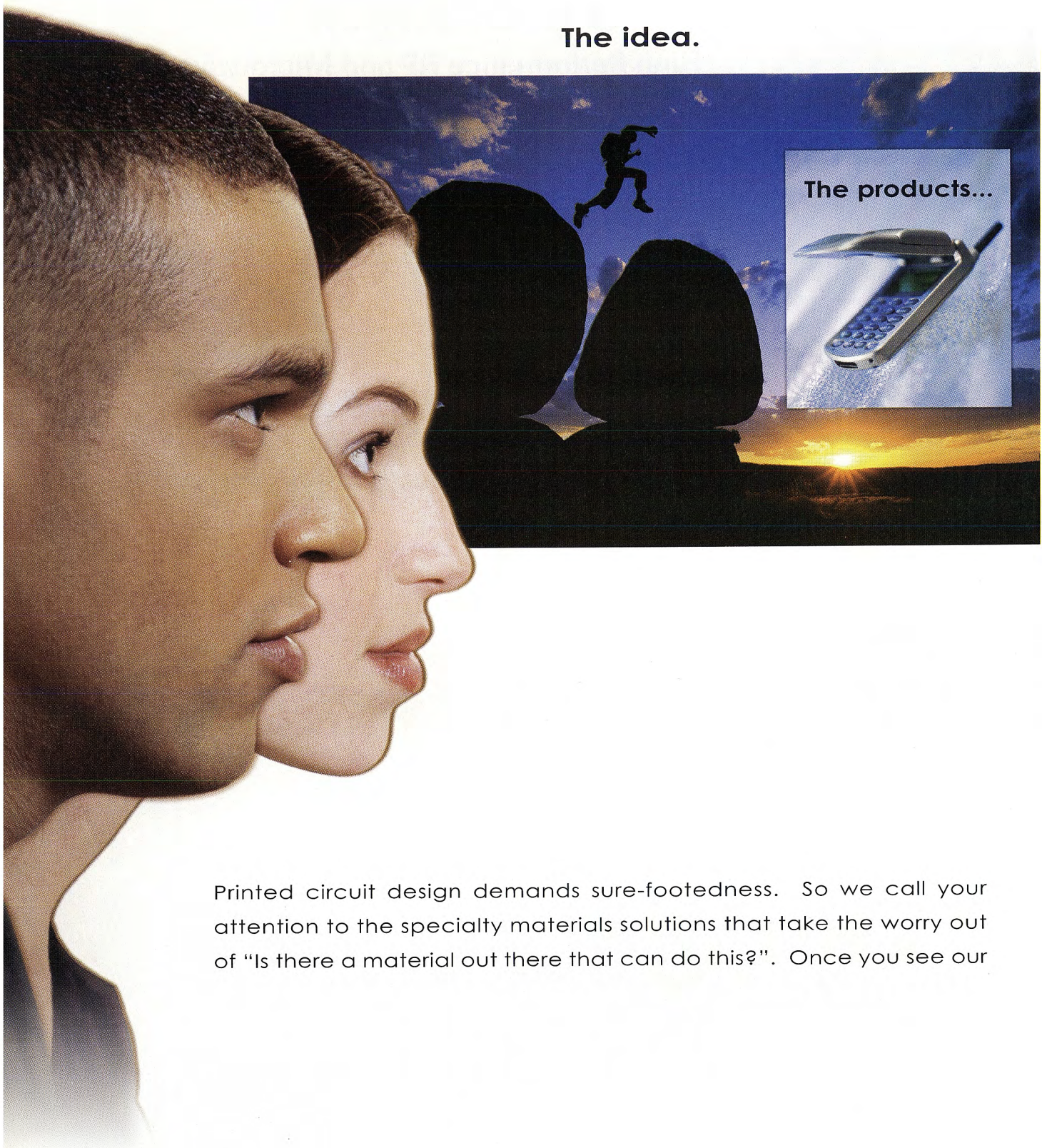

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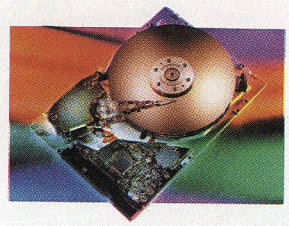

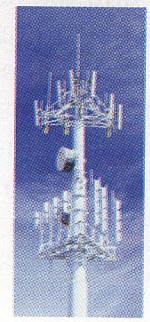

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Photo courtesy of Cascade Microtech, Inc.

Typical on wafer device characterization setups include two automated tuners like the Maury MT982E30 units (shown here mounted on a Cascade Microtech Summit 12651 probe station).

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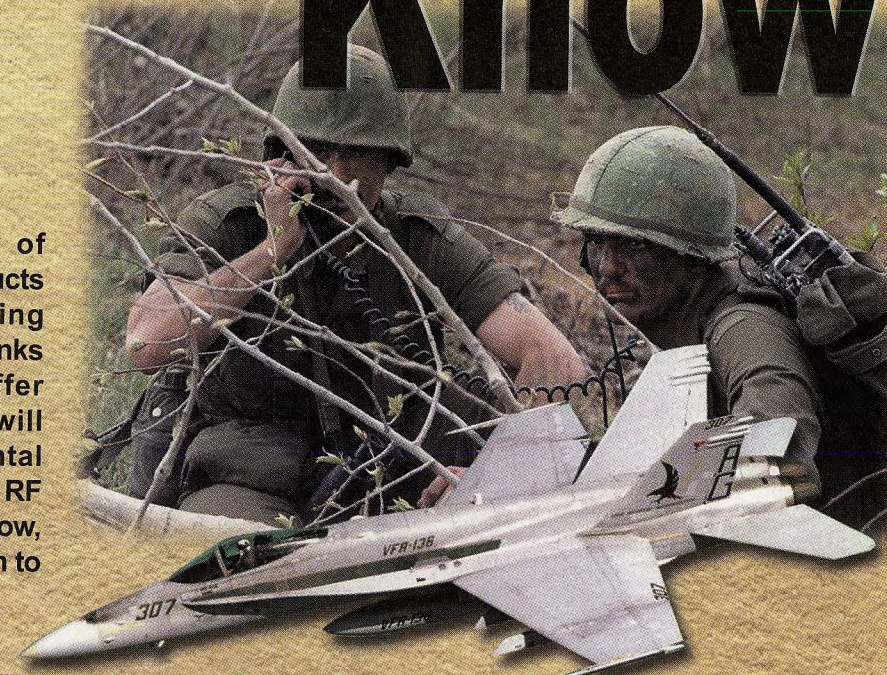

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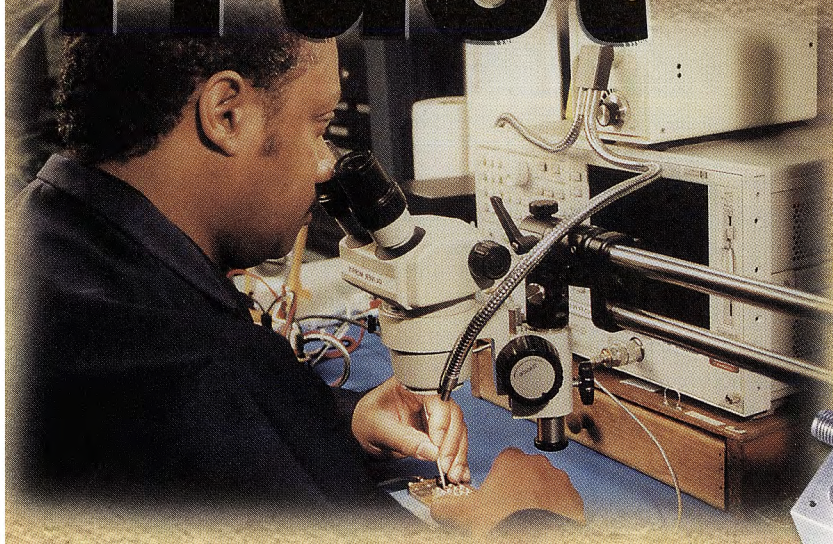

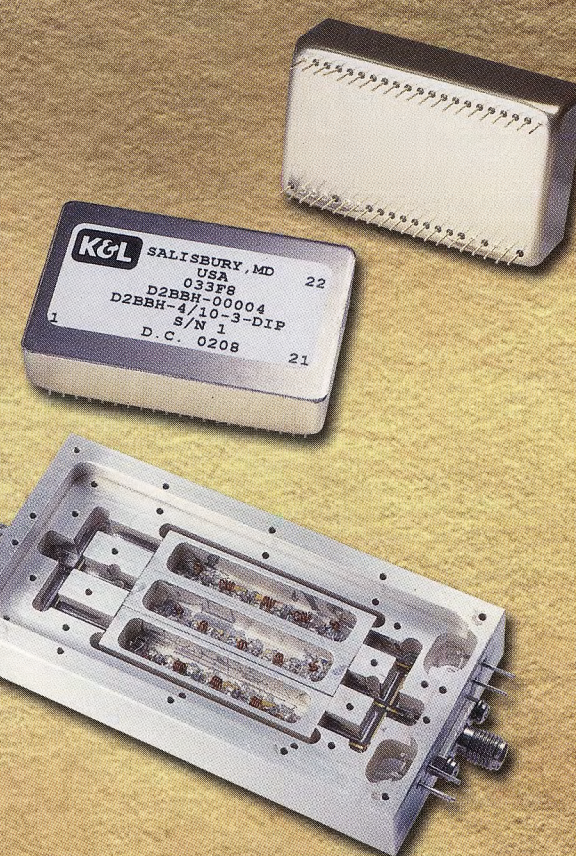

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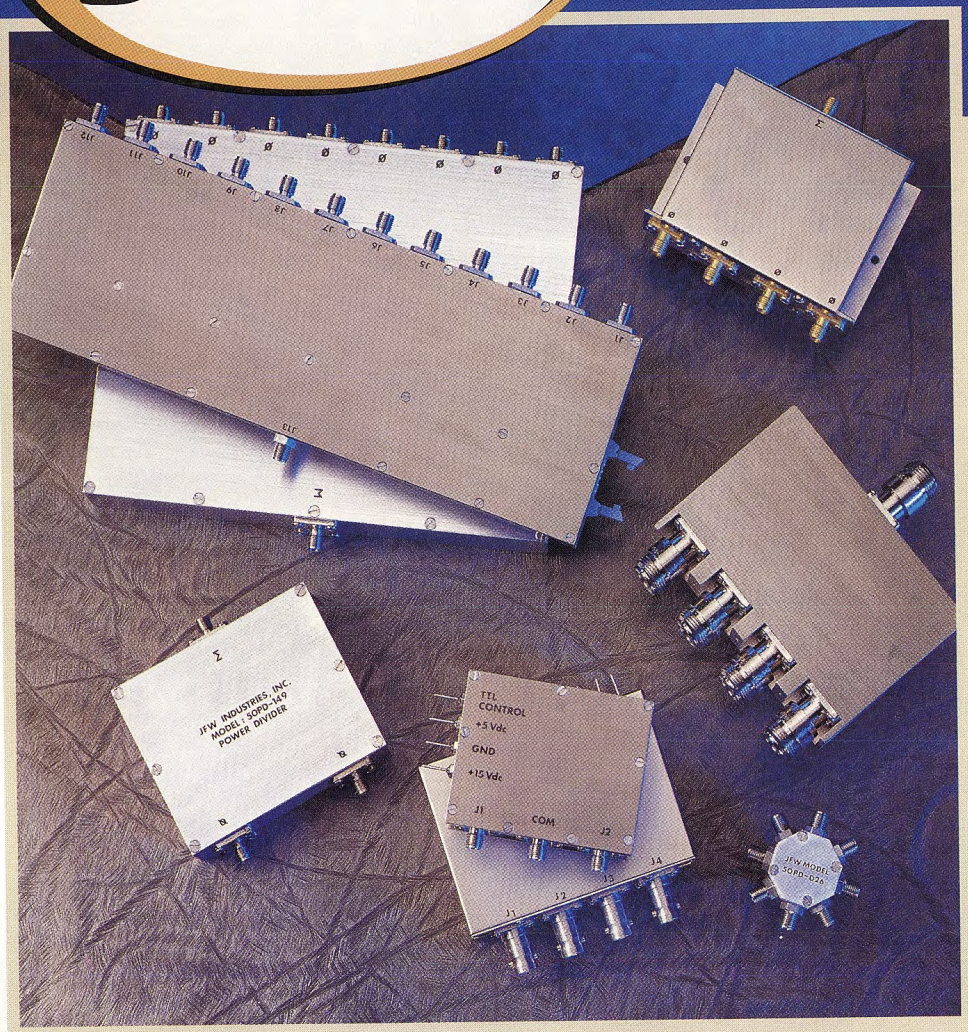

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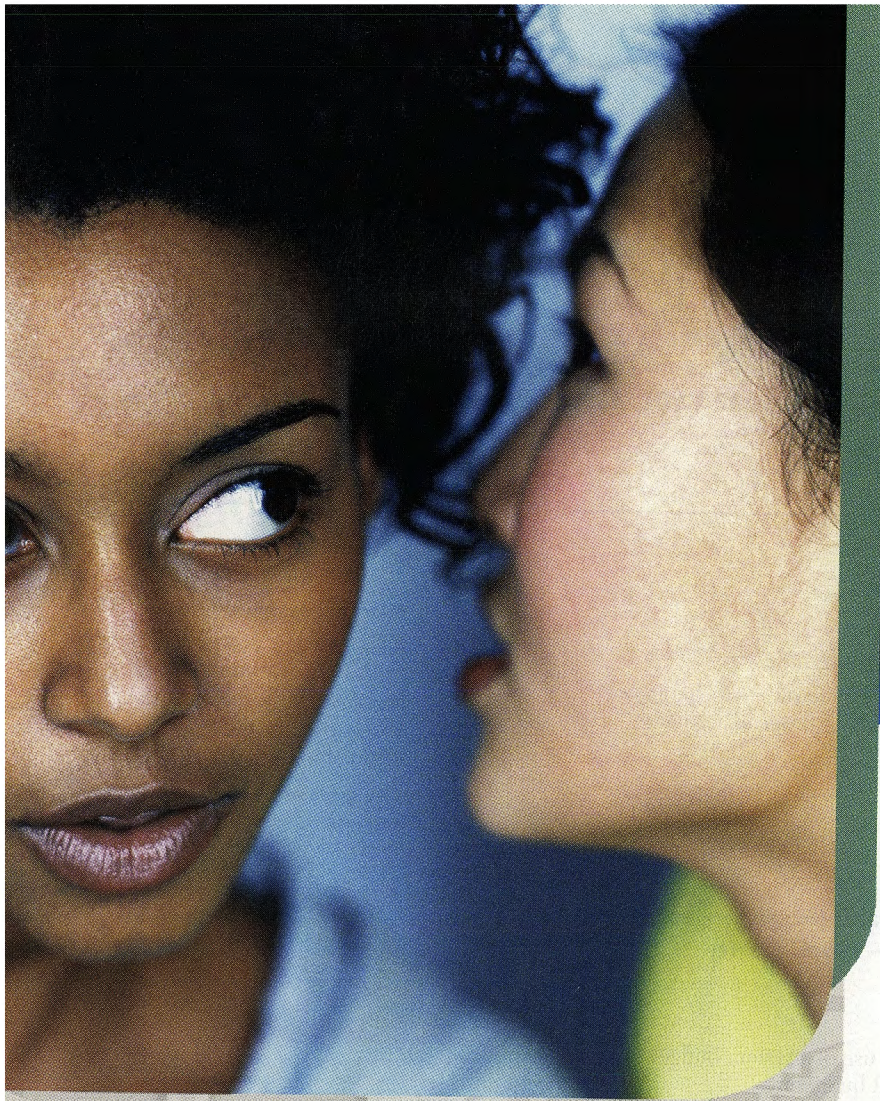

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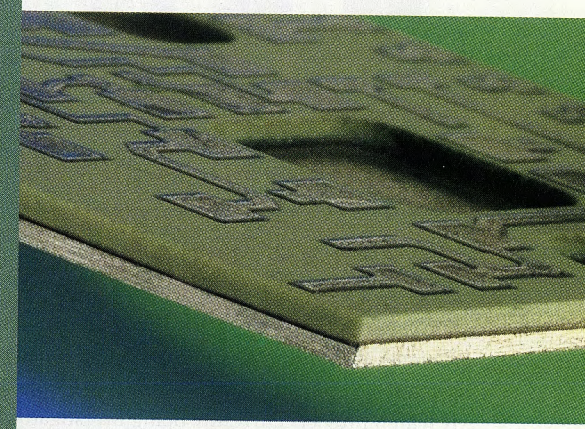

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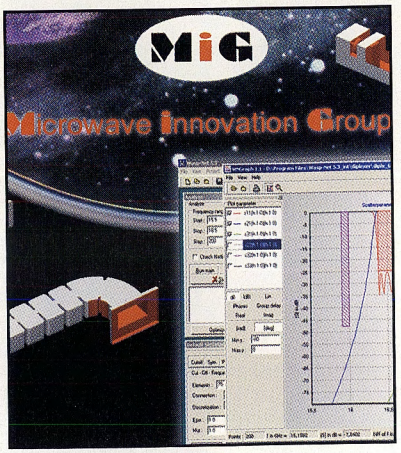

ON THE COVER

A three-dimensional electromagnetic-based CAD software tool is featured on this month's cover

Cover art courtesy of Microwave Innovation Group (MIG)

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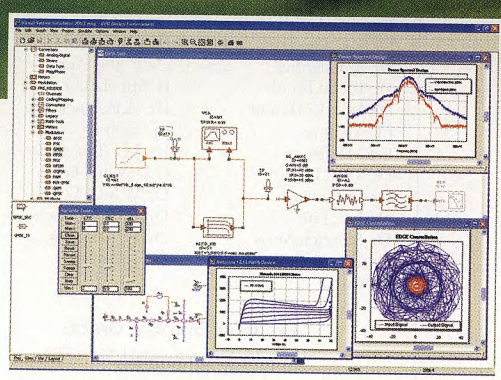

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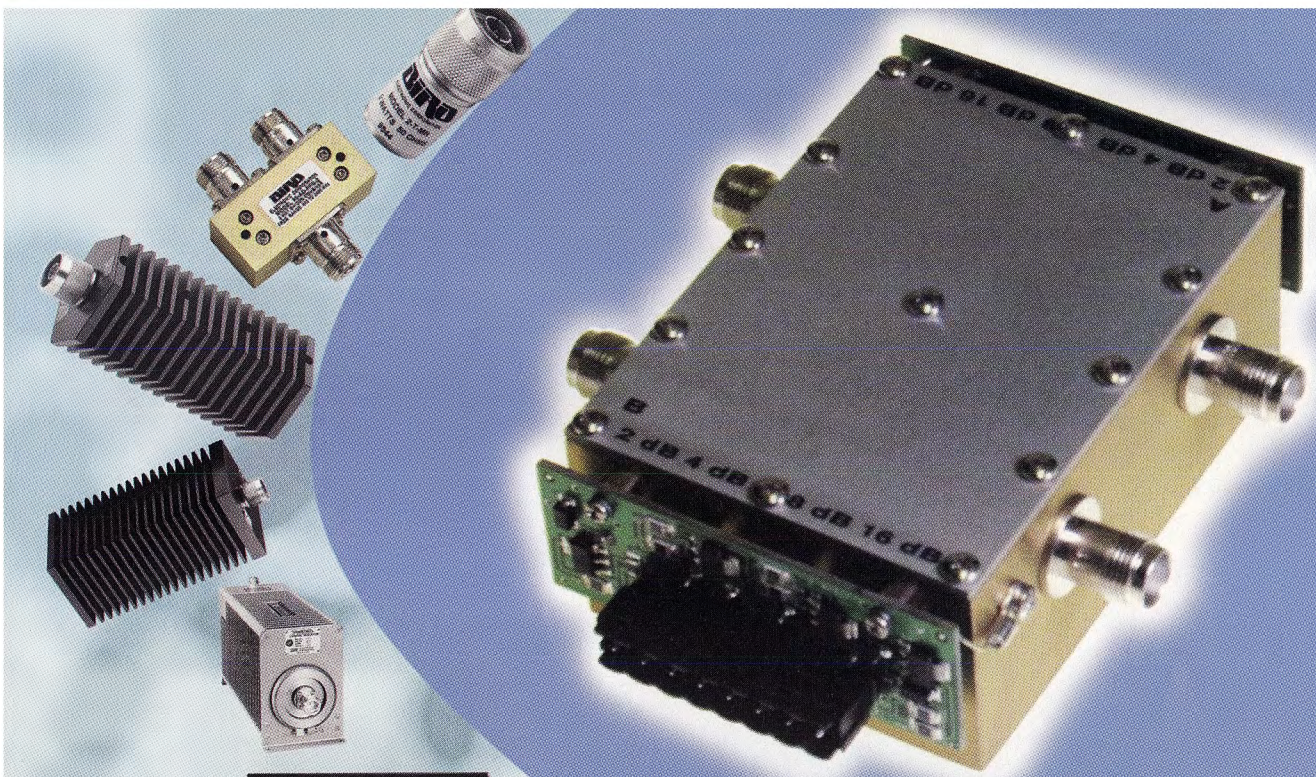

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Sponsors: IEEE Electron Devices Society, Solid State Circuits Society and Microwave Theory and Techniques Society. This symposium provides a forum to present the latest results in high speed digital, analog, microwave/millimeter-wave, mixed mode and optoelectronic integrated circuits. Topics: innovative RFIC device and circuit concepts, circuit design and fabrication, manufacturing technology and cost issues, CAE/CAM/CAT tools and techniques, IC testing and methodology, packaging technology, reliability, advanced device applications, systems applications, and optoelectronic and OEIC applications. The symposium will again offer the primer course "Basics of GaAs, InP and SiGe RFICs," which is an introductory-level class intended for those wishing to obtain a broad overview of RFIC technology. An exhibition of products from various vendors of materials, IC products, processing equipment, test equipment, CAD tools and foundry services specifically addressing the GaAs IC industry will also be featured. For further information, visit: www.gaasic.org.

2002 GHz Interconnect Workshop
October 27–30, 2002
Sedona, AZ

Sponsor: Rogers Corp. and Merix Corp. This workshop will focus on rapidly emerging technical and commercial opportunities in electronics, specifically relating to the high frequency interconnection and packaging of components and subsystems for wireless and high speed digital applications. The applications to be addressed will include high function cellular and satellite telephony, high speed computing, global positioning, collision avoidance, wireless LANs, Bluetooth and other. The challenges of managing signal integrity at these high frequencies while meeting more stringent cost constraints will be taken up by electronics professionals from a range of interdependent disciplines. For further information, contact: David Light, program chairman, VP and general manager, Flex2Chip (408) 894-0389, fax (408) 894-0438 or e-mail: dlight@sunright.com.

23rd Army Science Conference
December 2–5, 2002
Orlando, FL

Sponsor: Assistant Secretary of the Army (Acquisition, Logistics and Technology). The conference theme is "Transformational Science and Technology for the Army... a Race for Speed and Precision." The conference will feature presentations of papers and posters judged as best among those submitted by scientists and engineers from government, industry and academia. Topics: advanced materials and manufacturing, microelectronics and photonics, lethality technologies, biomedical, environmental and geosciences, power and energy, force protection/survivability, advanced computing and simulation, behavioral sciences and human performance, sensors and signal processing, biotechnology, nanotechnology, immersive technology, robotics, and IT/C4ISR. For additional information, visit: http://www.asc2002.com.

60th Microwave Measurement Conference
December 5–6, 2002
Washington, DC

Sponsor: Automatic RF Techniques Group (ARFTG). This conference will explore cutting edge microwave measurements for the industrial, academic, and government-related engineering communities. **Call for Papers.** Original papers demonstrating an approach to the characterization of microwave devices, circuits and systems are encouraged. Topics: test challenges for high power on-wafer devices, measurements for emerging technologies, nonlinear measurement and new developments in measurement instrumentation. **Deadline:**



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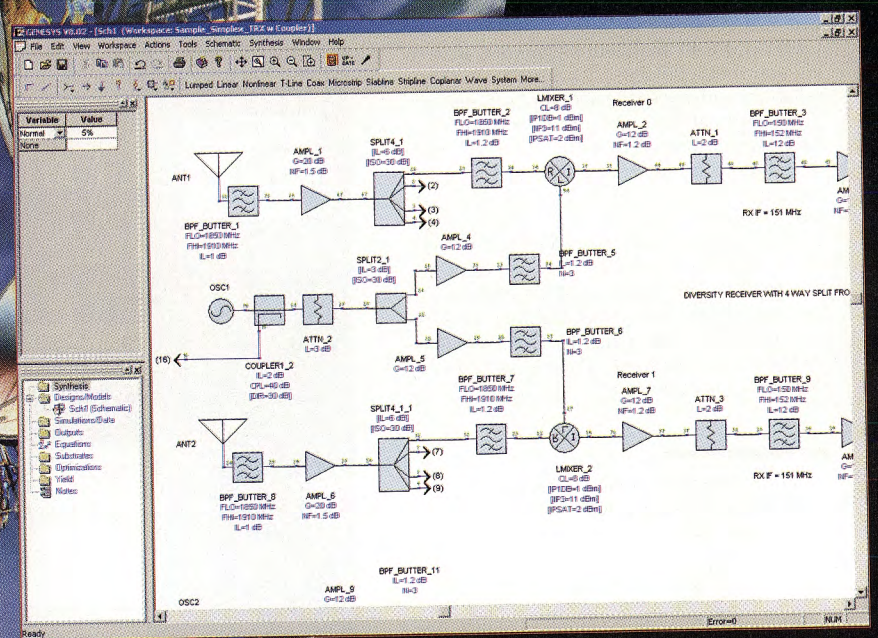

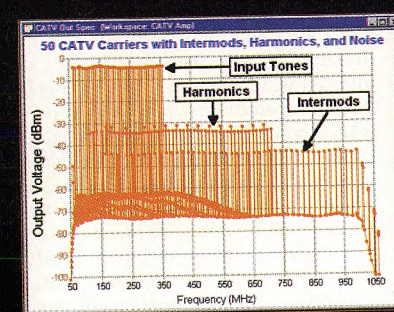

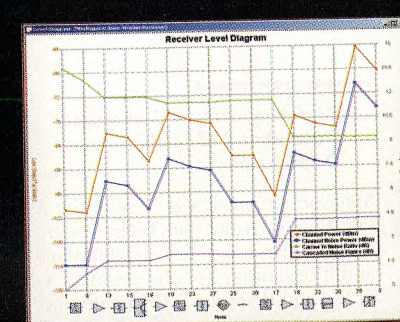

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September 9, 2002. For further information on abstract/summary submission, visit: www.arftg.org. The conference will also feature an exhibition, for information contact: Leonard Hayden, exhibits chair, Cascade Microtech (503) 601-1580, fax (503) 601-1601 or e-mail: leonard@cmicro.com. For more information on the conference, contact: J. Gregory Burns, conference chair, Northrup Grumman (410) 765-7331, fax (410) 981-4874 or e-mail: john_g_burns@mail.northgrum.com.

International Conference on Subsurface and Surface Sensing and Imaging IV
March 2–6, 2003
San Diego, CA

This conference reports advances and progress in the research and development of subsurface and surface sensing and imaging techniques, sensors and applications, and addresses the technical barriers encountered in multiple domains of subsurface and surface sensing and imaging. Topics include: surface and ground penetrating sensors, signal and data processing and propagation and modeling, material properties and characterizations, and cross-cutting commonalities across subsurface and surface sensing applications. Additional information is available at http://ee.tamu.edu/subsurface-sensing-conference. For further information, contact: Cam Nguyen, Department of Electrical Engineering, Texas A&M University, College Station, TX 77843 (979) 845-6259 or e-mail: cam@ee.tamu.edu.

IEEE International Symposium on Electromagnetic Compatibility
May 11–16, 2003
Tel-Aviv, Israel

This symposium will provide opportunities for EMC researchers, scientists, engineers and vendors to present the latest research results, discuss problems of current and mutual interest and exchange views and experience related to new EMC components, materials and equipment. **Call for Papers.** Papers should be submitted in English, either by e-mail or mail. For detailed instructions on file submission check the Instructions for Submissions on the Symposium Web site, www.ortra.com/emc2003. Templates for the preliminary manuscripts are also available on the site. If hard copy is made by mail the authors should send it on a disk with four copies to the Technical Program Committee at 2003 IEEE EMC Symposium Secretariat c/o ORTRA Ltd., PO Box 9352, Tel-Aviv 61092, Israel. **Deadline: July 15, 2002.** For further information, contact: ORTRA Ltd., 1 Nirim Street, PO Box 9352, 61092 Tel-Aviv, Israel +972-3-63844, fax +972-3-6384455 or e-mail: emc2003@ortra.co.il.

IEEE MTT-S International Microwave Symposium and Exhibition
June 8–13, 2003
Philadelphia, PA

This symposium will serve as the centerpiece of Microwave Week 2003. Topics: research, development and application of RF and microwave theory and techniques. **Call for Papers.** Technical papers for this symposium must be submitted via the IMS2003 web site (www.ims2003.org). Complete information on how to submit a paper and register for the conference, as well as other information can be found on this site. **Deadline: September 6, 2002.** In addition to IMS2003, a microwave exhibition, a historical exhibit, the RFIC symposium and the ARFTG conference will be held during Microwave Week 2003. The technical sessions will run Tuesday through Thursday of Microwave Week. Workshops will be held Sunday through Tuesday, and the ARFTG Microwave Measurements Conference will be held on Thursday and Friday. For exhibition information, contact: Kristen Dednah, Horizon House Publications, 685 Canton St., Norwood, MA 02062 (781) 769-9750 or e-mail: kdednah@mwjournal.com.

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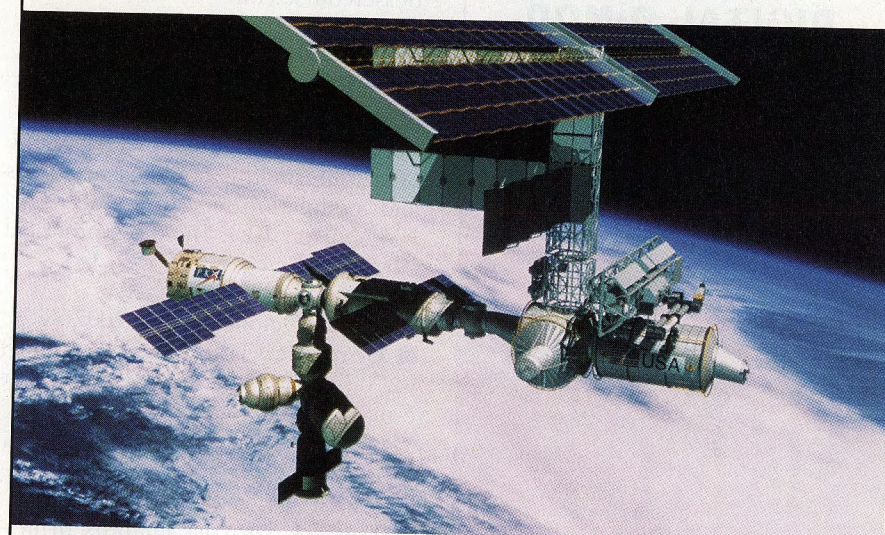

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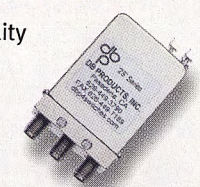

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WORKSHOPS & COURSES

RF Components and Systems for Short Range Wireless Transmission

■ **Topics:** Enables engineers to estimate the system requirements of wireless short range applications and to design a data transmission system in an unlicensed frequency band. The tools most frequently used in RF engineering are introduced using practical examples with few calculations.
■ **Site:** Sunnyvale, CA
■ **Dates:** October 7–11, 2002
■ **Contact:** Besser Associates, 201 San Antonio Circle, Building E, Suite 280, Mountain View, CA 94040 (650) 949-3300 or e-mail info@Bessercourse.com.

Spectrum Analysis Measurements

■ **Topics:** Theory of operation, understanding specifications, dynamic range, intermodulation measurements and modulation measurements (AM, FM, pulsed RF). Includes practical lab sessions.
■ **Site:** Winnersh, UK
■ **Dates:** October 15–16, 2002
■ **Contact:** Tracey Bull +44 118 9276741, fax +44 118 9276862 or e-mail: tracey_bull@agilent.com.

Network Analysis Measurements

■ **Topics:** Network analysis principles, S-parameters, architecture of vector network analyzers, operation, calibration techniques, time domain techniques. This course includes technical lab sessions.
■ **Site:** Winnersh, UK
■ **Dates:** October 17–18, 2002
■ **Contact:** Tracey Bull +44 118 9276741, fax +44 118 9276862 or e-mail: tracey_bull@agilent.com.

RF & Microwave Fundamentals

■ **Topics:** Understand the principles of RF/microwave engineering, and undertake RF measurements using power meters, spectrum analyzers and network analyzers. Introduction to noise figure and phase noise is also included.
■ **Site:** Winnersh, UK
■ **Dates:** October 22–25, 2002
■ **Contact:** Tracey Bull +44 118 9276741, fax +44 118 9276862 or e-mail: tracey_bull@agilent.com.

Introductory RF/Microwaves

■ **Topics:** Intended for engineers, managers and technicians who are new to RF/microwave and need an overview of the field so that they can become productive immediately.
■ **Site:** Baltimore, MD
■ **Dates:** November 7–8, 2002
■ **Contact:** R.A. Wood Associates, 1001 Broad St., Suite 450, Utica, NY 13501 (315) 735-4217 or e-mail rawood@rawood.com.

Wireless Engineering

■ **Topics:** Fundamentals are covered and applied using a hands-on design approach. Course principles are explored by the design of practical filters, diplexers and transistor amplifiers, giving participants a wide range of design experience. Fee: $2045.
■ **Site:** Baltimore, MD
■ **Dates:** November 11–15, 2002
■ **Contact:** R.A. Wood Associates, 1001 Broad St., Suite 450, Utica, NY 13501 (315) 735-4217.

RF Wireless System Design Fundamentals

■ **Topics:** Combines theory with real-life examples to provide participants with a complete foundation in digital communication techniques and their effects on RF circuit parameters, to help them close between traditional RF engineering design and the needs of modern communication systems. Fee: $1145.
■ **Site:** Sunnyvale, CA
■ **Dates:** November 20–22, 2002
■ **Contact:** Besser Associates, 201 San Antonio Circle, Building E, Suite 280, Mountain View, CA 94040 (650) 949-3300.

Advanced Wireless and Microwave Techniques

■ **Topics:** Antennas and filters are covered briefly, followed by a detailed discussion of figures of merit. Mixers and oscillator designs are evaluated, as well as defining, classifying and improving the efficiency and linearity of power amplifiers.
■ **Site:** Sunnyvale, CA
■ **Dates:** December 9–13, 2002
■ **Contact:** Besser Associates, 201 San Antonio Circle, Building E, Suite 280, Mountain View, CA 94040 (650) 949-3300.

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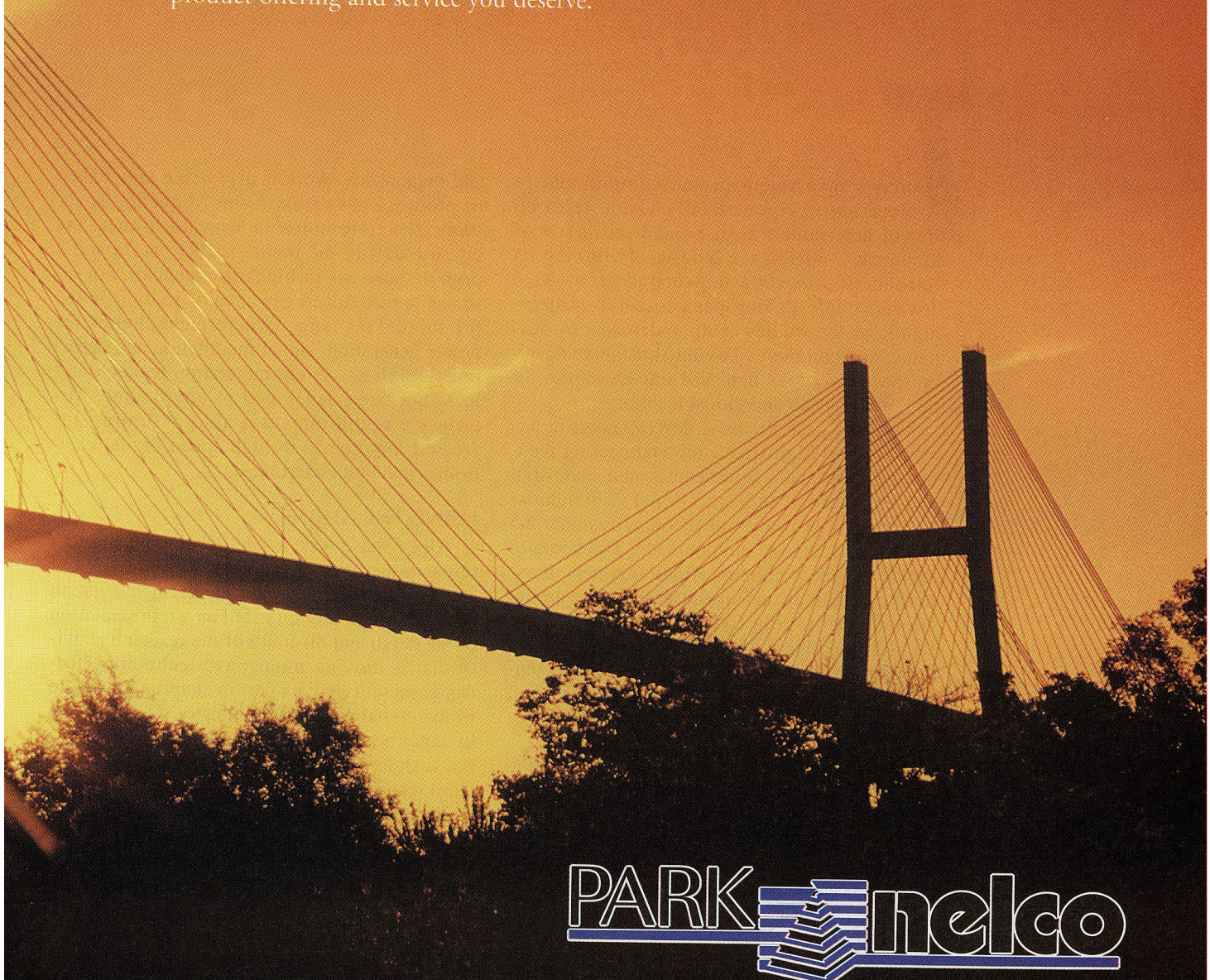

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Today's investment in and commitment to meaningful, commercially viable research will determine the shape and prosperity of tomorrow's microwave industry. Following its introduction in 2001 the second *Microwave Journal* guide to European research projects highlights the studies being undertaken by academic and commercial establishments to develop the innovations that will impact on the future of European and global technology.

Over the past 50 years, developments in microwave and high frequency engineering technology have made significant social, industrial and commercial impact. Global communications over microwave links, both terrestrial- and satellite-based, are commonplace. The boom in digital mobile communications saw new mass-market applications in the cell phone arena, Global Positioning Systems (GPS), satellite Digital Broadcast Services (DBS), etc., open up, and although the downturn in the telecommunications market has had a knock-on effect there is still significant development work being carried out.

A market that has survived a slump is the military sector, which is recovering well from cutbacks following the end of the Cold War. Here, the move towards electronic systems, with their associated size and weight reductions, has seen the microwave market benefit from system upgrades and modernization, and the development of new and increasingly complex systems.

Other areas which are advancing the exploitation of RF, microwave and millimeter-wave technology include intelligent transportation systems, RFIC tagging, radar, microwave heating, radio astronomy, and medical therapy and diagnostics. Work is also being undertaken to progress outwards in the frequency spectrum. There are moves downward to meet the upward shift in the traditional RF world and a push to make use of higher frequencies. For instance, a recognized new area of study is in the 0.1 to 10 THz range, where technologies for power generation, signal modulation and detection as well as system integration technologies have not been developed to any degree. Microwave techniques are also assuming increased importance in high speed digital electronics and optoelectronics.

USING THE GUIDE

All of these sectors are developing through research and this supplement aims to highlight some of the current projects under investigation across Europe. It is intended as a representation of the depth and diversity of the research activity that is moving microwave technology forward and will play its part in shaping the future of the global microwave industry. The listing is by country within each section, and each entry has a short profile of current research studies. Contact information is also included to aid readers wanting further details.

As well as providing wide ranging geographical coverage the guide includes a diversity of work ranging from materials development, through broadband wireless systems, to military, satellite and space applications. In order to concentrate resources and expertise there is wide collaboration across academic and com-

[Continued on page 24]

RICHARD MUMFORD
Microwave Journal *European Editor*

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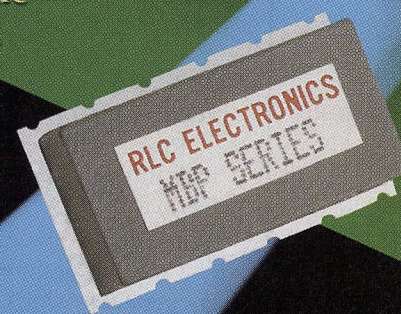

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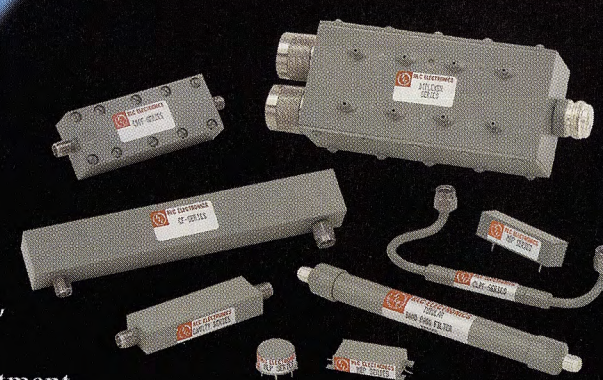

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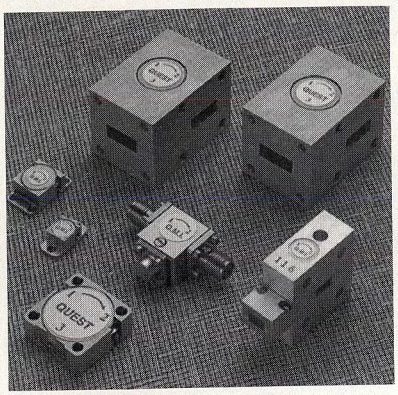

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mercial institutes; therefore, complimentary commercial and independent test houses are highlighted, as are Pan-European projects.

UNIVERSITIES AND ACADEMIC INSTITUTES

Alphabetically ordered by country the following entries for each university name the main departments involved in microwave research, cover the extent of the work currently ongoing, outline the key areas of research, in some cases focus on a project of particular significance and provide contact details. To provide some continuity but also to introduce new work, the entries are a mixture of updates of academic departments featured in the 2001 supplement, where progressive and additional work is being undertaken, together with details of new research from universities not previously featured.

AUSTRIA

Technical University of Vienna

Research undertaken in association with Infineon Technologies in Munich, Germany.

Department

Carrying on more than 12 years of cooperation, which began with a pilot project for a fully integrated direct conversion transceiver for a Digital Enhanced Cordless Telephone (DECT), the Institute of Communications and Radio Frequency Engineering, headed by Professor Arpad Scholtz, works in conjunction with Infineon Technologies, Corporate Research, under the direction of Werner Simburger. Concentrated in the field of RF circuits the joint initiative focuses on the design of high frequency circuits suitable for monolithic integration.

Research Activities

The main aim of the studies undertaken is to show that silicon and SiGe technologies are suitable for monolithic integration of high frequency circuits at frequencies approaching 100 GHz. This frequency regime used to be the domain of more expensive technologies like GaAs. The department develops circuits for analogue, digital and mixed applications, and although the work is in part devoted to basic research, it is primarily focused on developing future practical communications applications. Examples are wireless local area networks (WLAN) or point to multipoint systems.

Silicon and SiGe bipolar combine the potential to fulfil the technical specifications with the cost advantages, integration and manufacturing capabilities of standard silicon technologies. Due to Infineon's research potential circuits can be realized with state-of-the-art procedures. A new initiative focuses on the complementary metal-oxide semiconductor (CMOS) technology, especially for very high integration, and therefore circuits are being investigated on standard CMOS technologies.

Key Areas of Research

To illustrate the extent of the research undertaken, significant studies that have been or are ongoing will be highlighted, starting with the CMOS work referred to above. In this study a completely integrated 4:1 parallel-to-serial data multiplexer for high speed operation was realized in 0.12 µm CMOS. The circuit is composed from 2:1 multiplexer blocks. The multiplexer (MUX) works from DC up to 15 Gbps, which is the highest operating speed achieved by a 4:1 MUX in CMOS.

In another study a monolithic radio frequency power amplifier for 1.9 to 2.6 GHz has been realized in a 0.25 µm SiGe bipolar technology. The balanced two-stage push-pull power amplifier uses two on-chip transformers as input-balun and for interstage matching, and operates down to supply voltages as low as 1 V. A microstrip line balun acts as output matching network. At 1, 1.5 and 2 V supply voltages output powers of 20, 23.5 and 26 dBm are achieved at 2.45 GHz, with the respective power-added efficiency being 36, 49.5 and 53 percent.

In the field of oscillator development a 28 GHz monolithic quadrature voltage-controlled oscillator (QVCO) has been realized in a pre-production 0.4 µm SiGe bipolar technology with 85 GHz transit frequency. At 28.9 GHz, the circuit provides –14.7 dBm output power and phase noise of –84.2 dBc/Hz at 1 MHz offset. The two output signals are in quadrature with phase error of about 5°. Tuning of the QVCO may be done in the frequency range from 24.8 to 28.9 GHz, with nearly constant output power and the circuit consumes 25.8 mA from the 5 V voltage supply.

Other work concerns a 45 GHz SiGe active frequency quadrupler that claims to have the highest frequency

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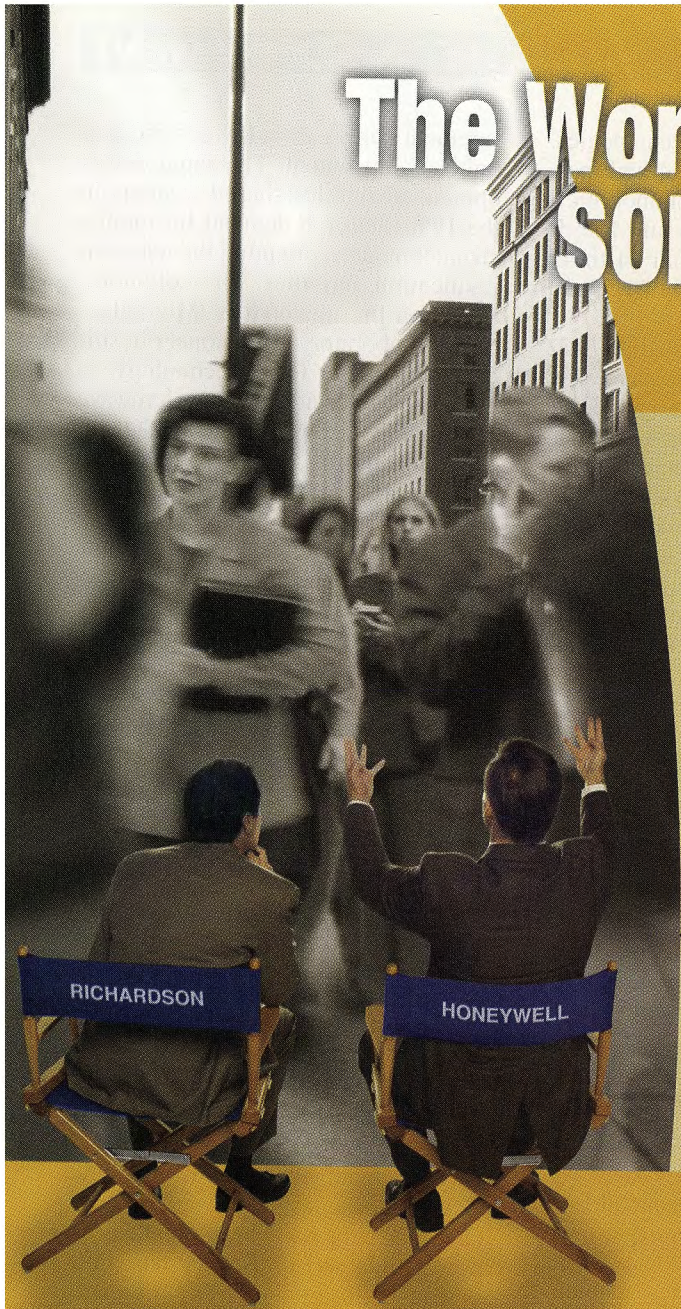

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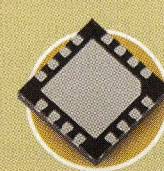

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AT4521	31.0 dB	5 bit serial	1.0 dB
AT4610	31.5 dB	6 bit parallel	0.5 dB
AT4611	31.5 dB	6 bit serial	0.5 dB

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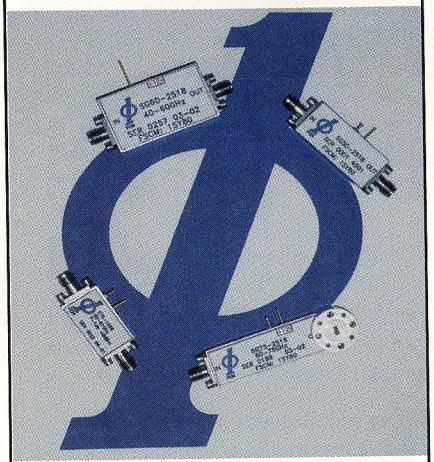

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Key Contacts

Professor Arpad L. Scholtz, Technical University of Vienna, Institute of Communications and Radio Frequency Engineering, Gusshausstrasse 25/389, A-1040 Vienna, Austria; Werner Simburger, Infineon Technologies AG, Corporate Research, High Frequency Circuits, Otto-Hahn-Ring 6, D-81730 Munich, Germany.

BELGIUM

Université catholique de Louvain, Louvain-la-Neuve

Department

The Department of Electrical Engineering is one of the five departments of the Faculty of Applied Sciences that comprises four laboratories, including the Microwave Laboratory headed by Professor D. Vanhoenacker-Janvier. The laboratory is participating in the Research Center in Micro and Nanoscopic Materials and Electronic Devices (CeRMiN), and is a member of the Laboratoire Européen en Microélectronique et Microsystèmes with IEMN, Lille (France).

Research Activities

The Microwave Laboratory, established in 1966, began by global modelling passive and active waveguide structures, loaded with dielectric and magnetic materials. Two years later, the field of activity was extended to the evaluation of the impact of the troposphere on microwave communication systems. The late 1970s were marked by the increase of satellite communication systems, the launch of ESA test satellites and associated measurement campaigns in which the laboratory contributed. The rapid development of wireless-based systems in the 1990s led to a demand for mobile channel models, orienting the telecommunication activities. The collaboration with the university's Microelectronics Laboratory — a pioneer in silicon-on-insulator (SOI) technology — led to the extension of the microwave circuit activities to microwave SOI integrated circuits for low power, low voltage applications and included opto-microwaves. Around 1985, a third activity started, the investigation of the interaction between electromagnetic fields and the nervous system. Recently, this research has moved towards the analysis of biological effects of microwave fields and their social impact in the field of mobile phones.

Key Areas of Research

Microwave and RF communications, wireless communications and satellite communications are key areas of research in which the microwave laboratory has more than 30 years experience of tropospheric radio wave propagation, from an experimental, as well as a simulation and global modelling standpoint.

In the field of satellite communications, models for depolarization and attenuation due to rain, as well as for scintillation due to clouds, have been developed and tested against measured data. Over the last few years, two specific problems have been handled: the use of time series to check fade mitigation techniques (FMT) for given satellite scenarios and the use of existing propagation data for nongeostationary satellite constellations.

For wireless communications, an original physical-statistical model based on the uniform theory of diffraction has been developed and validated with experimental data, in cooperation with the CCSR of the University of Surrey. It has been shown to be particularly useful for high altitude platform systems (HAPS) and fixed broadband wireless access.

The research projects in multiple input multiple output (MIMO) communications cover MIMO channel modeling and antenna coupling, together with the development of space-time algorithms. A physical scattering model has been derived in collaboration with the Smart Antenna Research Group of Stanford University and is

[Continued on page 28]

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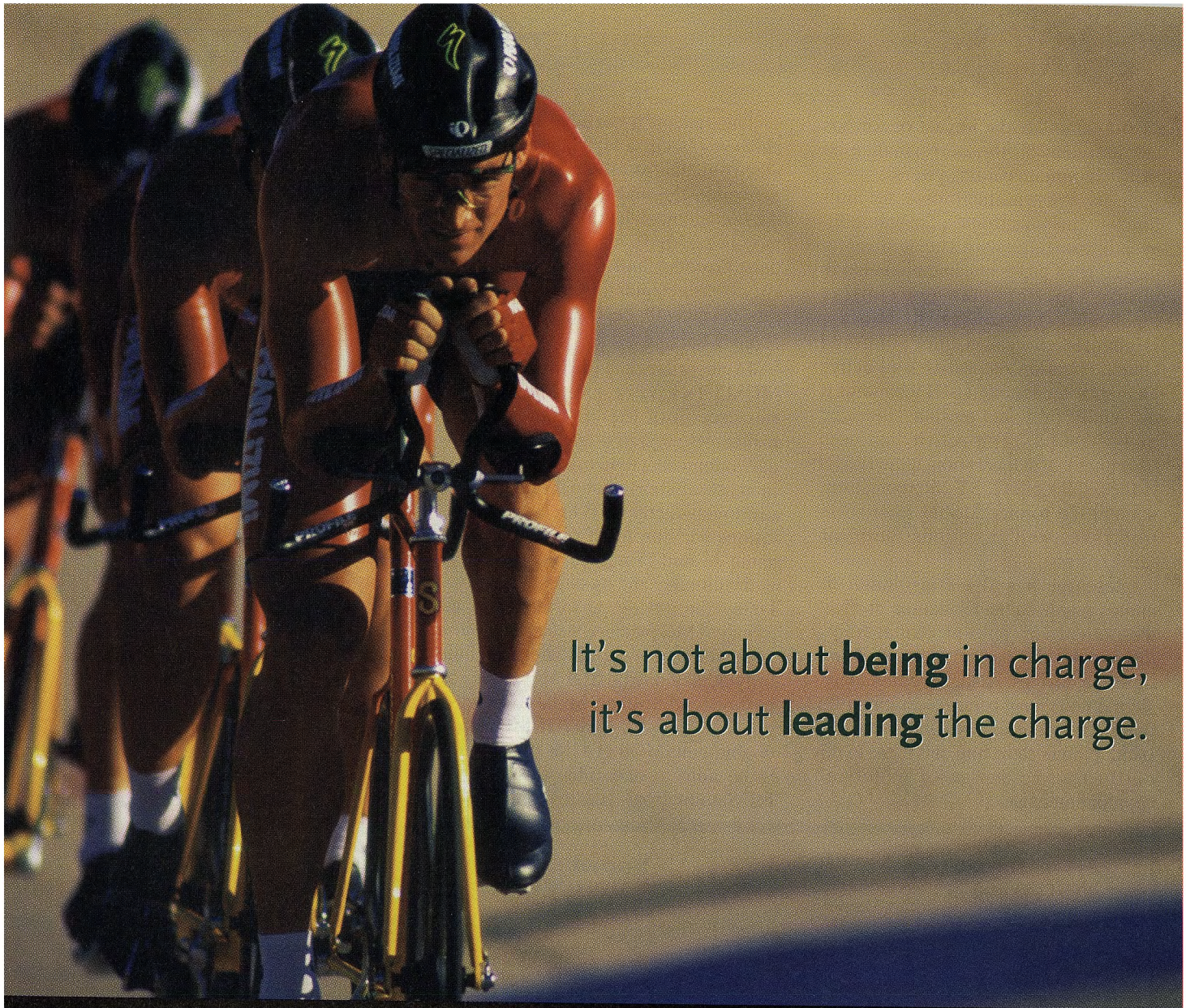

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used to simulate the impact of various mechanisms on the performance of MIMO communication systems.

In its work on microwave and millimeter-wave electronics, the laboratory is experienced in the wideband modeling of passive planar elements in microstrip, coplanar and slotline topologies. The main activity however is devoted to design, modeling and characterization of passive and active elements integrated in SOI technology, especially fully and partially depleted SOI MOSFETs. This activity has been developed in cooperation with IEMN (Lille), CEA LETI, ST Microelectronics and the former Alcatel Microelectronics, as well as various European universities.

Research has also considered the analysis and characterization of electro-optical and opto-electrical transducers and the optical control of microwave devices. Also, accurate analysis methods have been investigated for the modeling of narrowband and wideband planar radiating devices, especially for the design of wideband Vivaldi antennas.

The research activity in bio-microwaves is currently focused on bio-electromagnetic effects due to GSM networks, thermal effects induced on the human head due to 900/1800 MHz mobile phone fields, as well as standard protocol and genotoxic effects. An extensive epidemiological study on rats has recently been started.

Project Focus

In accordance with Moore's Law, MOSFETs have been rapidly scaled to improve both the cost and performance of integrated circuits. From today's point of view, mainly due to the increase of short channel effects, conventional silicon MOSFETs have limitations for minimum feature sizes of about 35 nm. Therefore, the laboratory is developing and systematically analyzing the analog performance of alternative MOS device structures over a wide frequency band. These include fully depleted (FD) SOI MOS, dynamic threshold voltage MOS (DTMOS), graded channel MOS (GCMOS) and double gate MOS (DGMOS), in order to be able to overcome the standard MOS limitations and make an appropriate device selection in baseband and RF design. Characterization techniques and models for active and passive elements implemented in silicon technology have been developed for successfully designing microwave oscillators as well as low noise amplifiers at 2.4, 5.8 and 12 GHz.

Future Projects

Three new research projects are being developed; the first investigates the characterization and development of microelectromechanical systems (MEMS) for low power RF applications. The second considers the synthesis, design and modeling of magnetic nanowire implants for tuneable integrated and hybrid passive planar circuits. Here, the substrate used for the circuits consists of an array of magnetic metallic nanowires embedded in a polymeric membrane. Third, ballistic nanodevices are being analyzed.

Key Contact

Professor Danielle Vanhoenacker-Janvier, Department of Electrical Engineering, Université catholique de Louvain, Louvain-la-Neuve. E-mail: vanhoenacker@emic.ucl.ac.be; Web site: www.emic.ucl.ac.be.

FINLAND

Helsinki University of Technology

Department

Professor Antti Räisänen heads the Department of Electrical and Communications Engineering where the Radio Laboratory and Signal Processing Laboratory have collaborated to form the Smart and Novel Radios (SMARAD) research unit. Key figures in this unit are Professors Pekka Eskelinen and Sergei Tretyakov from the Radio Laboratory, and Professors Visa Koivunen and Timo Laakso from the Signal Processing Laboratory.

Research Activities

SMARAD specializes in research into RF, microwave and millimeter-wave techniques and data communications signal processing. Areas of special interest include RF techniques for wireless data communications, radio channel modeling and measurement, new and smart materials and structures, smart (adaptive) antennas, receiver structures and architectures, and the signal processing algorithms they require. The results will impact particularly on future wireless communication systems. Sig-

[Continued on page 30]

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VSWR In/Out			1:2:1		
P1 dB Comp.	63.5	64.0		dBm	
Harmonics Out II, III	60	65		dBc	
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nificantly, the "Smart" of the research unit's acronym refers to adaptability of antennas or materials to RF signals or fields. To this end, in antenna measurement, work is being carried out on a novel method based on a radio hologram, which has already been successfully applied in testing the Odin satellite radio telescope.

Key Areas of Research

Three key topics will be highlighted here. First, under the auspices of Professor Räisänen is the study of radio holograms referred to above. Computer-generated holograms (diffractive elements) can be used for shaping millimeter-wave beams and for producing complex field configurations. The radio holograms being considered are of two distinct types, either amplitude or phase holograms. The former has been proven to be a feasible alternative as a focusing element in a compact antenna test range (CATR) in the mm-wavelength regime. Amplitude holograms have also been studied in other mm and sub-mm applications. In particular, the first experiments have been carried out in the mm-wave regime on the creation of nondiffracting radio wave Bessel beams, and on the creation of an electromagnetic vortex (a topological singularity that propagates with the electromagnetic field) in the radio wave field. The radio vortex could find applications, e.g., in direction finding and target ranging. New research on the design and fabrication of phase holograms for sub mm-wave applications has also commenced.

Professor Vainikainen is heading the study of antennas and radio wave propagation for mobile communications, particularly the antenna technologies required for future mobile radios. The research concentrates on developing small, multi-system, multi-element but low cost antennas that also have lowered radiation directed at the user of the mobile terminal. Another important area of antenna research is improved methods for characterizing the performance of the antennas, based both on laboratory measurements and the information on the propagation environments.

The propagation research deals with measurements of the multidimensional propagation channel and development of improved models of the radio propagation channel for system simulations. The latest models can be used to evaluate and design future adaptive antenna systems like MIMO antenna configurations that are expected to significantly increase the capacity of mobile radio systems.

Professor Tretyakov is investigating artificial composite layers and materials for use in radio engineering. As the artificial impedance surface near an antenna changes the distribution of the near field, less power is lost in the user's hand and head. The study optimizes the antenna so that the advantages of the artificial surface are most effectively utilized and new exotic composite materials (e.g., media with negative parameters) are being studied for microwave applications. Properties of waveguides containing exotic layers are studied. New wave solutions have been found: nondispersive waves, super-slow waves and periodical media with layers of "negative materials" are being considered. The possibility of designing a stop-band material with extremely wide stop bands has been found. Possible practical realizations of exotic materials are also being studied, as are metamaterials and layers with active and electrically controllable properties. Applications may be in wideband microwave absorbers and in antennas.

Key Contact

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FRANCE

University of Lille

Department

The Institut d'Electronique, de Microélectronique et de Nanotechnologies (IEMN) — Institute for Electronics, Microelectronics and Nanotechnologies — is headed by Professor Alain Cappy. It was founded in 1992 and is the result of the fusion of three laboratories: the High Frequency and Semiconductors Center, the Laboratory of Optoacoustic Electronics, and the Laboratory of Studies on Surfaces and Interfaces. Forming the Department Hyperfrequences et Semiconducteurs (Devices and Microwave Department) under the direction of Professor

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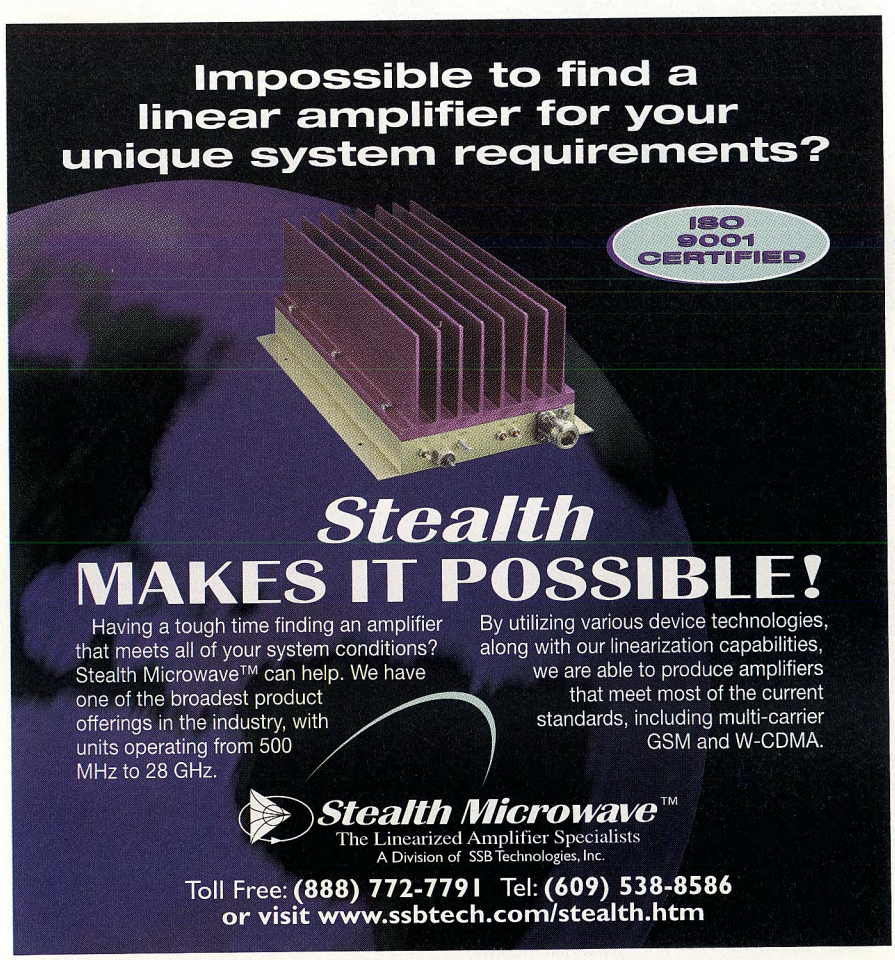



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Paul-Alain Rolland, the former is the largest, employing 160 permanent staff, and is where the majority of microwave research is carried out.

Research Activities

The key areas of research undertaken at IEMN include studies on modern electronics, innovative materials, microelectronics and nanoelectronics, microwaves, optoelectronics, electromagnetics, acoustics, ultrasound, microsystems, sensors and instrumentation. A key factor influencing the scope and effectiveness of the development work undertaken is that the department has at its disposal 1,500 m^2 of clean rooms devoted to III-V micro and nanoelectronics (from epitaxial growth to characterization) and to silicon microsystems and microtechnologies.

Key Areas of Research

The research at IEMN is organized around seven scientific themes, all except one of which, acoustics, have microwave applications. The first of these concerns material and nanostructures where studies include both experimental intensive activities — molecular beam epitaxy (MBE), near field microscopy — and theoretical work, from highly prospective fields (frontier between semiconductors and biological molecules) to domains close to applications such as increasing frequency and power of microwave transistors. A significant achievement here concerns a study on the relaxation of strained epitaxial layers, which has led to state-of-the-art metamorphic InP type high electron mobility transistors (HEMT) grown on GaAs substrates.

One of the major areas of activity is the study of microelectonics and microwave devices, which covers four main areas: the physical simulation of III-V devices to optimize their technological fabrication; the realization of III-V devices for operation at millimeter-wave frequencies, which includes high gain, low noise and ultra fast digital circuits (heterostructures InAlAs/InGaAs on InP or GaAs substrates) as well as power devices (GaInP/GaInAs power channel and GaN HEMT); silicon microelectronics devices, which encompasses the elaboration of electrical physio-chemical models to simulate the process and the electrical behavior of advanced CMOS and BiCMOS devices, and the study and realization of new CMOS architectures with Schottky source drain on SOI substrates; and quantum and terahertz devices, involving the design and fabrication of quantum wells nonlinear devices for the generation and transposition of sub-millimetric wavelength.

The main achievements of the work include: the realization and characterization of state-of-the-art metamorphic HEMT on GaAs with f_ts higher than 200 GHz for 100 nm gate length; the development of a 3D technology simulator for advanced components integrated on silicon; and the realization of a 290 GHz frequency tripler with 7 mW output power based on HBV diodes.

In the field of microtechnology and microsystems investigations are being carried out into MEMS for optical and microwave microsystems, on Si or III-V substrates, and microfluidics, with the latter being a new but growing area of activity.

Research into circuits and communication systems ranges from baseband signal processing to opto-milletric devices for local loop applications. The main challenges are to increase the frequency of operation by reducing the critical dimensions of active and passive components, and to develop new solutions for integration (mounting, interconnects, propagation structures and packaging).

Also being investigated are new telecommunication system architectures for local loop and ad-hoc networks to cover the last mile of the installation (interconnection of power lines, optical fibers, and 60 GHz radio channel for indoor and outdoor short-range high data rate applications). Significant achievements include: the design and realization of a two-stage 94 GHz InP low noise amplifier with 3.3 dB NF and 12 dB associated gain; an indoor fiber-radio link communication system at 60 GHz with a 155 Mbps data rate and lower than 10^{-5} raw BER; and a 1 V, 14 bit sigma-delta A/D converter using 035 CMOS technology.

Work in the optoelectronic and photonic circuits arena is mainly oriented towards optical communications and includes opto-millimetric device fabrication, optical switching, filtering and routing as well as optical modula-

[Continued on page 34]





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P1dB Output Power (dBm)	18	14.5	12.2	13.2	12.9
Noise Figure (dB)	4	5	3.8	4.2	5.3
Output IP3 (dBm)	32.0	28.0	24.5	27.5	26.2
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tion and photodetection up to 60 GHz. A new study concerning wavelength division multiplexing (WDM) is being carried out, based on add-drop multiplexers using photonic band gap (PBG) structures. Some significant results are the design and realization of a PBG add-drop multiplexer using a gallery mode resonator, a 1 × 4 "cascade" optical switch and a HBT-like three terminal edge-illuminated photodetector (GaInAs/InP) with RF cut-off frequency greater than 60 GHz.

The wide topic of microwave sensors and instrumentation mainly concerns the biomedical domain, food industries, transportation systems, passive imaging and signal processing. An area of microwave activity concerns radiometric systems, where 3 GHz multiprobe systems for mammography and thermotherapy controlled by radiometry, and 94 and 140 GHz real time passive imaging systems are under investigation.

Another area is non-destructive testing and specific instrumentation for signal processing.

Among the main achievements here is a fully integrated ultra fast space and time sampler (DC-10 GHz) with 60 dB dynamic range and six effective bits and a 94 GHz real time passive imaging system (limited to a linear focus plane array) using noise adding calibration and exhibiting a sensitivity better than 1 K.

Collaborations

Due to its size and wide range of research activities IEMN has numerous collaborations with academic and industrial laboratories, not only in France but also in the rest of Europe, USA, Japan and other Far East countries. Also, two common laboratories have been created with industrial societies. The first is in conjunction with Thales Research Technology and carries out work on GaN devices for high power microwave application. The second with RIBER studies large scale MBE epitaxial growth of phosphorous III-V materials.

Future Projects

The main objective is to focus on ultimate silicon and III-V devices and circuits (terahertz electronics), and on nanotechnologies for nano-optoelectronics, molecular electronics and biophysics.

Key Contact

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GERMANY

University of Erlangen-Nuremberg

Department

The Lehrstuhl für Hochfrequenztechnik (LHFT) — Institute of High Frequency Technology — was founded in 1969 and was directed first by Hans H. Brand until he retired in 1998. Since then, Lorenz-Peter Schmidt has held the chair. Today, two additional university teachers extend the teaching staff: Siegfried Martius (Microwave Technology) and, within the framework of a guest professorship sponsored by Lucent Technologies, Bernhard Schmauβ (Optical Communication Systems).

Research Activities

Planar circuit theory, technology and experimental verification at microwave and millimeter-wave frequencies, with applications in advanced communication and radar systems, are the core fields of research. The institute recognized that in the frequency range between 0.1 and 10 THz, technologies for power generation, signal modulation and detection as well as system integration technologies have not been developed to any degree. Therefore, one of its major research activities is dedicated to THz sources, waveguides and receiver component technologies. This work started many years ago with fundamentals in the field of quasioptical technology, molecular gas filled ring lasers, optically pumped by CO_2 lasers and sub-millimeter-wave frequency multipliers with varactor diodes.

In the field of laser technology and photonics, the main interests of research are in the development and optimization of laser beam sources and on laser-based measurement methods. Compact, RF-excited CO_2 lasers are under development, which can be applied to industrial material processing as well as in specific measurement systems in the laboratory.

Research activities in the field of optical communication technology concentrate on ultra high capacity

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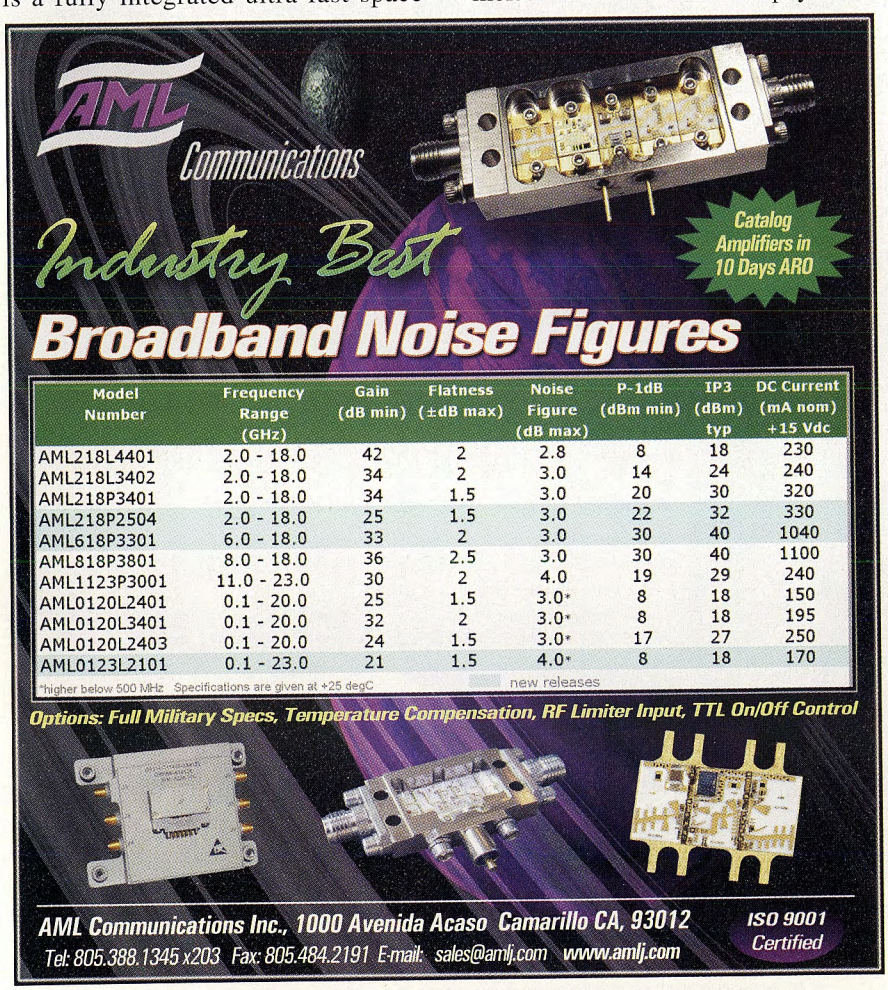

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Part no.	Freq.(GHz)	Gain	P1dB	IP3	Package Style
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AM152731WM	1.5 - 2.7 GHz	30dB	30dBm	39dBm	BM, QM
AM183031WM	1.8 - 3.0 GHz	33dB	31dBm	40dBm	BM, QM
AM304031WM	3.0 - 4.0 GHz	32dB	32dBm	39dBm	BM, QM
AM284231WM	2.8 - 4.2 GHz	32dB	32dBm	39dBm	BM, QM

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Key Areas of Research

Current research projects in the frequency range up to 150 GHz are dedicated to packaging and interconnect technologies for ultra broadband optical communication systems, including low temperature co-fired ceramic (LTCC) RF multilayer and novel substrate technologies development as well as multiport differential signal measurement technologies up to millimeter-wave frequencies. Further activities include microwave chip and module test methods, aimed at high volume, low cost in-production testing, and planar hybrid integrated circuits development, utilizing in-house thin-film and packaging technologies. Recently, a shielded anechoic chamber, equipped with a computer-controlled four-axis positioner for highly automated characterization of micro- and millimeter-wave antennas, has been installed and will be of help for ongoing work on antennas and sensors for short-range imaging, such as focal plane arrays.

At sub-millimeter-wave frequencies, the circuit design is based on planar as well as on metallic and dielectric waveguide technologies for the lower THz regime and utilizes quasi-optical technologies at frequencies above. Dielectric lenses, ellipsoidal mirrors, wire gratings, serving as beam splitters or polarization filters and other components have been developed. These components are being used for experimental THz systems like radiometers and imaging transmission measurement systems.

For improved laser beam shaping and wavelength selection in RF-excited, sealed-off CO_2 lasers, diffraction gratings with a novel structure are being developed and produced in the in-house electroplating facility. The examination of the gas compounds in such CO_2 lasers is carried out by using a highly sensitive diode-laser spectrometer set-up, based on fiber optical components. Investigations on solid state and fiber lasers as well as nonlinear optical effects are further activities in this area.

In the field of optical communication systems the major fields of interest are modeling and simulation of OTDM system components, link design for ultra high capacity systems, fiber optical regeneration techniques and advanced modulation formats for high spectral efficiency wavelength division multiplexing in next generation ultra long haul systems. A high performance physical layer transmission system simulator is used to analyze the influence of component characteristics on system performance.

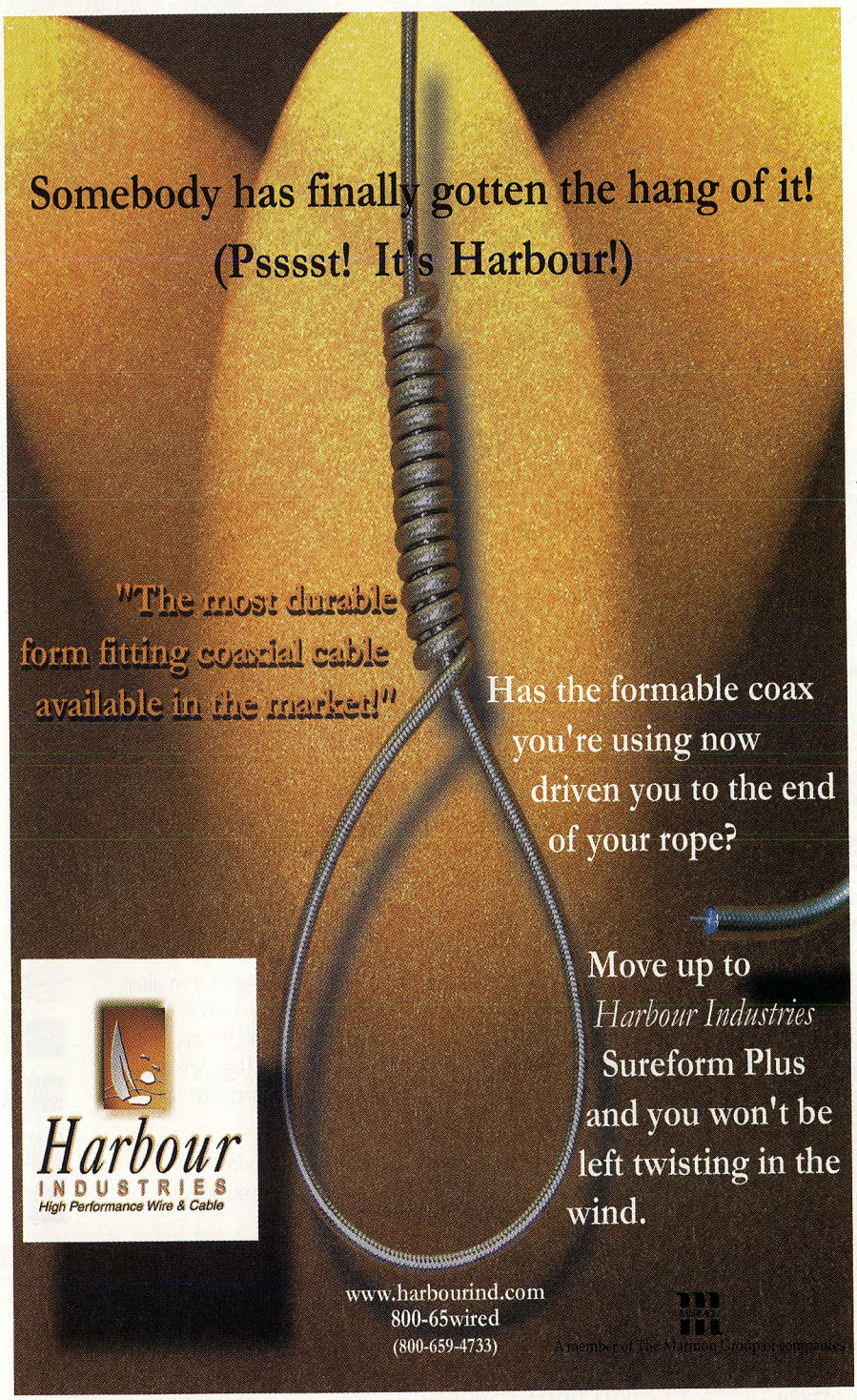
Collaborations

In research collaboration with groups from the University of Darmstadt and the University of Hamburg-Harburg, a vector 3D near field scanning system is being developed for 150, 300 and 450 GHz. This system will help to optimize the performance of novel quasi-optical oscillator and multiplier arrays within the project: Multi-Element Multi-Substrate Terahertz Integrated Circuits (MEMSTIC).

Project Focus

Recently, a quasioptical 2.5 THz radiometer has been developed, enabling simultaneous measurement of the O_3,

[Continued on page 38]



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OH and H_2O concentration in the upper atmosphere. As a local oscillator, a methanol ring-laser at 2522.8 GHz is used, delivering up to 50 mW of output power. It is pumped by an RF-excited grating tunable sealed-off CO_2 laser. Via a low loss, quasioptical diplexer the signal and the LO are fed to a mixer with recently developed substrate-less Schottky diodes, followed by a broadband, noise matched 6 to13 GHz IF amplifier.

In a DFG (German Research Foundation) sponsored research collaboration project, jointly conducted with a group from the University of Darmstadt, the application range of such Schottky mixer diodes is being extended to low noise operation at frequencies beyond 2.5 THz.

Key Contact

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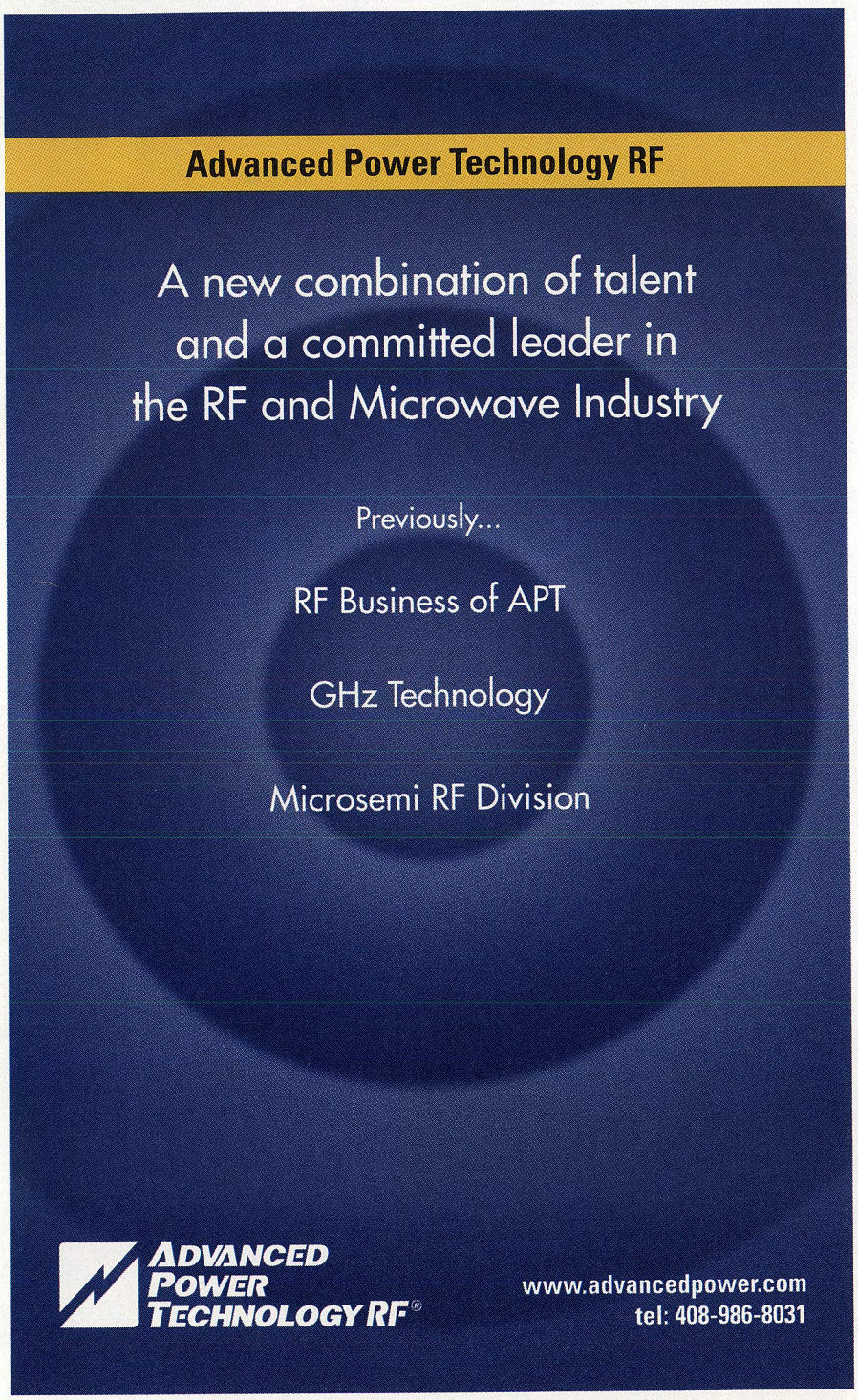

ITALY

Politecnico di Milano

Department

Professor M. Santomauro heads the Dipartimento di Elettronica e Informazione, where the group of researchers involved in studies on microwave circuits is coordinated by Professor G. Macchiarella.

Research Activities

The main research work of the department is concerned with propagation of microwave and millimeter-waves, and with microwave circuits. For the latter, activity began many years ago with the development of CAD procedures for post-coupled waveguide filters, and for comb and interdigital filters in slab line. Now, most of the studies in the microwave circuit field (both active and passive) are devoted to mobile communications applications.

Key Areas of Research

The design, theoretical synthesis and computer-aided tuning of microwave filters are three strategic areas of activity. Taking each in turn, the aim of work to develop a space mapping technique for filter design is to derive suitable equivalent circuits for various classes of multiple-coupled-cavity filters whose parameters are assessed through electromagnetic simulations. These circuits are then used in the space mapping technique, allowing a strong reduction of the computational efforts in the numerical optimization of complex electromagnetic filter structure. Also, a design approach based on space mapping has been developed for designing comb filters with a large b/λ ratio and studies are currently under way to apply it to dielectric dual-mode filters.

As far as filter theory is concerned novel methodologies are being studied for the synthesis of equiripple Chebycheff filters with arbitrary placed transmission zeros (either complex or imaginary). Original procedures have been developed which, starting from the required filter mask, enable the determination of the coupling coefficient of an arbitrary filter topology, built up as a cascade of triplet and/or quadruplet sections.

[Continued on page 42]

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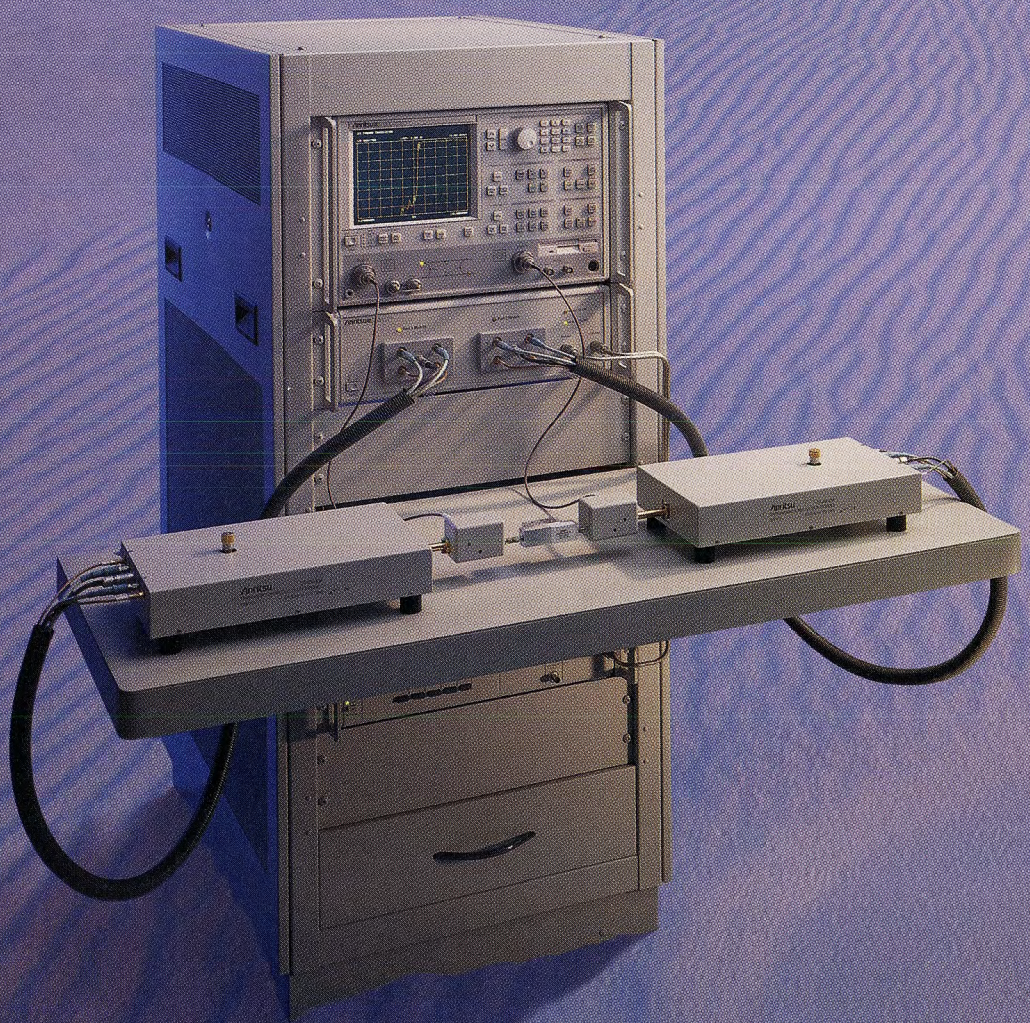



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In the field of computer aided tuning of microwave filters suitable strategies are being investigated for partial or complete tuning automation of generalized combline filters or duplexers. The procedures developed are based both on measurements of pre-tuned units and on equivalent circuits of the filters under alignment. In another study with obvious commercial applications various techniques are being investigated to improve the performances of linearized feed forward power amplifiers for last generation mobile systems.

Project Focus

A study commissioned by Forem, Italy, has yielded a general-purpose design program for multiple-coupled resonator filters with arbitrary placed transmission. The software is the result of studies performed over the last decade into filter synthesis and represents a very useful tool for designing high performance filters such as those used in mobile communications base stations. For a given set of electrical specifications, the program suggests some suitable topologies and computes the coupling coefficients, the external Q and the resonant frequencies of the resonators in the filters. These results can be used to fabricate various filter structures: generalized combline, dielectric single and dual-mode, etc.

Recently, the possibility of realizing asymmetric transmission zeros by coupling the input with the first two resonators (or the output with the last two) has been introduced, which can be employed to realize in-line filters with transmission zeros.

Future Projects

2001 saw the initiation of a research program investigating monolithic low phase noise oscillators using SiGe technology and supported by Ericsson Lab Italy. At present, studies are in progress concerning suitable design approaches for high Q monolithic inductors (both single and balanced).

Key Contact

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SWITZERLAND

Swiss Federal Institute of Technology, Zurich

Department

In the microwave technology domain there are two research groups with complementary research interests within the Laboratory for Electromagnetic Fields and Microwave Electronics, which is part of the Department of Information Technology and Electrical Engineering (D-ITET). Professor Vahldieck heads the Electromagnetic Fields (EF) Group, whilst Professor Bächtold leads the Microwave Electronics (ME) Group.

Research Activities

Shared projects between both groups focus on photonic band gap structures and on highly integrated front-end design for 5 GHz channel sounders in MMIC and LTCC technology. Singularly, the EF Group examines computational electromagnetics in the area of CAD of passive microwave/millimeter-wave components, electromagnetic compatibility, integrated optics and nano-optics. Current projects are on field theory-based optimization techniques for microwave and millimeter-wave filters using a novel combination of rigorous field solvers and generic circuit prototypes, numerical analysis and optimization of reverberation chambers, numerical field analysis of optical MQW rib waveguide structures in travelling wave photodiodes and their integration with passive uniplanar microwave and millimeter-wave antennas, LTCC-based miniaturized antennas, photonic band gap structures for guiding and filtering electromagnetic waves at nanometer wavelengths, numerical analysis of plasmon resonances, together with the study of left-handed media.

The focus of the Microwave Electronics Group is on MMIC design and characterization, measurement techniques, millimeter-wave device and circuit technology, optoelectronics and integrated optics. Over the last decade the emphasis has been on device modeling and circuit design for wireless communication applications using GaAs MESFETs foundry technology.

Key Areas of Research

Taking the Electromagnetic Fields Group first, key initiatives include work on the EM-simulator-based optimization of passive filters, diplexers

[Continued on page 44]

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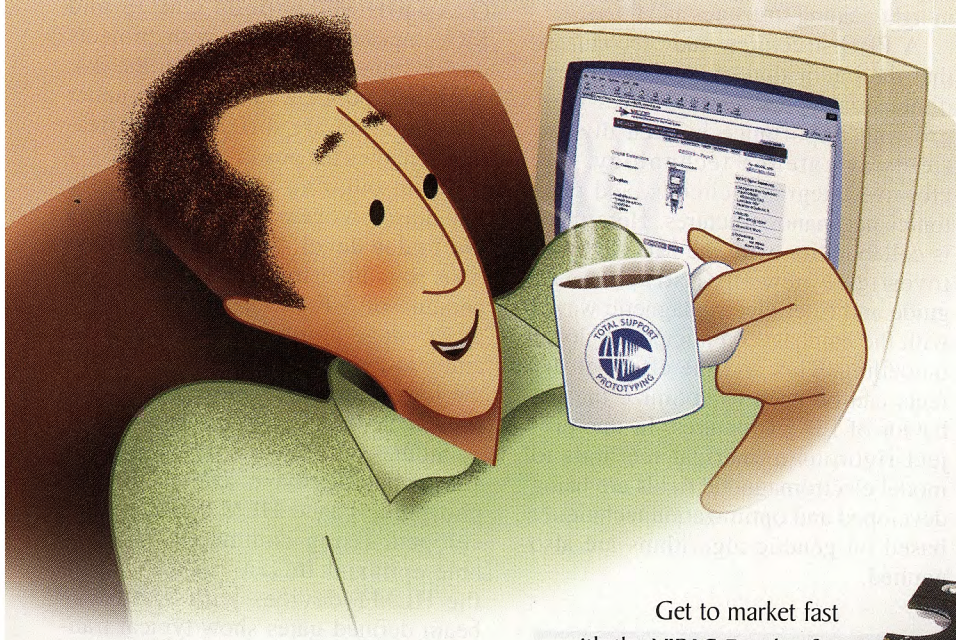

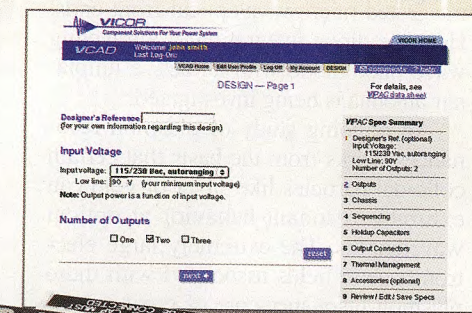

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and active filters. The aim is to develop fast optimization techniques that use EM-simulators only to generate an accurate surrogate model of the filter structure while the actual optimization takes place in the parameter space of that model. In conjunction with a field-based sensitivity analysis, mapping between model parameters and geometry becomes very accurate. With this technique the number of field simulator runs can be reduced significantly.

The group's project on MQW rib waveguide structures and integration with uniplanar microwave circuits sets out to characterize transitions between photonic waveguide structures and coplanar transmission lines for highly integrated microwave/optical front-ends. Here the direct integration of a traveling wave photodiode with an active uniplanar antenna is being investigated.

An ongoing study of plasmon resonances works from the basis that certain colloidal particles like silver or gold can exhibit a resonant behavior at optical wavelengths. The extremely large electromagnetic fields associated with these plasmon resonances are of great importance for surface enhanced Raman scattering and in applications where nanoparticles are used as biological markers. Under investigation is the realistic situation of nonregular-shaped nanoparticles and what has been found is an extremely complex spectrum of resonances. Also under study is the possibility of utilizing plasmon resonances in light guiding structures and filters.

A PBG structures study recognizes that the interaction of two- and three-dimensional periodic structures is of growing importance in such diverse fields as antenna technology, microwave integrated circuits, and photonics and nano-structures. Here there is collaboration with the ME Group to investigate new PBG structures to guide and filter electromagnetic waves with the emphasis on numerical global modelling. This and the effect of defects can be used to optimize the behavior of PBG structures. In this project rigorous numerical methods to model electromagnetic fields are being developed and optimization techniques based on genetic algorithms are also applied.

The Microwave Electronics Group has developed a fully integrated RF front-end for a smart antenna Hyperlan receiver, with three antennas providing the electronics for superposition of the three RF signals with controllable amplitude and phase. Presently MMIC developments are under way with commercial GaAs-MESFET, GaAs-pHEMT, silicon CMOS and SiGe bipolar processes with projects on RF-transmitter/receivers in the 2.4, 5, 10 and 60 GHz ranges. Also under consideration are different linearization schemes for power amplifiers.

In an ongoing project extremely low noise cryogenic HEMT amplifiers are under development for applications in radio astronomy. A noise temperature of 5 K has been measured in a two-stage amplifier operated at an ambient temperature of 15 K. This is the lowest amplifier noise temperature achievable with any technology.

Studies in mm-wave device and circuit technology have seen an indium-phosphide-based HEMT process developed. Using commercially available epitaxial InGaAs/InAlAs layers the HEMT devices with 0.2 µm e-beam defined gates show typical transit frequencies of 150 GHz. Recently the gate formation processes have been further developed for 0.1 µm gate length. Suitable models for active and passive coplanar on-chip devices have been developed and MMICs have been designed and manufactured for wireless short distance communication in the frequency range up to 60 GHz.

Ongoing projects are modeling and characterization of mode-locked laser diodes, 980 nm pump lasers, vertical cavity surface emitting lasers (VCSEL) and dense integrated optical components for WDM applications. Of particular interest are optical interconnects in electronic systems between boards and modules. Novel concepts of optical waveguide structures with new functionalities are now under investigation. Here, densification in the time scale and in the length scale is the leading paradigm for future terahertz photonics devices.

Key Contact

Professor R. Vahldieck, Swiss Federal Institute of Technology, Zurich, Switzerland. E-mail: vahldieck@ifh.ee.ethz.ch.

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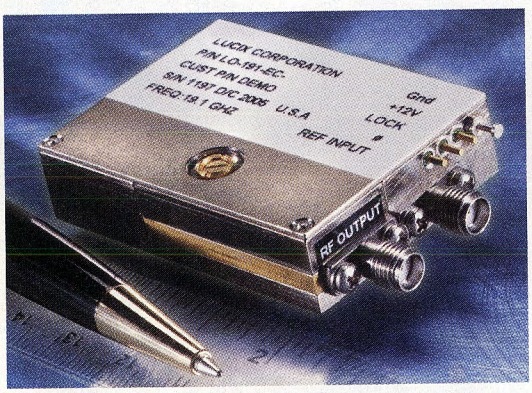

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TURKEY

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Department

Chaired by Bülent Özgüler, the Department of Electrical and Electronics Engineering has over 20 faculty members working in various areas of electrical engineering. Of these, Professor Abdullah Atalar (Provost and the former chairman of the department), Professor Ayhan Altintaş, Associate Professor Levent Gürel and Assistant Professor Vakur B. Ertürk are involved in the field of electromagnetics, antennas and microwaves and form the Electromagnetics (EM) group.

Research Activities

For many years, the EM group has investigated both theoretical and computational electromagnetics, as well as electromagnetic compatibility (EMC). In the area of computational electromagnetics, the main focus has been on the modeling of complicated geometries on computers, modeling EM phenomena using circuit-theory concepts by employing parasitic extraction, AWE and SPICE, and the development of powerful software packages using fast solvers both in time and frequency domains such as finite difference time domain (FDTD), fast multipole method (FMM) and method of moments (MoM).

For antennas, the design and analysis of broadband antennas as well as the analysis and synthesis of arrays (printed and conformal) have been the main areas of activity, with considerable success. Radar cross section (RCS) computations (and measurements), stealth studies and ground penetrating radar (GPR) simulations have also been considered.

EMC investigations include the measurement of GSM base stations, radiation from PCB and chip geometries as well as radiation from and coupling through apertures on enclosures and shields, together with crosswalk and signal-integrity issues.

Another key area of research is spectrum management and propagation simulation for broadcasting, wireless and personal mobile communications, and other services. The spectrum management activities in the department were started in 1994 by the development of radio and TV frequency plans for Turkey. At present, the research is mainly focused on wireless service bands. Finally, integrated circuits, the simulation of very large circuits, and micromachined sensors and actuators are other research activities.

Key Areas of Research

In the field of mass wireless and mobile communications, the blossoming of new technologies and services necessitate the efficient, productive and versatile utilization of frequency spectrum. Today's high speed computers facilitate reliable and fast simulation of propagation phenomena and consequently the National Frequency Management System has been developed for the Turkish Government. It is composed of a database management and spectrum engineering system, which includes propagation simulation, link analysis, coordination and database integration, and other ancillary analyses.

[Continued on page 48]





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For conformal antennas and arrays, the development of efficient and accurate analysis tools based on high frequency techniques are under study. In one part of this research, an analysis method based on a hybrid MoM/Green's function technique in the space domain has been developed in order to analyze microstrip structures (various antennas and arrays as well as feeding structures, etc.) on electrically large, material coated cylinders.

Another area being considered is the RCS computations of targets, where fast electromagnetic solution algorithms are being developed. Real targets are large and have complicated shapes; therefore, curved surface modeling and meshing methods are utilized for FEM analysis. Also, fast electromagnetic solution algorithms, using MoM, FEM, single and multilevel FMM techniques, are being developed to solve these electrically large problems.

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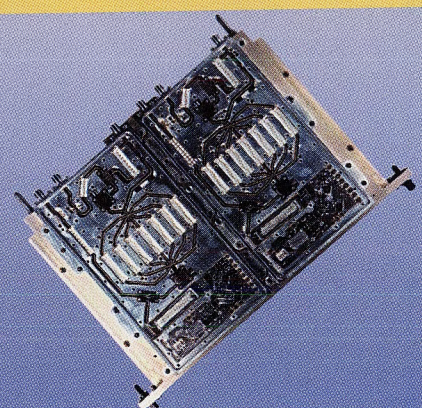

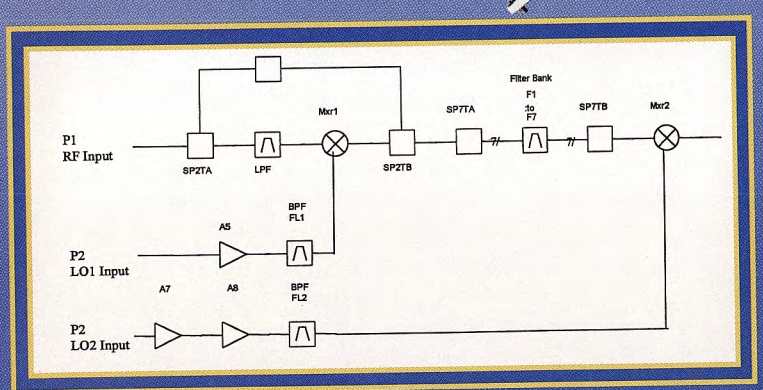

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Project Focus

One of the projects is the development of design and analysis tools for conformal microstrip arrays and antennas. Although many practical applications have stringent aerodynamic constraints that require the antennas conform to the host body, the majority of the research on microstrip antennas focuses on planar structures. Therefore, efficient and accurate tools are required.

Using a hybrid MoM/Green's function technique in the space domain, different microstrip geometries on electrically large dielectric coated bodies have been investigated. This method is very efficient for electrically large arrays on material coated (large) bodies but its accuracy and efficiency depends on the high frequency asymptotic-based representations of the appropriate Green's function for dielectric coated cylinders. Two different Green's function representations that complement each other have been developed and used interchangeably, based on where they are valid and efficient for arbitrary source and field points.

An aim of this study is to develop a CAD tool to investigate large printed phased arrays on coated cylinders, with some of the future goals being to extend this method to multilayer cylindrical structures and develop a design and analysis tool that can treat arrays and antennas on arbitrarily convex coated bodies.

Future Projects

Projects under consideration include the development of fast and accurate design and analysis simulation tools for coupling, radiation and scattering of arbitrary and electrically large geometries using different techniques and combining different methods. Other possible fields of study are the design of novel antenna structures for broadband applications and the development of simulation tools for broadcasting, wireless and personal mobile communications.

Key Contacts

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[Continued on page 55]



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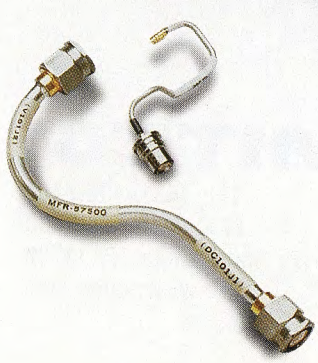

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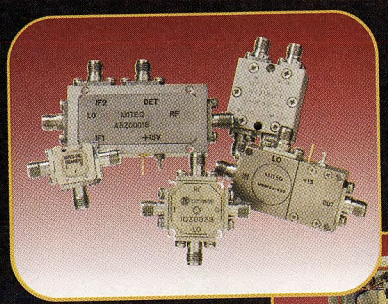
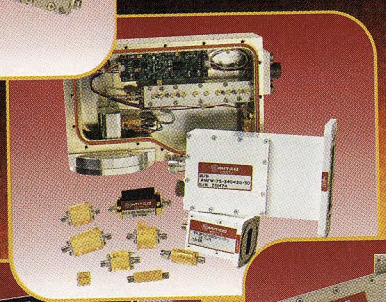
FROM COMPONENTS TO SYSTEMS



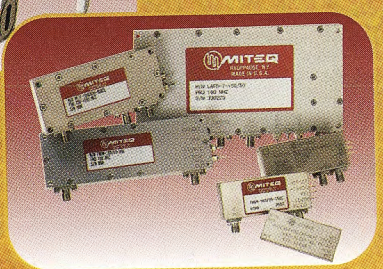
MIXERS TO 60 GHz

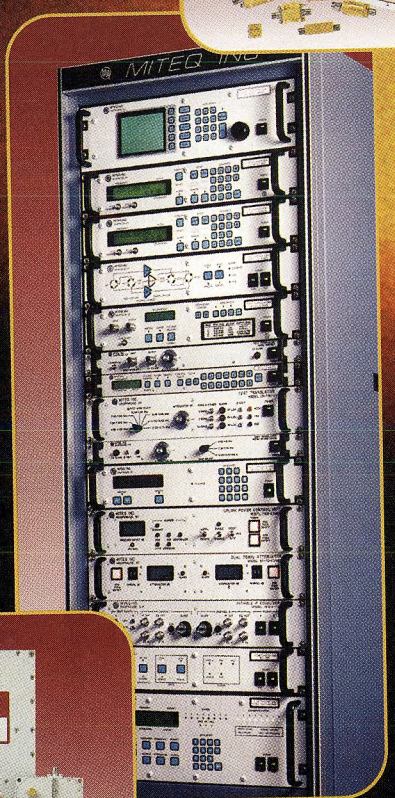
- Single-, double-, and triple-balanced
- Image rejection and I/Q
- Single-sideband, BPSK and QPSK modulators
- High dynamic range
- Active and passive frequency multipliers



AMPLIFIERS TO 60 GHz

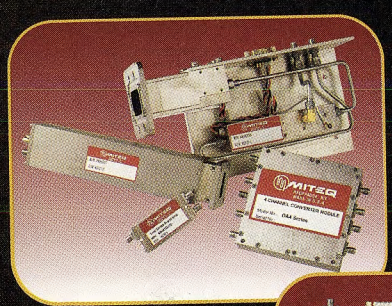
- Octave to ultra-broadband
- Noise figures from 0.35 dB
- Power to 10 watts
- Temperature compensated
- Cryogenic





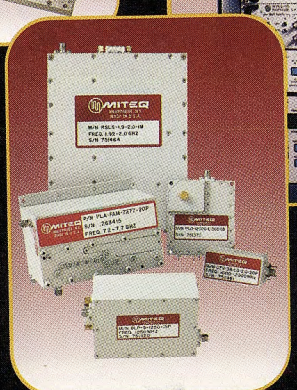
INTEGRATED SUBASSEMBLIES TO 60 GHz

- Integrated up/downconverters
- Monopulse receiver front ends
- PIN diode switches
- Ultra-miniature switch matrices
- Missile receiver front ends
- Switched amplifier/filter assemblies



IF AND VIDEO SIGNAL PROCESSING

- Logarithmic amplifiers
- Constant phase-limiting amplifiers
- Frequency discriminators
- AGC/VGC amplifiers
- I/Q processors
- Digital DLVAs



FREQUENCY SOURCES TO 40 GHz

- Free-running VCOs/DROs
- Phase-locked cavity oscillators
- Phase-locked coaxial resonators
- Synthesizers for SATCOM
- Fast-tuning communication synthesizers

SATCOM EARTH STATION EQUIPMENT TO Ka-BAND

- Synthesized up/downconverters
- Test translators
- LNA systems
- 1:N redundancy units
- INMARSAT products
- FM modems

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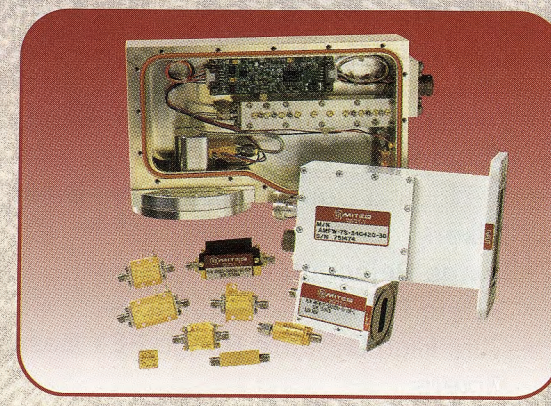
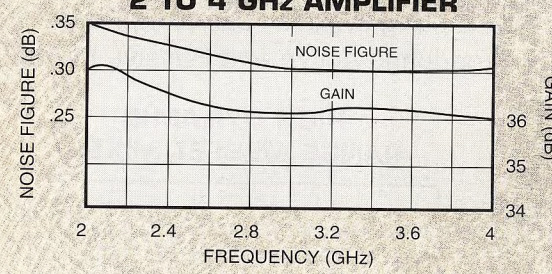
GaAs FET AMPLIFIERS TO 60 GHz

- **Low Noise, Medium Power** and **High Power** Designs
- **Moderate** to **Ultra-Wideband** Designs
- **Coaxial, Waveguide, Surface Mount** and **Microstrip**
- **Cryogenically Cooled** LNAs
- **SATCOM** LNAs
- **High Data Rate (Fiber Optic)** LNAs
- **Amplifier Subsystems**

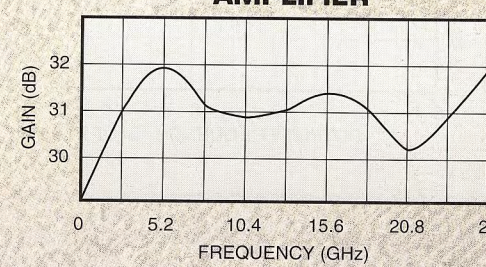


NOISE FIGURE PERFORMANCE BASELINE	
2 to 4 GHz	**0.35 dB** noise figure
2 to 8 GHz	**0.8 dB** noise figure
6 to 18 GHz	**1.3 dB** noise figure
26 to 40 GHz	**2.5 dB** noise figure
C-band SATCOM LNA	**30 K** noise temperature
Ku-band SATCOM LNA	**65 K** noise temperature
2 to 4 GHz at 77 K ambient	**10 K** noise temperature
6 to 18 GHz at 77 K ambient	**50 K** noise temperature

ULTRA-LOW NOISE 2 TO 4 GHz AMPLIFIER



100 MHz TO 26 GHz AMPLIFIER



Bandwidth Performance Baseline

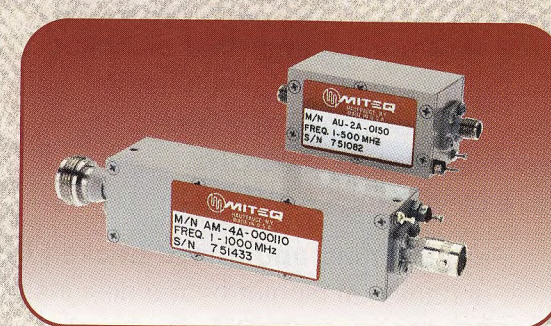
2 kHz to 15 GHz for high data rate applications
2 to 40 GHz in one unit (broadband ELINT)

Output Power Performance Baseline

2 to 8 GHz	**2 watts** (at 1 dB compression)
6 to 18 GHz	**1 watt** (at 1 dB compression)
14 to 14.5 GHz (Ku-band)	**5 watts** (at 1 dB compression)

BIPOLAR AMPLIFIERS

- Frequency Range 10 kHz to 2 GHz
- Broadband **Low-Noise Amplifiers**
- Available from **Stock**



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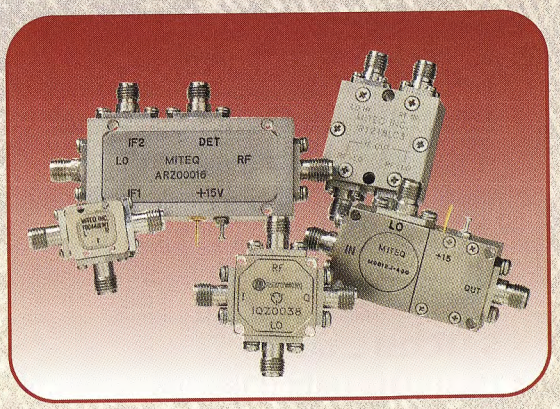
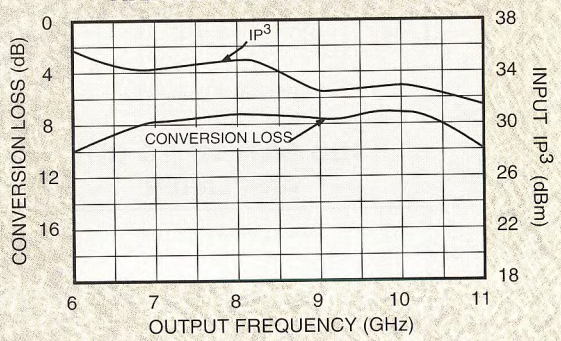
MIXERS AND FREQUENCY MULTIPLIERS TO 60 GHz

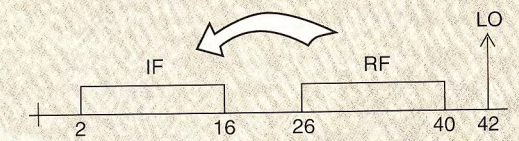


- Low Loss, Moderate to Octave Band **Balanced Mixers**
- Broadband **Double- and Triple-Balanced Mixers**
- **Image Rejection Mixers**
- **Single Sideband Modulators**
- Ultra High Dynamic Range **FET Based Mixers**
- Microwave **Phase Detectors and I/Q Mixers**
- Microwave **QAM, QPSK and Biphase Modulators**
- **Sampling Mixers** (Sampling Phase Detectors)
- Broadband Active and Passive **Multipliers**

HIGH DYNAMIC RANGE MESFET MIXER

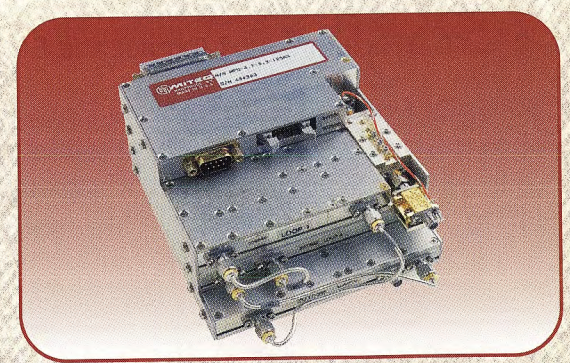


MILLIMETER-WAVE BLOCK CONVERSION



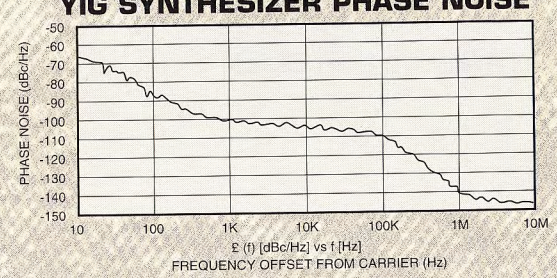
BLOCK CONVERSION MIXER TB0440LW1	
RF and LO	4 to 44 GHz
IF	0.5 to 20 GHz
Conversion loss	10.5 dB

FREQUENCY SOURCES TO 40 GHz



- **Frequency Synthesizers**
  Phase-locked loop communication band synthesizers
  Single-loop fast acquisition synthesizers
  Octave band YIG-based synthesizers
- **Free-Running and Phase-Locked VCOs**
  Cavity and coaxial resonator designs
  Fundamental to 4 GHz
  Multiplied to 40 GHz
  Octave band L-C VCOs
- **Free-Running and Phase-Locked DROs**
  Fundamental bipolar-based designs to 12 GHz
  FET designs to 25 GHz

4 TO 8 GHz YIG SYNTHESIZER PHASE NOISE



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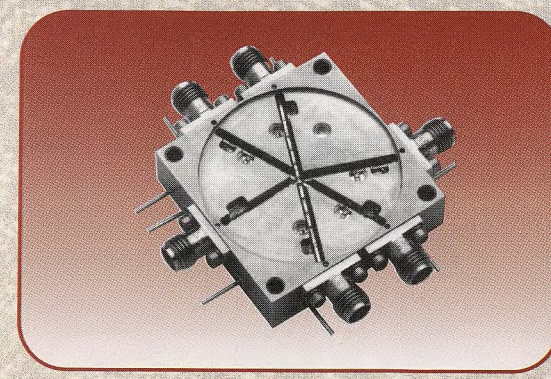
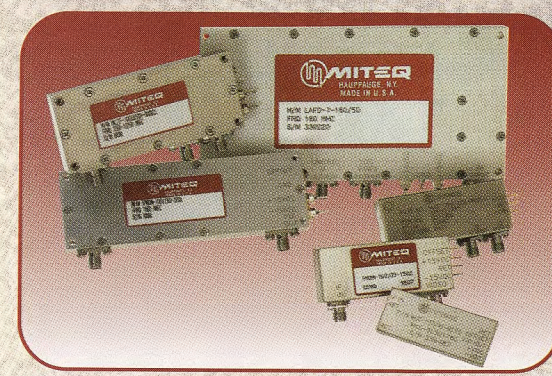
MICROWAVE CONTROL PRODUCTS TO 26 GHz

- **Pin Diode Switches,** Reflective and Nonreflective, SPST through SP7T with up to 80 dB Isolation
- **Pin Diode Attenuators,** Current Controlled 10% Bands
- **Power Dividers,** 2-Way to 16-Way Power Dividers to 26 GHz

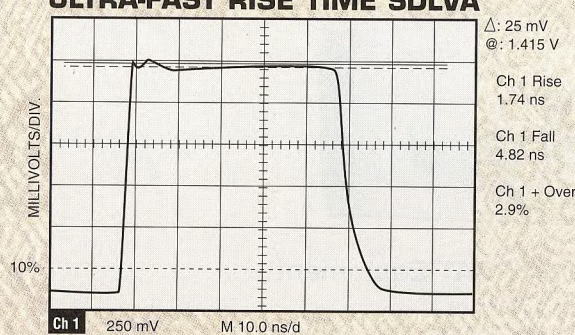


IF SIGNAL PROCESSING COMPONENTS

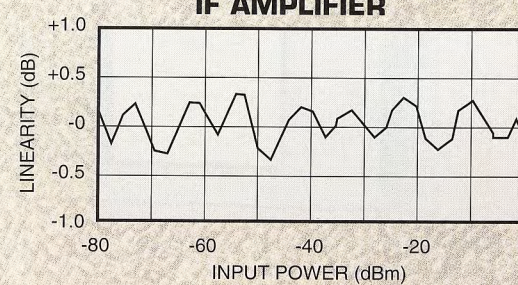
- **Logarithmic Amplifiers** to 2 GHz
- **SDLVA** and **DDLVA** High Speed Logarithmic Amplifiers to 6 GHz
- **Constant Phase Limiting IF Amplifiers** to 1200 MHz
- **Frequency Discriminators** to 2 GHz
- **Variable** and **Automatic Gain-Controlled Amplifiers**
- **AFC Processors**



ULTRA-FAST RISE TIME SDLVA



ENHANCED LINEARITY LOG IF AMPLIFIER



INTEGRATED ASSEMBLIES AND CUSTOM-ENGINEERED EQUIPMENT

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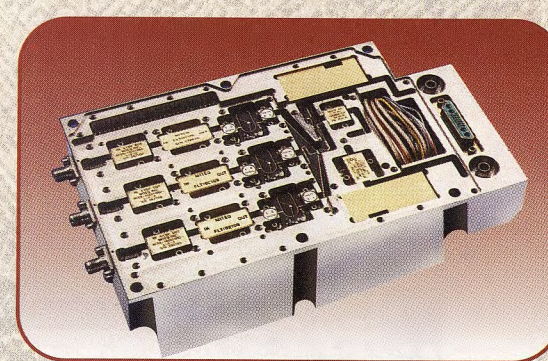

- Remote Exciter Modules
- Monopulse Receivers
- SAR Exciter/Receiver Systems
- Research and Development Subsystems
- Space-Borne Components
- Three-Channel Monopulse Receiver Front Ends
- Five-Channel Phase Interferometer Receiver Systems

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Converters

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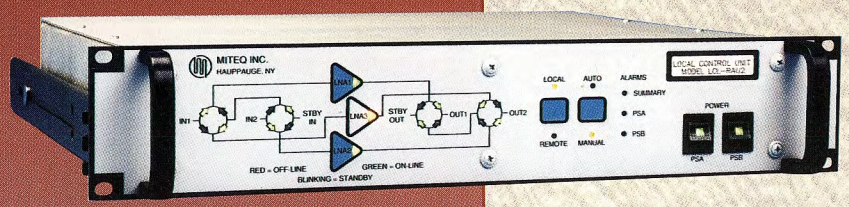
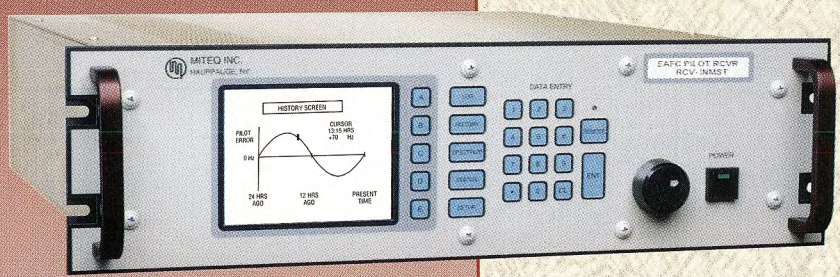
  Multiband (combined C-, X- and Ku-band)



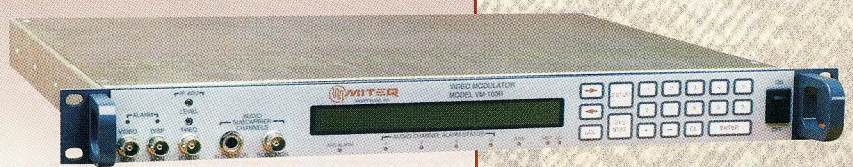
LNA Plate
Assembly and
Control Unit

- **1:1 and 1:N Redundant Switchover Units**
- **Low-Noise Amplifiers and Redundant Amplifier Systems**
- **Variable Group Delay and Amplitude Slope Equalizers,** 70 and 140 MHz
- **Test Translators**



INMARSAT
EAFC Receiver

- **INMARSAT Equipment**
  Converters
  EAFC pilot receiver
  Translators
  Pilot generators
- **Uplink Power Control Systems**
- **Custom-Designed Subsystems to Customer Specification**



VM100R
Video Modulator

- **Video Modulators and Demodulators**
- **Video/Audio/IF Redundancy Switching Systems**
  1:1, 1:4 (up to four) and 1:N (up to eight)

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THE NETHERLANDS

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Department

The International Research Center for Telecommunications-transmission and Radar (IRCTR) is allied to the Faculty of Information Technology and Systems (ITS). The director of the center is Professor L.P. Ligthart.

Research Activities

The IRCTR has been established to execute project driven research in several areas: antennas and propagation, radar and radar systems, remote sensing, wireless communications and mobile networks, and electronic systems for positioning and navigation. At the core of the center's work is internationalization, which manifests itself in scientific cooperation with recognized national and international research organizations and industries. To foster close relations with these partners an Industrial Advisory Board was established, tasked with guiding the direction of the research carried out. The general approach is to combine fundamental research with practical applications. For that reason the IRCTR research concept includes the realization of demonstrator systems, proving the value of research results.

Key Areas of Research

Consider the five areas of research outlined above starting with antennas and propagation. Here, the research focuses on the design, development and realization of smart, adaptive, reflector/array antenna systems and wideband wave propagation models. In the coming decade higher frequencies will be used for different radio and radar applications. For these millimeter-wave activities, IRCTR has outstanding indoor and outdoor measurement facilities, including an anechoic room and network and vector analyzers up to 110 GHz.

The research on radar and radar systems converges towards radar design techniques with emphasis on wideband radar and multi-parameter/Doppler-polarimetric radar, radar networks, radar navigation, integrated radar communication and security systems. The research program of the remote sensing sector focuses on radar earth observation and on multi-sensor remote sensing of the atmosphere. The main motivation for this research is an increased general interest in and acknowledgement of the importance of the earth as a system.

Research on wireless communications addresses key issues in technologies, protocols and architectures for future systems, and networks supporting ubiquitous communications. The increase in wireless transmission capacity, number of mobile end systems, dynamicity in traffic profiles and heterogeneous networks necessitates fundamental studies validated with demonstrators, emulators and test beds.

Finally, for electronic systems for positioning and navigation, studies focus on the improvement of the performance parameters, accuracy, integrity, availability and continuity of service. There is a strong emphasis on partici-

[Continued on page 57]



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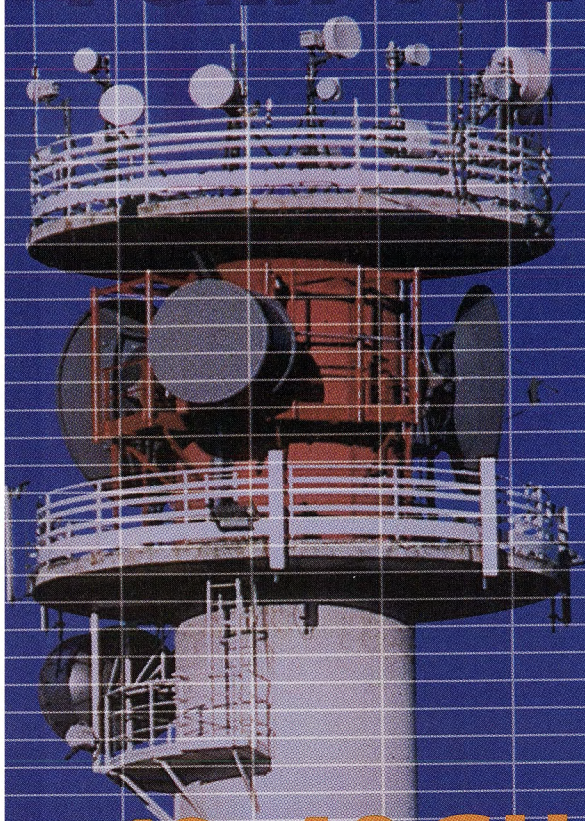

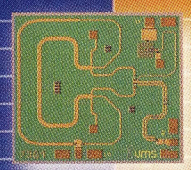

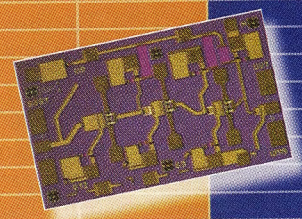

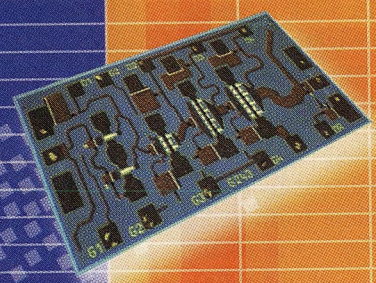

10-40GHz

Low Noise Amplifiers

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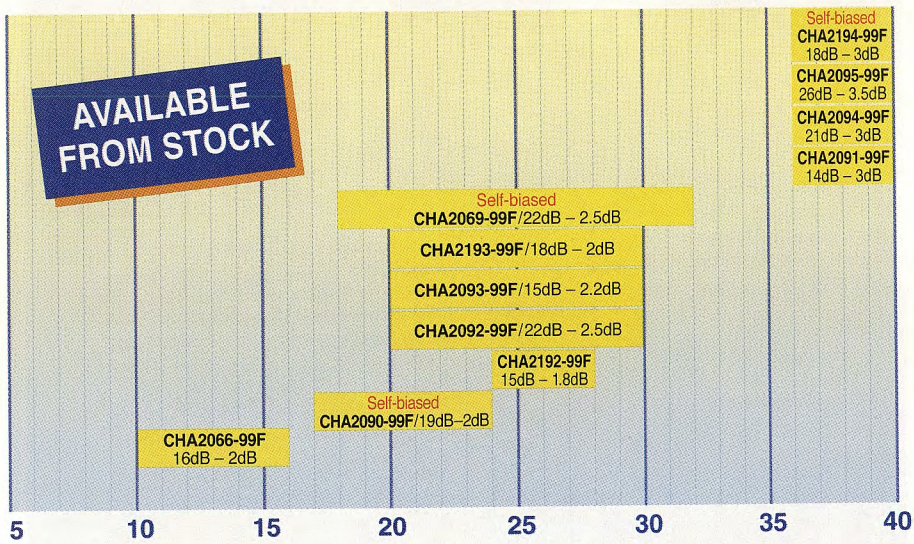

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MISTRAL GAGNANT - 01 41 19 45 46

pation in interdisciplinary and international programs on integration of communications, positioning and navigation. Instrumentation issues play an essential role.

Project Focus

Using its extensive experience on near field antenna measurements and its expertise in time domain measurements, the IRCTR carries out a full-scale research program on the development of a new generation of ground penetrating radar (GPR) systems. It includes the development of concepts for video impulse GPR and a stepped frequency continuous wave radar (SFCW radar), the development of improved GPR-antennas (including adaptive antennas), the development of a multi-sensor platform for precision high resolution subsurface imaging and the development of new methods of subsurface imaging based on interferometry and polarimetry.

The overall aim is to investigate new improved GPR technology, which will allow the creation of new GPR systems with challenging specifications. One of the promising application areas for GPR is humanitarian de-mining. Worldwide, enormous amounts of landmines are hidden in the ground. In TU Delft a multi-disciplinary research consortium has been set up to investigate solutions for this problem. In the context of a project funded by the Dutch National Technology Foundation (STW), a demonstrator for a humanitarian de-mining system making use of advanced GPR will be realized.

A second example is the IRCTR research on multi-static radar for automotive applications. During the past few years an X-band demonstrator containing five static antennas has been realized. Currently the project focuses on field experiments with real vehicles. In parallel with these experiments, new technology for higher frequencies is being investigated. Together with the universities of Achen and Birmingham research is being done on 35 and 70 GHz technologies for these applications.

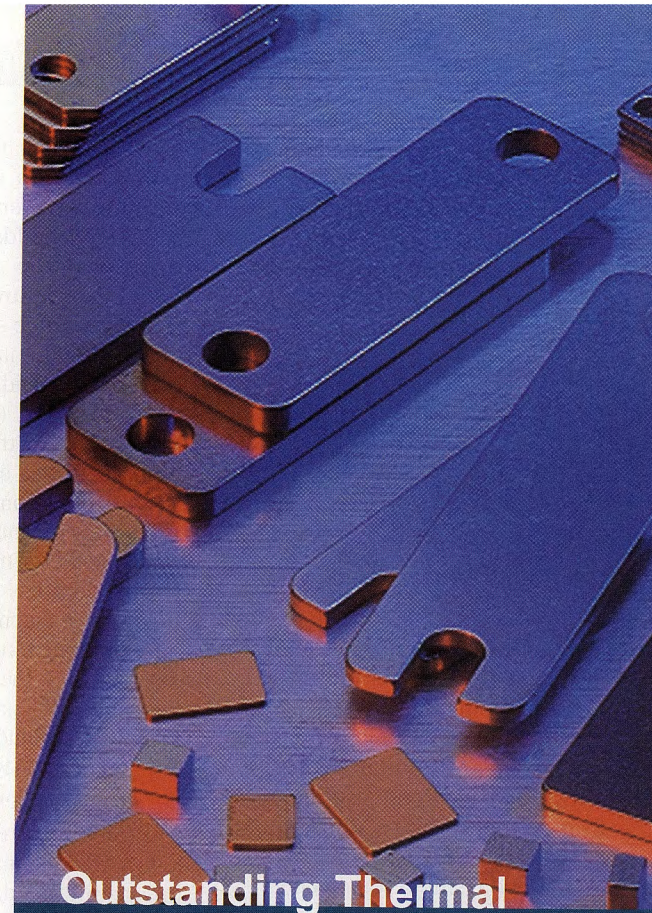
Also, the Delft Program for Hybridized Instrumentation and Navigation Systems (DELPHINS) focuses on improving the pilot vehicle interface for navigation and guidance in order to increase safety in future air traffic environments. In the context of the project a compact display electronics unit for in-flight use is developed and integrated with the MIAS positioning system. The first flight tests were successfully performed resulting in the world's first demonstration of a GPS-based Tunnel-in-the-Sky Electronic Flight Instrument System (EFIS) display. At present, DELPHINS technology is being applied in the context of the NASA Aviation Safety Program, the Boeing 737-900 Technology demonstrator and the King-Air laboratory aircraft of Ohio University.

Future Projects

The center is well known for building the Doppler-polarimetric research radars DARR and TARA. One of the challenging activities for the coming years will be operationalization of CESAR, the Cabauw Experimental Site for Atmospheric Remote Sensing. In the context of this multi-disciplinary initiative an ambitious test site for atmospheric research will be realized at the premises of the Dutch National Meteorological Institute (KNMI) at Cabauw (near to Lopik, the Netherlands). The Transportable Radar System (TARA) will play a central role in this research initiative.

In the area of wireless communications a number of projects are carried out with leading industries and providers. Current research focuses on transmission schemes like OFDM,

[Continued on page 58]



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WCDMA and transmission techniques like space-time coding (including research on smart antennas). The realization of a third generation tested is proposed. In the near future projects on personal area networks will be started.

Key Contacts

Professor L.P. Ligthart, director of IRCTR or A.C. de Ridder, controller of the IRCTR. Tel: (+31) 15 278 1034, fax: (+31) 15 278 4046; Web site: www.irctr.tudelft.nl.

UNITED KINGDOM

Loughborough University

Department

The Wireless Communications Research Group (WCRG) in the Department of Electronic and Electrical Engineering conducts the microwave-engineering research under Professor Vardaxoglou. This group also includes the Center for Mobile Communications Research (CMCR), which is the department's flagship research center.

Research Activities

Focused on antenna and wireless systems, the research interests include applications in mobile and satellite communication systems, microwave and mm-wave engineering. Much of the activity builds on a foundation of expertise in the area of resonant and periodic structures, exploited as frequency selective surfaces (FSS), in addition to metamaterials such as electromagnetic band gap (EBG) and double negative (DNG) structures. Responding to the needs of industry, the CMCR was established in 1998 to exploit this strong research caliber in the design of antennas and associated components for mobile applications.

The work has focused on the miniaturization of antennas, with emphasis on preserving their in-use efficiency through isolation from the application, low user-proximity influences on the products and a significant reduction to the specific absorption rate (SAR) in the user.

Key Areas of Research

Projects currently running include low SAR antenna research and design for mobile handsets, 3G communications antennas, optically activated microwave circuits and antennas, frequency selective surfaces, metamaterials, electromagnetic and photonic band gap structures, arrays and FSS for mm-wave applications, local multipoint distribution system (LMDS) flat plate antennas, multichip interconnects and RF systems.

Project Focus

As technologies are integrated to multi-function applications, antennas have to perform a wide range of tasks to meet the pan-world demand on personal telephony and mobility. Against this background the CMCR has forged considerable expertise in the analysis and design of such systems. Using a (32x) computer cluster, the department has the capability of undertaking simulations with the degree of sophistication that is required to meet the stringent design demands. The design prototypes are produced using the latest in photolithographic imaging, etching, laser and microwave measuring technologies. This includes the full 3D pattern characterization and efficiency assessment of handsets.

Owing to health precautions, the SAR safety requirements are now widespread and mobile phone handsets will have to produce lower exposure levels. Developing expertise gathered from the Global Positioning System antenna product, prototype antennas for cellular telephones have been created to reduce emissions into the body by as much as 85 percent.

The breakthrough occurred using a combination of the benefits of the PC cluster and innovative laser technologies used in the manufacturing processes. This puts the university in an excellent position to be the leaders as low SAR solution providers in the UK for the telecom industry.

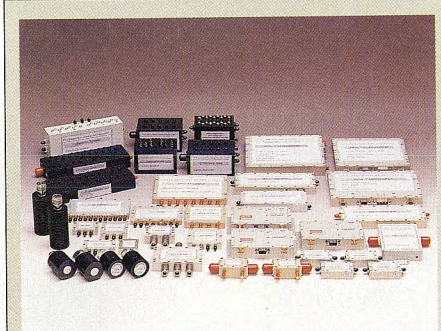
Similar patented technology products are now being designed specifically for Bluetooth, Personal Communications Network (PCN) and Universal Mobile Telecommunications System (UMTS). These antennas reduce the need for filters (thus lowering component costs) and for a large ground plane (low handset interaction). They can be embedded into the handset using a balun to isolate electrical noise, which increases the reliability and signal strength of short-range devices, such as Bluetooth.

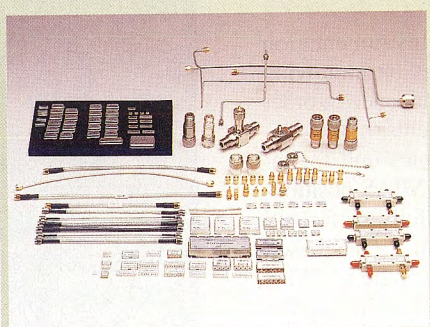
Collaborators

The work by the WCRG has been funded by the UK Engineering and Physical Sciences Research Council

[Continued on page 60]

Microwave Components & Systems





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(EPSRC), in addition to companies such as Sarantel, GEC, British Aerospace, Orange and regional small to medium enterprises (SMEs). The group also has major collaborative programs with the Queen's University of Belfast, Northern Ireland, the Politechnico di Torino, Italy, and the University of Patras, Greece.

Key Contact

Professor Vardaxoglou, Wireless Communications Research Group, Department of Electronic and Electrical Engineering, Loughborough University, Loughborough, Leicestershire, LE11 3TU, United Kingdom. E-mail: J.C.Vardaxoglou@lboro.ac.uk; Web site: www.lboro.ac.uk/departments/el/ (publications list).

Queen's University of Belfast

Department

The High Frequency Electronics Research Group is headed by Professor Vincent Fusco and its activities include RF, microwave, millimeter-wave packaging, nonlinear circuits, and active and passive antenna technologies, as well as low loss THz filters.

Research Activities

The physical resources available to the group are of the highest industrial standard. Facilities include soft/hard-board production and thermally controlled small/large signal V-band monolithic microwave integrated circuit (MMIC) probing. Anechoic chamber facilities are also available, and the group also has a full suite of Agilent's ADS linear and nonlinear design software together with Ansoft's HFSS, Microstrips, Sonnet and Momentum electromagnetic simulators. The group has its own networked CAD facility comprising 20 UNIX and PC workstations. There is access to a fully equipped machine shop with two CNC lathes for production of mechanical enclosures and two wire bonding machines for use with microwave devices, with a research engineer and a research technician providing technical support.

Commercial Support

Belfast is a major UK center for the design and application of MMICs as well as active and passive antennas. Consequently, the group has expertise and technical skills that are focused on the creation of novel front-end solutions with added functionality and reduced complexity for a variety of applications. Research programs are designed to produce synthesis and analysis tools, and experimental demonstrators for these novel wireless front-ends. These circuits are elements for insertion in low cost products for commercial and consumer applications such as WLAN and low cost phased array radars. Work programs combine advanced nonlinear device and EM circuit simulation, analytical methods and experimental practice, in order to realize MMIC, MIC and antenna circuitry.

Current projects are sponsored by the Engineering and Physical Sciences Research Council (ESPRC), the EU, via the N. Ireland Industrial Research and Technology Unit (IRTU), and by industry. The QUB group has a number of well-established links with UK and international industry including OMMIC, AVX-Kyocera, M/A-COM and TDK, which has an industrial implant on site at the QUB HF laboratories.

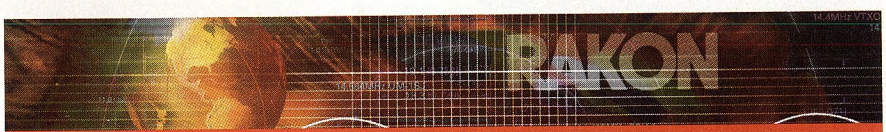
Key Areas of Research

Examples of typical projects include smart structures for mm-wave front-ends and integrated self-tracking antennas. In the former project, the group created the first reported complete self-tracking, mm-wave, 60 GHz dual-channel transceiver, based on nonlinear analogue phase synthesis techniques. Advanced fabrication technologies were also examined for low cost mixed technology MMIC multi-chip carrier realization. The second project investigated the theoretical and practical basis for the realization of all silicon antennas and integrated homodyne receivers operating at 60 GHz.

Also, research on active and passive antennas for portable radio systems has shown the advantages as well as the limitations of electromagnetic simulators. Consequently, new EM theory applicable to these structures and measurement techniques are being investigated. This work has yielded a number of novel structures for mobile and base station antennas, some of which have been patented.

In the area of microwave and millimeter-wave mixer design new techniques have been developed for the creation of phase conjugate mixers for use in self-tracking antenna applica-

[Continued on page 63]



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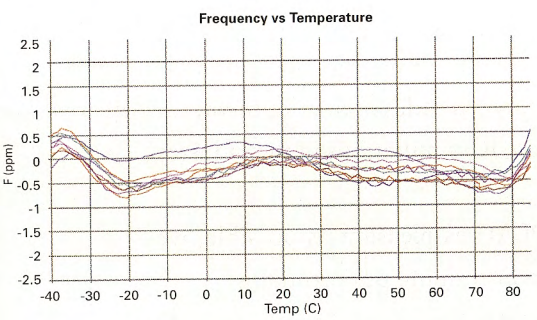

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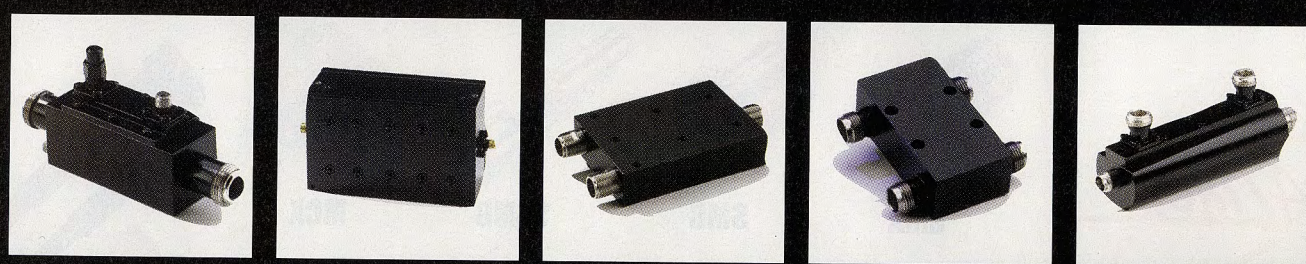

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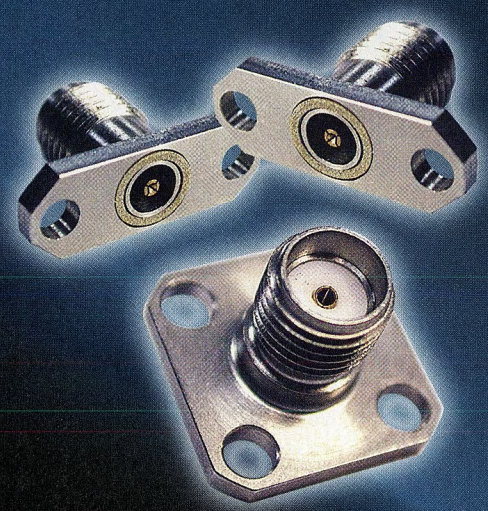

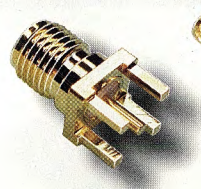

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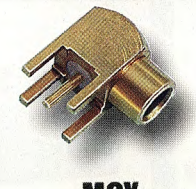

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tions. This, together with the department's work on micro-machining and integrated antenna realization, has lead to all silicon self-steered receivers and ultra low loss silicon interconnects for use at millimeter-wave frequencies.

Recently the QUB High Frequency Research Group has been leading work on the creation of ultra low loss frequency selective surfaces using advanced micro-machining techniques for space borne applications. This work is being carried out in collaboration with Astrium, Rutherford Appleton Laboratories, the N. Ireland Semiconductor Research Center and Loughbrough University. Work on advanced electronic packaging techniques including electromagnetic/thermal modeling of flip chip MMIC devices is also being carried out.

Project Focus

Other ongoing work represents a major extension to the concepts currently used in the development of low cost beam steered reflect arrays, since it includes the possibility of pattern control and direct signal modulation, using a totally integrated silicon solution that is compatible with standard processing technology. Beam formation and other control functions are executed under DC control of diode properties, and no additional RF components such as conventional phase shifters are required. Consequently, a broad variety of applications become available, such as self-steered sensors, electronically controlled beam-steered antenna for broadband mobile communications applications for imaging sensor, active RCS control, and direct DC to microwave signal phase encoding.

The key techniques being developed here are spatial phase shifters that exhibit low reflection loss. To concurrently achieve this and polarization agility the group is developing a new class of low series resistance silicon diodes based on a novel silicon-on-insulator (SOI) technology. Waveguide simulation techniques are being extensively deployed to investigate infinite array behavior. Finite array behavior, as well as electromagnetic codes, is also being developed so that demonstrator behavior can be accurately assessed.

Key Contact

Professor Vincent Fusco, High Frequency Research Laboratories, Queen's University of Belfast, Ashby Building, Stranmillis Rd, Belfast BT9 5AH, Northern Ireland: Tel: +44 28 9034 2076; fax: +44 20 9066 7023; e-mail: v.fusco@ee.qub.ac.uk; Web site: www.qub.ac.uk/hfeg.

Commercial/Independent Research

One area that has witnessed a lot of change is the commercial and independent research field, with the slump in the telecom market having significant impact. Commercial reality has also hit home with the move towards less Government funding putting the pressure on to get industrial backing and support. Against this background, commercial confidentiality and competitive sensitivity often limit what companies are willing to divulge. Therefore, *Microwave Journal* is grateful to those who have contributed.

[Continued on page 64]

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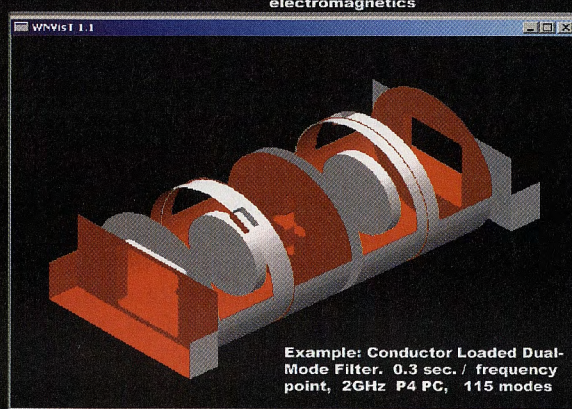

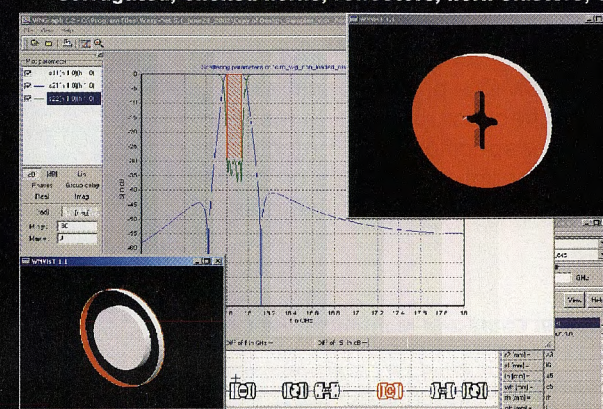

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National Physical Laboratory

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RF and Microwave Research Team, NPL, Teddington, UK.

Research Activities

The research carried out by the team is undertaken to push existing microwave technology to its limits to develop the most accurate measurements and instrumentation. This research underpins electrical measurements carried out within UK industry and the National Measurement System Policy Unit (NMSPU) of the Department of Trade and Industry (DTI), which funds the work to ensure that UK industry can have confidence in the measurements it performs on an international scale.

Studies focus on microwave measurement standards in transmission media such as hollow waveguides, coaxial lines, dielectric waveguides and planar lines in high frequency integrated circuits. The four main measurement parameters — power, attenuation, impedance and noise — are highly interdependent, and progress in the development of measurement standards in this field requires a predominantly integrated approach. The main application areas for guided wave standards are those served by the following industries: telecommunications, aerospace, defense, radar, EMC, and health and safety.

As NPL develops new solutions to overcome the challenges of realizing the most accurate measurement standards, it forges new techniques and technology that can be applied to the development of new microwave measurement and test instrumentation for all these industrial sectors. Technical advances in these areas are dependant on new applications of technology and the "stretching" of existing technologies to develop new capabilities. Significant impetus behind the need for new technologies is the drive to increase the functionality, complexity and speed of electronic circuits. This requires electrical quantities to be measured at higher frequencies and with greater accuracy than ever before.

Key Areas of Research

NPL is focusing on developing innovative approaches to the realization of national standards for microwave measurements in power, attenuation, impedance and noise. Much of this research is focused on developing new measurement capabilities in response to industrial requirements. For example, it is extending its existing traceable power measurement capabilities to allow the measurement of peak power for wireless communications. It is also investigating new mechanisms for disseminating accurate traceable measurements across the country by providing remote calibrations via the Internet.

The National Physical Laboratory also has a comprehensive EMC and dielectric materials measurement research capability. Research is carried out on a range of EMC measurement techniques. In particular, investigations of more cost-effective measurement methods using fully anechoic rooms, GTEM and EUROTEM cells, and reverberation chambers are being carried out to refine these methods and ensure that they are technically viable.

[Continued on page 66]

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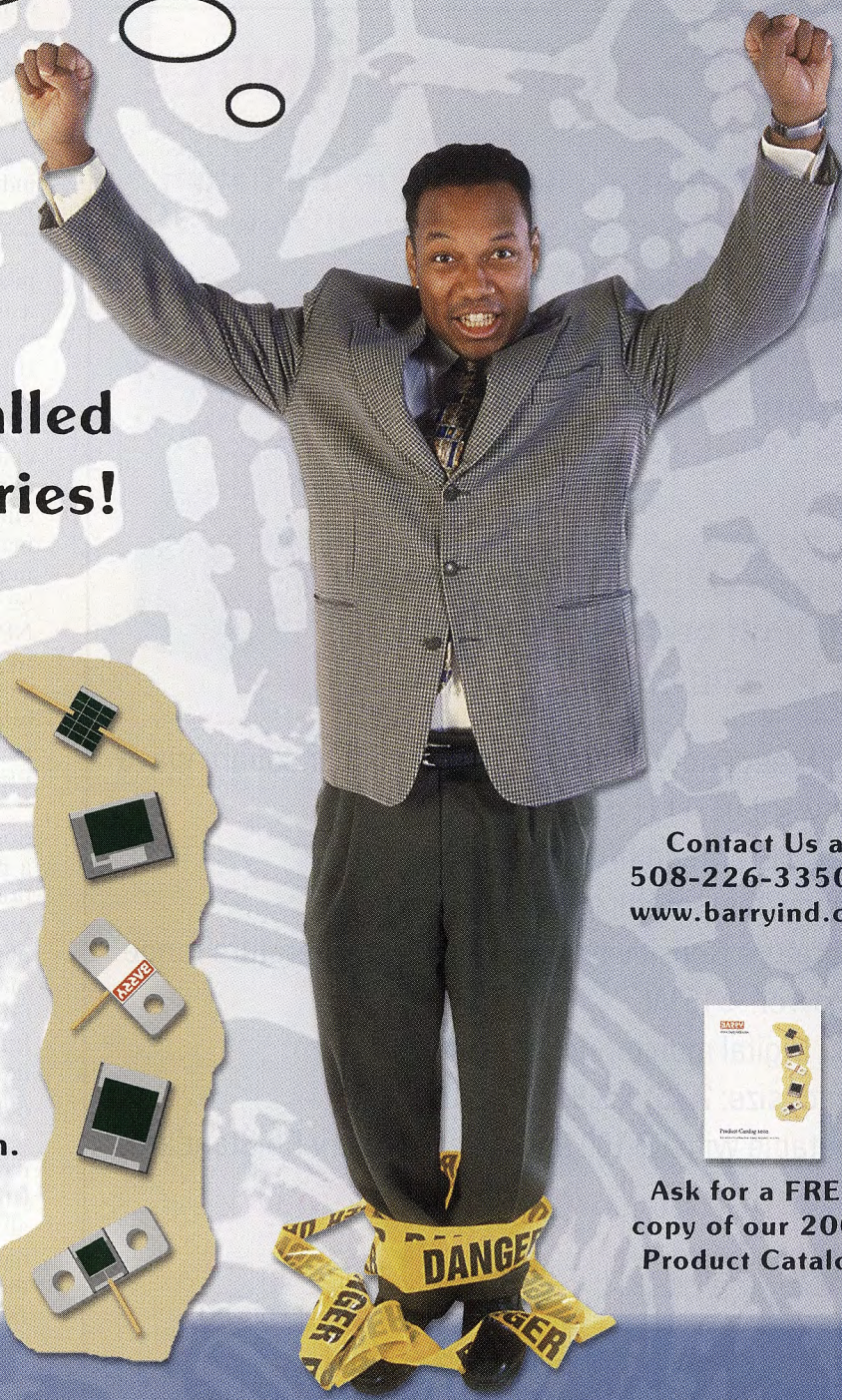

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In the field of dielectric materials measurement, NPL carries out research to evaluate new, more cost-effective measurement techniques. Currently, research is underway to evaluate techniques for measuring properties of thin films from RF to millimeter-wave frequencies, to study the metrology of structured, active and "smart" composite materials, and to improve the accuracy of dielectric resonator measurements for higher permittivity, lower loss materials.

There are two directions being followed for the development of microwave measurement capabilities: improvements and extensions to existing standards to support the more demanding use of existing technologies and frequencies, particularly for mobile communications; and the development of standards up to and beyond 100 GHz. In addition, as many users are seeking calibration over a continuous range of frequencies rather than at "spot" frequencies, that capability is also being developed. Techniques are also being developed for making measurements of passive intermodulation (PIM) products.

With some guided wave standards being barely in advance of industrial requirements, there is a need to re-examine the technical basis upon which current standards are realized with the objective of identifying technologies and techniques, which could result in step improvements in the primary standards. NPL is also working with a range of instrumentation manufacturers to integrate the developments in measurement technology into new products and systems. The transfer of technology from the Government research at NPL to UK and worldwide industry is a high priority.

Project Focus

A particular project investigated the measurement of overhead power lines using a new non-contact electro-optic sensor. The research required the modification of an existing sensor, in which NPL was in the development, for a new sensor application and the characterization of its performance in experimental trials. The voltage and current signature recorded in trials matched that expected by the customer indicating that this new sensor could be applied to this new application. NPL is currently performing a project to investigate the provision of measurement standards to support the mobile and satellite communications markets, specifically for measurements of PIM and antenna noise.

Part of the Mobile Telecommunications and Health Research Program is a project to provide traceable calibrations to microwave parameters in support of dosimetry studies into the physiological effects of electric and magnetic fields emitted by commercial GSM mobile phones and Terrestrial Enhanced Trunked Radio (TETRA) devices.

Future Projects

Projects are proposed to investigate the existing standards base on the existing RF and microwave standards of all principal quantities of power, attenuation, impedance and noise, review the status and limitations of these artifacts and/or systems, and propose new or novel means by which a future generation of standards with lower uncertainties might be achieved.

[Continued on page 68]

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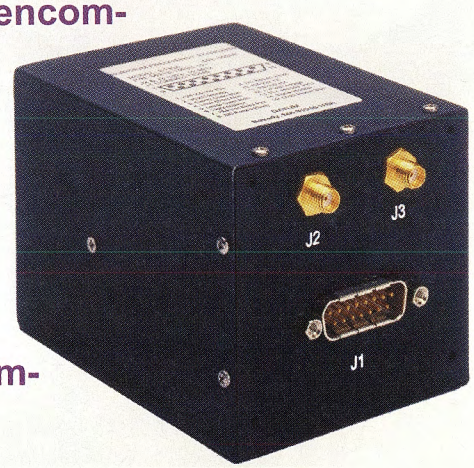

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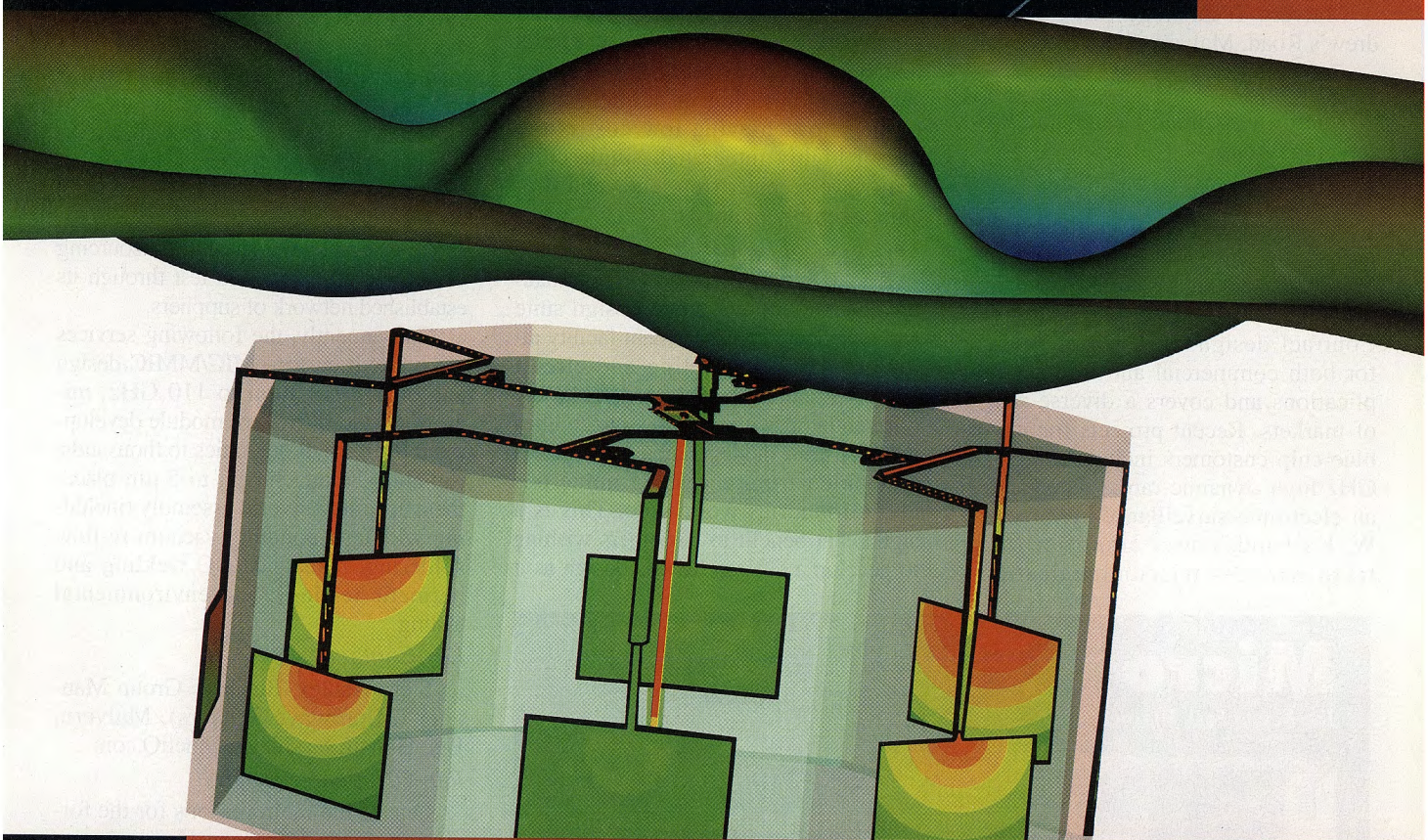

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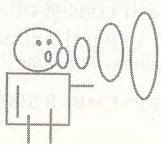

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RESEARCH ESTABLISHMENT

QinetiQ

Malvern Technology Park, St. Andrew's Road, Malvern, UK.

Department

Microwave Circuit Design and Prototyping Group.

Research Activities

The group has considerable experience in the design of hybrid MIC and MMIC-based sub-systems covering the 1 to 100 GHz frequency range. Contract design work is undertaken for both commercial and military applications and covers a diverse range of markets. Recent projects for major blue-chip customers include a 2 to 18 GHz high dynamic range receiver for an electronic surveillance system, a 1 W, Ka-band, power amplifier for a fixed wireless telecommunications link and a 94 GHz receiver, using indium phosphide MMIC technology, for a cloud profiling radar.

The Microwave Circuit Design and Prototyping group is actively involved in developing state-of-the-art MMIC components and low cost assembly techniques for realizing ultra broadband mm-wave receivers. These subsystems are used in QinetiQ's patented mm-wave security scanner systems that are supposedly set to revolutionize security monitoring in public places. Critical to achieving low cost is the use of highly integrated, single chip, mm-wave receiver front-ends and flip-chip assembly methods.

Key Areas of Research

The design team has access to a state-of-the-art computer aided design suite and a dedicated measurement facility allowing device modeling and circuit characterization up to 110 GHz. A key differentiator in the group's capabilities is the custom model database that it has assembled from accessing numerous GaAs foundries worldwide. This is a significant benefit to customers wishing to develop a custom MMIC design as it has allowed the design team to build up a portfolio of "right first time design" success.

Prototyping Facility

Complimenting the design team is a state-of-the-art prototyping facility. The facility offers a unique rapid prototyping service claimed to be unsurpassed for responsiveness in Europe, allowing customers to develop working prototypes in weeks rather than months. Low volume manufacturing of advanced microwave and mm-wave modules covering the 5 to 100 GHz frequency range is available internally. Alternatively, for customers requiring higher volume quantities, or mass production, then QinetiQ can provide bespoke design solutions with outsourcing of volume assembly and test through its established network of suppliers.

Consequently, the following services are offered: custom MIC/MMIC design and characterization to 110 GHz; microwave and mm-wave module development from small quantities to thousands; flip-chip die attachment to 5 µm placement accuracy; hybrid assembly (including wire/tape bonding, vacuum re-flow soldering, resistance/DC welding and hermetic testing); and environmental testing.

Key Contact

Steve Ashley, Business Group Manager (Microwave Sensors), Malvern, UK. E-mail: saashley@QinetiQ.com.

Pan-European Research

One of the main reasons for the formation of the European Union was to foster and encourage cross-border cooperation and one area where this has been successful is in the research field. Testimony to this are the projects featured, where an area in need of study has been identified and the leading exponents in the field assembled, with clear goals and objectives.

RESEARCH PROJECT

CANVAD – Carbon Nanotubes for Microwave Vacuum Devices

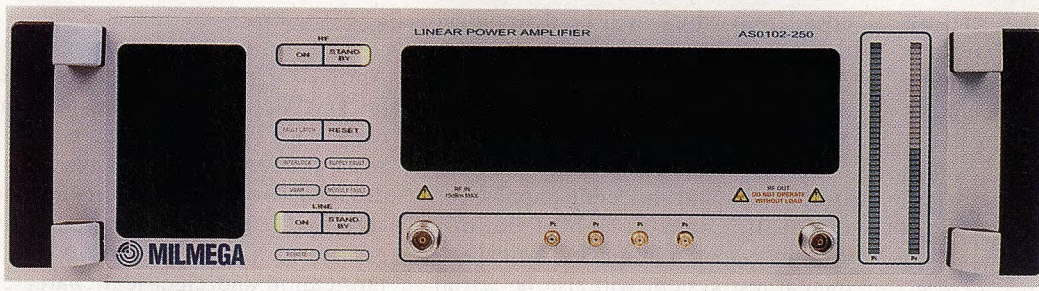
Objective

The aim is to demonstrate that CNT-based cold cathodes can satisfy the future telecommunications requirement for high frequency (30 to 100 GHz) compact and low cost microwave amplifiers. Its objective is to achieve an emission current density of 1 A/cm^2 modulated at 30 GHz from a CNT-based cold cathode. The cold cathode will consist of an array of CNTs with an integral extrac-

[Continued on page 70]



HIGH POWER
Microwave Amplifiers



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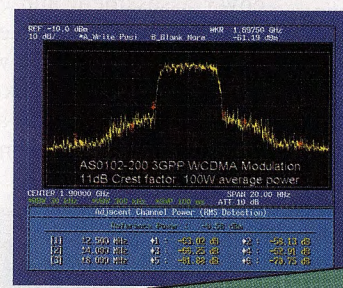

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250W in a 3U unit

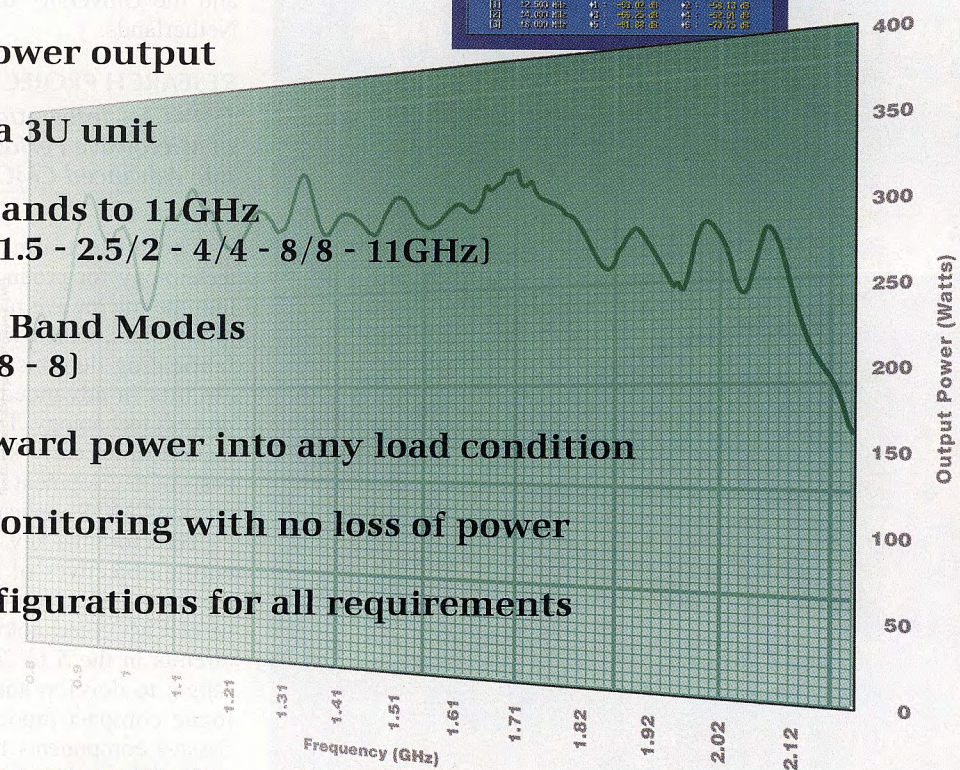
Octave bands to 11GHz (0.8 - 2.2/1.5 - 2.5/2 - 4/4 - 8/8 - 11GHz)

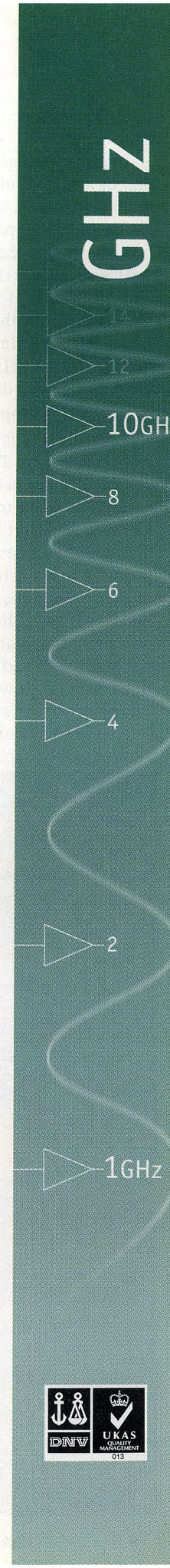
Multiple Band Models (0.8 - 4/0.8 - 8)

Full Forward power into any load condition

Power monitoring with no loss of power

Port configurations for all requirements





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tion grid positioned 5 to 10 μm from the CNT emitters.

Intermediate goals are the fabrication of arrays of identical and vertically aligned CNTs, and the design/fabrication of low capacitance CNT-based field emission cathodes. The study will aim to verify that 1A/cm^2 of emission current can be obtained in DC mode from the cathodes, and using a RF modulated input, validate that the device delivers 30 GHz modulated current at a density of 1A/cm^2.

Work Description

This project is divided into seven work packages. The first, nanolithographically defined growth of aligned nanotubes aims to produce arrays of identical and vertically-aligned CNTs. This will be achieved by using a three-pronged approach — precise control of the size and the position of the catalyst dot by nanolithography, selection of a high temperature diffusion barrier for high yield and uniformity, and optimization of growth parameters to obtain selective growth of nanotubes.

The objective of the second is to fabricate a cathode that integrates the array of CNTs with an extraction grid positioned 5 to 10 μm away from the array. This includes the design of a low capacitance and high transparency extraction grid, and the determination of a suitable technology to integrate the CNTs with the grid to form the compact cathode.

The third work package relates to the emission properties of the cathodes, from which will be determined the emission current density (~1 A/cm^2), emission uniformity, energy distribution of the emitted electrons, and stability/lifetime of the cathodes. Following on, the fourth provides the simulations and modeling support for the preliminary design of the microwave vacuum amplifier. An experimental test system will also be set up to measure the emission current density modulated at 30 GHz.

Work packages five and six will cover assessment and evaluation and dissemination and implementation, respectively, while seven will ensure that the project will be executed in the most effective fashion and the results are fully exploited technologically and commercially.

The progress of the project will be measured using the main deliverables: nanolithographically defined growth of aligned CNTs, design and fabrication of CNT-based cathode with a capacitance of 2 to 3 pF/mm^2, and cathodes delivering 1 A/cm^2 emission current densities modulated at 30 GHz.

Project Progress

The project started on the 1st of April 2002 and is due for completion on 31st March 2005. Being at such an early stage there are, as yet, no new results concerning microwave vacuum devices. However, first results concerning the nanolithography-localized growth of aligned nanotubes and the fabrication and electrical characteristics of carbon nanotube-based microcathodes have been published.

Collaborators

The prime contractor is Pierre Legagneux, Thales Research & Technology, Orsay, France. E-mail: Pierre.legagneux@thalesgroup.com. Project partners: Thales Electron Devices, France; Cambridge University, UK; Fribourg University, Switzerland; and the University of Groningen, the Netherlands.

RESEARCH PROJECT

IMPACT – Integration of Microwave Performance into Advanced CMOS Technology

Objective

The project aims to push CMOS technology for products operating well into the microwave radio frequencies (5 to 20 GHz), which will be achieved by fabricating demonstrator devices and circuits in advanced 100 nm CMOS process technology. The aim is the realization of an early knowledge and the basis of development for future high frequency CMOS applications.

Therefore the key technical and scientific objectives of IMPACT include the following: to evaluate the added value of CMOS technology for microwave circuits in the 5 to 20 GHz frequency range; to develop and implement analogue compact models for active and passive components for frequencies up to 50 GHz; and to develop and integrate active and passive devices suited for high frequency applications in advanced CMOS technology.

[Continued on page 72]



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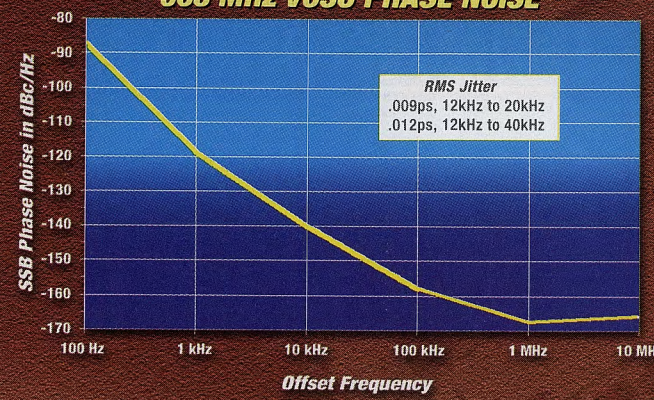

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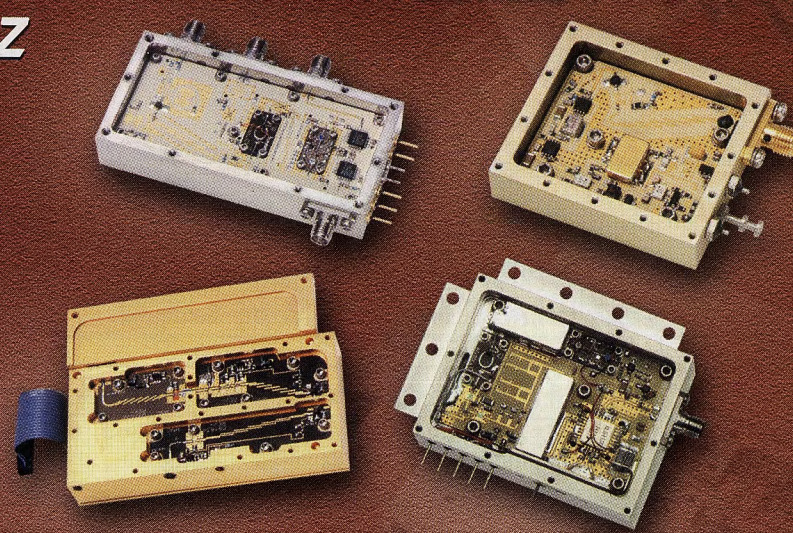

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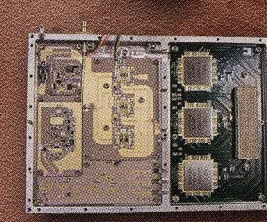

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Work Description

First, design work is needed to define demonstrator devices and circuits that represent the application domain of microwave CMOS technology. In order for this design activity to be sufficiently accurate and predictive, compact models need to be developed that properly describe the high frequency behavior of all circuit elements. Then, active and passive devices need to be defined and integrated, not only to electrically test the validity and accuracy of the compact models, but also to fabricate the demonstrator circuits.

To carry this out three technical work packages have been defined: circuit design, modeling and process optimization. Initially, existing 100 nm front-end CMOS technology will be used to obtain model parameters for active devices. Similarly, a first model description of passive devices will be derived from earlier integration and modeling experience. Using this information, and in successive iterative loops, the CMOS technology will be optimized using the input obtained from the design and modeling groups.

At the end of IMPACT, an optimized CMOS technology for microwave frequency operation will be available together with improved models for active and passive devices, and optimized design methodologies for microwave circuits and systems.

Project Progress

The early availability of MOS transistors fabricated within the IST-HUNT project has made it possible to carry out a detailed characterization and modeling of the 100 nm CMOS technology as one of the first activities within the study. Both MOS Model 11 (MM11) and Chalmers parameter sets have been made available to the consortium for circuit design and technology optimization. Currently, NMOS transistors with cut-off frequency in excess of 120 GHz and maximum operating frequencies above 80 GHz are available. It is expected that layout and technological optimizations will bring maximum operating frequencies well above 140 GHz.

The work on transistor optimization is being carried out in parallel with the development of RF passives in an advanced copper/oxide back-end of line, with the possibility of fabricating inductors either in the top levels of metallization or in a post-processed way using BCB and copper. Models based on initial experiments and on electromagnetic simulations have been provided to circuit designers.

A mask set specifically designed for IMPACT is currently being finalized. It contains an extensive set of RF front-end circuits (LNAs, VCOs, etc.) designed to operate at frequencies ranging from 5 to 40 GHz. Some of the circuits include electrostatic discharge (ESD) protection schemes designed to be effective at very high operating frequencies without compromising circuit performance. This mask set also contains a broad range of technology characterization vehicles which, combined with the results obtained from the circuits, will allow for further circuit and technological optimization in the second learning cycle foreseen within the project.

Milestones

The project officially started on September 1st, 2001, with a total duration of

[Continued on page 74]

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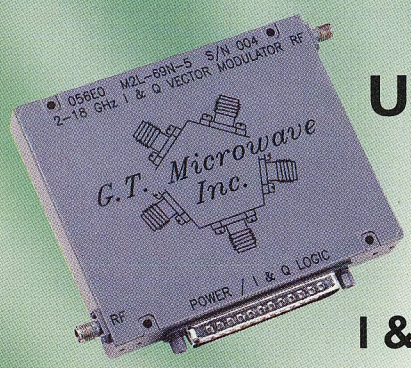

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2.0-6.0			12.0 dB	1.80:1
6.0-18.0			12.0 dB	1.90:1
16.0-24.0	±22.0°	±2.00 dB	15.0 dB	2.20:1
2.0-18.0	±22.0°	±3.00 dB	16.0 dB	2.20:1

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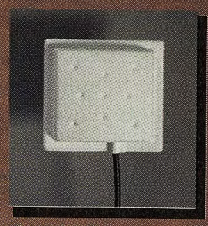

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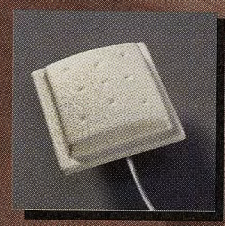

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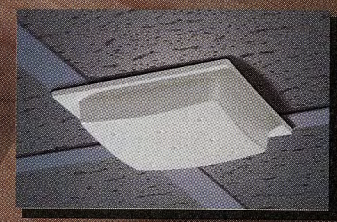

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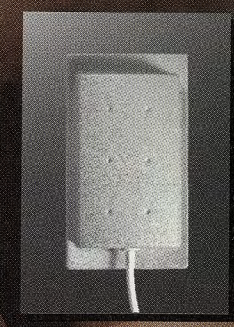

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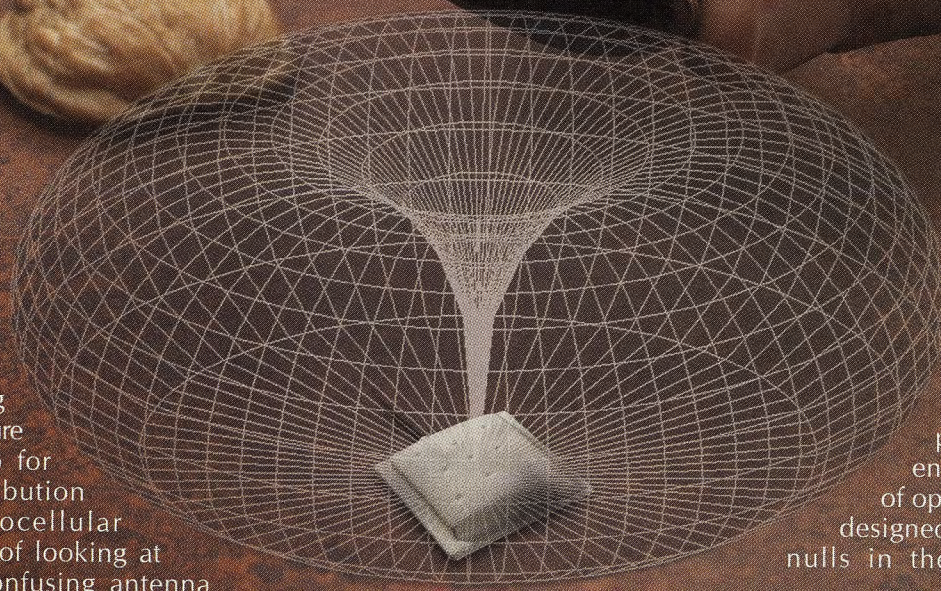

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39 months. The main milestones of the project include the aforementioned two full mask sets for circuit evaluation, model verification and technology optimization taped out in May 2002 and September 2003, respectively.

Two public workshops for result dissemination are set for February 2003 and November 2004, while internal reports on models for active and passive devices are scheduled for April 2003 and November 2004. Finally, optimized CMOS devices for microwave applications should be available at the end of the project in November 2004.

Collaborators

The project coordinator is Goncal Badenes, Interuniversitair Micro-Electronica Centrum (IMEC), Leuven, Belgium. E-mail: Goncal.Badenes @imec. Partners: Ericsson AB, Sweden; Ericsson Microelectronics, Sweden; Philips Research Laboratories, the Netherlands; Innovative Technology Solutions, Belgium; and Chalmers University of Technology, Sweden.

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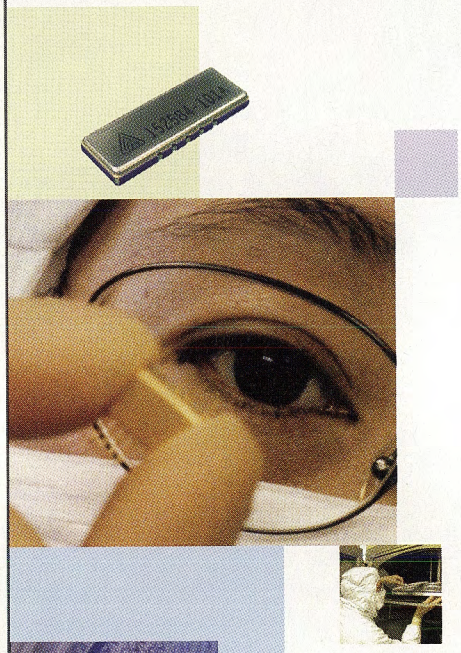

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RESEARCH PROJECT

MIPA – MEMS-based Integrated Phased Array Antennas

Objective

The focus is on the development of MEMS and related technologies for millimeter-wave transceivers applied to car radar systems working at 77 GHz or satellite multimedia data links in the upper Q band (40/50 GHz). The aim is that the development of MEMS-based millimeter-wave modules and their assembly to antenna front-end prototypes with redundancy power routing (space application) or phased array antenna feeding (automotive) will demonstrate the enormous innovative potential of MEMS technology in the millimeter-wave range. In order to ensure the possible widespread application of these RF MEMS-based components into commercial products, packaging and reliability issues will be specifically addressed.

The MIPA consortium comprises leading European companies in microwave product development and microsystems technology with expertise in wafer fabrication, packaging, reliability assessment and commercial exploitation.

Work Description

Initial work is on the specification of MEMS devices and MEMS-based sub-modules such as redundancy switches, phase shifting devices, power routing networks, together with the specification of the assembly of these devices and modules to a space and an automotive prototype for operation at 50 and 77 GHz, respectively.

A major part of the study is the design of these devices by using electromagnetic and thermo-mechanical simulation tools to serve the wafer processing with layouts and important technology related information. The wafer processing deals with the microfabrication of single MEMS switches, their monolithic integration to yield more complex on-wafer sub-modules as phase shifters or routing networks. It entails the fabrication of on-wafer matching and bias structures, and other passive components. Therefore, a lot of technology work and development in the microsystems area will be done during the wafer processing.

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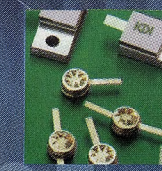

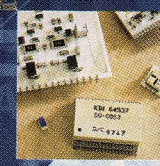



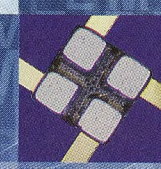



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With regard to the specific requirements of the space and automotive industrial sector, the work related to packaging and hermetic sealing of MEMS-based sub-modules (to protect them against impairment through environmental conditions) will constitute the largest part of the study. In particular the performance of the devices at the envisaged frequencies for operation (50 and 77 GHz) after their packaging will be investigated in depth.

To exploit MEMS devices for millimeter-wave applications, their reliability under all possible conditions must be known. Therefore, efforts will be directed towards the determination of the long-term behavior (both mechanical and electrical) of millimeter-wave MEMS in order to identify weak points in the technology and fabrication process flow. This will be done with specific regard to space and automotive conditions (vibration, temperature, humidity, etc.).

To demonstrate the potential of MEMS at millimeter-wave frequencies, MEMS-based antenna front-ends will be developed and characterized, one for a 50 GHz space communications system and one for a 77 GHz car radar. This work will be supported with the development of other millimeter-wave components, such as array antennas, in order to build MEMS-based integrated phased array prototypes.

Project Progress

With a scheduled duration of 36 months the project began on August 1st, 2001, and is due for completion on July 31st, 2004. At this stage the applications have been fully defined and specified, and the project is running as planned with the first run of RF MEMS ready to go into fabrication with first reliability recommendations.

Collaborators

The prime contractor is Olivier Vendier, Alcatel Space Industries, Nanterre, Île de France, Hauts-de-Seine, France. E-mail: olivier.vendier@space.alcatel.fr. Collaborative partners: Centre National d'Etudes Spatiales (CNES), Interuniversitair Micro-Electronica Centrum (IMEC), Coventor, Robert Bosch and Universite de Rennes.

CONCLUSION

Research is vital for the future of the microwave industry worldwide. Despite current financial constraints and the consequential constriction of resources there must be investment in projects that have commercial value, with commitment to practical development in order for the industry to evolve. One of the keys to achieving this will be to foster and encourage a spirit of cooperation between research institutes, focused on concentrating resources and expertise, not only across Europe but globally.

ACKNOWLEDGEMENTS

The author would like to thank all those individuals, institutes and test houses who supplied research material for this supplement.

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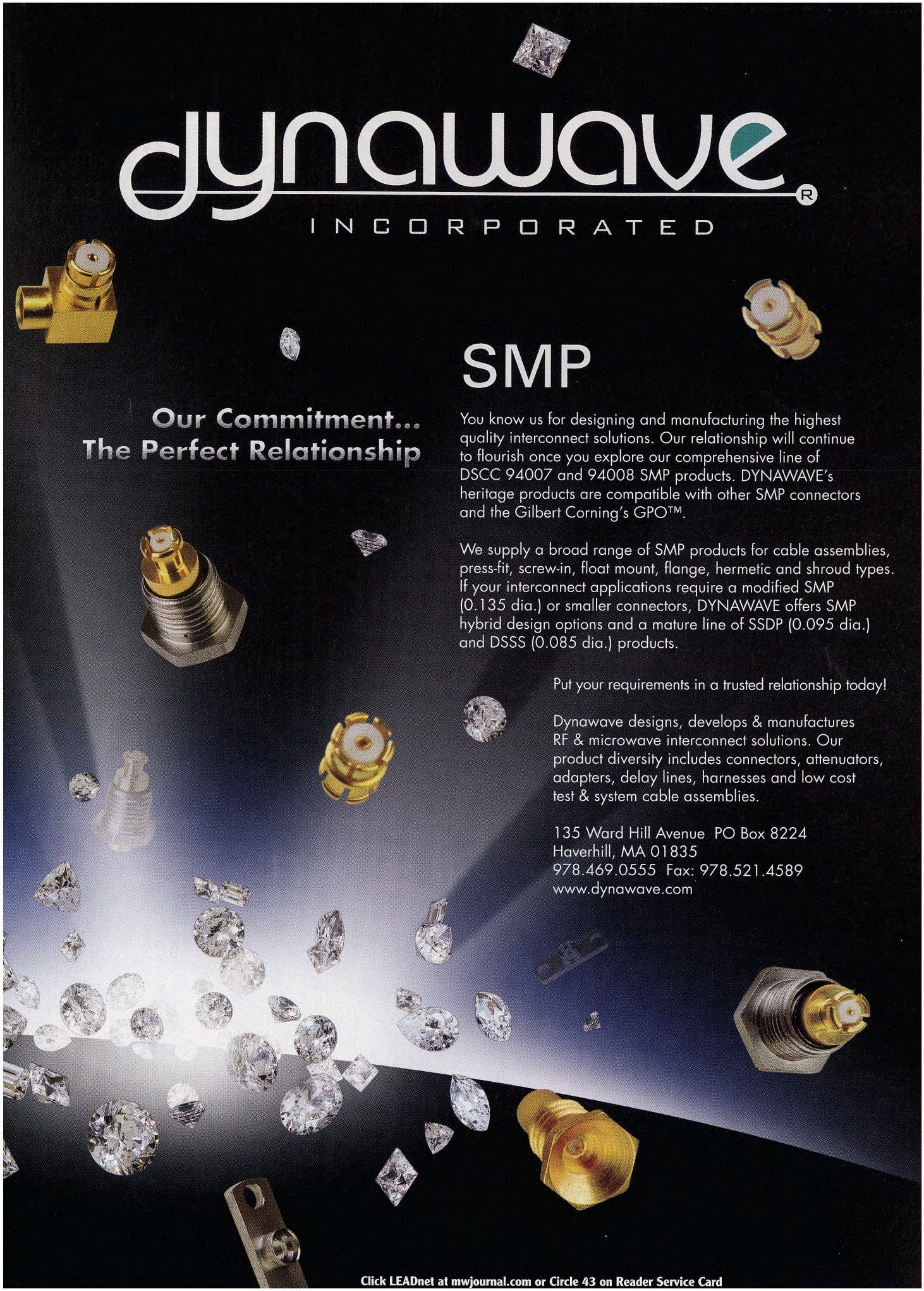
As an ongoing feature, European microwave research activities will be regularly reviewed in *Microwave Journal*. If you are currently working on a relevant project in Europe please contact Research@mwjournal.com, outlining your work and giving contact details. ■

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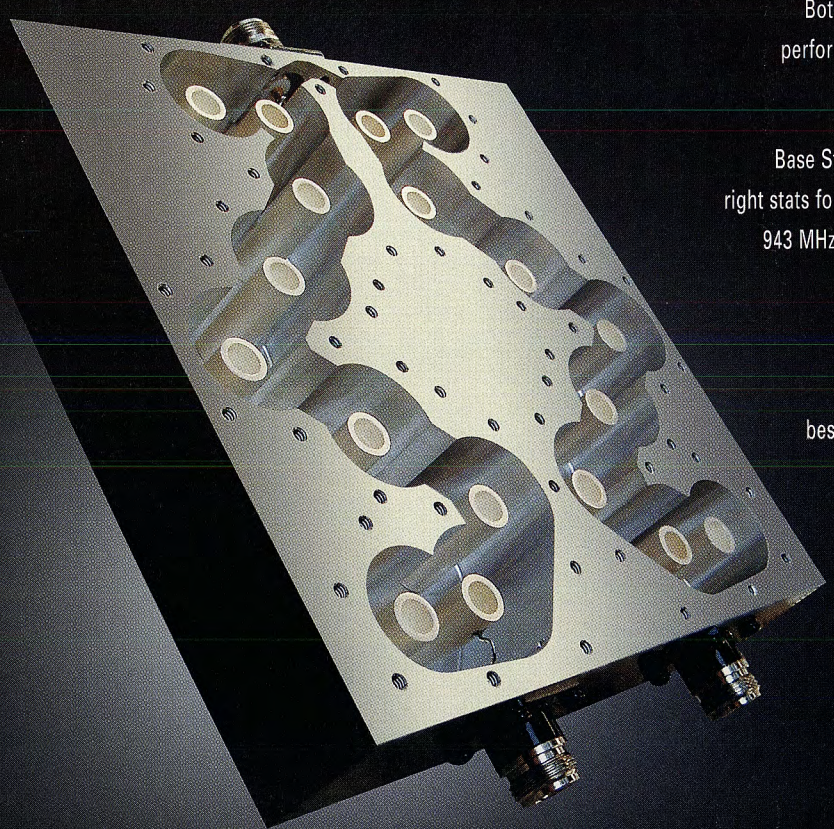



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FCC Initiates Proceeding to Promote Commercial Development of mm-wave Spectrum

The Federal Communications Commission (FCC) has initiated a proceeding to examine methods to promote the commercial development and growth of spectrum in the 71–76 GHz, 81–86 GHz and 92–95 GHz bands. Non-government users have never before occupied these bands. Specifically, the FCC seeks comments on its proposed rules to allow use of these spectrum bands for a broad range of new fixed wireless services. Potential uses of this spectrum include high speed wireless local area networks, broadband access systems for the Internet, point-to-point communications, and point-to-multipoint communications. These special uses are possible because of the shorter wavelengths, which are about three to five millimeters, and because of other technical characteristics that differentiate the 71–76 GHz, 81–86 GHz and 92–95 GHz bands from other bands.

Currently, this region of the spectrum is essentially undeveloped and available for new uses. Accordingly, the FCC seeks to develop a flexible and streamlined regulatory framework that will encourage innovative uses of the spectrum; accommodate future developments in technology and equipment; promote competition in the communications services, equipment and related markets; and advance the potential sharing between non-Federal Government and Federal Government systems. Additionally, the FCC anticipates that its proposals will encourage the use of technologies developed in military and scientific applications in a broad range of new products and services, such as high speed wireless local area networks and broadband access systems for the Internet.

Background:

In July 2000, the Commission held a public forum on possible new uses of the 92–95 GHz band. Several speakers at the forum indicated that due to recent technological developments, new uses of this band are approaching practicality. In addition, in July 2001, Loea Communications Corp. experimented with technology it developed for use of the 71–76 GHz and 81–86 GHz bands. As a result, Loea filed a petition requesting the establishment of service rules for the licensed use of the 71–76 GHz and 81–86 GHz bands on September 10, 2001.

Specifics of the adopted notice:

The Commission seeks comments on the following issues regarding the use of the 71–76 GHz, 81–86 GHz and 92–95 GHz bands:

- Updating allocations in the 71–76 GHz, 81-86 GHz and 92–95 GHz bands to reflect changes in the international allocations made at the 1987 and 2000 world Radio Conferences;
- Developing an appropriate band plan for the 71–76 GHz, 81–86 GHz and 92–95 GHz bands;
- Providing for unlicensed use in some or all of these bands;
- Authorizing the new licensed services under Part 101 of its Rules and the new unlicensed devices under Part 15 of its Rules;
- Licensing the spectrum administered under Part 101 by geographic areas, site-based areas or some other scheme.

For more information, contact Michael Marcus at the Office of Engineering and Technology: (202) 418-2418 or mmarcus@fcc.gov.

Lockheed Martin Selects Endwave as Supplier for Comanche Radar Program

Endwave announced that it has entered into a multi-million dollar contract with Lockheed Martin Missiles and Fire control Co. to design the RF Receiver unit for the Comanche Radar system used in the Boeing RAH-66 Comanche Helicopter. The contract with Lockheed Martin, a primary sub-contractor to The Boeing Co. for the Comanche radar program, calls for Endwave to design the radar receiver unit, and to manufacture and deliver prototype and evaluation units that will be used in qualification trials within the complete radar system.

"We are honored to have been selected by Lockheed Martin Missiles and Fire Control for this important program, particularly at a time when our nation's security is of such a large concern," said Ed Kieble, chief executive officer and president of Endwave Corp. "It is gratifying for Endwave to be able to apply its unique millimeter wave technology, design expertise and manufacturing resources toward the development of this advanced radar system. We are proud to offer our services to a program that will help safeguard the men and women of our armed forces who risk their lives to protect our freedom."

"Endwave proved to be a highly capable and reliable supplier of the Longbow Fire Control Radar (FCR) program," stated Benny Smith, program manager, Comanche FCR, Lockheed Martin Missile and Fire Control. "We are pleased to once again utilize Endwave expertise and extend their role further in the design and production of this critical component for the Comanche Radar system."

The Comanche radar, a derivative of the proven Longbow Fire Control Radar used on the Apache attack helicopter, delivers the same high performance in a streamlined package to support the stealth mission. Its millimeter-wave technology provides unequalled target detection, location, classification and prioritization. The Comanche Radar system also uses the Longbow Hellfire missile for fire-and-forget capability in all weather conditions.

The selection of Endwave for the Comanche Radar program represents an expansion from Endwave's role as a component supplier to Lockheed Martin for the Longbow radar program, under which Endwave designed and continues to produce low noise amplifiers (LNA) for the Longbow Fire Control Radar used on the Apache attack helicopter. Under the Comanche program, Endwave will deliver a higher level of integration, as the RF receiver unit for the Comanche is a LRU (line replaceable unit) that integrates the LNA component with other active components in a complete subsystem assembly.

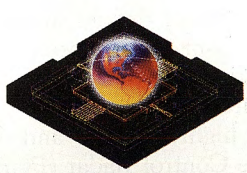
Raytheon Teams with Lockheed Martin for FAA Air Traffic Control Modernization

Raytheon Co. will join Lockheed Martin's national team to design and develop the next generation En Route Automation Modernization (ERAM) program for the Federal Aviation Administration (FAA). Raytheon will perform as a major subcontractor to Lockheed Martin, along with other air traffic management (ATM) industry leaders such as Computer Sciences Corp., Boeing, Northrop Grumman and Harris Corp.

Raytheon brings to the ERAM team extensive en route air traffic management system experience in the critical areas of flight and surveillance data processing. This experience has been gained through Raytheon's 50-year legacy of ATM system development and most notably its partnerships with the Deutsche Flugsicherung GmbH (DFS) in Germany, NAV CANADA in Canada and the FAA in the US. Raytheon has a long history of developing and introducing advanced open software architectures to its ATM partners that provide efficient and cost-effective long term system growth and evolution. In addition, Raytheon's ATM systems engineering experience, from the current en route back-up channel, or Direct Access Radar Channel (DARC), to the next generation terminal automation system, Standard Terminal Automation Replacement System (STARS), will enable Raytheon to leverage proven technology and engineering processes that are directly applicable to ERAM.

"Raytheon is pleased to perform as a major subcontractor to Lockheed Martin for ERAM and we are confident that the FAA will be getting a world class team to provide a solution for modernization of the world's most complex en route ATM system," said Steve Teel, vice president of Business Development for Raytheon's Command and Control, Communications and Information Systems. In addition, Lockheed Martin will join the Raytheon Standard Terminal Automation Replacement System (STARS) team. As a subcontractor to Raytheon, Lockheed Martin will apply its expertise in high density TRACON operations to assist in the transition of Common ARTS to STARS at very large TRACON facilities.

Bob Eckel, vice president of Raytheon Air Traffic Management Systems, said, "We believe that this partnership with Lockheed Martin will leverage the best capabilities of both companies to offer the FAA effective solutions for ERAM and STARS, bridging the terminal and en route airspace. Lockheed Martin's addition to the STARS team will ensure timely and safe transition of the large high density TRACON facilities from the existing automation system to STARS." ■



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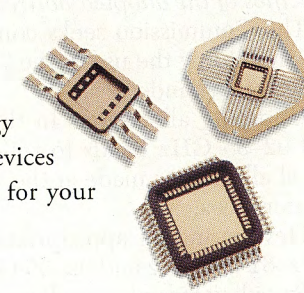

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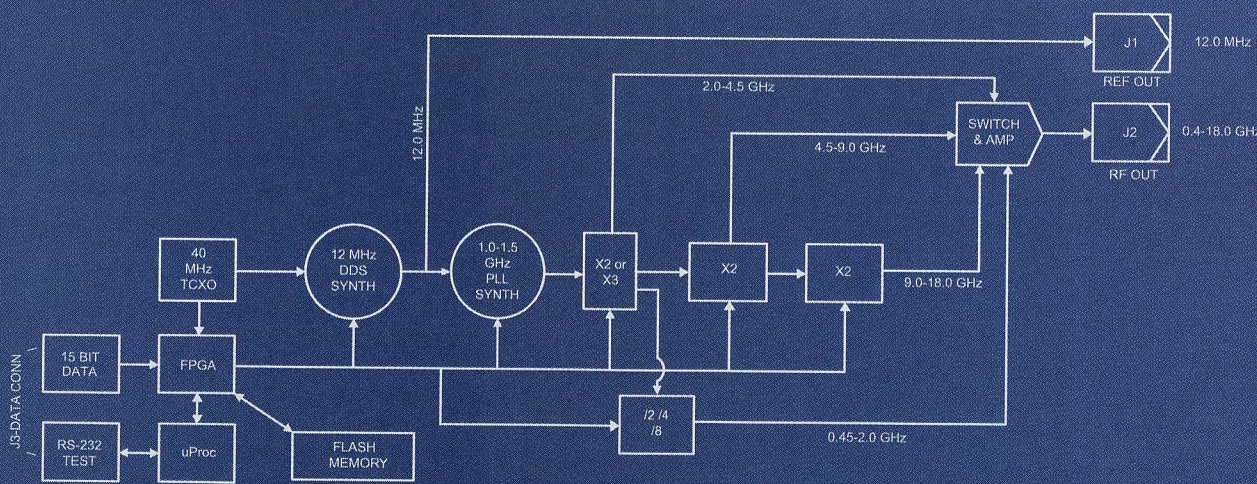

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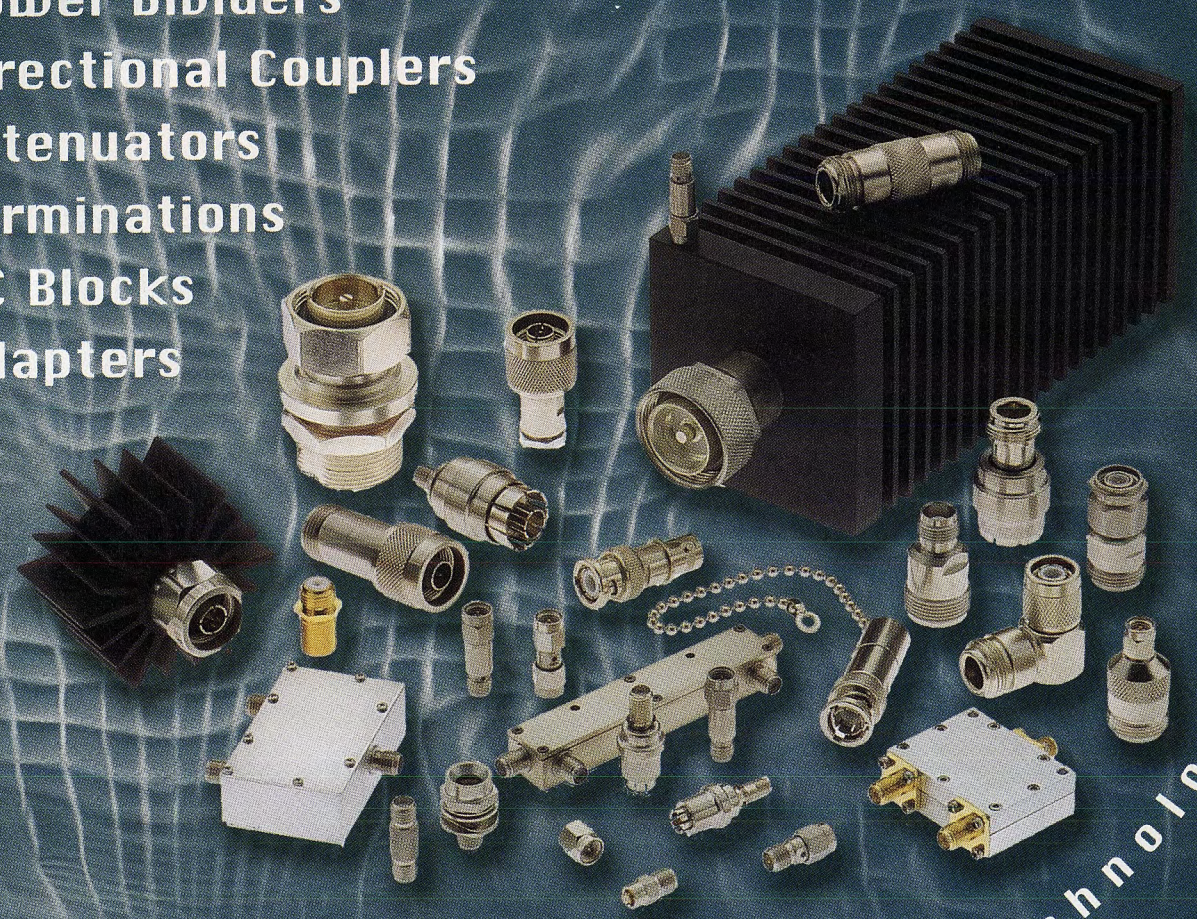

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INTERNATIONAL REPORT

Martin Streetly, International Correspondent

Thales Launches CATS

French-based contractor Thales Airborne Systems used the 22-28 July Farnborough International Air Show to showcase its latest airborne electronic warfare (EW) product, the Compact Airborne Threat Surveyor (CATS). Operating within the E- to K-band (2 to 40 GHz) frequency band, CATS is a combined radar warning, electronic support (ES) and EW suite management system that is designed for use in helicopter, unmanned aerial vehicle (UAV) and transport aircraft applications. As such, it provides real-time battlespace awareness, radar threat warning and alert, an ES capability with a data recording facility and real-time sensor-to-shooter target geo-location data. System components include a processor unit and up to six antenna modules and the system as a whole makes use of Thales' proprietary phase measurement threat localisation technique. CATS can be installed as either a stand-alone unit or in an integrated configuration that is compatible with glass cockpits and UAV navigation/data link systems. In its stand-alone format, the system is used with a kneeboard or a dedicated cockpit colour display that has provision for interfacing with the host platform's mission and avionic systems. Other system features include a user programmable software library and built-in test. Equipment weight is given as 15 kg (without display) and at the time of its announcement, it is believed that in the first instance, Thales was pushing CATS for installation on platforms such as the pan-European NH-90 helicopter and A400M next generation transport aircraft.

AMS Wins Radar Contracts in Ecuador, Hong-Kong and Turkey

The Anglo-Italian Alenia Marconi Systems (AMS) joint venture has been awarded air traffic control radars contracts in Ecuador, Hong-Kong and Turkey with a joint value of approximately US$34 million. Taking the countries in the order given, Ecuador's Civil Aviation Authority is acquiring a US$5 million air traffic management (ATM) system for Guayaquil airport which will comprise an AMS ATCR-33S primary radar and a SIR-S Mode S secondary surveillance radar. This package will replace the site's existing radar system and builds on an area control centre turnkey contract Ecuador awarded AMS during 2001.

For its part, the Hong-Kong award (valued at US$6 million) covers the supply of an ATCR-44S long range radar for installation on Mount Parker, from where it will form part of the en-route radar surveillance coverage of aircraft flying in the vicinity of Hong-Kong's Chek Lap Kok international airport. When combined with another long range radar that was installed at Sha Chau during 1998, the new package will facilitate wider area coverage, a reduction in blind zones and better tracking continuity during hand-off between one radar coverage area and another. Prior to this latest contract with Hong-Kong's Civil Aviation Department, AMS had provided an automated air traffic control system for the Territory's Kai Tak airport which was commissioned during 1985.

In the third of the three cited contracts, AMS is supplying Turkey's Civil Aviation authority with six Mode S secondary radars, three medium range ATCR-33S primary radars and a logistical support package in a deal valued at US$23 million. Taken together, these various equipments are to be used to modernise the country's air traffic control system and are to be installed at sites in Ankara, Erzican, Istanbul, Korcik, Milas-Bodrum and Yalova. Looking at the technology involved in greater detail, the ATCR-33S sensor is an S-band (2 to 4 GHz) band sensor that is suitable for both ATM and approach control applications and can be equipped with either a G-33 conventional reflector antenna or an ALE 3 × 5 planar array. The ATCR-44S radar operates in the L-band (1 to 2 GHz) and is suitable for TMA and approach/en-route control applications. It makes use of a solid-state transmitter and can be fitted with either a G-14 conventional reflector antenna or the company's ALE 3 × 5 planar array. For its part, SIR-S is a Mode S capable monopulse secondary surveillance radar that conforms with Eurocontrol POEMS requirements, is fully solid-state and is fitted with an ALE 9 open array antenna.

Rosoboronexport Promotes Detachable COMINT System

The Russian Federation's Moscow-based Rosoboronexport export agency is offering a detachable communications intelligence (COMINT) system that can be easily incorporated aboard any type of utility helicopter. Operating within the 30 to 2000 MHz frequency band, the package comprises an onboard equipment set (made up of four laptop computer-equipped workstations) and a retractable antenna assembly that is installed in a suitable location on the host aircraft's belly. It is designed to establish electronic orders of battle; monitor illegal paramilitary/smuggling activity; support search and rescue operations and provide a border/territorial water surveillance capability. System functions include automatic search, detection and identification of emitters; high speed panoramic analysis of the frequency of received signals; automatic, multi-emitter direction-finding (DF) within the 30-1200 MHz sub-band and position location; the creation of signal, emitter and target databases and the presentation of COMINT data overlaid on an electronic map. In terms of specific performance, the equipment's DF accuracy, sensitivity, frequency measurement accuracy and dynamic range are given as 2° to 5°, 2 μW, 2 kHz and 60

dB, respectively. In terms of potential platforms, it is believed that the system has been flown aboard the MIL Mi-8 helicopter and is at least applicable to the same company's Mi-17 design.

Indra Reveals New Air Defence Radar

Spanish contractor Indra has launched a new 2-D air defence surveillance radar under the trade name RAVEN. Operating within the I/J-band (8 to 20 GHz) frequency range, RAVEN is described as being a frequency modulated continuous wave (CW) type of equipment. It comprises an antenna/antenna drive assembly, a dual Power PC processor, a control unit, an AMD-K6 PC operator console, an antenna mast, a Mk XII identification friend-or-foe interrogator and a radar trailer, and is designed to detect and classify aircraft flying at low and very low altitudes. It can operate as a stand-alone unit or can be linked to a command post (via cable (RS-422 interface) or bi-directional radio) or a number of weapon terminals (one-way radio). Overall, the system has been designed to minimise its visibility to hostile electronic support systems, with proofing measures including a low radiating power value, CW functionality and state-of-the-art processing. Indra further notes that alongside its primary air defence role, RAVEN is also suitable for ground traffic control and border surveillance applications and that it forms part of its COAAAS-L anti-aircraft artillery command and control post architecture. Here, two RAVEN radar are teamed with an engagement control unit (designated as the UCE equipment) and a terminal at each weapon site within the particular air defence network. For its part, the UCE collects and merges data coming in from the two radars, carries out a threat assessment and assigns weapons to targets. Using a combat radio network, UCE controls both its radars and assigned weapon systems via data links and if no UCE is available, the COAAAS-L's RAVEN radars can hand off data directly to the individual weapon system terminals. Other RAVEN radar system features include frequency agility, Doppler processing (fixed and moving clutter map for target classification), automatic track while scan, the use of constant false alarm rate algorithms for false alarm management and C/C++ radar processing and Ada operator console software. System range, sidelobe value, beamwidth (azimuth/elevation), power consumption/output and mean time between failure/mean time to repair are given as 20 km (instrumented), < 40 dB RMS, 1.7°/17°, 400 W/< 20 W and > 1200 h/15 minutes, respectively. ■

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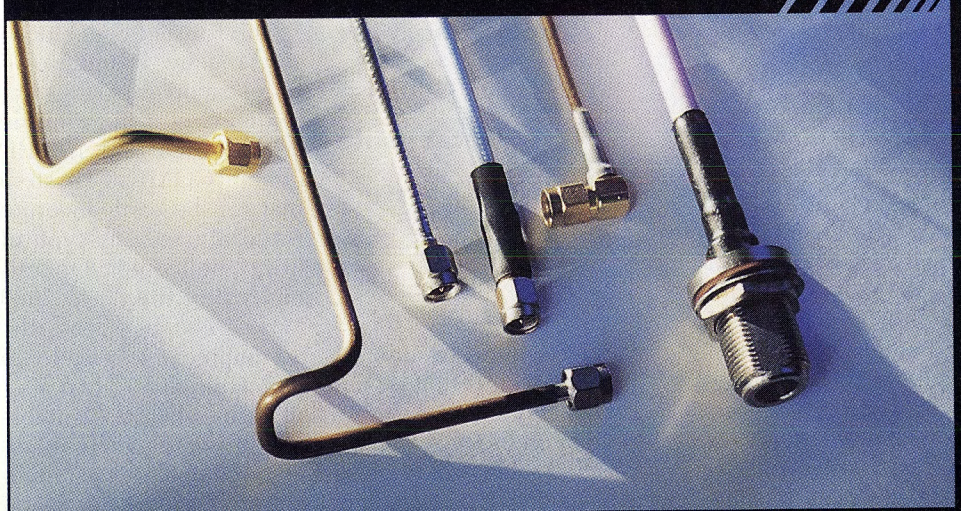

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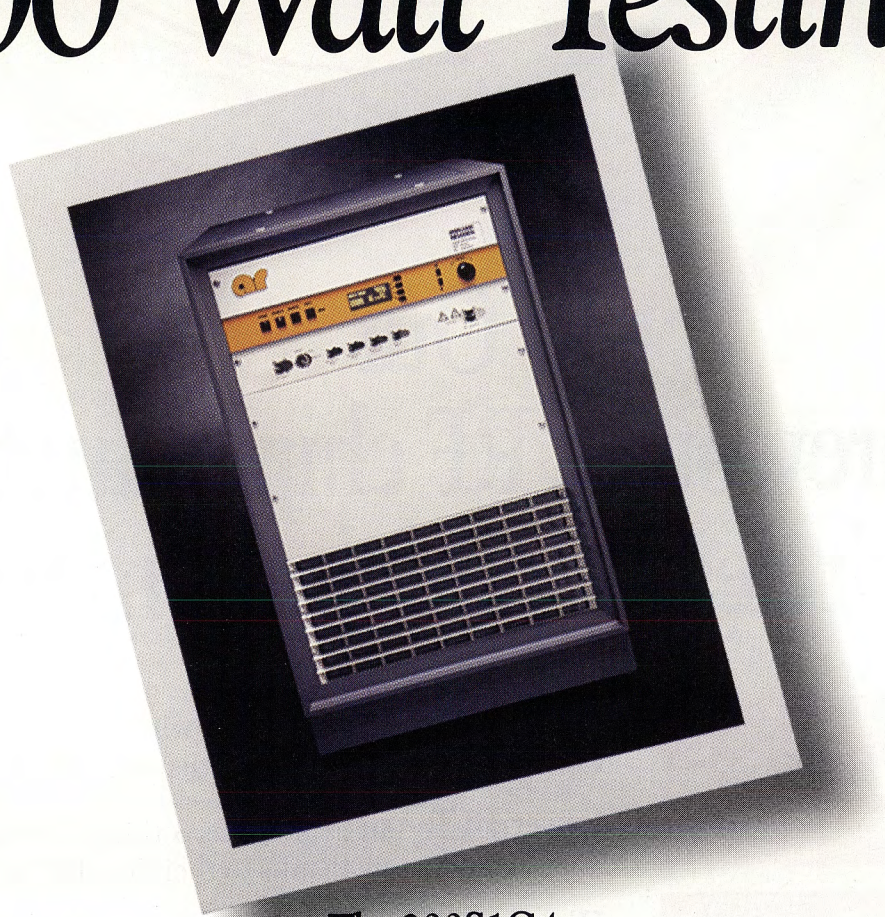

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Loral Skynet Marks 40th Anniversary of Telstar 1

On July 10, 2002, Loral Skynet marked the 40th anniversary of the launch of Telstar 1, the world's first active communications satellite built by Skynet's predecessors at AT&T and Bell Laboratories.

Telstar 1 was launched from Cape Canaveral aboard a Boeing Thor Delta rocket and soon thereafter broadcast the first live television signal from Andover, ME, to Goonlilly Downs, England and Pleumeur-Bodou, France. The transmission showed the American flag streaming over the Andover earth station to the sound of the "Star Spangled Banner." The same day, Telstar carried the first long distance telephone call via satellite between AT&T's then chairman, Fred Kappel, and US vice president Lyndon B. Johnson.

During its seven months in orbit, Telstar 1 dazzled the world with live images of baseball games, plays, musical performances, news broadcasts, scenes of the World's Fair in Seattle, WA, and a US Presidential news conference. More than 200 million people watched as the United States and 16 European countries exchanged numerous live video signals of national monuments and famous images, including the United Nation Building, Niagara Falls, the Eiffel Tower and the Statue of Liberty.

Telstar 1's technology differed from previous "passive" satellites — large reflective balloons that reflected radio signals — in that it received a signal from the ground, amplified it and sent it back to earth. The technology on Telstar 1 set the standard for all communications satellites that are in use today.

Telstar 1 had the ability to transmit either one television channel or roughly 500 simultaneous telephone calls. One of today's most advanced communications satellites, by comparison, can carry more than 500 television channels and thousands of data circuits. An experimental satellite, Telstar 1 remained in orbit for seven months, ceasing transmission in February 1963.

Since 1962, Skynet has operated 14 satellites carrying the Telstar name. Skynet is currently constructing three new satellites — Telstar 8, Telstar 13 and Estrela do Sul 1 — that will carry on the Telstar heritage.

Comparison Between Telstar 1 and One of Today's Most Powerful Satellites

	Telstar 1	*Telstar 7 (launched 9/99)*
Size	Spherical — 34" dia.	18' × 18' × 102' (deployed)
Weight at launch	171 lbs	8300 lbs
Power	15 W	10 kW (beginning of life)
Lifespan	7 months	15+ years (expected)
Cost	$6M	$200M (approx.)

Demand for Broadband Access Remains High

Broadband subscriber numbers continue to gain momentum in an effort to meet the ever-increasing demand for broadband access. Availability of broadband access will remain the biggest challenge for many regions of the world where infrastructures are not built-out or have just begun implementation. Key highlights of the broadband market include:

- In late 2001, the total number of worldwide DSL subscribers exceeded the total number of worldwide cable modem subscribers.
- In the US, cable modem subscribers continue to outnumber DSL subscribers by a wide margin. At the beginning of 2002, in the US, there were 7.12 M cable modem subscribers and 4.6 M DSL subscribers.
- Other broadband technologies, such as satellite broadband, Fiber-to-the-Home (FTTH), and wireless provide services to only 5 percent of total worldwide broadband subscribers.

In the US cable modem service has enjoyed almost 100 percent penetration in the residential market, while only mustering up a very small percentage of penetration in the business community. On the other hand, DSL is deploying broadband service at a much faster rate via online service self-installs, but certainly lacks the residential penetration of broadband that cable has managed to create. The triple play by the cable industry, providing a bundled package of voice, video and high speed access to the Internet has given them the edge, especially when compared to DSL. The triple play strategy used by the cable companies must be employed by the DSL industry for continued success in the broadband market place.

The remaining three broadband access technologies, fixed wireless, satellite and FTTH, are expected to continue competing in their own identified niche markets. Fixed wireless MMDS, (Multi-channel, Multi-point Distribution System) is on hold, waiting for those much talked about and anticipated second generation solutions that are seen as solving the high cost of truck rolls in deploying fixed wireless broadband services. LMDS (Local Multi-point Distribution System) continues to suffer from the high cost of providing broadband access, but certainly has a reasonable opportunity to continue growth in the medium and large business sectors.

The unlicensed band of fixed wireless is beginning to enjoy some rather impressive gains in the market capturing broadband subscribers, especially in the tier two and three markets using the 802.11 wireless standard. Wireless Internet Service Providers (ISP) have established themselves as the purveyors of the new 802.11 broadband to potential subscribers seeking high speed access to the Internet in cells with up to three miles of reach. To date, some 1500 wireless ISPs have established themselves as fixed wireless service providers. Each ISP has a minimum of 20 subscribers, currently, and in some cases, ISPs have managed to attract up to 4000 subscribers.



The satellite broadband access technology, as a connection to the Internet for high speed service, has had its challenges over the last couple of years in providing broadband services. Satellite service started off fairly strong in 2000 with a year-end subscriber count of 90,000 connections installed. It seemed as though satellite service was on its way to successfully competing head-on with the other broadband access technologies, however that was not to be, as it ended with a less than optimal showing, when compared to DSL and cable.

For additional information, contact Ernie Bergstrom: ebergstrom@reedbusiness.com.

It's Raining MEMS

Despite tough economic conditions overall, microelectromechanical systems (MEMS) continue their upward trend, according to In-Stat/MDR. The high tech market research firm reports that every major market has now embraced the technology and that mature segments will see relatively low compound annual growth rates (CAGR), and that in others, such as the communications and consumer markets, MEMS has only just begun to scratch the surface. As a result, worldwide revenues for MEMS are forecast to grow from $3.9 B in 2001 to $9.6 B in 2006.

While venture capital funding is certainly down, it is by no means out, and MEMS start-ups continue to emerge. However, considerable fabrication overcapacity currently exists and it appears that the situation will only worsen over the next year.

In-Stat/MDR also found that:

- The shift from sensor driven revenues to non-sensor driven revenues continues. In 2001, non-sensor devices comprised nearly a third of total MEMS revenues, whereas by 2006, they will account to almost half.
- The overall average selling price (ASP) for MEMS will actually increase 25 percent over the next five years, as more expensive, non-sensor devices enter the market.
- Unit shipments will double over the next five years, from 1.8 B units in 2001 to 3.61 B units in 2006. This is the result of both the introduction of new devices, as well as the emergence of new application opportunities.
- The communications and consumer sectors will see the highest CAGRs, based on revenues, through 2006, at 151.4 and 42.2 percent, respectively. However, the computer market will remain one of the largest revenue-generating segments, moving from second place in 2001 to first place in 2006. ■

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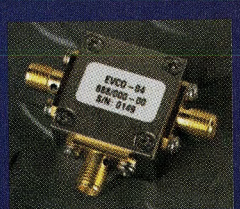

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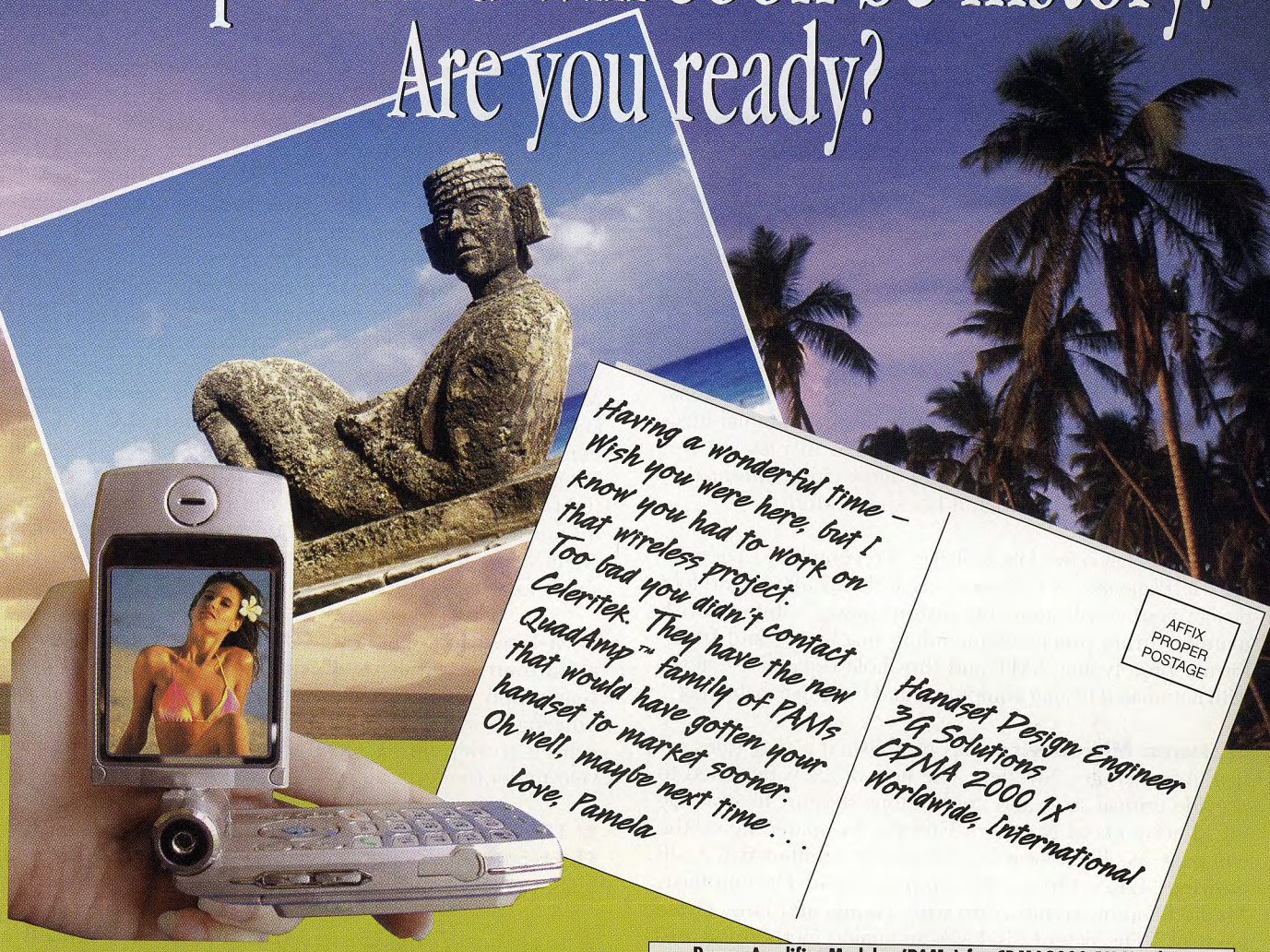

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- ❑ On-Board DC Power Down Mode

Power Amplifier Modules (PAMs) for CDMA2000 1X Handsets

Model	Frequency	Power Output	Gain	Efficiency	Vcntrl
CHP0205-QM	824-849 MHz	16-28 dBm	29 dB	38%	Low
		≤16 dBm	21 dB	10%	High
CHP1206-QM	1720-1780 MHz	16-28.5 dBm	27 dB	38%	Low
		≤16 dBm	22 dB	9%	High
CHP1207-QM	1850-1910 MHz	16-28.5 dBm	27 dB	38%	Low
		≤16 dBm	22 dB	9%	High



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INDUSTRY NEWS

Spectrum Control Inc. has acquired all of the outstanding common stock of **FSY Microwave Inc.** The purchase of FSY will enable Spectrum Control to expand its existing SPECWAVE line of ceramic-based wireless products and custom engineered wireless solutions.

Texas Instruments Radio Frequency Identification Systems announced the launch of its RFID European Product Information Center (EPIC), in Freising, Germany. An extension of Texas Instruments' semiconductor Product Information Centers, support staff at the EPIC is now available to assist customers with technical support questions regarding products and applications. Assistance is available in multiple languages.

BAE SYSTEMS has opened a consolidated business site in Fort Worth, TX. The office, Fort Worth Operations, brings about 75 people and some $200 M in annual business activities into one administrative infrastructure. Specifically the new location will allow closer interaction between BAE SYSTEMS and Lockheed Martin.

Lambda has moved its Melville, NY, complex to a new facility in Plainview, NY. Operations at the 27,000 square foot design center will focus on custom power solutions with manufacturing processes including machining and transformer prototyping, SMT and thru-hole capabilities, along with automated testing equipment and burn-in capabilities.

Sirenza Microdevices has established a new sales office in Stockholm, Sweden. The new office is designed to provide critical sales and applications support to strategic OEM accounts in Northern Europe. In related news, the company has been awarded US patent number 6,373,346 entitled "Laser Driver Pre-emphasis and De-emphasis Method and/or Architecture with Tuning and Duty Cycle Control." The patent discloses an analog method for pre-shaped data in order to improve the signal-to-noise ratio of VCSEL-based fiber-optic transmitters.

Technology and Devices International Inc. (TDI), headquartered in Gaithersburg, MD, since its inception in 1997, is moving the entire TDI operation to a state-of-the-art facility in Silver Spring, MD. The new facility encompasses 32,000 square feet and includes expanded manufacturing and R&D space for crystal growth, epitaxial deposition and material characterization.

Funk Software announced that its Odyssey™ WLAN access control and security solution, based on the IEEE security standard 802.1x, will be carried by **TerraWave Solutions**, a distributor of WLAN products and custom WLAN solutions. The companies have signed a distribution agreement enabling TerraWave to sell Odyssey as a WLAN accessory and to incorporate it into custom WLAN implementations developed for TerraWave customers. In addition to Odyssey, TerraWave will offer Funk Software's complete line of security products.

Taconic and **Teradyne Inc. Connection Systems Division (TCS)** have reached an agreement to co-manufacture and market Taconic's patent-pending TacPreg™ material for large format PWB applications at both Teradyne's La Verne, CA, facility and Taconic's plants in Petersburgh, NY, and Mullingar, Ireland. In related news, **Isola AG** announced the formation of an industry alliance with **Taconic Advanced Dielectric Division**. Together, the companies will develop and produce substrate materials for high speed, digital printed circuitry applications. The alliance between the companies will leverage Taconic's product development core competency in the very high frequency microwave domain and Isola's strengths in PCB fabricator technical support and worldwide manufacturing to develop and produce superior substrate materials for high speed digital printed circuitry applications.

Motorola Inc.'s Semiconductor Products Sector and **DuPont Air Products NanoMaterials LLC** plan, under the terms of a recent agreement, to collaborate on an advanced copper chemical mechanical planarization (CMP) formulation. Motorola will provide its CMP formulation for 0.13 to 0.10 micron design rules to DA NanoMaterials, which will manufacture and market the slurry formulation globally.

M-Wave Inc. announced that **Crown International, a Harman International company**, has signed a three-year supply chain management agreement with M-Wave utilizing its virtual manufacturing concept. The company expects to ship up to $2 M of printed circuit boards per year under the terms of the agreement.

TRL Technologies Inc., a subsidiary of **Richardson Electronics**, has been awarded QS-9000 registration from Underwriters Laboratories Inc.

Merrimac Industries Inc. has been granted a patent further protecting its proprietary Multi-Mix® Microtechnology integrated modules. The company had previously obtained patent protection for its unique processing of Multi-Mix products. The new patent establishes Merrimac's rights to the resulting products and provides Merrimac with patent protection on its total solution.

RF Micro Devices Inc. has begun high volume production shipments of power amplifier modules to **Samsung**. Shipments of the global system for mobile communications PA modules represent the company's first PA sales to Samsung. The PA modules complement ongoing sales to Samsung of small signal devices.

Semflex Inc. was awarded Lockheed Martin Corp.'s highest level of supplier recognition, the STAR Supplier Facility Award.

[Continued on page 92]

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■ **Superconductor Technologies Inc.** has been named to Deloitte & Touche's "Technology Fast 50" program for the Los Angeles, CA, area. The program is a ranking of the 50 fastest growing technology companies in the area; rankings are based on the percentage of growth in fiscal year revenues from 1997 to 2001.

FINANCIAL NEWS

■ **RF Micro Devices Inc.** reports sales of $103.9 M for the first quarter ended June 30, 2002, compared to $70.1 M for the same period in 2001. Net income was $2.3 M (1¢/diluted share), compared to a net loss of $28.4 M (17¢/share) for the first quarter of last fiscal year.

■ **TESSCO Technologies Inc.** reports sales of $69.1 M for first quarter ended June 30, 2002, compared to $59.9 M for the same period in 2001. Net income was $1.1 M (25¢/diluted share), compared to $283 K (6¢/diluted share) for the first quarter of last year.

■ **REMEC Inc.** reports sales of $59.1 M for the first quarter ended May 3, 2002, compared to $58.9 M for the same period in 2001. Net loss was $5.2 M (21¢/diluted share), compared to a net loss of $9.2 M (21¢/diluted share) for the first quarter of last year.

■ **Superconductor Technologies Inc.** reports sales of $6.1 M for the second quarter ended June 29, 2002, compared to $4.2 M for the same period in 2001. Net loss was $6.6 M (29¢/diluted share), compared to a net loss of $4.1 M (23¢/diluted share) for the second quarter of last year.

■ **SpaceBridge Semiconductor Corp.** announced the completion of a $21 M (Canadian) financing round led by **SGF Tech**. SGF invested $17 M in support of SpaceBridge's ongoing new product development and marketing efforts.

■ **Antenova** has secured $9.4 M of second round venture capital for its small and directional antenna technology, from a consortium led by **Quester** and **Cambridge Gateway Fund**. This round is almost double the size of Antenova's first round in 2001.

■ **Applied Wave Research Inc. (AWR)** and **CMEA Ventures** have completed AWR's Series B preferred stock financing totaling $7.4 M. CMEA, who will be taking an equity position and providing representation on AWR's board of directors, led the round. The investment will be used to accelerate the development of the company's high frequency electronic design automation solutions and expand AWR's worldwide sales organization.

■ **Marconi Applied Technologies** announced a £72 M management buyout with European venture capitalist **3i**. The move will help secure jobs and aid future development of the business across its locations worldwide. Marconi Applied Technologies is to be re-named **E2V Technologies**.

CONTRACTS

■ **Cree Inc.** has been awarded government contracts totaling $26.5 M, if fully funded, over a three-year period from the Office of Naval Research and Air Force Research Laboratories for silicon carbide MMIC process development. The US Navy, the Missile Defense Agency and the Department of Defense's Title III program jointly funded these contracts.

■ **HUBER+SUHNER** has been awarded a two-year subcontract by General Dynamics Decision Systems to supply microwave assemblies for the Navy's STANDARD Missile Program. The subcontract is valued at $550 K with work to be performed at the Essex, VT, facility. General Dynamics is the prime contractor on the program.

■ **TECOM Industries Inc.**, a TRAK Communications company, has received a contract award from General Dynamics Advanced Information Systems, Mountain View, CA. TECOM will provide both crossed polarized log periodic antenna systems and high frequency monopole antennas to be used in surveillance and intelligence gathering applications.

■ As part of a recently concluded high volume production agreement, the RF Components division of **Raytheon Co.** will supply **Telson Electronics** with the RMPA0951A-102 GaAs HBT power amplifier for the handset manufacturer's TD8600 single-band, dual-mode handset for the Korean and Chinese markets. The agreement marks the first in a series of anticipated production orders between the two companies.

PERSONNEL

■ Cushcraft Corp. has named **Gregory S. Czuba** as its president and chief operating officer. Previously, Czuba had been president of REMEC Wireless, where he led 300 employees in the design, development and manufacture of wireless radio and filter products.

■ KVH Industries has hired **Patrick J. Spratt** as the company's chief financial officer. Spratt succeeds Richard Forsyth, who will remain with the company in the role of VP, finance. Spratt brings 30 years of finance and operations experience to the company.

■ Unity Wireless Corp. announced that **Brian Nixon** and **Doron Nevo** have joined the company's board of directors. Nixon was also named to the non-executive position of vice chairman. Nixon brings over 20 years of corporate and entrepreneurial leadership experience to the board. Most recently, he was senior VP, business solutions with BCE Media Inc. Nevo brings more than 20 years of business experience in high technology and telecommunications to the board. Nevo is president and CEO of Kilo-Lambda Technologies Ltd.

■ Schema has appointed **Roni Abiri** as chief technology officer and **Andrew Burroughs** as chief marketing officer. Abiri brings over 20 years of experience in the telecom industry and will focus on the development of future wireless technologies. Burroughs comes to Schema with

[Continued on page 94]

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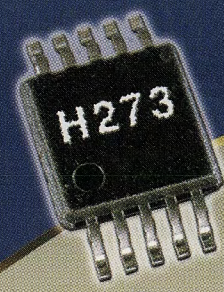

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NEW!	HMC425LP3	6 Bit Digital	2.4 - 8.0	0.5 to 31.5	LP3	$8.22
	HMC273MS10G	5 Bit Digital	0.7 - 3.7	1 to 31	MSOP10	$1.70
	HMC306MS10	5 Bit Digital	0.7 - 4.0	0.5 to 15.5	MSOP10	$2.49
	HMC307QS16G	5 Bit Digital	DC - 4.0	1 to 31	QSOP16	$2.49
	HMC230MS8	3 Bit Digital	0.75 - 2.0	4 to 28	MSOP8	$1.25
	HMC288MS8	3 Bit Digital	0.7 - 3.7	2 to 14	MSOP8	$1.35
	HMC290	2 Bit Digital	0.7 - 4.0	2 to 6	SOT26	$1.05
	HMC291	2 Bit Digital	0.7 - 4.0	4 to12	SOT26	$1.05
	HMC173MS8	VVA	0.8 - 2.0	0 to 30	MSOP8	$2.24
	HMC210MS8	VVA	1.5 - 2.3	0 to 40	MSOP8	$2.24
NEW!	HMC346MS8G	VVA	DC - 8.0	0 to 32	MSOP8	$1.65
	HMC346LP3	VVA	DC - 15.0	30	LP3	$7.67

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ACTUAL SIZE

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MSOP10 14.8mm² 
QSOP16 29.4mm² 
LP3 9mm² 

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over 18 years experience in global telecommunications and the wireless industry, and brings an extensive background in a wide range of fields.

■ Corning Gilbert Microwave Products has named **Carolyn Case** VP of business development. In this new role, Case will lead the company's microwave products business and accelerate the strategic new business ventures for Corning Gilbert worldwide.



▲ Cameron Selogie

■ Semflex Inc. has appointed **Cameron Selogie** as the company's VP and general manager. He will be responsible for developing and implementing growth and profit strategies in all functional areas of the operation.

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■ CMC Wireless Components has appointed **Chris Mosher** East Coast sales director. Mosher has a background in ceramic microelectronic packaging as well as a technical background in material science.



▲ Chris Mosher

■ Sirenza Microdevices has named **Sam Taban** the company's strategic accounts director for Sweden and Finland. Taban will work out of the company's new sales office in Stockholm, Sweden, and brings years of experience in a succession of key design and marketing positions with a number of wireless OEM manufacturers.

■ Zentrix Technologies Inc. has named **Krista Lynch** to its inside sales team as account representative for the powder metals products group. In this position, Lynch is responsible for customer service of the company's copper/tungsten heatsinks used in the wireless and optoelectronics industries.

■ Trompeter Electronics has named **Joe Anderson** field sales engineer for the Dixie States territory of Georgia, Alabama and East Tennessee. Prior to joining the company, Anderson was a regional sales engineer for Atlanta Cable Sales.

WEB SITE

■ **American Beryllia Corp.** has introduced a new Web site, www.americanberyllia.com, that provides product designers with complete information on the company's ability to press, extrude, and fire BeO to suite a wide variety of product development requirements. The site includes a brief company overview, information on manufacturing capabilities and services inclusive of material preparation (forming), firing, and finishing methods available to meet exact customer requirements.

REP APPOINTMENTS

■ **Link Microtek** has been appointed as exclusive UK distributor for Japanese ceramic filter manufacturer **UBE Electronics**. Link Microtek will be supplying UBE's complete range of low profile surface-mount filters and high performance dielectric filters and diplexers.

■ **Schumacher**, a unit of **Air Products and Chemical Inc's global Electronics Division**, has signed a long term agreement with **Dow Corning** to serve as the global master distributor of three new liquid chemical vapor deposition precursors — Z4MS,™ ZTOMCATS™ and Z2DM.™

■ **Vitelec Electronics** has named **Charcroft Electronics** as a franchised distributor. The move is designed to carefully match customers with the distributor that provides the best fit in terms of area of expertise. The agreement covers Vitelec's RF coaxial connectors and cable assemblies for defense, aerospace, instrumentation, contract manufacturing and industrial applications.

■ **Phase One Microwave Inc.**, Rocklin, CA, has made a series of new rep appointments. **Boston Micro-Components** will handle the New England states of Vermont, New Hampshire, Connecticut, Massachusetts and Rhode Island. **Northern Technical Sales** will be responsible for upstate New York and **J-Square Marketing** will cover metro New York, including Long Island and northern New Jersey. **Scientific Devices-Phila.** will handle eastern Pennsylvania, Delaware and southern New Jersey. **Eastern Tech Corp.** will be responsible for Maryland, Virginia and Washington, DC, while **Q-Mark** will handle Ohio, western Pennsylvania, Indiana, Kentucky and Michigan.

■ **Hittite Microwave Corp.** has appointed two new sales representative firms to serve customers in India and Taiwan. **Syratron Marketing Private Ltd.**, headquartered in Bangalore, will handle sales in India, while **Bandtek International Co. Ltd.** will cover the market in Taiwan.

■ **M-tron Industries Inc.** has signed **Arrow Electronics** as a distributor. Arrow is one of the largest distributor's of electronic components and computer products. The partnership between the two companies is designed to help raise the bar for customer expectations in frequency control devices products and supply chain management.

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OPTIMIZING LINK PERFORMANCE, COST AND INTERCHANGEABILITY BY PREDICTING RESIDUAL BER: PART II — NONLINEARITY AND SYSTEM BUDGETING

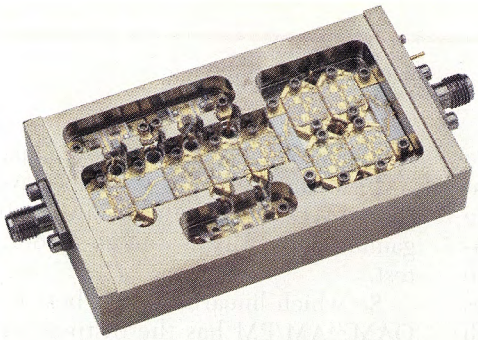
This is the second part of a two-part tutorial on residual BER prediction for cost optimization of oscillator phase noise and power amplifier linearity. Today's demanding digital modulations require a different type of analysis at 'normal' receive power levels than for the familiar link budgets used at 'threshold' to assure high quality error free data transport. Residual BER prediction allows the radio designer to optimize the cost of the key analog components that, despite the revolution in digital signal processing, often still represent the majority of a data link's cost.

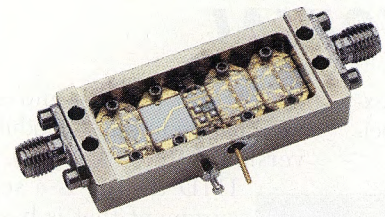
In part I, the economic case from the network operator's perspective was reviewed and it was found that as operators improve their residual BER performance, their market space is expanded from simple voice applications to e-commerce transactions and other data traffic which demands ultra low error rates. Next, the residual BER performance was found to be primarily a function of the combination of the radio system's sources phase noise and the power amplifier (PA) nonlinearity impairments.

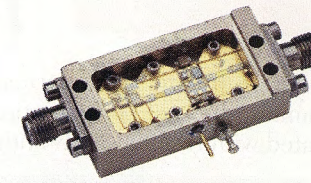
A Gaussian symbol distribution resulting from random noise was statistically related to the probability of a symbol error using σ, the standard deviation. This was refined for the phase noise specific case by the realization that the RMS phase noise, integrated over the appropriate limits, is equivalent to the standard deviation. Thus, it is possible to characterize and account for the phase noise impairment's effect on the symbol error rate, one of the two primary influences on residual BER. Now nonlinear distortion is considered and a

[Continued on page 98]

KENT K. JOHNSON
Agilent Technologies







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Ultra broadband

Model	Freq. Range GHz	Gain dB min	N/F dB max	Flatness +/–dB	1 dB Comp. pt. dBm min	3rd Order ICP typ	VSWR In/Out max	DC Current mA
JCA018-203	0.5–18.0	20	5.0	2.5	7	17	2.0:1	250
JCA018-204	0.5–18.0	25	4.0	2.5	10	20	2.0:1	300
JCA218-506	2.0–18.0	35	5.0	2.5	15	25	2.0:1	400
JCA218-507	2.0–18.0	35	5.0	2.5	18	28	2.0:1	450
JCA218-407	2.0–18.0	30	5.0	2.5	21	31	2.0:1	500

Multi-octave amplifiers

Model	Freq. Range GHz	Gain dB min	N/F dB max	Flatness +/–dB	1 dB Comp. pt. dBm min	3rd Order ICP typ	VSWR In/Out max	DC Current mA
JCA04-403	0.5–4.0	27	5.0	1.5	17	27	2.0:1	550
JCA08-417	0.5–8.0	32	4.5	1.5	17	27	2.0:1	550
JCA28-305	2.0–8.0	22	5.0	1.0	20	30	2.0:1	550
JCA212-603	2.0–12.0	32	5.0	3.0	14	24	2.0:1	550
JCA618-406	6.0–18.0	20	6.0	2.0	25	35	2.0:1	600
JCA618-507	6.0–18.0	25	6.0	2.0	27	37	2.0:1	800

Medium-power amplifiers

Model	Freq. Range GHz	Gain dB min	N/F dB max	Flatness +/–dB	1 dB Comp. pt. dBm min	3rd Order ICP typ	VSWR In/Out max	DC Current mA
JCA12-P01	1.35–1.85	35	4.0	1.0	33	41	2.0:1	1000
JCA34-P02	3.1–3.5	40	4.5	1.0	37	45	2.0:1	2200
JCA56-P01	5.9–6.4	30	5.0	1.0	34	42	2.0:1	1200
JCA812-P03	8.0–12.0	40	5.0	1.5	33	40	2.0:1	1700
JCA1218-P02	12.0–18.0	22	4.0	2.0	25	35	2.0:1	700

Low-noise octaveband LNAs

Model	Freq. Range GHz	Gain dB min	N/F dB max	Flatness +/–dB	1 dB Comp. pt. dBm min	3rd Order ICP typ	VSWR In/Out max	DC Current mA
JCA12-3001	1.0–2.0	40	0.8	1.0	10	20	2.0:1	200
JCA24-3001	2.0–4.0	32	1.2	1.0	10	20	2.0:1	200
JCA48-3001	4.0–8.0	40	1.3	1.0	10	20	2.0:1	200
JCA812-3001	8.0–12.0	32	1.8	1.0	10	20	2.0:1	200
JCA1218-800	12.0–18.0	45	2.0	1.0	10	20	2.0:1	250

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Model	Freq. Range GHz	Gain dB min	N/F dB max	Flatness +/–dB	1 dB Comp. pt. dBm min	3rd Order ICP typ	VSWR In/Out max	DC Current mA
JCA12-1000	1.2–1.6	25	0.75	0.5	10	20	2.0:1	80
JCA23-302	2.2–2.3	30	0.8	0.5	10	20	2.0:1	80
JCA34-301	3.7–4.2	30	1.0	0.5	10	20	2.0:1	90
JCA56-401	5.4–5.9	40	1.0	0.5	10	20	2.0:1	120
JCA78-300	7.25–7.75	27	1.2	0.5	13	23	2.0:1	120
JCA910-3000	9.0–9.5	25	1.3	0.5	13	23	1.5:1	150
JCA910-3001	9.5–10.0	25	1.4	0.5	13	23	1.5:1	150
JCA1112-3000	11.7–12.2	27	1.4	0.5	13	23	1.5:1	150
JCA1213-3001	12.2–12.7	25	1.4	0.5	10	20	2.0:1	200
JCA1415-3001	14.4–15.4	35	1.6	1.0	14	24	2.0:1	200
JCA1819-3001	18.1–18.6	25	2.0	0.5	10	20	2.0:1	200
JCA2021-3001	20.2–21.2	25	2.5	0.5	10	20	2.0:1	200

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system budget is constructed to examine the cost considerations associated with residual BER budgeting.

... a system budget is constructed to examine the cost considerations associated with residual BER budgeting.

NONLINEARITY DISTORTION

Having reviewed quadrature amplitude modulation (QAM) digital radio concepts, a basic noise model and the extension of that noise model to phase noise, let's now examine nonlinear distortion as it applies to residual BER. As with the noise case, common nonlinear models will be reviewed first. The ones best for solving the problem of predicting residual BER will then be isolated.

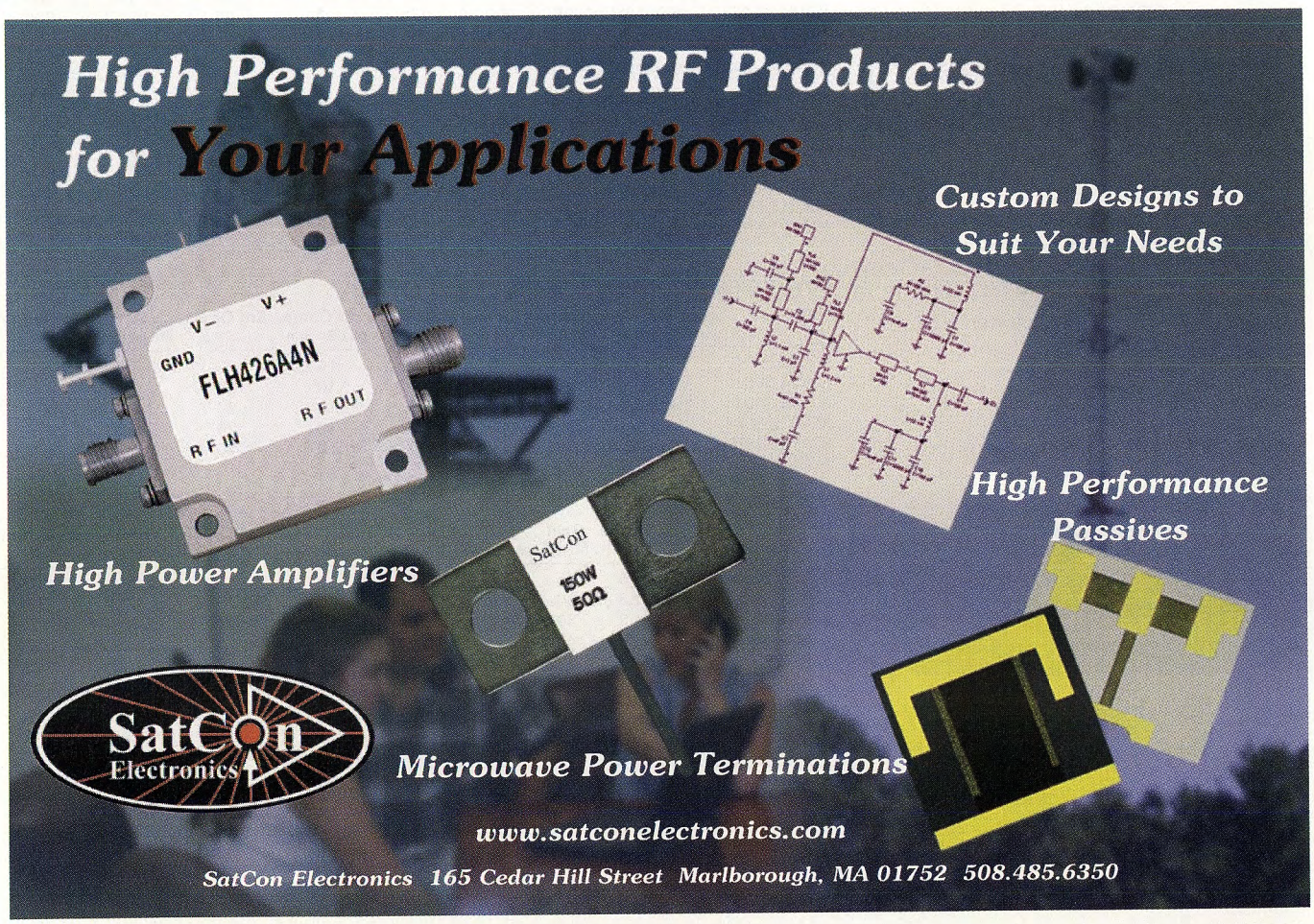
Commonly used linearity metrics are two-tone intermodulation distortion (IMD) testing and amplitude modulation to phase modulation conversion testing (AM/PM). Two-tone IMD testing is a scalar measurement that is based on the internal mixing of harmonics generated in the device at high powers. It is indirectly related to BER and has long been used as a figure of merit. Unfortunately, correlation studies of BER vs. IMD have shown correlation as low as 85 percent, making system residual BER performance uncertain. Despite the inaccuracies of IMD, it has traditionally been the test for linearity characterization (mostly because of the perception of lower equipment costs).

AM/PM testing is a vector measurement typically requiring a vector network analyzer (VNA). It is based on measuring a relative microwave phase shift as power is increased. AM/PM is directly related to the BER mechanism and is an analytical part of the residual BER system budget. Recent decreases in the cost of vector network analyzers now make AM/PM measurement less expensive than IMD measurement and it is gaining popularity as a more modern test.

So which linearity test is best for QAM? AM/PM has the distinct advantage of being the best choice for high quality of service (QoS) systems where residual BER is of importance. Let's examine why AM/PM is the measurement of choice.

At low power levels, amplifiers exhibit a linear behavior, such that small signals are amplified by a fixed amount of gain. Given some power input, the amplifier is said to behave linearly if the power output is a fixed ratio larger. As the input signal grows larger, a point is reached where the output signal will stop getting bigger and the amplifier is said to be saturated. The linear relationship between input and output no longer exists. Many measurements have been devised to characterize this phenomenon.

[Continued on page 100]



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AG202	15 dB	+20 dBm	+7 dBm
AG203	20 dB	+20 dBm	+7 dBm
AG302	15 dB	+27 dBm	+13 dBm
AG303	20.5 dB	+27 dBm	+13 dBm
AG402	15 dB	+33 dBm	+17 dBm
AG403	20.5 dB	+32 dBm	+17 dBm
AG503	19 dB	+29 dBm	+15 dBm
AG602	14 dB	+33.5 dBm	+18.5 dBm
AG603	17.5 dB	+33.5 dBm	+18.5 dBm
AG604	21 dB	+33 dBm	+18 dBm

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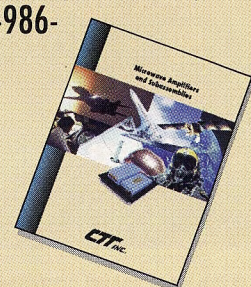

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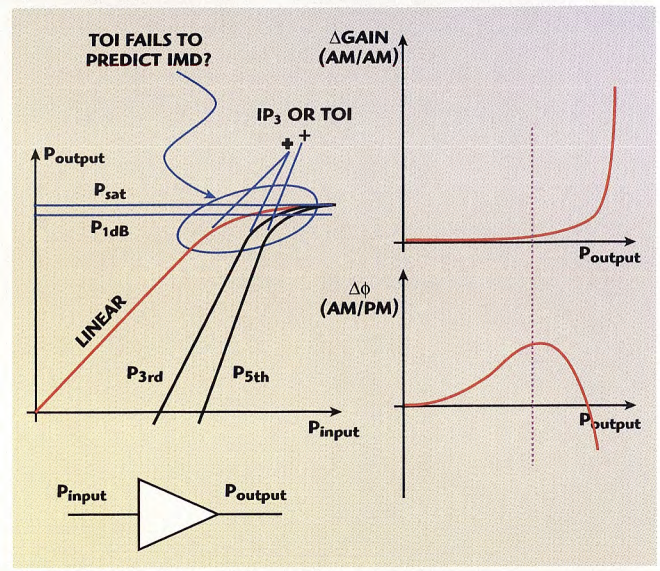

Fig. 1 Common amplifier linearity metrics.

Gain compression is a term used to describe the difference between the saturating amplifier's performance and the theoretically ideal performance. The so-called P1dB is a measure of the output power at 1 dB of gain compression.

Two-tone intermodulation (IMD) is a measurement designed to predict the amount of unwanted modulation energy created by the nonlinear saturation process. It measures the third- or fifth-order intermodulation products. A third-order intercept point can be calculated from the third- and fifth-order products, which is helpful in predicting the level of intermodulation distortion.

Though commonly used, none of these linearity metrics is ideally suited for predicting the residual BER because PAs are operated in a region where an abrupt change in device linearity occurs where IMD and the third-order intercept (TOI) point measurements fail.

To predict residual BER, linearity metrics that directly relate to the QAM vector in amplitude and phase are needed. Gain compression, or the difference between the ideal linear gain and the actual gain, is an amplitude modulation due to amplitude modulation conversion (AM/AM).

AMPLITUDE AND PHASE DISTORTION

As the power is increased, the phase delay through an amplifier begins to change as it nears saturation. This change in phase shift as the power is increased or modulated is AM/PM modulation. As will be seen later, this modulation is additive to the QAM vector. AM/AM and AMPM are unwanted modulations that affect the accuracy of where the symbol point position on the constellation falls.

The two graphs of ***Figure 1*** show the distortions in relation to each other (that is with the same power scale). Note that significant phase shifts occur before significant amplitude shifts appear. Typically, only a few tenths of a degree of AM/AM occur while several degrees of AM/PM

[Continued on page 102]

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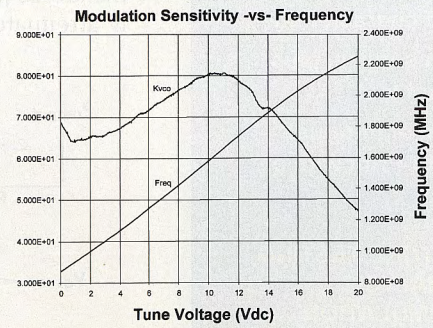
VCO790-1500T	1000-2000	0.0 - 20.0	-98 dBc/Hz	+5 V	+2 dBm	0.5 x 0.5 x 0.18 in.
VCO790-2300T	2100-2500	1.0 - 4.0	-89 dBc/Hz	+5 V	+3 dBm	0.5 x 0.5 x 0.18 in.
VCO793-600T	400-800	0.0 - 20.0	-104 dBc/Hz	+12 V	+7 dBm	0.5 x 0.5 x 0.18 in.
VCO793-1500T	**1000-2000**	**0.0 - 20.0**	**-99 dBc/Hz**	**+12 V**	**+7 dBm**	**0.5 x 0.5 x 0.18 in.**

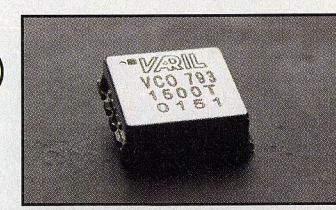
Actual data for VCO793-1500T

Phase noise from HP3852 for 1000-2000 MHz VCO



Tuning Sensitivity from HP3852 for 1000-2000 MHz VCO





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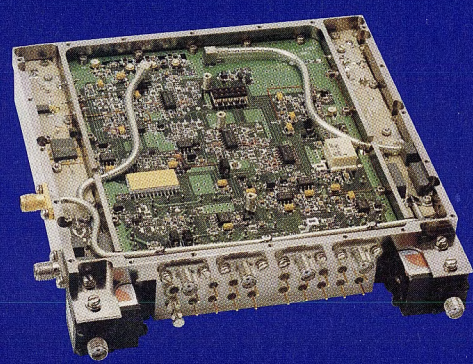

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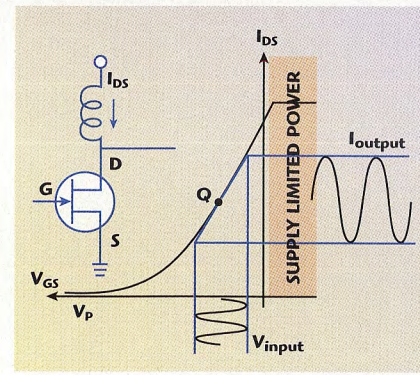

Fig. 2 Simplified amplifier model.

have built up. The QAM modulation is much more sensitive to the AM/PM distortion and a few degrees of distortion are quite significant, whereas 0.1 to 0.3 dB of AM/AM has little effect. This phenomenon allows a key simplifying assumption that AM/AM is a secondary effect and can be ignored in the analysis.

Sometimes it is helpful to review the mechanisms that actually generate these unwanted distortions in the power amplifier, providing insight into the controlling factors. The simple GaAs MESFET model, shown in ***Figure 2***, will be used to illustrate the principles. To keep it simple, the effects of microwave matching circuits that are of finite bandwidth and linear in nature are omitted. The GaAs FET voltage-to-current characteristic behaves as a square law device. If driven with a small signal input voltage, the current is modulated about the *Q* point on the output. Typically, most QAM microwave power amplifiers are built from class A designs for maximum linearity.

The raw DC power supplied to the FET to establish the *Q* point must be limited to constrain the device's operating temperature. Minimizing the device's operating temperature slows the semiconductors defect migration to assure a long operating life.

Next, let's see how AM/AM and AM/PM IMD products are created in the device. In a two-tone IMD test, identical amplitude tones separated slightly in frequency are injected into the input of the amplifier. The power supply cannot deliver additional current so the superimposed sine waves are clipped. This gives rise to second, third harmonics, etc., which mix together forming the IMD products, as illustrated in ***Figure 3***. This mixing action actually takes place in the device junction and often the harmonics are substantially attenuated by the band-limited output matching networks. Thus, it is often not possible to directly compute the intermodulation products using the measured harmonic power for microwave amplifiers. However, it is a simple process to measure the relative attenuation of the IMD products with a spectrum analyzer.

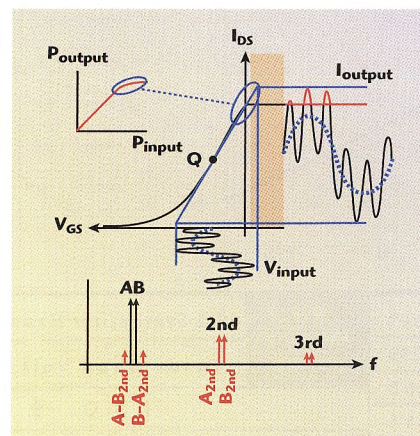

Fig. 3 Two-tone intermodulation distortion.

Does saturation really produce

[Continued on page 104]

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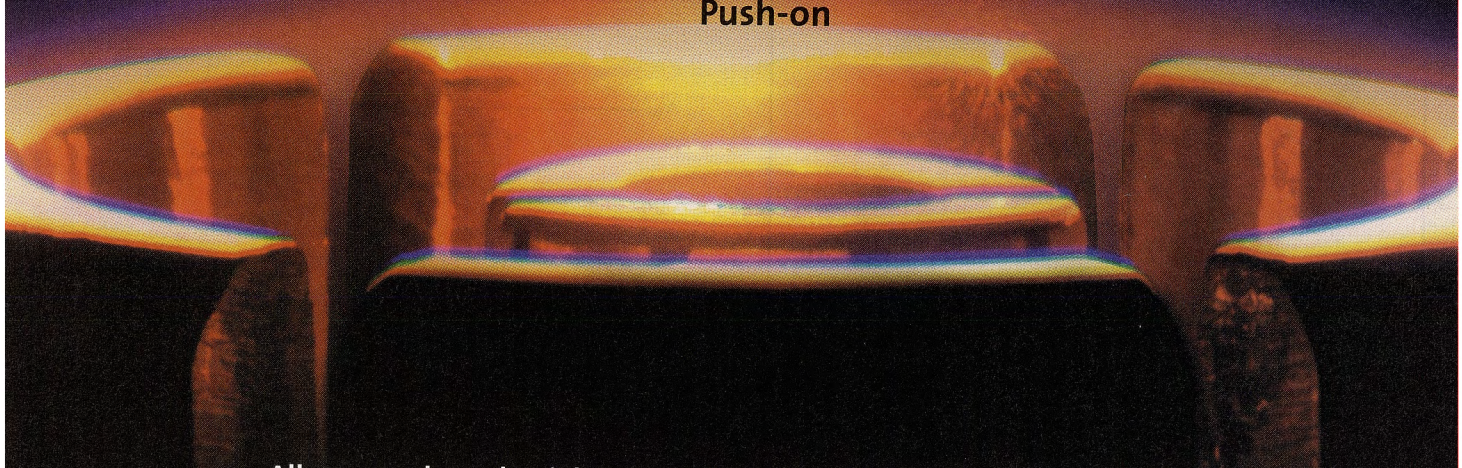

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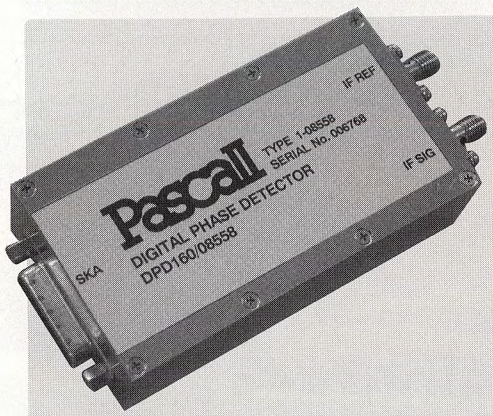

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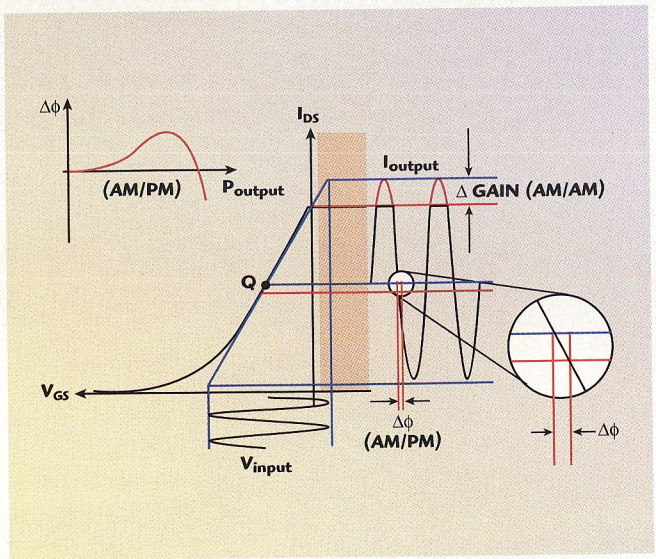

Fig. 4 AM/AM and AM/PM conversion mechanisms.

such an abrupt clipping of the two sine waves? Well, that depends very much on the particular FET and how it is biased. Forward gate rectification can be very abrupt, while pinch off or the square law curve are much more subtle saturation characteristics. Hence, the amount of harmonic energy available to be converted into intermodulation products is very dependent on the abruptness of the nonlinearity. Here lies the major problem with using IMD to predict BER from correlation studies. The IMD measurement is just a single point on the P_{Output} *vs.* P_{Input} curve and only predicts linearity for small signal characteristics, but QAM modulation operates over a range of vector amplitudes near saturation that include abrupt changes in linearity.

The AM/AM mechanism is very simple to examine with the amplifier model. If a single sine wave is fed to the amplifier and the power source cannot supply the necessary current, the amplitude is clipped, resulting in a reduced output. This reduction is gain compression or AM/AM. AM/AM is easily measured with either a source and spectrum analyzer or a network analyzer.

The phenomenon that gives rise to AM/PM again begins with the power source limitation creating a clipping or mushing of the waveform. Since the top of the waveform is not correctly amplified, the average value or zero crossing is offset from the original position. This offset in zero crossing occurs where the sine wave has finite slope creating a phase shift in the output signal.

It is interesting to note that if the input signal is increased still further, clipping on the bottom of the sine wave would occur as the output begins to resemble a square wave. Clipping at both ends causes the average offset to come back towards that of the original sine wave; hence, the characteristic rise and fall of the AM/PM curve. The AM/AM and AM/PM mechanisms are illustrated in ***Figure 4***. It is also important to note that the microwave matching circuits strongly affect the impedance, hence the voltage and current relationship, as well as the clipping on the output of the device, are affected.

[Continued on page 106]

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The AM/PM phase shift as a function of signal amplitude or vector length distorts the ideal symbol location of the QAM symbol constellation, as shown in ***Figure 5***. Outer symbols have the largest vector length and suffer the most AM/PM distortion. AM/PM testing is typically done with a CW sine wave (though it is possible and even necessary to occasionally measure it with a modulated signal and vector signal analyzer (VSA)). This is an important fact because it relates a CW parametric test to the actual distortion impairment of the QAM symbol constellation.

The ability to relate a parametric analog test to the actual error mechanism provides the means to predict digital error rates from traceable standards. So how does one relate the vector length to known traceable standards? And what range of vector lengths do we need to measure the distortion? What do the power meters used to setup the transmit power actually measure? A power meter measures the RMS CW or modulated power. Testing AM/PM with a CW source requires relating the average modulated power to the average CW power.

MODULATED POWER LEVELS

At first glance, the constellation geometry can be used to calculate the RMS vector length. However, the worst-case AM/PM occurs at the longest vector length or highest peak power. Calculating the peak-to-average ratio from the constellation to correct the measured power is an important step in determining what CW test signal power is necessary for AM/PM testing.

A peak-to-average power correction is only one part for determining the highest power at which to test AM/PM. In between symbol states the vector overshoots the boundaries of the constellation. The so-called 'overshoot power' or 'trajectory power' represents the longest vector length. Though understood, the overshoot phenomena is beyond the scope of this tutorial, so let's simply say that it is a function of baseband filtering α.

What test conditions are necessary to properly characterize the distortion of the power amplifier? The gain and phase distortions need to be characterized over the range of modulation powers. This means that AM/PM should be tested from the smallest vector needed to produce the modulation to the largest vector (including overshoot), or in other words, over the vector range. Correction factors for peak-to-average and overshoot powers, typically about 3

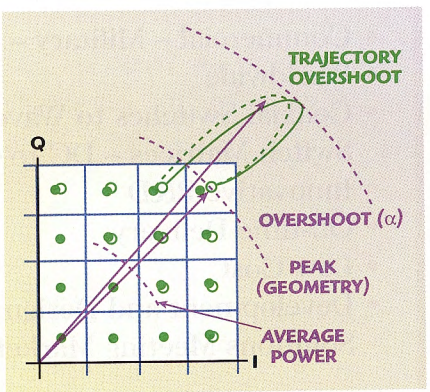

Fig. 5 AM/PM and QAM power levels.

[Continued on page 108]

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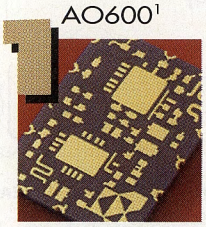

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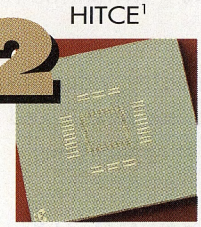

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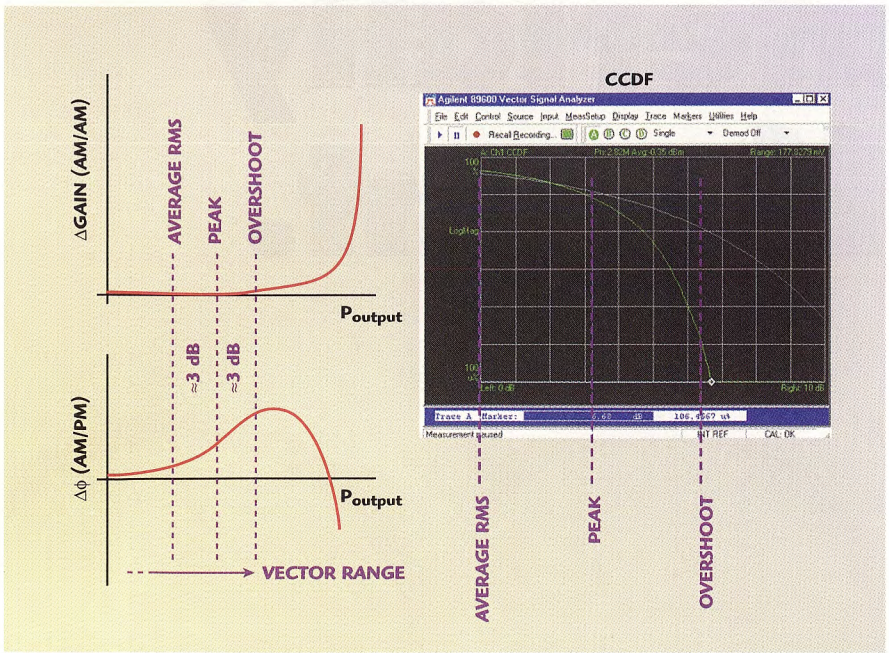

Fig. 6 Test conditions using CCDF.

dB each, must be added to the average power to come up with the overshoot power. Similarly, minimum-to-average power can be subtracted from the average power to determine the lowest power required. In practical terms the low power limit can be set to where no appreciable AM/PM modulation is observed, eliminating the need to calculate minimum to average.

The important thing is that the amplifier's linearity is actually measured at the overshoot power where the distortion will be the most significant. Testing at average power (what the power meter measures) would be very misleading. One approach to determining the appropriate vector range is to measure the complementary cumulative distribution function (CCDF) of the modulated signal. This VSA test shows the overshoot or trajectory vector length, as shown in ***Figure 6***.

There are two types of AM/PM measurements, spot and swept. The classical diagram of AM/PM or $\Delta\phi$ versus power level, often seen in linearizer work, is a spot frequency versus swept power measurement. This measurement is best suited for fixed frequency operation since the matching, hence AM/PM, is usually a function of frequency. Another approach is to use a swept frequency measurement at a spot power delta. This measurement is best suited for broadband devices that operate over a range of frequencies. It requires the assumption that the

[Continued on page 110]

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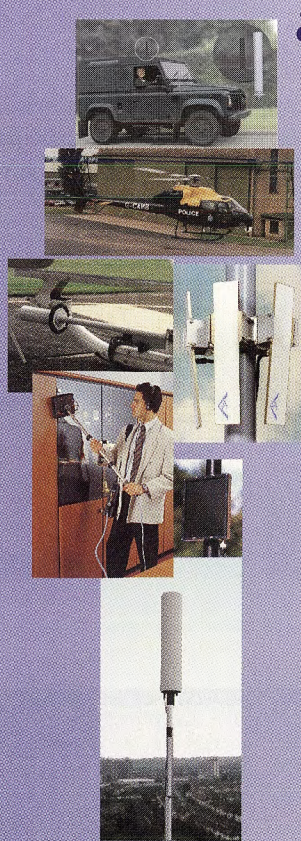

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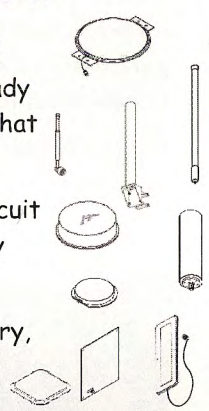

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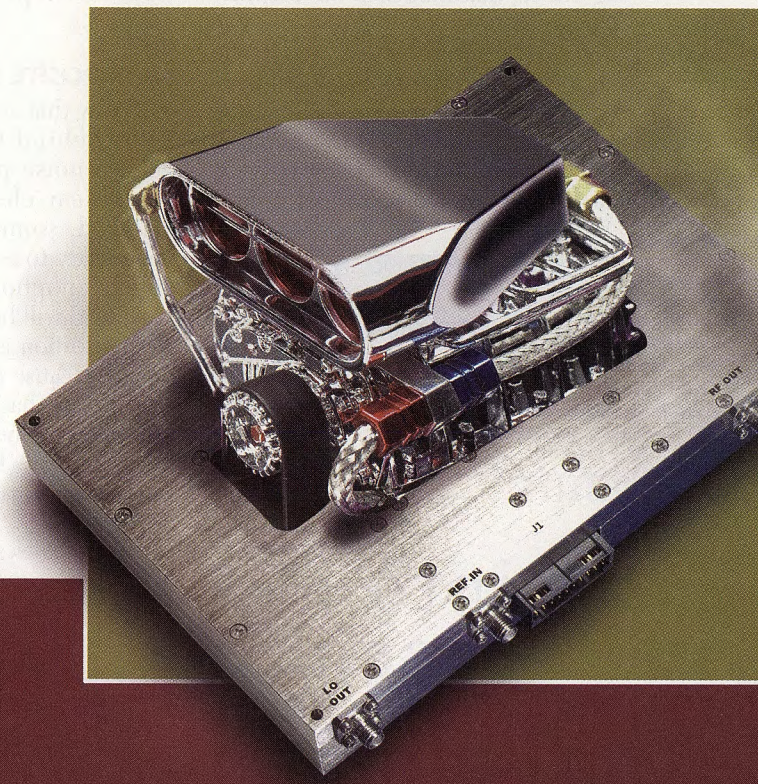

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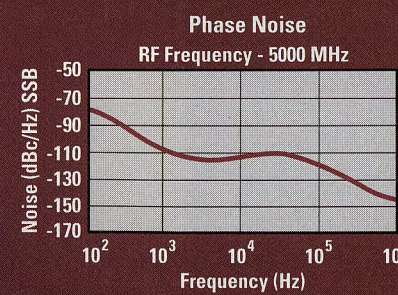

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AM/PM increases monotonically over the power range of interest, which is virtually always the case for QAM signal amplifiers. These two approaches are shown in ***Figure 7***.

The swept frequency AM/PM measurement requires the PA output power to be calibrated across the band of interest at a low power (power cal). Next, the phase is calibrated to zero with the PA in place (since this is a relative measurement). Finally, the power is increased to the overshoot power and the AM/PM across the band can be observed. AM/PM measurements must be done quickly to avoid junction-cooling effects that influence the accuracy of the measurement. If it is not possible to make the measurement quickly, the more complicated complex stimulus/response method is required. Often, the author has found that QAM amplifier designers optimize their designs for maximum saturated power out or lowest IMD at high power. Power amplifiers used in high QoS links should be optimized for minimum AM/PM over the vector range across the band of interest (swept frequency, spot delta power).

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Now that some of the basic principles behind QAM digital radio, a phase noise probability model and nonlinear elements have been reviewed, some of the mathematics necessary to combine them as well as the assumptions and approximations involved will be considered.

Distortion is directly additive to the noise because it operates on the vector itself. This has the effect of offsetting the mean value of the probability density function (PDF), as shown in ***Figure 8***. Distortion by itself has no error

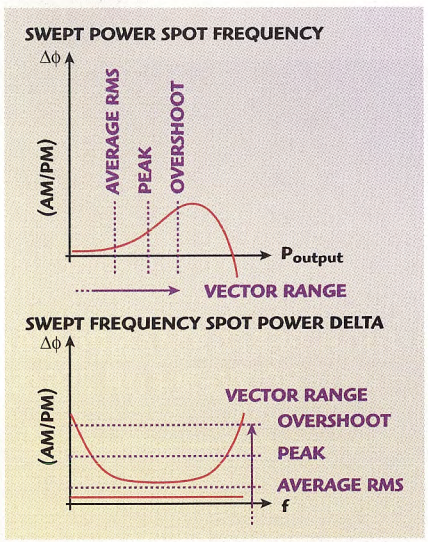

Fig. 7 Spot vs. swept measurements.

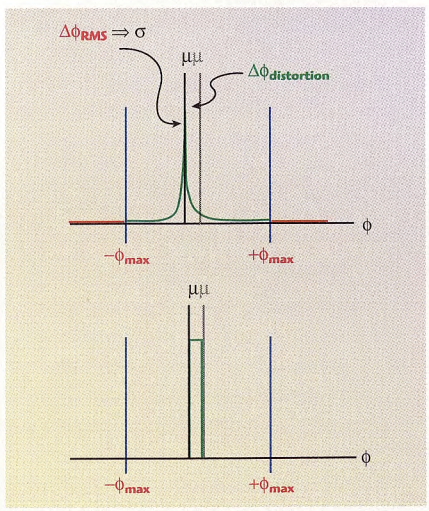

Fig. 8 Noise and distortion.

[Continued on page 112]

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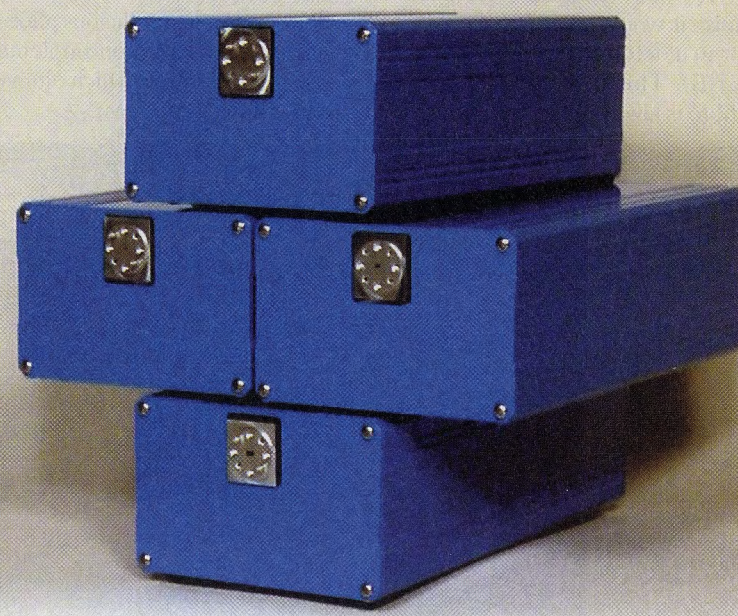

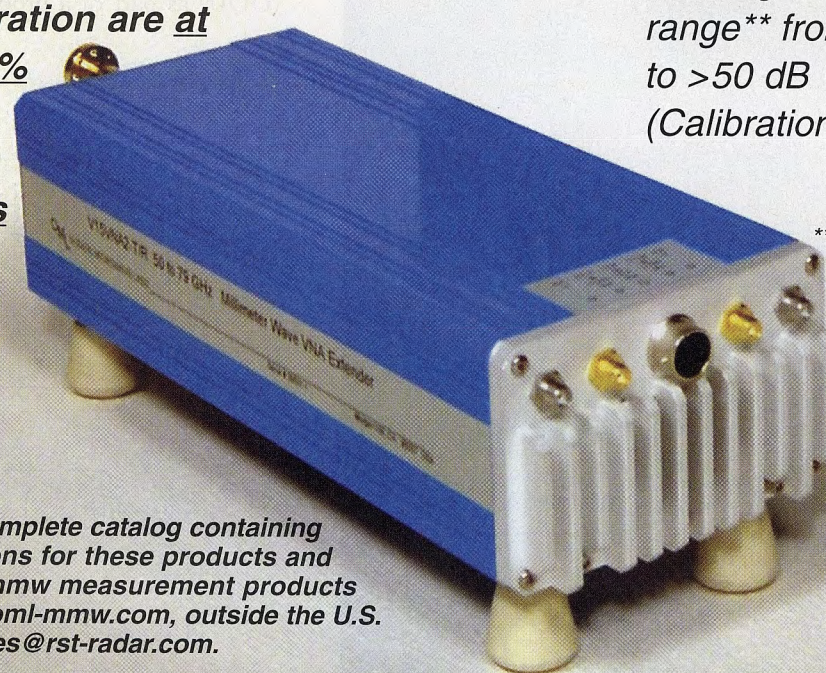

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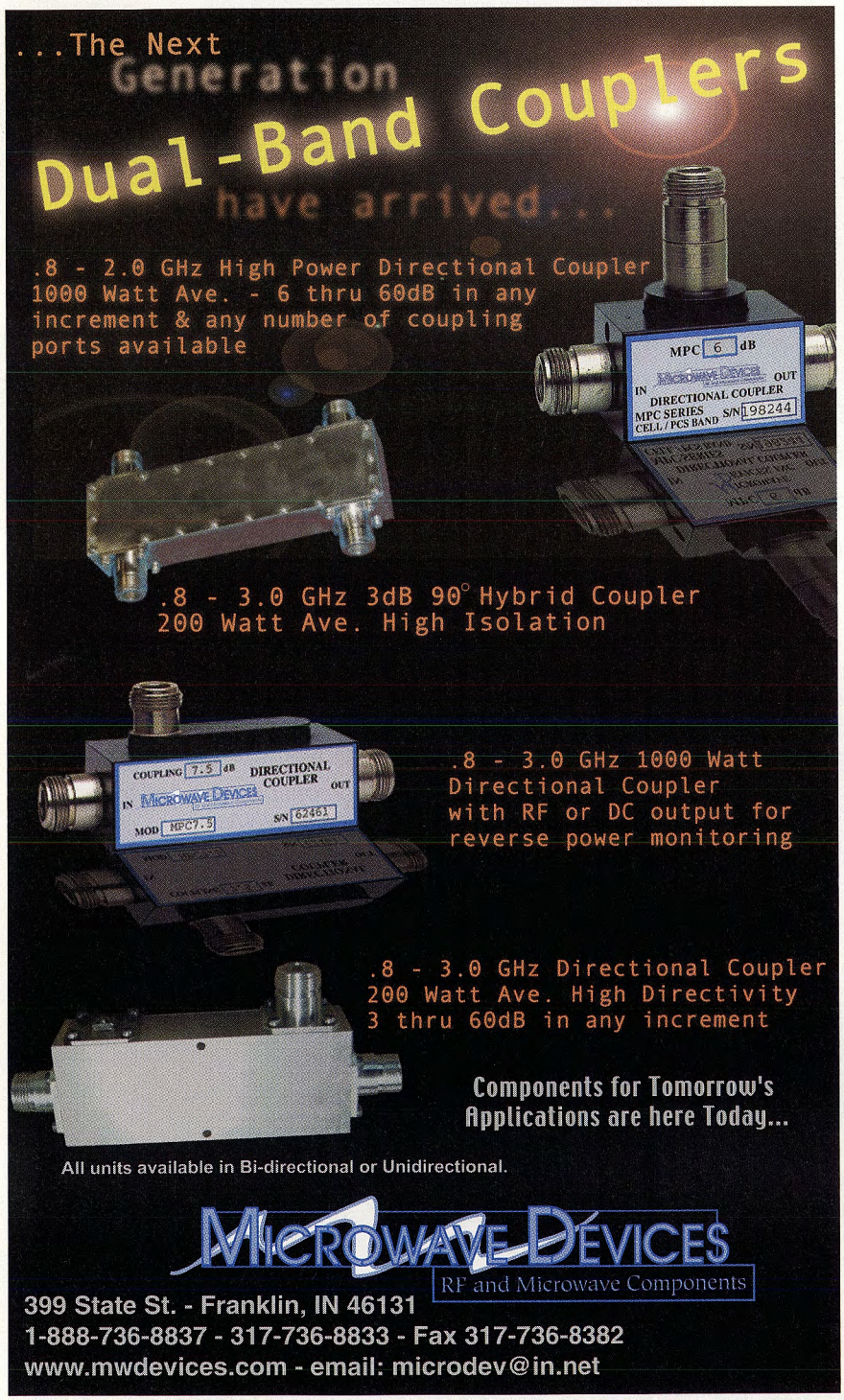
probability density function — it is purely deterministic. At first this might seem counter-intuitive, but it requires the randomness of phase noise to create random dribbling errors. What if the distortion was so large that the sample point fell beyond the symbol boundary? It would make an error, but without noise it would always make the same error in a deterministic way (non-varying BER). This does not happen because there is always noise present.

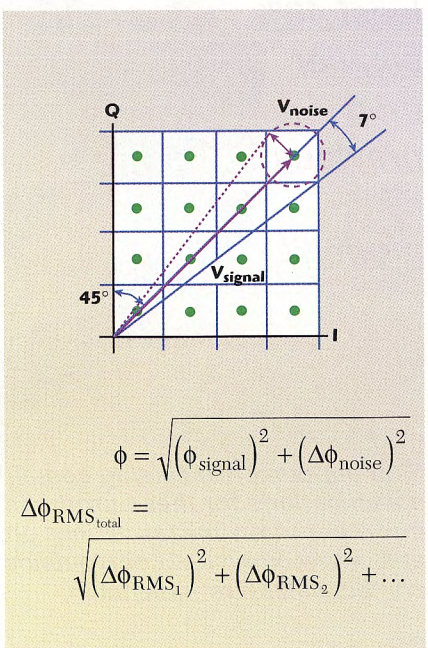
Residual BER is a function of both the power amplifier linearity and the phase noise of all the sources in the system. This is a very important point, for there is often disagreement over whether the PA or one of the sources is to blame for dribbling errors. The answer is that they both influence the error floor and only a judicious allocation budget (usually based on implementation cost) can sort out which element is bringing the system down.



The system phase noise can be represented by a noise vector, which adds geometrically to the desired modulation vector, as shown in ***Figure 9***. Noise from more than one source can be added geometrically to obtain the total noise for the system.

The sources in the modem and the conversion process all contribute to the overall system phase noise. Thus, residual BER is a function of both the modem and RF sources. Both transmitter and receiver sources affect the residual BER. These are very important points. It is not possible to evaluate the system residual BER without both the modem and the RF. Likewise, it is not possible to evaluate the system residual BER without both the modulator/transmitter and receiver/demodulator. This means that loop-back testing to exonerate the modem from dribbling error problems is not a valid approach. In addition, most golden transmitters and golden receivers are not valid for testing residual BER. Only golden units with sources and amplifiers that have worst-case phase noise and distortion can be used for testing residual BER (a difficult proposition to construct).

Remember not to use golden modems or wireless outdoor units (ODU) as part of a production proc-



▲ *Fig. 9 System phase noise and geometric effects.*

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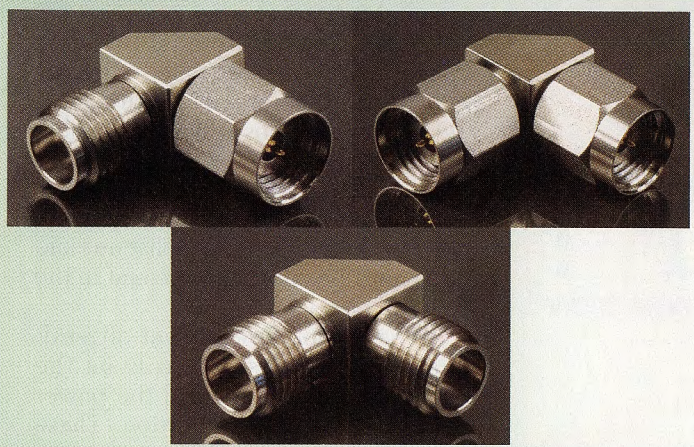

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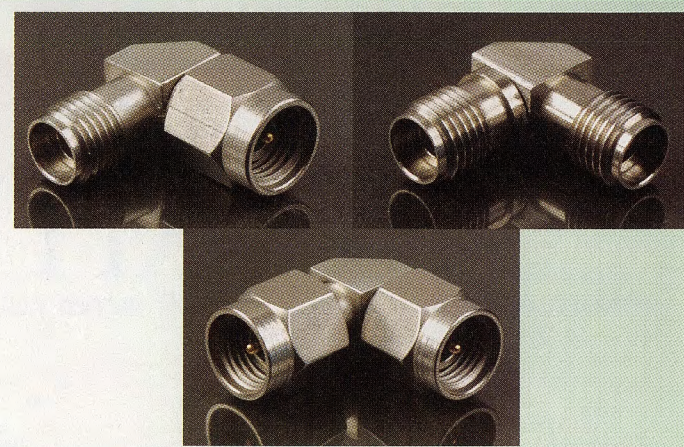

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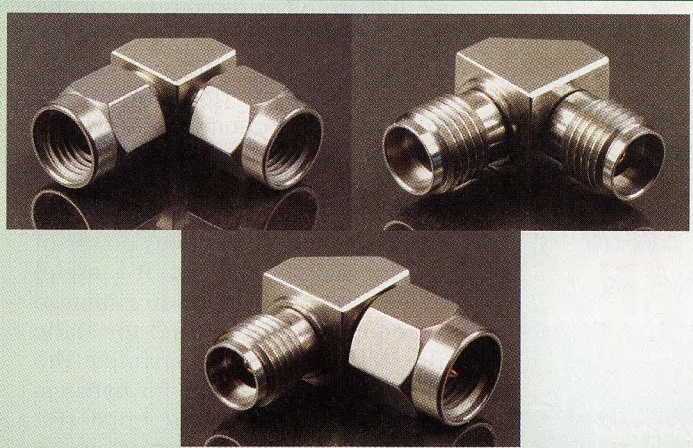

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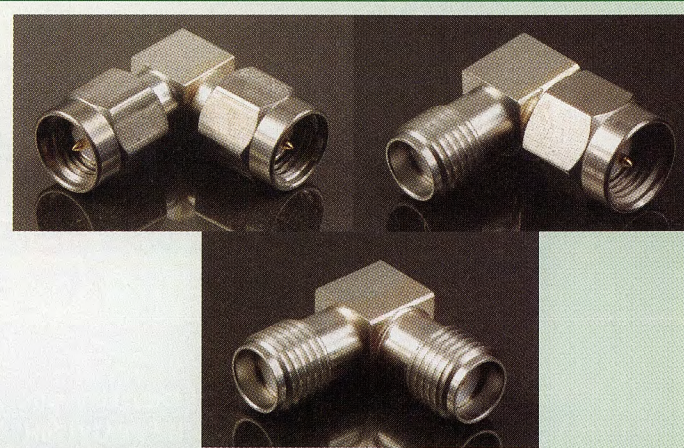

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ess when measuring residual BER. The golden modem, or golden ODU, with its better than worst-case performance, can easily mask other problems in a radio chain, causing a unit passing in production tests to dribble errors during operation in the field. High QoS systems require parametric testing of the primary phase noise and distortion components to guarantee consistent interchangeable part performance. The QAM symbol constellation has some important geometric effects to consider. The outer symbol points can tolerate the least angular error. In the 64 QAM constellation, the outer most point can tolerate a maximum of 7.7° of error before making a symbol decision error versus the inner most point, which can tolerate 45° of error. The outer most point also has the longest vector length and corresponding highest angular distortion. The maximum angular error is symbol location dependent, but the phase noise is a constant for all symbol points. Thus, the number of sigma to the boundary is dependent on the symbol location, with the outer symbols having the fewest sigma to the boundary.

The error probability of each symbol must be weighted, based on the probability of symbol occurrence. Usually, symbols are equi-probable and symbol boundaries are setup on a simple grid pattern. There are some QAM modulations where probability of occurrence and grid patterns are not so simple (usually to take advantage of the fact most errors are made on the edge of the constellation) and this must be taken into account in the system model.

The model development of residual BER focuses primarily on the source's phase noise and the power amplifier AM/PM distortion. These key components usually represent the greater part of the residual error budget and are often responsible for the vast majority of the cost of the radio. There are other secondary contributors to the error floor, including group delay distortion or inter symbol interference (ISI).

In most cases group delay distortion is not a significant factor largely because of the tremendous power of modern digital equalizers. It is useful to be aware of its effects to minimize the equalization required for static filter effects and to maximize the equalizer's performance for dynamic channel fading. In some burst systems, where equalizer performance is limited, group delay distortion should be taken into account.

There are many other secondary contributors to the symbol error mechanisms. In this simple model, they are assumed to be insignificant, which in practice is usually the case. Filters introduce group delay into the modulated channel. The spectral energy associated with a change in phase is dependent on the magnitude of phase modulation. Small changes in phase occupy small bandwidths; large changes in phase occupy larger bandwidths. The delay difference associated with the two spectrums pro-

[Continued on page 117]

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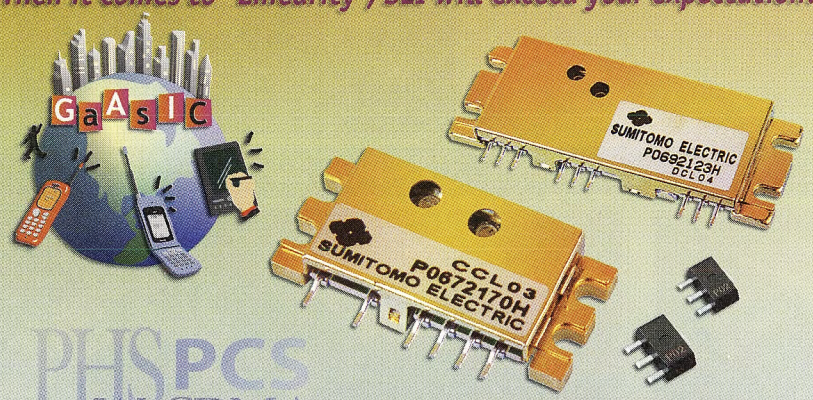

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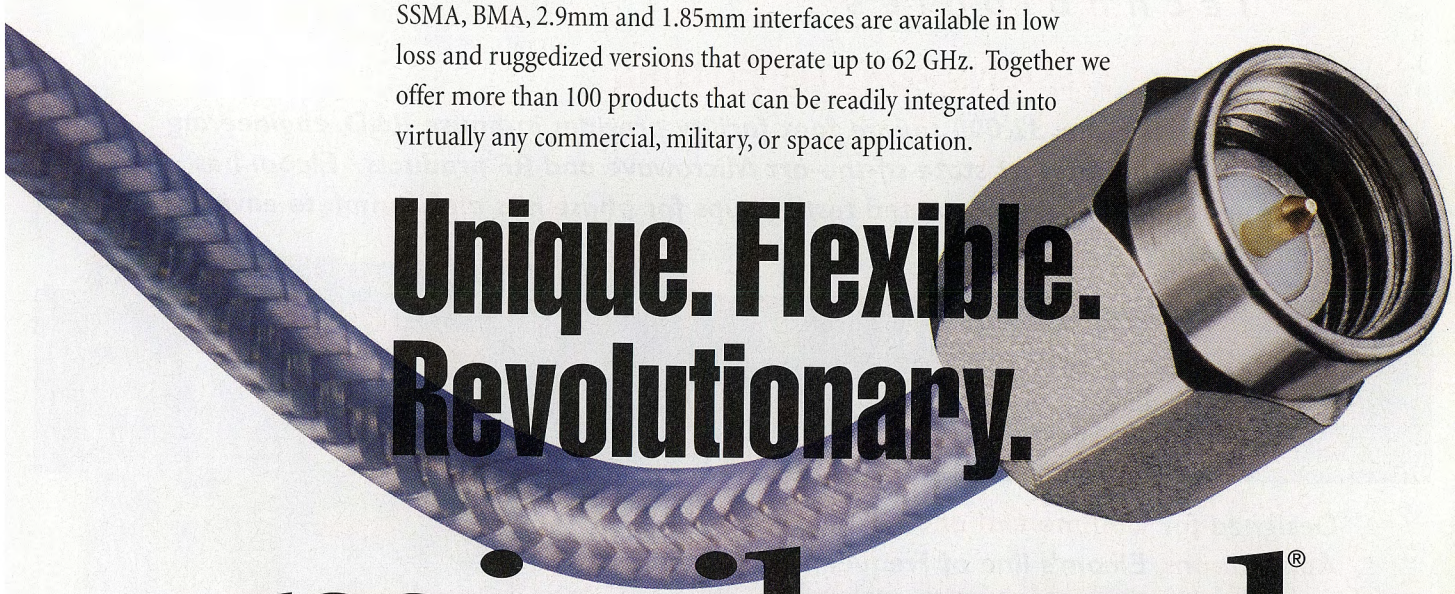

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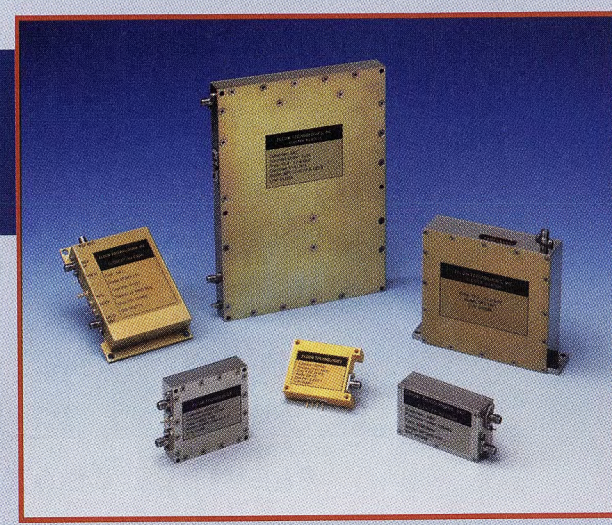

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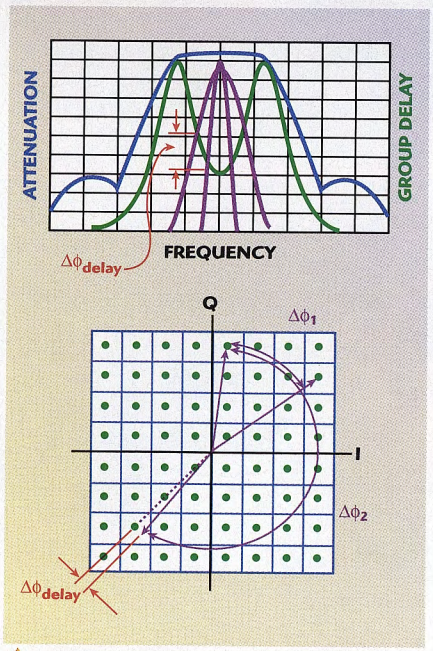

Fig. 10 Group delay distortion.

duces a phase error on the modulation vector, as shown in ***Figure 10***. This error is based on the previous symbol sequence and is another way of looking at intersymbol interference (ISI). Fortunately, for most modern digitally equalized radios, the equalizer reduces this error to an insignificant portion of the residual BER budget and can be ignored.

There are many approaches to measuring the different error mechanism types. Among the most popular are noise figure analyzers (NFA) for random noise characterization, spectrum analyzers (SA) for phase noise integration (high performance applications require phase noise test sets) and vector network analyzers (VNA) for AM/AM and AM/PM measurement.

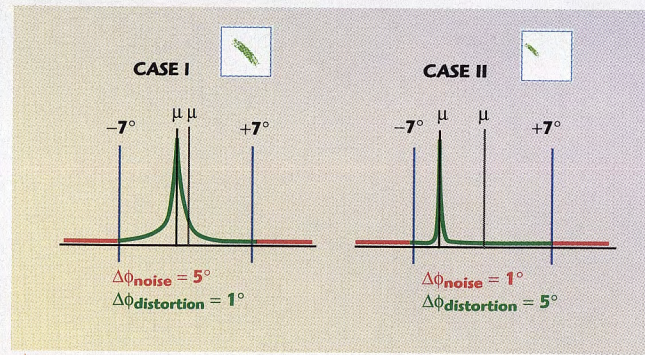

Fig. 11 Two scenarios involving phase noise and distortion.

Delay distortion can be measured either with a VNA or a vector signal analyzer (VSA). VSAs also excel at identifying spurious interference with tools like error vector spectrum.

At this point the question is why not use error vector magnitude (EVM) measurements to estimate BER versus separate AM/PM and phase noise measurements? Let's examine two scenarios, one with a lot of phase noise and little distortion and one with little phase noise and lots of distortion, as shown in ***Figure 11***. Which has the lower BER? Which has the lower EVM? The one that has the least number of sigma to the boundary will have the highest BER, hence the high phase noise example will have high BER (case I, $\sigma = 1.2$ vs. case II, $\sigma =$

[Continued on page 119]

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2.0). If the RMS phase noise and distortion components are added both scenarios have 6°. They have the same EVM, which is a summation of effects. It does not differentiate between random effects, which add geometrically and possess probability densities, from distortion effects, which add directly and are deterministic. EVM is useful because its characteristics can tell us something about the nature of the problem or where the signal was degraded, but it cannot be directly related to BER, the acid test for the network operator. EVM must be decomposed into the different types of error mechanisms, so the appropriate mathematics (statistical or deterministic) can be applied to relate those components to BER. However, the characteristics of the error vectors themselves can provide tremendous qualitative insight to the trained eye when it comes to diagnosing problems.

EXAMPLE SYSTEM BUDGET

Let's review an example residual BER system budget to try and pull all these concepts together into a practical technique. The goal is to predict the residual BER of a 64 QAM radio design by assignment of phase noise and AM/PM performance. The first step in predicting residual BER is to calculate the symbol vector lengths for every point in the constellation. Using symmetry simplifies the work by only requiring the computations for a single quadrant. Second, the maximum possible phase error for each symbol is calculated. Third, the phase noise and distortion components are allocated on a trial basis. Fourth, the symbol error probability and BER are calculated from the normalized probability density function. If the results are unacceptable, reallocation of the phase noise and distortion components must be repeated until the desired results are achieved. Finally, once the desired residual BER has been achieved, the phase noise and distortion allocations must be subdivided across the system.

Let's see how this procedure works with some real numbers. First, using the Pythagorean theorem, calculate the magnitude of each symbol vector in the constellation. Using symmetry the work can be simplified by only calculating a single quadrant.

$$A_{iq} = \sqrt{I_i^2 + Q_q^2} \qquad (1)$$

The peak symbol magnitude, or in some cases magnitudes (128 QAM), can be determined. Summing up each vector and dividing by the total number of vectors gives the average vector length. The peak-to-average ratio can be calculated by dividing the peak symbol vector by the average symbol amplitude. The peak-to-average ratio is usually expressed as a twenty-log ratio so the power variation due to the constellation geometry can be assessed. The peak-to-average ratio expressed in decibels is also used in conjunction with the trajectory overshoot to determine the correct maximum power to test AM/PM conversion. In practice, how-

[Continued on page 120]

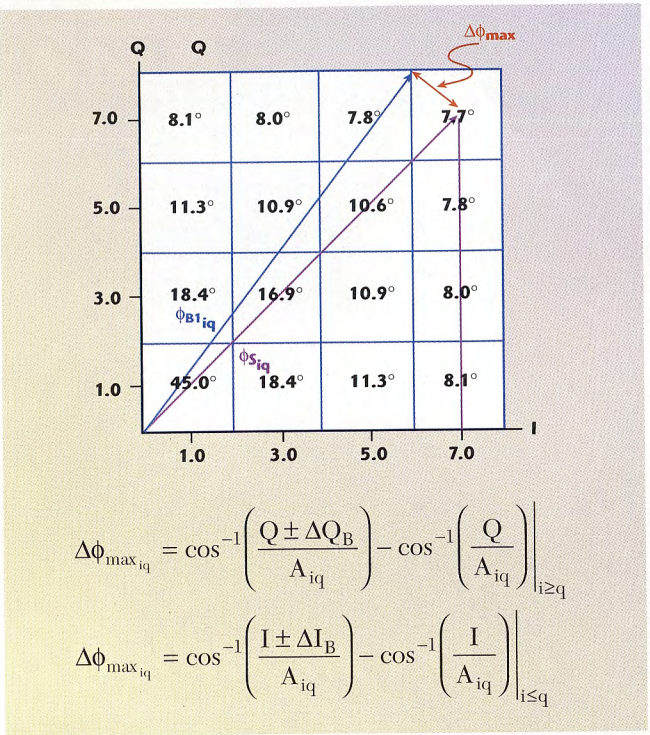

Fig. 12 Maximum phase error.

ever, it is usually best to measure the CCDF to determine the overshoot power rather than attempt to calculate it.

Using the constellation geometry, the maximum permissible phase error to the symbol boundary can be calculated. It begins by calculating the angle to the symbol point (ϕ_{iq}) using an arc cosine relationship and realizing that the symbol vector length previously calculated is the hypotenuse of the triangle, as shown in ***Figure 12***. Similarly, the angle to the symbol boundaries (ϕ_{B1iq} and ϕ_{B2iq}) can be calculated by adding or subtracting the distance from the symbol point to the boundary and then using the arc cosine relationship. Two equations are necessary depending on where the symbol point is located in the constellation. Symbol boundaries are intersected either on the horizontal axis, vertical axis or on both axis (diagonal) with angular rotation of the vector. Subtracting the symbol point angle from the boundary angle gives the maximum angular error permissible ($\Delta\phi_{Max}$) before an incorrect symbol is detected.

An important simplification can be made by assuming that the clockwise and counter-clockwise maximum angular error ($\Delta\phi_{Max}$) is the same. Alhough these angles differ slightly, the small difference can easily be neglected.

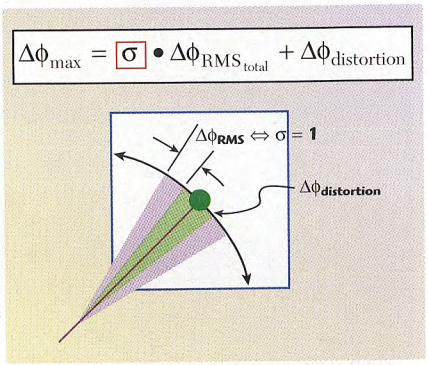

Fig. 13 Phase and distortion allocation.

The geometry of the constellation locks down the maximum angular error ($\Delta\phi_{Max}$). The angular error is composed of a distortion component and some number of sigma times the phase noise component (neglecting other possible error sources, which is generally a good assumption), as shown in ***Figure 13.*** Next, an allocation of the distortion component and phase noise component must be made. Proper allocation between distortion and phase noise can have a significant impact on the overall cost of the system. This cannot be understated, of course, because these allocations affect the performance requirements of the sources and power amplifier, the most costly parts of the radio (typically 60 percent of the overall cost). This is where true system expertise and a sound budget really pay off.

[Continued on page 122]

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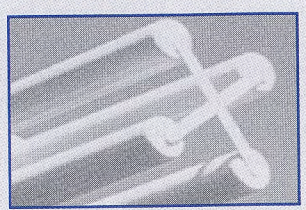

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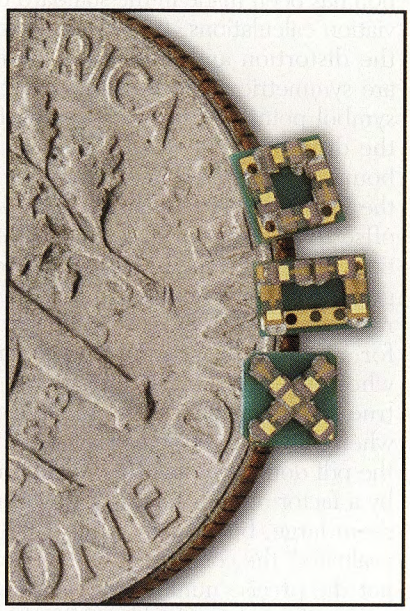

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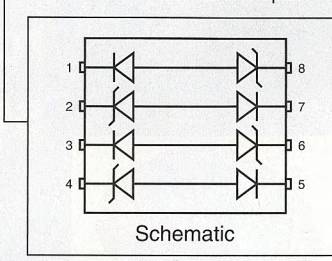

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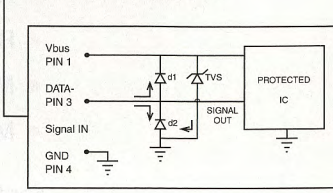

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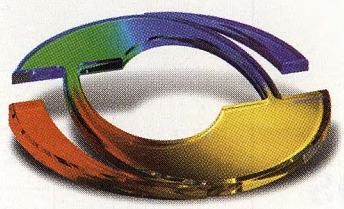

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Though it is beyond the scope of this article to delve into the economics of the allocation (this topic should be relegated to the experienced system engineer), a couple of guidelines may be helpful. High QoS systems requiring fiber-like error rates generally require seven to eight sigma making the total phase noise requirement around 10 percent of the maximum angular error. The distortion allocation is usually lowest cost, just below 50 percent of the total maximum angular error. As the frequency increases, the 20log(N) multiplication of phase noise favors more of the budget being allocated to phase noise. A typical allocation for the 64 QAM example of 3.000° of AM/PM distortion and 0.600° of total RMS phase noise is assumed.

The previous equation can be solved for sigma (σ_{iq}) for each of the constellation points. It can easily be seen in ***Figure 14*** that the number of sigma to the boundary is much lower for the outer states than for the ones close to the origin. This means that virtually all the residual errors occur in the outer most symbol points.

An important simplifying assumption has been made in the standard deviation calculations. It is assumed that the distortion and noise components are symmetric about the center of the symbol point and that accounting for the differing number of sigma to the boundary has been neglected due to the fact that AM/PM has the effect of offsetting the mean in a single direction. At first glance this may seem like a gross approximation, but in practice it results in relatively reasonable errors for a couple of reasons. In the case where there is almost no distortion, true symmetry does exist. In the case where distortion is large, a single tail of the pdf dominates and the model is off by a factor of two. A factor of two may seem large, but usually when BER is evaluated, the concern is the exponent, not the precise number (rarely does it matter if it is 1.0×10^{-12} or 2.0×10^{-12}; it is more important to know if it is 10^{2} versus 10^{-8}). If the application requires that extra precision, it is necessary to have two separate tables, one to account for clockwise boundary errors and another to account for counter clockwise errors.

SIMPLIFYING ASSUMPTIONS

The number of sigma to the boundary enables the use of the normalized pdf to calculate the probability of each symbol error (P_{iq}).

The integral of the pdf has no closed form solution, but there are both tables and spreadsheet functions

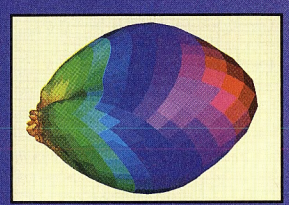
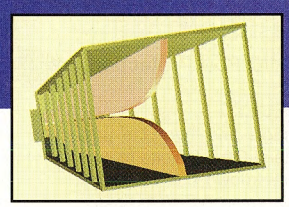
$$\sigma_{iq} = \frac{\left(\Delta\phi_{\max_{iq}} - \Delta\phi_{\text{distortion}}\right)}{\Delta\phi_{\text{RMS}_{\text{total}}}}$$

Q \ I	1.0	3.0	5.0	7.0
7.0	8.6	8.3	8.0	7.8
5.0	13.8	13.2	12.6	8.0
3.0	25.7	23.1	13.2	8.3
1.0	70.0	25.7	13.8	8.6

(σ_{iq})

Fig. 14 Standard deviation.

[Continued on page 124]

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PE4235	DC–4000	35	15	0.42	40	6L MLPM
PE4237	DC–4000	50	30	0.46	44	6L MLPM
PE4239	DC–3000	45	27	0.65	31	6L SC70
PE4242	DC–3000	45	27	0.65	31	6L SC70
High-Isolation Absorptive SPST Cable and RF Switches						
PE4232	DC–1300	80[b]	30	0.75	53	6L MLPM
PE4240	DC–1300	80	30	0.75	47	6L MLPM
PE4246	DC–5000	80	30	0.75	55	6L MLPM

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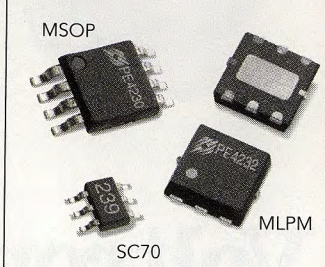

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such as NORMDIST (x, μ, σ,C), which make it very easy to solve.

$$P_{iq}\left(\Phi > \Delta\phi_{Max}\right) \approx 2 \bullet \int_{\Delta\phi_{Max}-\Delta\phi_{Distortion}}^{-\infty} \frac{1}{\sqrt{2\pi\sigma_{iq}^2}} \exp\left[-\frac{(\phi-\mu)^2}{2\sigma_{iq}^2}\right] d\phi \quad (2)$$

Once the individual symbol probabilities have been calculated, they can be averaged to yield the probability of a symbol error, as shown in ***Figure 15***. In this example, the probability of a symbol error is approximately 1.7×10^{-13}. This is quite good and on a par with fiber-optic performance. It is also important to note that this is before forward error correction (FEC), where an additional one or two orders of magnitude improvement could be obtained.

The symbol error probability must now be converted to the BER or probability of a bit error. The conversion of symbol errors to bit errors is bit mapping dependent (that is the arbitrary assignment of six different bits to each symbol in the constellation), as illustrated in ***Figure 16***. Generally speaking, when mapping the bits to symbols, it is important to try to make adjacent symbols differ by as few bits as possible. Ideally, only a single bit differs in the adjacent symbols and a symbol error creates only a single bit error (there is no error multiplication).

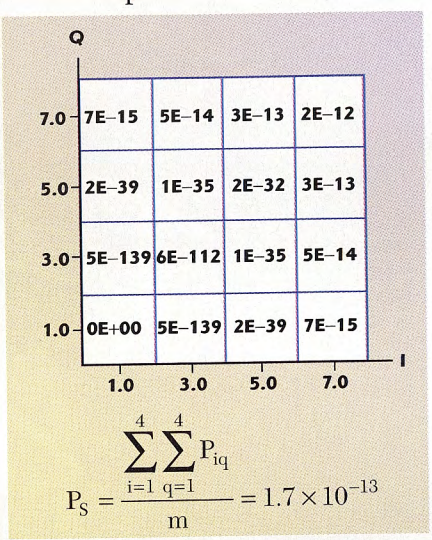

Fig. 15 Symbol error probability.

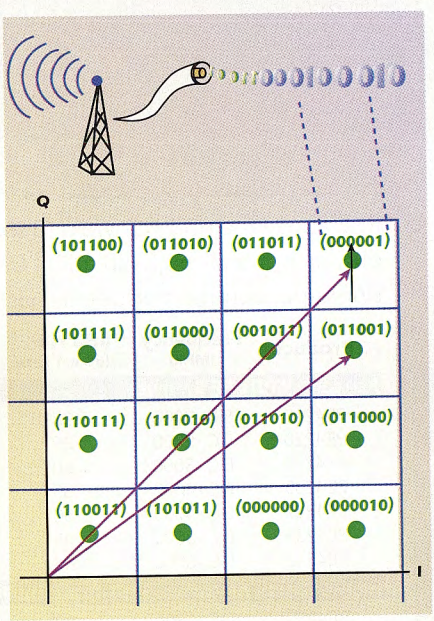

Fig. 16 Bit error rate (probability).

[Continued on page 127]

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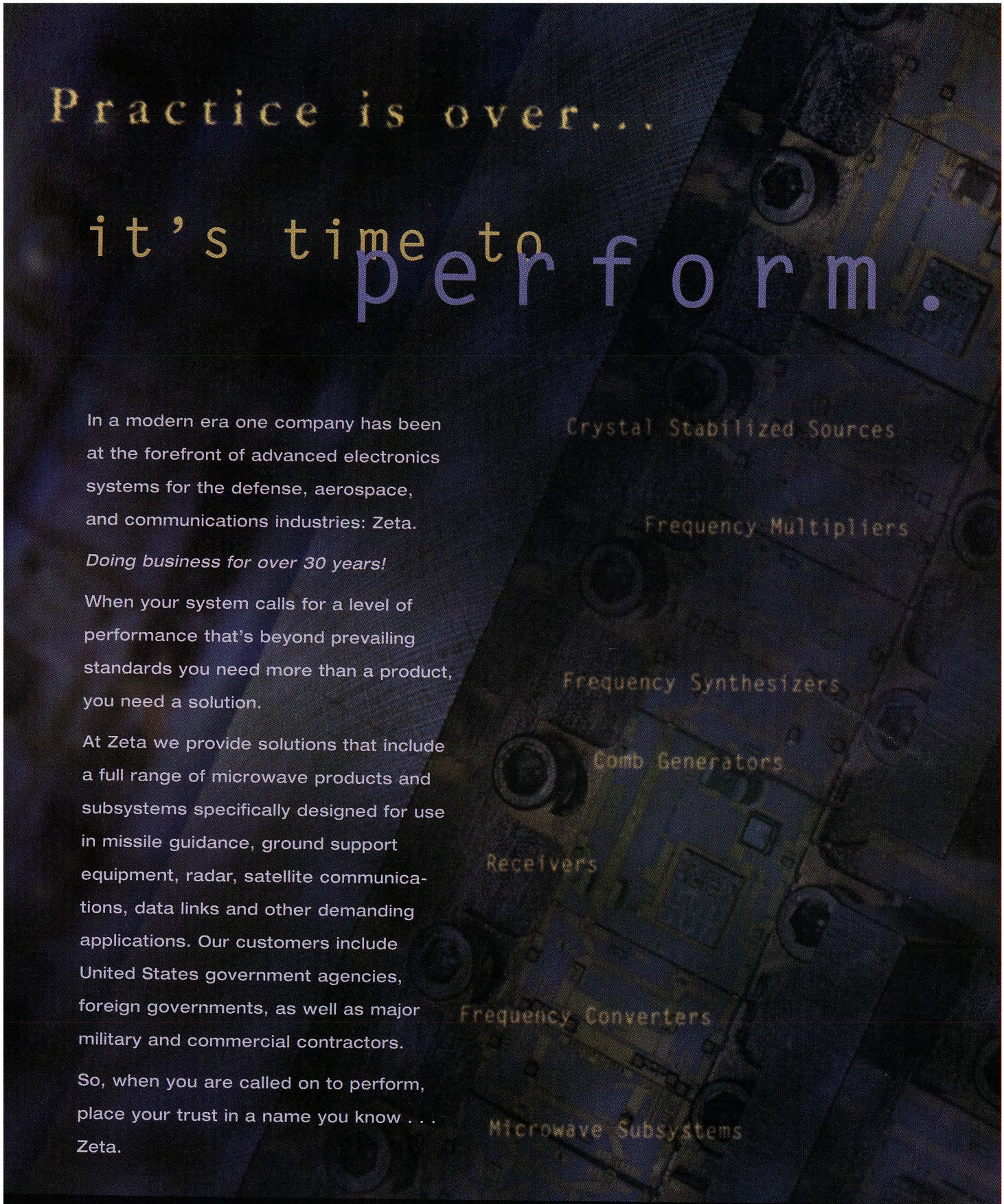

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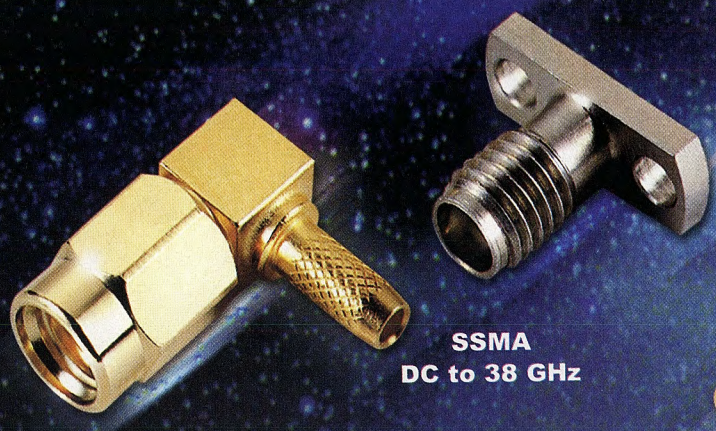

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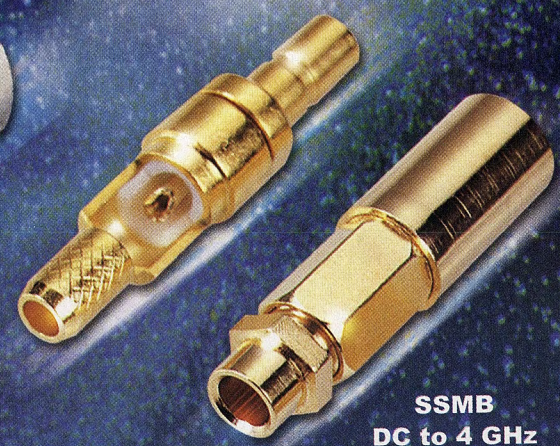

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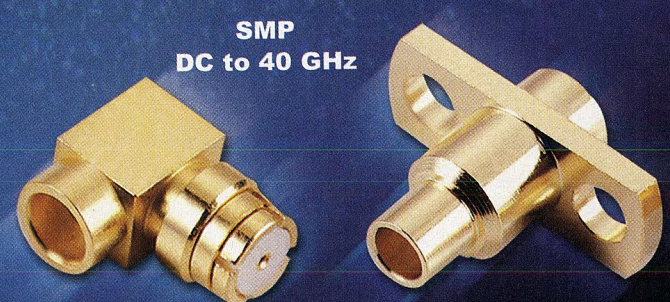

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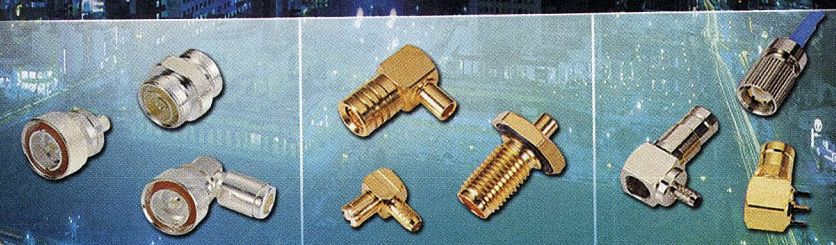

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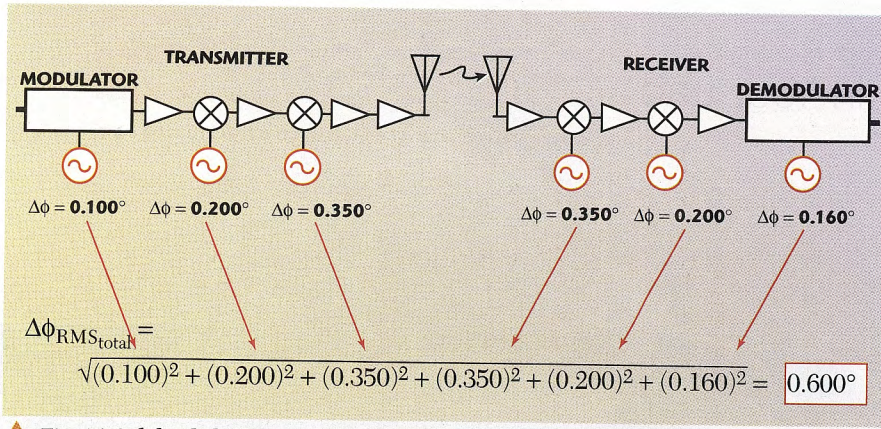

Fig. 17 Subdivided allocation budget.

The conversion factor between symbol errors and bit errors is typically low. Again, the focus is usually on trying to access the order of magnitude rather than the specific number for high QoS systems. Thus, in practice, with most bit mappings, it is usually a close approximation to assume a symbol error results in a single bit error. The symbol error probability calculated is usually a close approximation of the BER. If the calculated BER is acceptable, no reallocation of distortion or phase noise is necessary. The final step is to subdivide the total allocation into the components of the system that generate it.

In the case of phase noise, the example system has six different sources, which must total up to the 0.600° allocated (see ***Figure 17***). Recalling that noise adds in an RMS fashion, each of the source's integrated phase noise is geometrically summed to add up to the 0.600° allocated. Again the system engineer chooses the phase noise requirement of each source to minimize cost. The key consideration is the 20log(N) relationship of multiplied noise (high frequency sources tend to have more noise than low frequency sources).

A similar subdivision of the distortion budget can be made, but to a lesser extent. It is generally wise to reserve approximately 10 percent of the distortion budget for secondary effects such as incompletely compensated group delay and PA power leveling. The skill of the system engineer in making the right allocations and subdividing the budget into practically realizable values significantly affects the cost and competitiveness of the radio system.

The quiz presented at the beginning of the first part of the article to illustrate some important points will now be revisited. Radio dribbling errors (small numbers of errors scattered across time, versus a large single burst of many contiguous errors) at normal received signal levels is a classic sign of a residual BER problem.

- A digital radio dribbles errors, the modem is then looped back on itself and is error free. Therefore, the RF must be bad – *False*.

The modem loop-back test is of little value for residual BER because the major contributors to the residual error floor (PA, up/down conversion sources) are removed, hence a very unrealistic evaluation of system performance is made.

- The dribbling radio's PA is swapped into an error free radio link, which then begins to dribble. The PA is thus the cause of the errors – *False*.

The technician is often convinced in situations like this that because the problem follows a specific PA, that PA must be the cause, but often it is not. The residual BER is a function of all the phase noise sources as well as the distortion sources. It is the total that matters, thus the only way to identify which element is at fault is to establish a worst-case maximum budget for each contributor and then test them independently. ***Appendix A*** shows the outer symbol angular data for three example links.

In the example, the T/R link shown in case no. 1 exceeds the maximum angular error, causing it to dribble errors at an unacceptable rate. Again, technicians suspect the power amplifier in situations like this. Indeed, if the

[Continued on page 129]

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PA of case no. 1 is swapped with the PA of case no. 2, a radio that is working fine, link no. 2 will begin to dribble errors (note that most of the numbers are the same). Similarly, the link of case no. 3, which starts out okay, will also begin to dribble errors when the technician swaps the PA from case no. 1 for the PA of case no. 3. The technician is now convinced in situations like this that because the problem followed the "bad" PA, it must be the cause. As a result a $3000 PA gets put to the side as scrap.

But are all those PAs really unusable? Actually, they may be fine. Consider ***Appendix B***, where a system residual BER budget specification (shown on the left), has been constructed . Notice that if the crystal oscillator from the demodulator in case no. 1 had met its specifications, then link no. 1 would perform fine with the original PA.[1]

The author has encountered this exact case in two different companies where the cost of the modem source was ~$10 versus the ~$3000 for the PA. Said another way, improvements in the PA would cost hundreds or thousands of dollars to make versus improvements in the demodulator source, which would cost pennies. Likewise, system engineers make or break a product's economic viability when choosing the allocation between phase noise and linearity. A noisy frequency conversion or modem oscillator can make the power amplifier's cost unacceptable, just as poor PA performance can drive up the cost of an LO frequency synthesizer.

- It is possible with IMD and phase noise to predict if a QAM radio will dribble errors – *False*.

Many vendors use IMD and phase noise to predict if a QAM radio will dribble errors. This approach is purely empirical. IMD is also a spot power characterization and does not account for the effects of changing compression characteristics as a function of power over the vector range. Worse yet, IMD is often applied just below saturation where its prediction utility is of little value (clipping begins to dominate versus square law curves). While it may seem easy to measure error rates at different power levels and correlate them with IMD measurements, the correlation coefficient can be as bad as 85 percent for 128 QAM. Said another way, 15 out of every 100 radios would fail their residual error count. AM/PM (which is most accurate when clipping begins) and phase noise being analytically related to the BER can calculate the error rate exactly.

- Phase noise has less of an effect than distortion – *False*.

Often times, dribbling errors focus attention on the PA because it is usually the easiest component to change performance by reducing the transmit power. The PA then seems to have the greatest effect on residual BER. Note, however, the integrated phase noise contribution is multiplied by the number of sigma (σ) required for an acceptable error rate (usually between seven and eight for high quality systems). Thus, changes in phase noise have a much greater impact than changes in distortion. Unfortunately, phase noise usually cannot be adjusted like PA output power, so this sensitivity is rarely observed with practical hardware.

CONCLUSION

The residual BER budgeting process is a key analysis in producing a cost-effective wireless data link that meets the QoS requirements demanded by the network provider. Using a combination of phase noise and AM/PM distortion measurements, the sources and PA can be characterized to deliver consistent combined residual BER performance, where "golden" modems and EVM techniques cannot.

This article has covered the process for predicting the worst-case residual BER from the analog metrics, which influence it, versus empirical approaches, many of which simply do not work. Accurate characterization of these metrics is an essential part of providing the most system for the money. It is also essential for many new wireless access systems, where high quality service is required with multi-year rollouts of customer premise equipment interfacing to existing base stations (LMDS, MMDS, etc.). The system engineer who judiciously allocates a residual BER budget creates a significant competitive advantage in product cost as well as interchangeability necessary for today's radio products.

[Continued on page 131]

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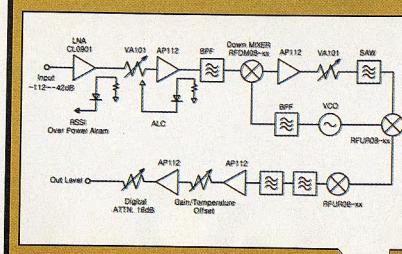

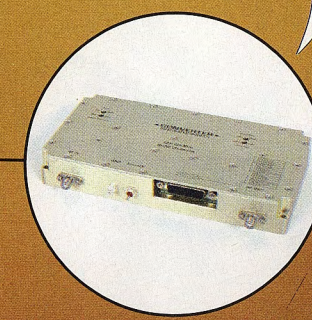

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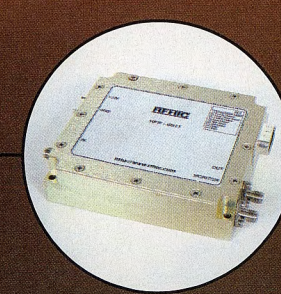

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More information on this topic, including a system BER spreadsheet, is available at http://www.tmintl.agilent.com/us/BroadbandSymp.shtml, or contact the author at kent_k_johnson@agilent.com. ■

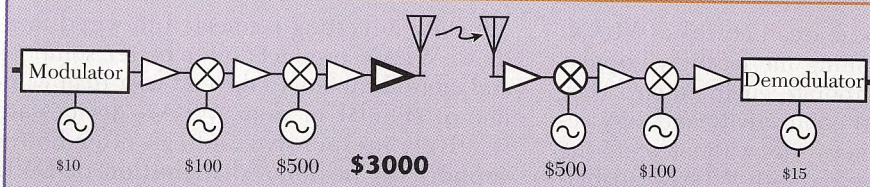
Reference

1. K.K. Johnson, "Optimizing Link Performance, Cost and Interchangeability by Predicting Residual BER: Part I — Residual BER Overview and Phase Noise," *Microwave Journal*, Vol. 45, No. 7, July 2002, pp. 20–30.

APPENDIX A

OUTER SYMBOL DATA FOR THREE EXAMPLE LINKS

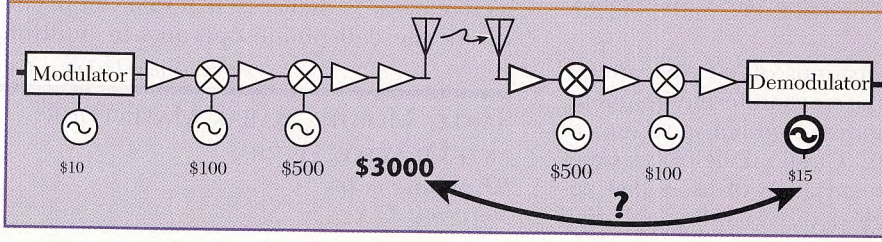
	Spec.	Case 1		Case 2		Case 3	
Modulator phase noise		0.10		0.10		0.10	
1st Tx LO phase noise		0.20		0.20		0.20	
2nd Tx LO phase noise	?	0.30		0.30		0.30	
PA distortion		2.69	→	1.50	→	2.00	
Other distortion		0.30		0.30		0.30	
1st Rx LO phase noise		0.35		0.35		0.35	
2nd Rx LO phase noise		0.20		0.20		0.20	
Demodulator phase noise		0.30		0.32		0.35	
		2.99	0.63	1.80	0.64	2.30	0.65
Total angle error	7.69	7.88		6.77		7.39	



APPENDIX B

SAME EXAMPLES SHOWING RESIDUAL BER BUDGET SPECIFICATIONS

	Spec.		Case 1		Case 2		Case 3	
Modulator phase noise		0.10		0.10		0.10		0.10
1st Tx LO phase noise		0.20		0.20		0.20		0.20
2nd Tx LO phase noise		0.35		0.30		0.30		0.30
PA distortion	2.70		2.69	→	1.50	→	2.00	
Other distortion	0.30		0.30		0.30		0.30	
1st Rx LO phase noise		0.35		0.35		0.35		0.35
2nd Rx LO phase noise		0.20		0.20		0.20		0.20
Demodulator phase noise		0.16		0.30		0.32		0.35
	3.00	0.60	2.99	0.63	1.80	0.64	2.30	0.65
Total angle error	7.69		7.88		6.77		7.39	



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DESIGN CONSIDERATIONS FOR MULTIMODE MULTIBAND WLANS

Wireless local area networks (WLAN) are becoming increasingly popular in the corporate environment. They provide high speed connectivity and easy access to corporate networks without requiring wiring. Flexibility is key with WLAN capability. In a corporate environment, individuals can be mobile and at the same time constantly be connected to their corporate network. This will allow a person to move to different parts of a building, download presentations from their corporate server and give presentations in different rooms. In a hotel setting, meetings can be held and groups can download presentations, surf the Web or easily download e-mail with WLANs. The ease of use, convenience of having no cords and affordable prices are making WLANs popular at home as well. The ease of use comes from the fact that anyone can deploy a WLAN network in a building. All that is required is an access point and a few WLAN cards and notebook PCs. One needs only to attach the access point to the server or PC, follow the installation instructions for loading the software on to the server and notebook with the WLAN card plugged into the notebook PC, and a WLAN is ready for use.

The main applications of WLANs are expected to be in the corporate environment, telematics (automotive), and hot spots such as hotels and airports. These public places experience a high concentration of users that demand mobile high data capability, and find difficulty in getting connected to wired locations. WLAN products offer better solutions and more flexibility to the end user than wireline or cellular modem. WLAN devices are relatively inexpensive and can offer better support for in-home distribution of DVD quality video, audio and other media applications.

This article discusses how RFICs with advanced architectures will play a key role in improving performance and lowering the cost of WLANs and other wireless systems.[1] How the new standards will solve many of the current problems associated with wireless LANs, including speed, capacity, congestion, interference and security, is also considered. Novel multiband multimode WLAN products based on new IEEE 802.11g standards and innovative wireless ICs are discussed. Tradeoffs in designing multimode WLAN products, specifically devices operating under IEEE 802.11 a, b and g modes,[2] are presented. This means that no matter where it operates, the WLAN card will identify the standard used at that location and will switch to the appropriate mode, IEEE 802.11a, b or g. This roaming methodology is similar to that of a cell phone, where the cell phone operates in multiple

[Continued on page 134]

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modes, such as analog or digital, and selects the appropriate mode for that location. This article focuses on some of the outstanding engineering challenges, and addresses issues regarding transceiver architecture and semiconductor process technologies.

WLAN STANDARDS

WLAN standards developed by the IEEE 802.11 standards body have been evolving over the last few years. The Wireless Ethernet Compatibility Alliance (WECA) group is the organization that performs interoperability testing and certification. The benefits of using standards such as those published by the IEEE are countless. Compliance with the IEEE 802.11 standards makes it possible for interoperability between multiple-vendor appliances and the chosen wireless network type. This means that an 802.11-compliant access point can be purchased from one vendor and a PC card from another vendor while being assured that they will both interoperate within an equivalent 802.11 wireless network, assuming that the 802.11 configuration parameters are set correctly in both devices. Standards compliance also increases price competition and enables companies to develop wireless LAN components with lower research and development costs. Interoperability prevents dependence on a single vendor for appliances. Products having a WECA logo of wireless fidelity (Wi-Fi) identifies that the 801.11b WLAN cards from different vendors are interoperable. Similar WECA interoperability certifications are being developed for 802.11a and the upcoming 802.11g standard. ***Table 1*** summarizes the various relevant wireless standards.

TABLE I

THE VARIOUS RELEVANT WIRELESS STANDARDS

	Bluetooth	*802.11b (Wi-Fi)*	*802.11g*	*802.11a*	*HiperLAN/2*
Frequency (GHz)	2.4	2.4	2.4	5.0	5.0
PHY	FHSS	DSSS	OFDM	OFDM	OFDM
Throughput (Mbps)	0.721	11	22–54	54	54
Range (ft)	30	200–300	200–300	100–150	100–150
Standard ratified	2001	1999	1Q03	1999	2Q02
Chips available	now	now	2Q03	4Q01	—
Product available	high volume	high volume	2Q03	1Q02	limited

Most of the current WLAN products being deployed are based on the IEEE 802.11b standard operating at 2.4 GHz and are also certified by WECA as Wi-Fi-compliant products. The IEEE generated 802.11a standard is for WLAN devices in the 5 GHz band operating up to data rates of 54 Mbps. The IEEE 802.11a standard provides more bandwidth and channels than the 2.4 GHz band. In addition, the 5 GHz spectrum has less of the interference that plagues the 2.4 GHz band. The IEEE 802.11g standard is being developed to offer up to 54 Mbps data rates at 2.4 GHz using orthogonal frequency-division multiplex (OFDM) modulation. Development of the final IEEE 802.11g standard will take another three to nine months.

Overall, the use of OFDM at 2.4 GHz will increase the need for more linear PAs and high performance RFICs for that band. These events may slow down the 5 GHz demand a bit, but the 5 GHz band will continue to yield better data throughput because there are no legacy protocols to be accommodated, interference is minimal (no microwaves, portable phones or Bluetooth) and there are eight to 12 channels versus three for the 2.4 GHz band. The higher number of channels leads to an increased capacity for the 5 GHz band.

A chip set is being created that operates in multiple modes, that is IEEE 802.11 a, b and g, thus offering a migration path from the 11 Mbps

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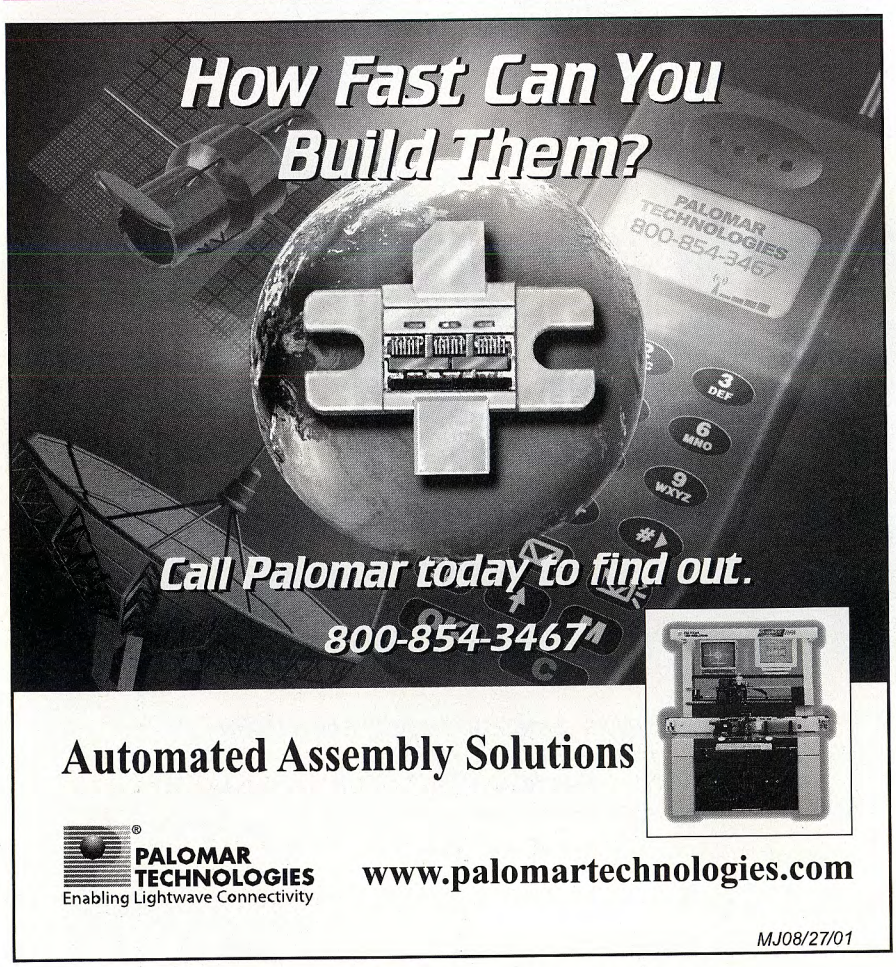

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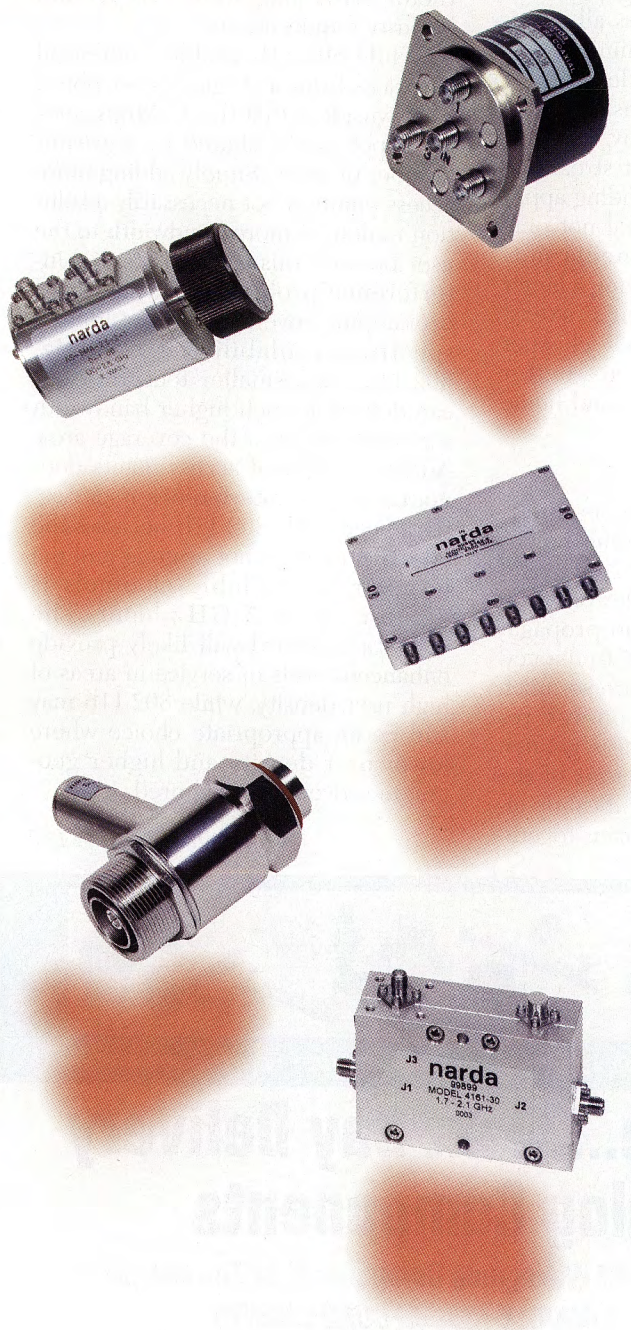

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802.11b standard to the 54 Mbps 802.11a standard, allowing users to take advantage of the higher data rates and improved connectivity. This dual-band WLAN product will enable interoperability between high speed IEEE 802.11a-compliant networks operating in the 5 GHz band and current generation IEEE 802.11b-compliant networks operating in the 2.4 GHz band.

WHY ARE DUAL-BAND MULTIMODE WLANS IMPORTANT?

There are many benefits in using a multimode dual-band WLAN device. Since the 802.11b standard for wireless LANs was finalized in 1999, there has been explosive growth in the adoption of WLAN technology. Products compliant with 802.11b operate within the 2.4 GHz ISM band at data delivery rates of up to 11 Mbps, whereas 802.11a WLAN solutions operate in the unlicensed 5 GHz bands and can deliver higher data rates of 54 Mbps. This means that users and network managers are faced with a choice between 802.11a and b. Unfortunately, the choice is not always clear or easy and the result is often confusion.

Existing Investment and Migration

The rate of adoption and implementation of 802.11b networks is already considerable, taking advantage of reduced prices as the technology matures. The number of users and available access points is already significant, and maintaining backward compatibility will be important as users roam across a variety of networks.

Throughput

Networks compliant with 802.11b support a maximum throughput of 11 Mbps that is shared across all users. With a low number of simultaneous users, this may well be adequate for many of today's applications. But with up to 54 Mbps offered by 802.11a, networks can also support streaming video or other such demanding applications. This makes it ideal not only for supporting future media networks, but also for supporting a larger number of simultaneous users. 802.11b cards are generally cheaper than 802.11a cards and are better suited for lower data rates and home applications.

Effective Range

There could be noticeable differences between the operating ranges of 802.11b networks at 2.4 GHz and 802.11a at 5 GHz. This derives from three aspects. First, radio propagation varies as a function of frequency. Second, since data rates are so much higher in 802.11a, the energy required to resolve the data is greater. Third, the physical properties of the network environment significantly affect the impact range. Taken together, the effective coverage area for an 802.11a network will likely be smaller than that for 802.11b. The range of 802.11g devices is expected to be higher than for 802.11a devices because of better propagation at 2.4 GHz, but 64 QAM OFDM modulation will reduce the range compared to the 802.11b devices due to higher vector error magnitude (EVM) and linearity requirements.

While 802.11b enables increased coverage from a single access point, its downside is that the 11 Mbps service is potentially shared by a greater number of users. Simply adding more access points is not necessarily a solution to deliver more bandwidth to the user because this causes potential interference problems as a result of overlapping coverage and the limited spectrum availability at 2.4 GHz. 802.11a has a smaller footprint, but can deliver a much higher bandwidth service to users in the coverage area. Adding additional access points does not create the interference issues experienced with 802.11b because the effective range is not as great and the number of available channels is greater in the 5 GHz band. The 802.11a standard will likely provide enhanced levels of service in areas of high user density, while 802.11b may still be an appropriate choice where lower user density and higher geographic coverage is required.

[Continued on page 138]

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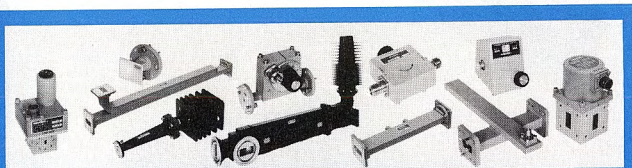

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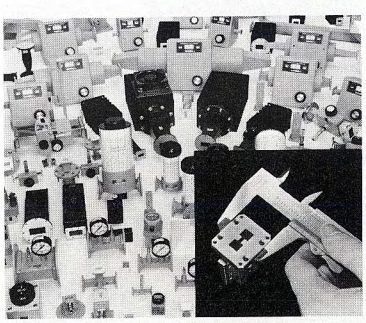

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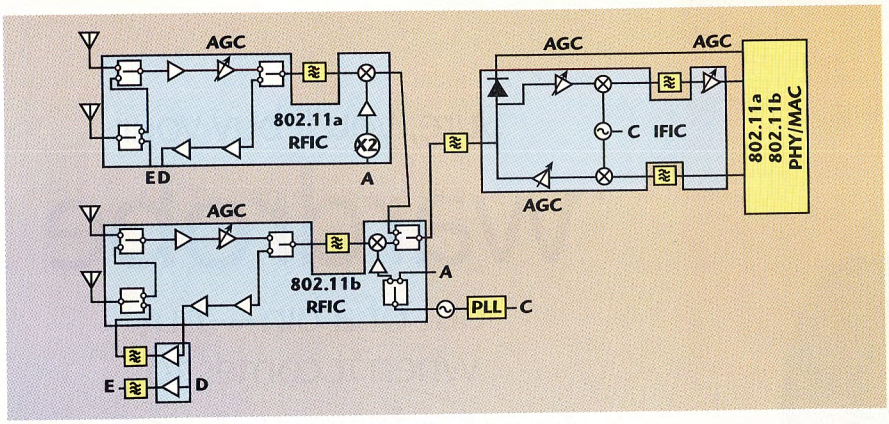
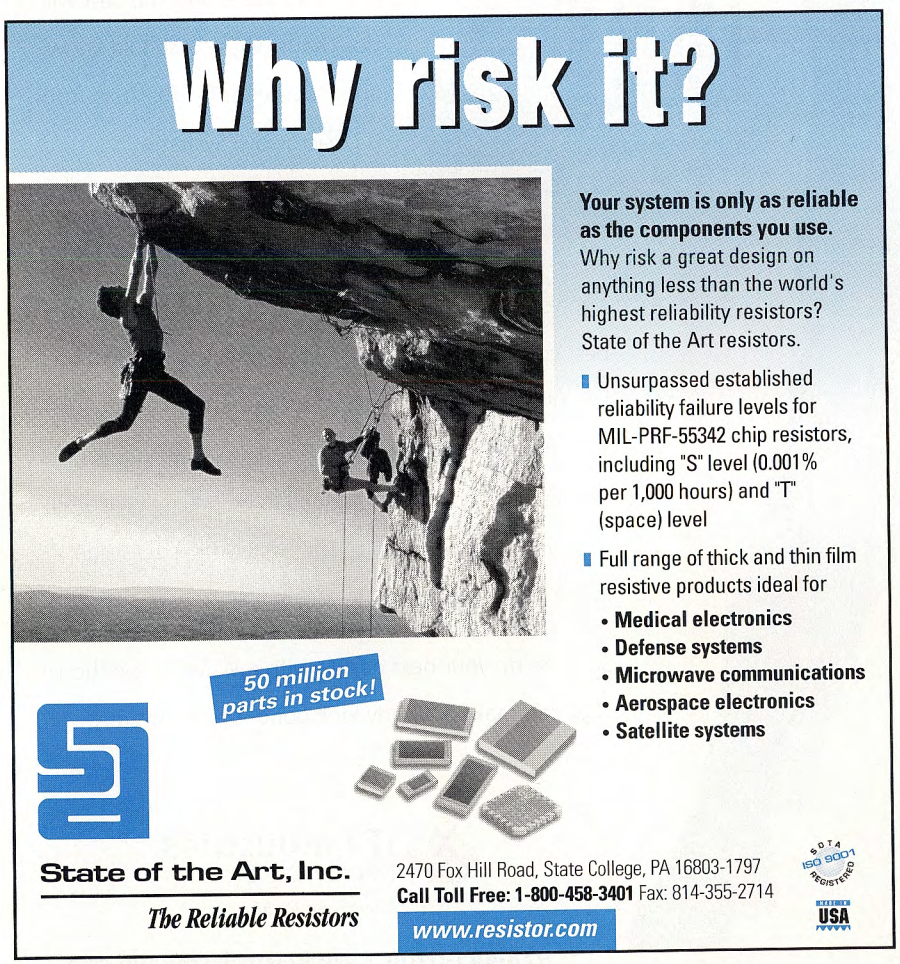


▲ *Fig. 1 Block diagram of a dual-band multimode WLAN chipset.*

Benefits of Dual-mode

Just as cell phones operate seamlessly across various standards, it is believed that 5 and 2.4 GHz networks are complementary and will coexist for a long time. With the rapid adoption of Wi-Fi 802.11b networks, both users and operators require a migration path to 802.11a. Having to choose between 5 and 2.4 GHz is not appropriate since both bands have advantages and disadvantages. By delivering a cost-effective dual-mode solution, network managers can comfortably choose to deploy an appropriate mix of 5 or 2.4 GHz coverage throughout the area as the user profile dictates. The user will then be able to seamlessly roam throughout the coverage area, independent of the prevailing service, while accessing high data rate services where available.

Considering all the possible benefits of the multimode operation, a number of IC chipset providers are developing a set of WLAN ICs that will offer multiband and multimode operation just like the multimode cell did for the cellular market. Currently, the IEEE 802.11b standard at 2.4 GHz with 11 Mbps maximum speed is being deployed worldwide for WLAN application. However, as these WLAN networks become popular, the available 83 MHz bandwidth will not be enough to meet the needs of all the users. For higher data rates and higher capacity, IEEE 802.11g and IEEE 802.11a will offer good solutions. Many companies are already developing 802.11a products, which offer 54 Mbps maximum data rates and 200 MHz bandwidth in various 5 GHz bands. A LAN card using the IEEE 802.11a standard, however, does not work with an access point using the IEEE 802.11b standard. In fact, many large companies, like Microsoft, Compact and others, want these incompatibility problems solved and would prefer a multimode LAN card that operates in multiple bands. Such cards are not widely available at low cost today but the RFIC technology discussed here will make it a reality within the next few months.



WLAN SYSTEM DESIGN

Design considerations for a single-band 802.11a, b or g are somewhat simpler than for a multiband multimode WLAN since it is more difficult to meet all the specifications over multiple bands and still have low cost IC designs. Generally, the OFDM modulation used in 802.11a and g has tougher linearity and phase noise specifications. Also, the higher frequency "a" devices need higher frequency RFIC processes. The 802.11b specifications are the easiest from the radio perspective.

Dual-band Multimode WLAN System Architecture

A dual-band wireless LAN system architecture that allows operation in 802.11 a, b and g modes poses significant challenges. The problem becomes even more complex as one puts constraints that a tri-mode WLAN IC chipset must be only slightly higher cost than the existing 802.11a products.

The block diagram of such a multimode chipset is shown in ***Figure 1***. These chips have state-of-the-art per-

[Continued on page 141]

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The 2003 IEEE Radio Frequency Integrated Circuits 2003 Symposium (RFIC-2003) will be held in Philadelphia, Pennsylvania on June 8–10, 2002. For the latest information, visit: www.rfic2003.org

Electronic Paper Submission/Communication: Technical papers must be submitted in an electronic form via the RFIC-2003 web site www.rfic2003.org — **Hard Copies are not accepted.**

Technical Areas: Papers are solicited describing original work in RFIC design, fabrication, testing and packaging to support RF applications in areas such as, but not limited to:

- **Cellular System ICs and Architectures:** GSM, EDGE, TDMA, CDMA, 3G, WCDMA, GPS
- **Wireless Data System ICs and Architectures:** Bluetooth, WLAN, 802.11x, MMDS, UWB
- **Broadband System ICs and Architectures:** Cable, TV Tuner, HDTV, xDSL
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Proposals Invited: Proposals for forming special sessions, Sunday workshops, special sessions, and panel sessions are invited. Please see http://www.rfic2003.org/.

Technical Format: The technical sessions will be held for three days from Sunday through Tuesday. Workshops will be on Sunday. Several invited sessions and talks will take place during the conference.

Microwave Week 2003: The RFIC 2003 will be in conjunction with the IEEE MTT-S International Microwave Symposium (IMS). Microwave Week 2003 will continue with the International Microwave Symposium and Exhibition, and the Microwave Historical Exhibit.

The guest program will include tours to city historic sites, museums and scenic trips to Lancaster County, Longwood Gardens, Valley Forge, New Hope and Atlantic City.

Electronic Submission Deadlines

Proposals for short courses workshops, panel and special sessions:	6 September 2002
Technical Paper Summaries in .DOC or .PDF format:	9 December 2002
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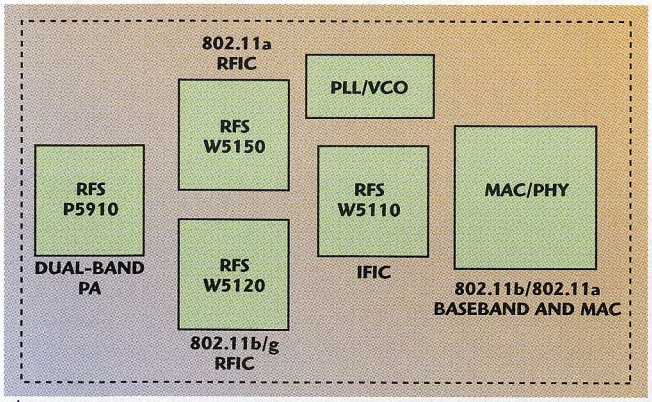

▲ *Fig. 2 Dual-band multimode WLAN chipset using RF chips and a baseband MAC/PHP chip.*

formance for 2.4, and 5 to 6 GHz band WLAN applications, addressing the IEEE 802.11b, 802.11a and g requirements in a single RF chipset. The chip yield and cost indicates that this dual-band multimode IC can be offered at only a slight premium over the single-band 802.11a IC solution. Higher levels of IC integration are planned for the near future to lower the costs even further.

In determining the appropriate transceiver architecture, cost, performance and form factor have emerged as the main selection criteria. Therefore, a thorough analysis of these criteria is the best method for qualifying the merit of the architecture for a dual-band WLAN transceiver. The dual-band WLAN system architectures can either use separate radios or share some components of the two-radio system to lower the cost. The proposed architecture shown here shares the IF chip, and the RF first down-conversion is done with separate chips.

There are cost, performance and risk tradeoffs between zero IF (ZIF) and dual-conversion architectures. ZIF architectures get rid of some of the filters that, if chosen carefully as in the proposed architecture, cost very little. These SAW filters are commonly used in cellular designs and are in volume production at low cost already. The other issue with the ZIF architecture is the risk and time-to-market. The traditional dual-conversion scheme has been chosen to minimize the risk and to get to the market quickly at low cost.

Some of the common problems inherent with the ZIF architecture are DC offset, flicker noise and LO pulling. DC offsets are mainly generated by the LO leakage which self-mixes, thereby creating a DC component in the signal chain that affects the receiver performance and can cause the baseband stages to saturate. Flicker noise, also known as 1/f noise, is a low frequency device noise that can corrupt signals in the receiver chain. Another concern with direct conversion is the pulling of the LO by the PA output mismatch variations, which affects the direct up-conversion process. This is because the high power output, which has a spectrum centered around the LO frequency, can disturb (pull) the transmitter VCO. Each of these issues can be addressed with careful design, and ZIF architectures have been successfully used in high volume cellular applications. However, the challenges are significant when you consider multiple bands and the extra performance required for the high data rate OFDM WLAN systems. This may require more IC design/fab iterations to resolve all these issues and meet all the WLAN system specs. Based on a cost, performance and risk analysis, it is believed that there will be a number of good ZIF and dual-conversion architectures deployed in the initial WLAN systems.

In today's competitive environment, system design is not just a technical challenge but also a business strategy. In an environment where time-to-market, cost and performance are all critical to success, a thoughtful system design can save a great amount of development time and facilitate product evolution. ***Figure 2*** shows a dual-band multimode WLAN chipset using the RF chips discussed here and a baseband Media Access Control/Physical Layer (MAC/PHY) chip.

A combination of SiGe and GaAs technologies are used to achieve performance, cost and time-to-market benefits to address the WLAN RFIC market. These chips will provide a va-

[Continued on page 143]

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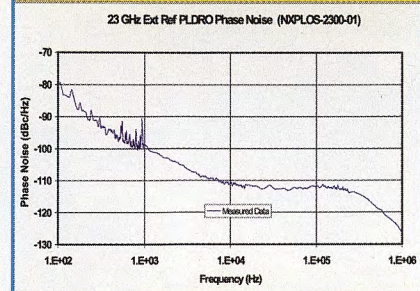

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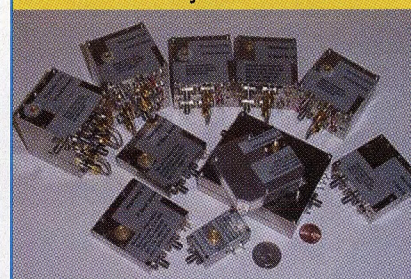

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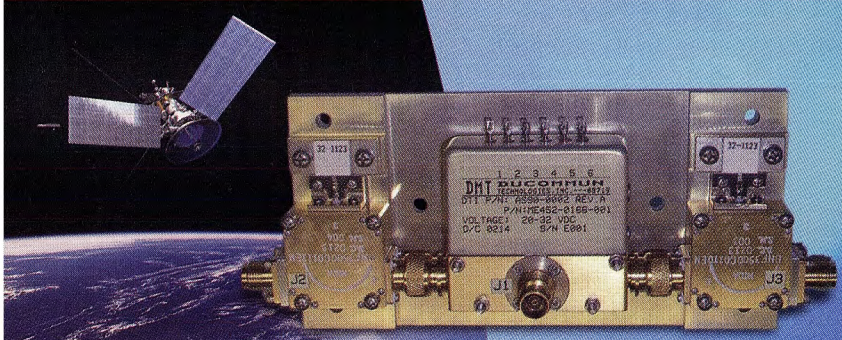

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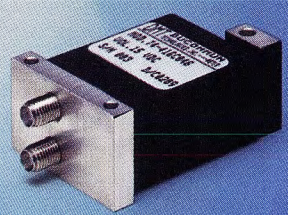

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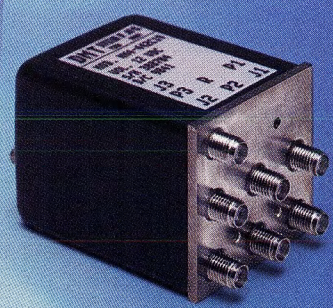

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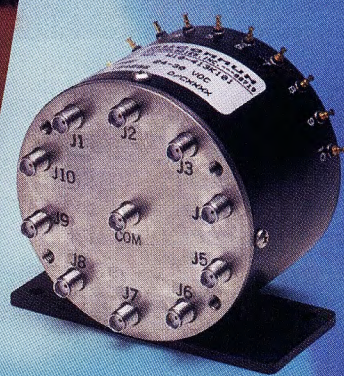

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riety of complete chipset options when combined with a baseband MAC/PHY chip.

Integrated Cellular WLAN System

ICs that will allow easier integration of WLAN and cellular networks are also being developed. The new flexible transceiver architecture will enable wireless convergence of cellular (GSM/GPRS/WCDMA) and WLAN networks. This will give mobile users a single platform for traditional cellular voice communications, as well as truly high speed data communications using 802.11a, b and g standards.

The convergence of cell phone technology and WLAN technology will lead to an integrated mobile computing device (cell phone, PDA, notebook computer) that can communicate with both the existing cell phone infrastructure (for voice) and WLAN networks for high speed data applications.

At today's throughput of 11 or 54 Mbps, WLAN technology will out-perform 2.5G or 3G in terms of deployment cost and data rates. However, the 3G networks will have wider coverage area compared to WLAN networks. A WLAN overlay, creating "hot spots" within the existing cellular infrastructure, is a quick and simple way for the carriers to begin offering competitive and truly high data rate services.

The IC architectures being developed for an integrated cellular/WLAN device will offer lower cost and higher performance than is achievable by having separate cell phone and WLAN cards. The performance improves in terms of device size, battery life and coverage area due to sharing of resources and use of advanced system architectures. There are significant design tradeoffs in designing RFIC for an integrated WLAN and cellular 2/3G system. Those will be discussed in a future article on that subject.

RFIC DESIGN TRADEOFFS

In this section, some of the RFIC's design tradeoffs are highlighted, which designers have to consider when designing RFICs for wireless LAN applications. These are process technology tradeoffs, cost versus performance issues and single versus multiband architectures. Whether the dual-band WLAN products succeed will be determined predominantly by their cost compared to a single-band product. The dual-band WLANs may reach critical mass only if consumers are willing to pay the extra cost for them, relative to increasingly cheaper 802.11b systems.

RFIC Technology Choices

For wireless LAN application, the RFIC technologies must be chosen carefully to meet the challenging cost and performance objectives. In order to achieve the lowest cost solution, all of the RF circuitry must be integrated on as few high yield chips as possible. From the performance side, RFICs must be able to have high output power, high linearity and low current. Many IC technologies, including GaAs MESFET, HBT and PHEMT, as well as Si CMOS, SiGe BiCMOS and HBT technologies, are considered to obtain unique solutions to solve complex cost versus performance tradeoffs.

To perform an optimum WLAN chipset design, one needs expertise in a combination of skills, including RF system design, semiconductor process and IC design, packaging and antenna technologies. Traditional (silicon) semiconductor processes have difficulty supporting higher performance at higher frequencies and are useful only in very short-range data transmissions, such as the Bluetooth standard, popularized by silicon semiconductor companies.

Each of the SiGe, GaAs and InGaP[3–5] processes have benefits for particular applications within the wireless markets. In determining the optimum process technology one needs to determine how to utilize the strengths of each process technology to meet the WLAN IC cost and performance objectives. One approach for a WLAN chipset is to utilize GaAs and SiGe technologies in a multichip module to offer high performance and a cost-effective, highly integrated, chipset solution. The time-to-market and risk are also important considerations in the decision process. Consequently, for a high performance front-end, a GaAs process is used for LNA, PA and switch components. For the up- and down-conversion either SiGe or GaAs

[Continued on page 144]

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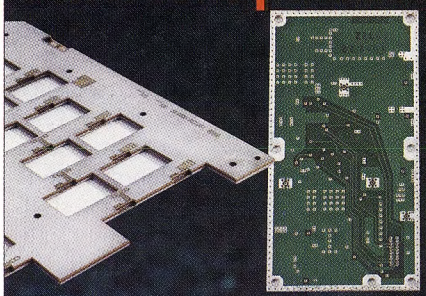

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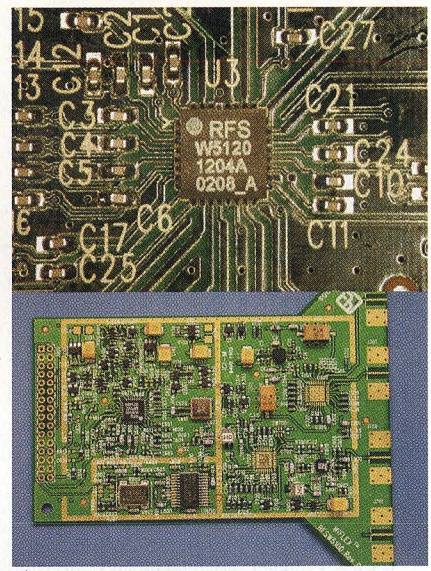
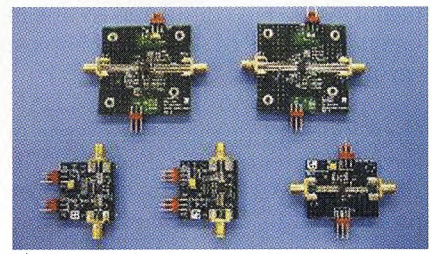
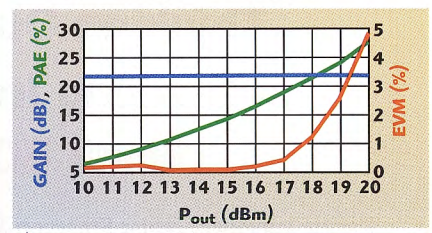


▲ *Fig. 3 The transceiver IC chipset.*



▲ *Fig. 4 HBT power amplifiers.*



▲ *Fig. 5 Measured performance of a 2.4 GHz HBT WLAN PA.*

processes can be useful. For a single-band WLAN solution, a CMOS process may be adequate for low performance levels, but for high performance multiband ICs, SiGe and GaAs may have an advantage over other technologies. This multichip module approach allows one to meet the performance, cost and time-to-market objectives with minimal risk.

The overall product cost is mostly attributed to the cost of semiconductor die, packaging and testing. For a complex IC such as a dual-band WLAN transceiver, where the die area is much larger than the single function ICs, die cost dominates these calculations and forces a move towards the low cost CMOS processes. On the other hand, the performance of the OFDM-based systems put a great demand on the performance (linearity, phase noise, etc.) of the transceiver, dictating a process equipped with high frequency bipolar capability. Therefore, the selection process should provide an appropriate balance between cost and performance if the development is expected to have a high probability of success. A combination GaAs/SiGe multichip module (MCM) solution with 90 percent of the functions in a low cost SiGe process offers a good compromise for many conflicting requirements.

Highly Integrated WLAN ICs

A complete chipset for a dual-band multimode WLAN card to meet IEEE 802.11a, b and g requirements is being developed. A combination of GaAs, MESFET/HBT, SiGe HBT and Si CMOS technologies are used to achieve high performance, low cost and quick time-to-market for the WLAN IC market. These ICs, coupled with baseband ICs, will form a complete chipset solution and a reference design for WLAN application. The HBT power amplifier technology offers higher power levels and linearity than is achievable with Si CMOS technology. Similarly, GaAs MESFET and PHEMT technologies offer high performance front-ends with low loss switches, PAs and LNAs with good noise figure. The competing Si CMOS technology cannot offer the performance these chips can offer. A photograph of a complete chipset assembled on an RF reference board is shown in ***Figure 3***.

Power Amplifiers

In the power amplifier area, many unique and innovative solutions can be offered. For both WLAN and broadband wireless access (BWA) markets, as one goes to high data rates and higher modulation levels, the performance requirements for PAs increase in terms of linearity, efficiency and error vector magnitude (EVM). With the GaAs HBT and MESFET PA solutions, stringent efficiency and linearity requirements can be met to maximize throughput at high orders of digital modulation. With these solutions, the end user receives the maximum range, data rate and battery life simultaneously. ***Figure 4*** shows examples of HBT power amplifiers. ***Figure 5*** shows measured

[Continued on page 149]

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Call for Papers

The IEEE MTT-S International Microwave Symposium 2003 (IMS2003) will be held in Philadelphia, Pennsylvania, Sun., June 8 through Fri., June 13, 2003, as the centerpiece of the Microwave Week 2003. Technical papers describing original work in research, development and application of RF and microwave theory and techniques are solicited.

Electronic Paper Submission/Communication: Technical papers for this symposium must be submitted via the IMS2003 web site (www.ims2003.org). Complete information on how to submit a paper and register for the conference, as well as other important information, can be found at the IMS2003 web site.

Technical Format: The technical sessions will run Tuesday through Thursday of the Microwave Week. Workshops will be held on Sunday, Monday and Friday. The RFIC Symposium (www.rfic2003.org) will be held Sunday through Tuesday, and the ARFTG Microwave Measurements Conference (www.arftg.org) will be held on Thursday and Friday.

Proposals Invited: Workshop (Tutorial through Expert level), Special Session (Focused and Honorary) and Panel/Rump Session proposals are invited. To suggest topics or volunteer to help organize/participate in a Workshop, Special Session or Panel Session, contact the appropriate committee member listed on this page. Special sessions highlighting this year's theme, *Liberty Through Microwaves*, are highly encouraged.

Microwave Week 2003: In addition to the IMS2003, a microwave exhibition, an historical exhibit, the RFIC Symposium and the ARFTG Conference will also be held in Philadelphia during Microwave Week 2003. This year, joint IMS/RFIC and IMS/ARFTG sessions will again be held on Tuesday and Thursday, respectively, as part of the technical sessions. Papers of general and special interest for the joint IMS/RFIC and IMS/ARFTG sessions are solicited.

The guest program will include tours to Philadelphia's historic sites and museums, and scenic trips to Lancaster County, Longwood Gardens, Valley Forge, New Hope and Atlantic City.

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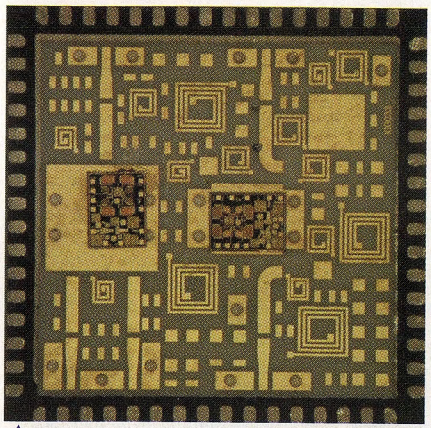
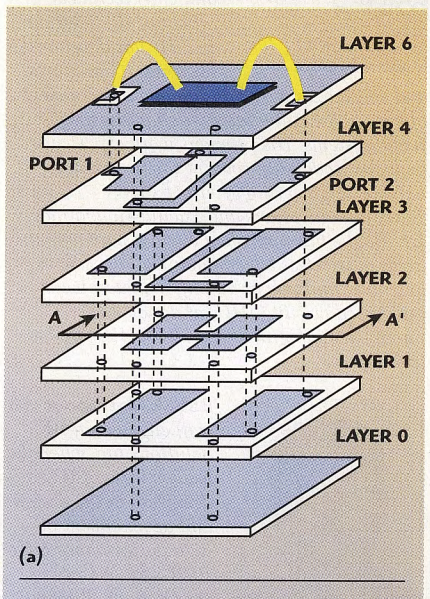


Fig. 6 An MCM on a ceramic substrate.



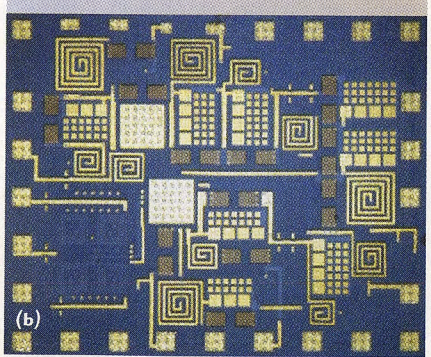


Fig. 7 3D passive components on LTTC with an IC on the top layer; (a) structure and (b) IC chip.

data demonstrating the performance of a 2.4 GHz HBT WLAN PA.

Multichip Module Technology

The MCM solution combines many IC process technologies in a single package to provide an optimized solution that lowers product cost and improves performance. The WLAN market asks for lower cost and better performance in the RF section. The best solution to meet these needs is to use compound semiconductor technologies such as GaAs for the higher performance RF section, and SiGe or CMOS for the lower performance RF or IF section. In order to meet the linearity and sensitivity requirements for this market, an LNA, front-end switch and PA may require a PHEMT process. An example of implementing this multichip module technology with a PA, LNA and switch is shown in ***Figure 6***.

In order to combine multiple ICs in a MCM, various packages or substrate materials are used, such as PCB laminates, alumina, low temperature cofired ceramic (LTCC), glass and BT resin. Various passive components such as inductors, capacitors, resonators, filters, power combiners and splitters are developed using multiplayer ceramic substrates at very low cost. In this manner, 200 discrete passive components, such as inductors, capacitors, resistors, filters and antennas, can be replaced by a $0.20 LTCC substrate. Working with LTCC, however, requires significant experience in device modeling of 3D embedded passive components. In some products, the die cost is lowered by using semiconductor materials mainly to obtain the required active transistors. Most of the desired matching and filtering is done on a LTCC or soft board module, which has lower cost than the IC substrate material.

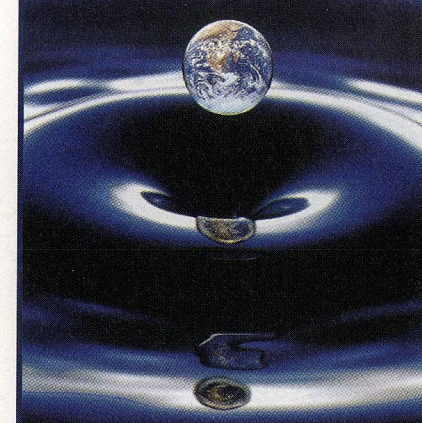
Figure 7 shows an example of MCM cost reduction, minimizing the use of expensive semiconductor materials, and using an LTCC substrate for passive components. Smaller size, lower cost and higher integration are maintained with this method.

FUTURE TECHNOLOGY IMPROVEMENTS

In the future, the trend for higher integration, coupled with clever architectures and proper mix of technologies, will lead to even lower cost and significant performance improvements in WLAN systems. As the WLAN costs continue to improve, these systems will work over a wider range using improved sectored antenna technology. Another interesting development to watch in the future is the integration of dual-band antennas, and dual-band front-end and trans-

[Continued on page 150]

QUARTZ



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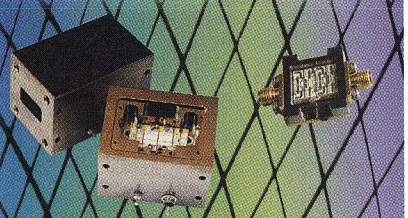
VSWR (I/O):	2.0:1	1.5:1
Current (Amps):	.260	3.8



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VSWR (I/O):	2.0:1	2.0:1
Current (Amps):	.150	3.6

MODEL:	MSH-6544402-DI	MSH-6706805-TC
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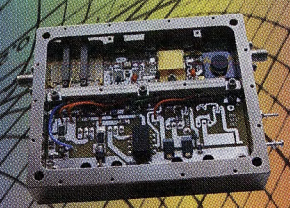
Current (Amps):	.200	.110



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ceiver modules. This further reduces cost and size, and improves overall system performance. Various wireless systems including WLAN, cellular, 3G and BWA systems will overlap over larger coverage areas. The user will be able to pick and choose which system he or she wants to use depending on their location. A number of promising technologies and the need for further integration levels will continue to push the need for RFIC designs and multichip module capability.

CONCLUSION

This article has shown that WLAN technology will have a key role in future wireless networks. Advances in IC technologies will lead to higher integration, lower cost and higher performance WLAN systems. This will enable low cost multimode, multiband wireless LAN cards, which will allow a WLAN card to operate in IEEE 802.11b, a or g modes. There are many design and process tradeoffs in developing these multimode WLAN cards. There is no single best approach, but there are a number of good architectures and approaches to designing these WLAN ICs with many tradeoffs. MCM technologies will allow integration of different ICs and passive components including inductors, capacitors, filters and antennas into a small package. These advanced IC and MCMs will also enable the convergence of cellular 2.5G and 3G networks with the WLAN network making PDAs and cell phones converge into a single device.

ACKNOWLEDGMENT

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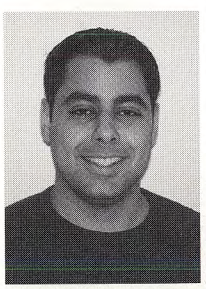
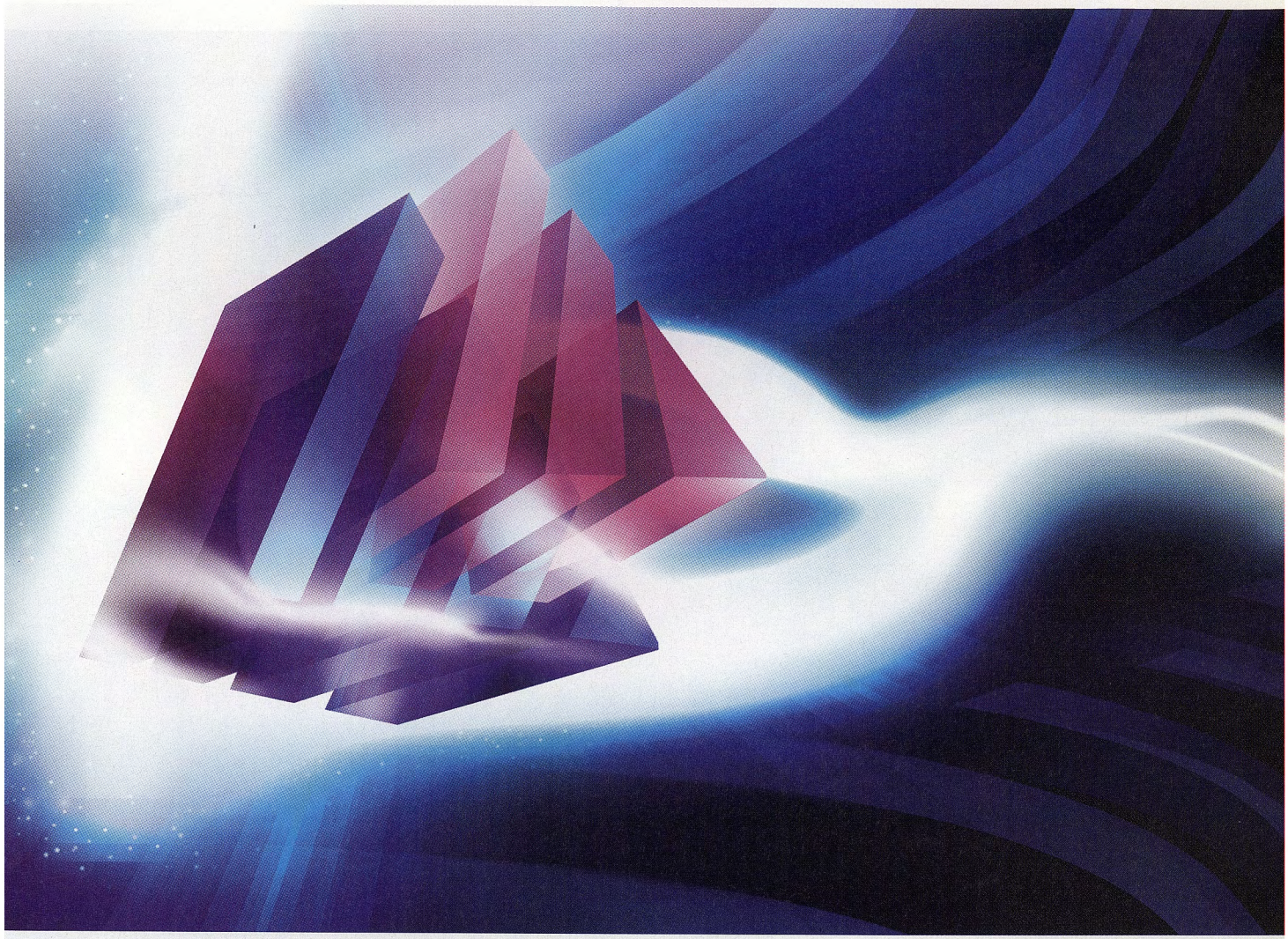


Babak Matinpour *is a staff engineer at RF Solutions Inc. where he leads a team of IC designers in the design and development of high performance SiGe RFICs for WLAN applications. Prior to joining RF Solutions, he participated in the design and development of SiGe RFICs with National Semiconductor, and K-band HEMT receiver ICs with Raytheon RF Components. Dr. Matinpour has published over 20 IEEE papers and has presented several conference presentations regarding compact and high performance GaAs and SiGe RFICs. He currently serves on the technical program committee for the MTT symposium.*



Drayton Avera *received his BS degree in electrical engineering from the Georgia Institute of Technology. Today he is the VP of business development for RF Solutions Inc. in Atlanta, GA. He has over 16 years of engineering experience developing RF and wireless products. Prior to joining RF Solutions, he held the position of director of engineering at LinkaNet Labs/DTS in Norcross, GA. Earlier in his career he held various engineering and management positions at both Motorola and NASA.*



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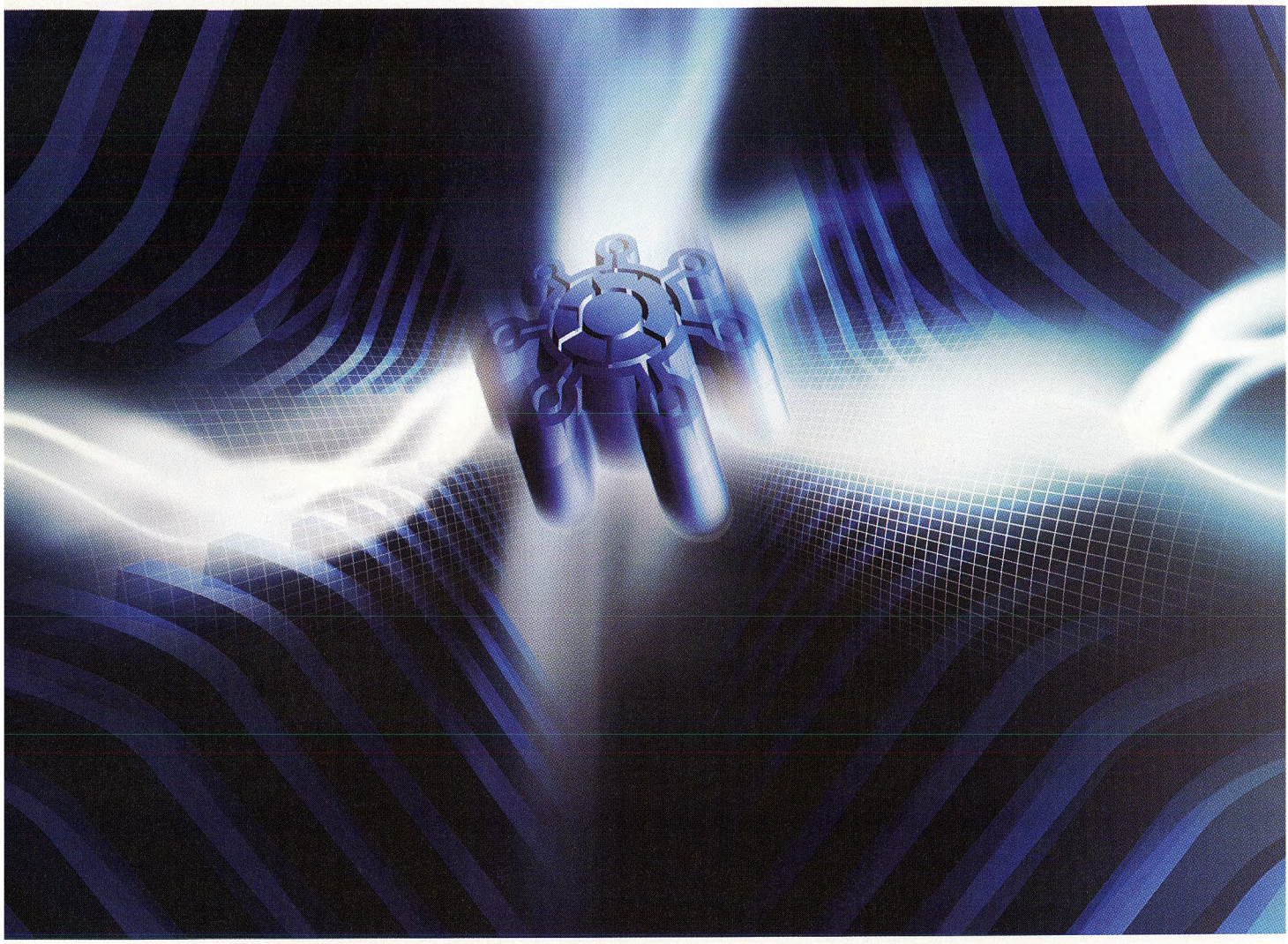

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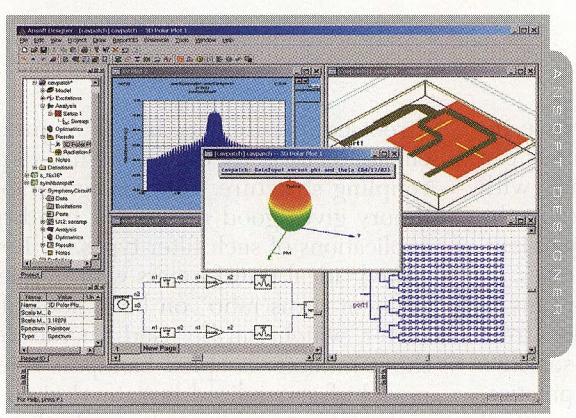

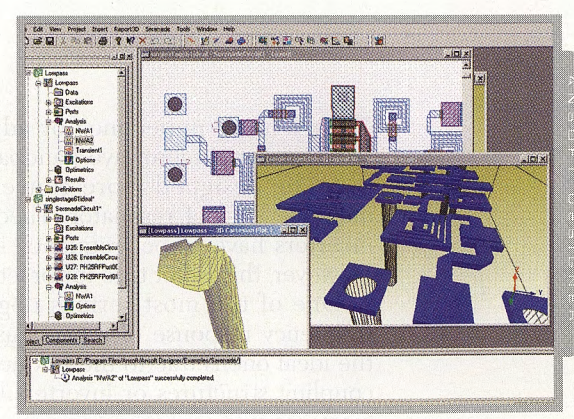

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THE DESIGN OF BANDPASS FILTERS CONSIDERING FREQUENCY DEPENDENCE OF INVERTERS

In general, practical inverters have frequency-dependent impedance or admittance. The equivalent circuits of several widely used inverters are investigated, consisting of ideal inverters plus frequency-dependent real and/or immittance parts. One of the most serious degradations in frequency response of bandpass filters is due to the existence of the immittance of the inverters while they are assumed ideal during the filter design. In this article, a new design method is presented, where all inverters are divided into two parts, an ideal inverter and a frequency-dependent immittance part, with the latter absorbed into the adjacent resonators as an immittance or immittance slope parameter. Based on the proposed method, several bandpass filters are designed and compared with those based on the standard filter design method. The designed and measured responses are in good agreement.

By using impedance or admittance inverters, microwave bandpass filters can be designed more conveniently with only one kind of resonator. Theoretically, the inverters have to be frequency independent. However, this is not true for practical cases.

One of the most serious degradations in frequency response of a bandpass filter from the ideal one is due to the frequency-sensitive coupling structures or inverters.[1] In practice, many circuits can operate as inverters even if they are not ideal ones. Because of the frequency dependence of the inverters, microwave filters designed with the standard method,[1] in which the inverter values are taken only at the center frequency, have to be modified, or optimized using various methods.

L. Young[2] offered a bandwidth contraction factor and a deviation of center frequency for direct-coupled cavity filters to predict the change caused by the frequency-dependent coupling structure using design graphs. The theory gives good results for bandwidths in applications of such filter types. R. Levy[3] suggested "ideal transformers with frequency-dependent turns ratio" on both sides of the inverter, which can be used for the design of shunt inductor-coupled bandpass filters. The model of generalized inverters[4] gives an easy and more general way to apply the inverter concept to the discontinuity network. A generalized design approach[5] using inverter imped-

[Continued on page 156]

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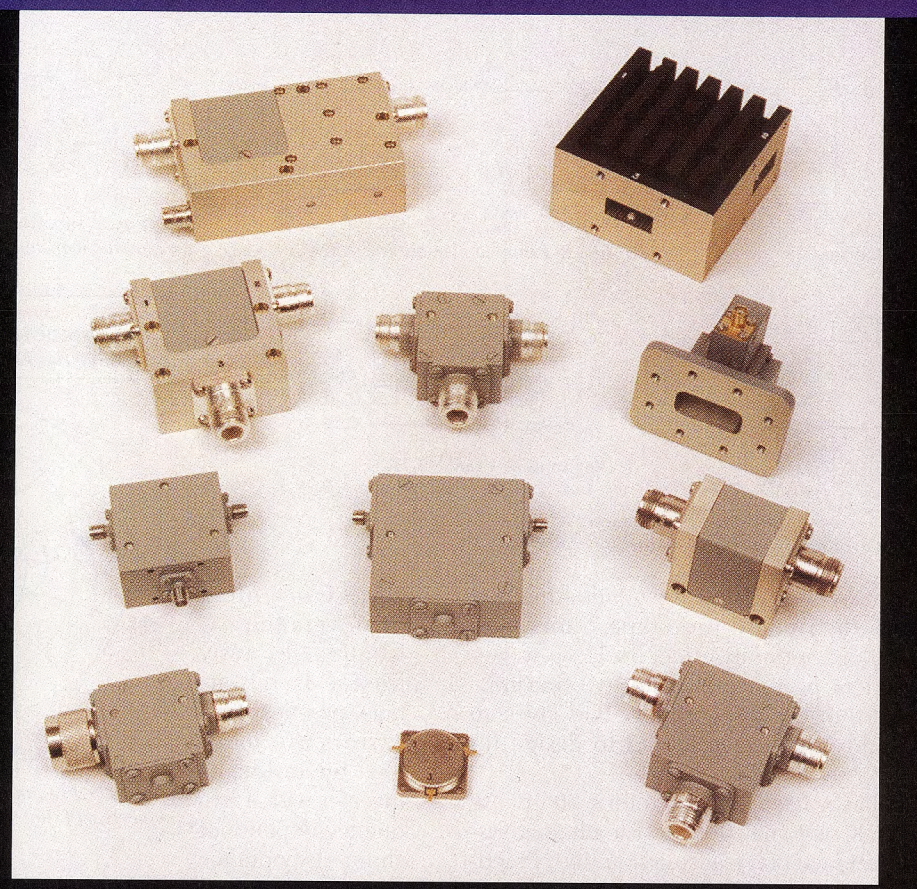

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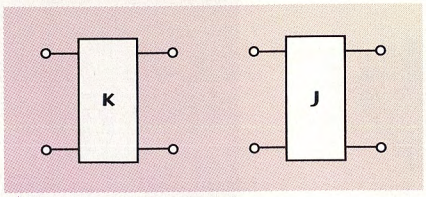


Fig. 1 Ideal K and J inverters.

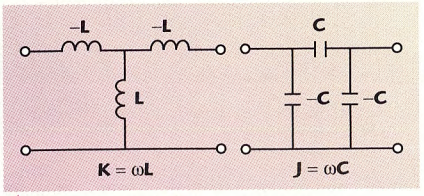


Fig. 2 Lumped element inverters.

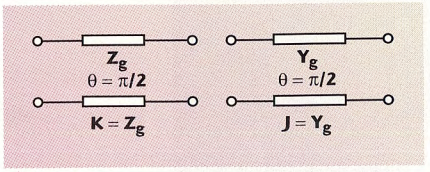


Fig. 3 Inverters using a transmission line of quarter wavelength.

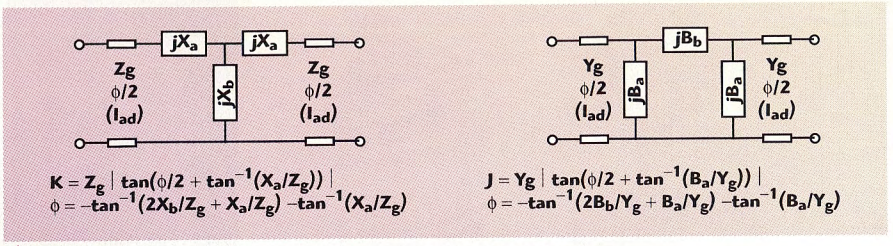


Fig. 4 Inverters using arbitary elements and transmission lines.

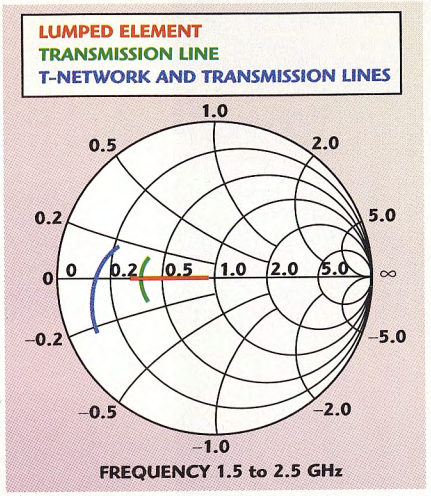
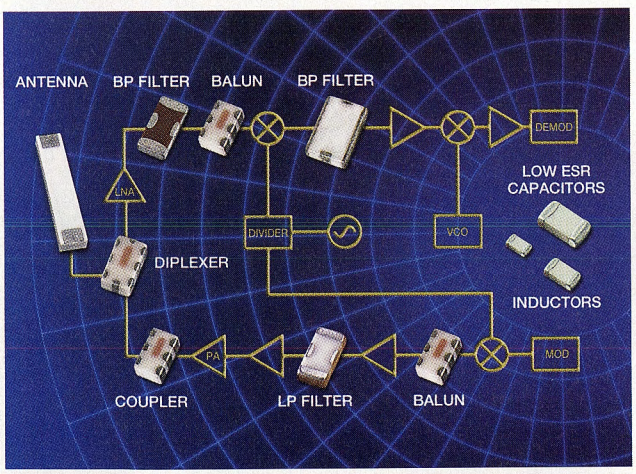


Fig. 5 Frequency-dependent S_{11} properties of the inverters.

ances and associated reference planes is a general method to design filters with distributed prototype filters, and considers the junction discontinuity effect itself. However, the frequency-dependent properties of the two transmission lines on both sides of the discontinuity that gives an impedance ratio should be also considered to design filters more exactly.

An ideal inverter has a fixed plus or minus 90° phase shift and a parameter K or J analogous to the characteristic impedance or admittance of a transmission line. Practical inverters that are used in standard filter design operate like an ideal inverter at only one center frequency and deviate from ideal performance at frequencies away from it. In this article, practical J inverters are modeled by an ideal J inverter with a frequency-dependent shunt susceptance on each side. In the design process these susceptances can be absorbed into adjacent shunt resonator susceptances to compute improved values for the resonator slope parameters. The case of K inverters is analogous, except that series reactances and series resonators are used.



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TYPICAL INVERTERS

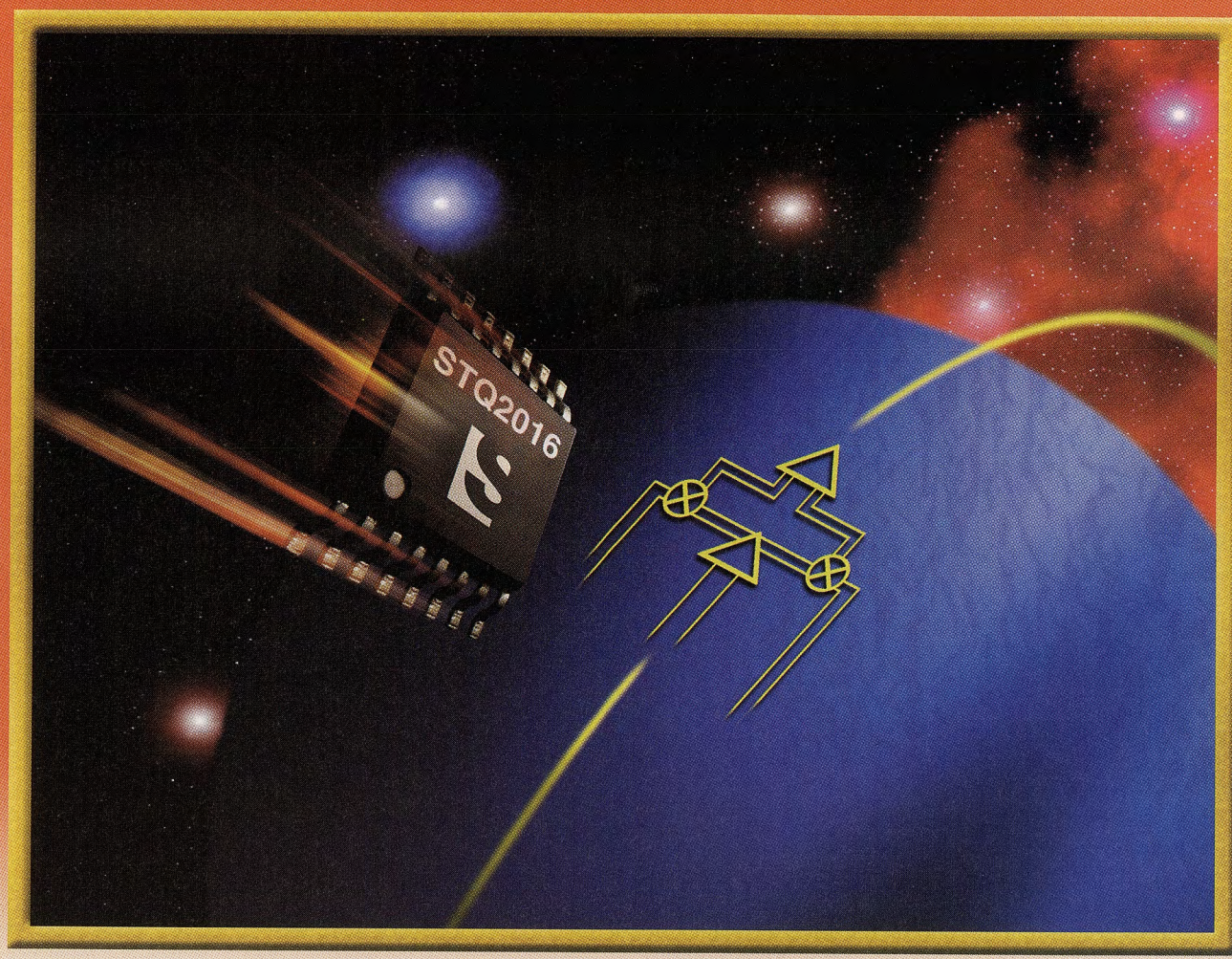
One standard method to design a bandpass filter uses impedance or admittance inverters. The ideal K and J inverters shown in ***Figure 1*** have well-known ABCD matrices given in Equation 1, and have frequency independent characteristics.

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_K = \begin{bmatrix} 0 & \pm jK \\ \pm j/K & 0 \end{bmatrix}$$
$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_J = \begin{bmatrix} 0 & \pm j/J \\ \pm jJ & 0 \end{bmatrix} \quad (1)$$

On the other hand, typical inverters have one of three types of frequency dependence: (1) only the real part depends on the frequency (***Figure 2***); (2) only the imaginary part depends on the frequency (***Figure 3***); or (3) both parts depend on the frequency (***Figure 4***). Each inverter can be represented by one port S-parameters on a Smith chart by terminating one port by a constant load of 50 Ω, as shown in ***Figure 5***.

In the case of the inverter made of lumped elements, only the real part depends on the frequency. This is not serious for filter design, because such frequency dependence of the inverter value does not affect the characteristics of the resonators, and the inverter values and res-

[Continued on page 158]



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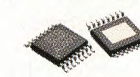

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Model	Frequency Range (MHz)	Output P1dB (dBm)	Carrier Feedthrough (dBm)	Sideband Suppression (dB)	IM3 Suppression (dB)	Broadband Noise Floor (dBm/Hz)	LO Drive Level (dBm)	Phase Error (deg)	Amplitude Balance (dB)
STQ-2016*	700–2500	+3	-40	40	65	-155	-5	±0.5	±0.05
STQ-3016†	2500–4000	+1	-40	33	50	-153	-6	±2.5	±0.10

*f_{LO} = 2,000 MHz; †f_{LO} = 3,500 MHz

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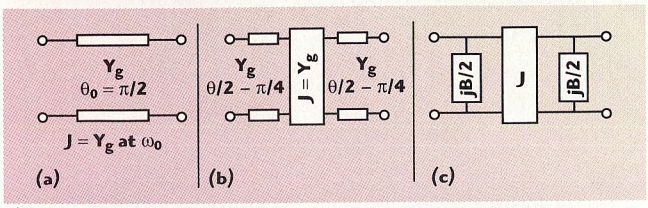


Fig. 6 A line as an inverter (a) and its equivalent circuit with ideal inverter (b), (c).

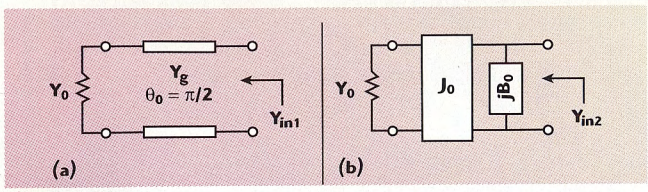


Fig. 7 A line as first-stage inverter (a), and equivalent circuit with ideal inverter (b).

onator slope parameters change linearly with frequency ω as $J = \omega C$ and $b = \omega C_r$, hence the coupling coefficients k ($k=J/b$) remain constant. However, for both the first and the last stages of the bandpass filter, the inverters are not directly applicable but one of the negative elements must be removed, which could introduce small deviation from the theoretical performances.

The inverters of the type (2) and the type (3) have different frequency characteristics from the type (1) inverter. Their immittances change as the frequency varies. Such frequency dependence degrades the filter response because the slope parameters and/or the inverter values do not change linearly as the frequency varies. Such inverter characteristics are discussed theoretically as well as their effect on the performance of the bandpass filters for the transmission line type and the more general type. By comparing the ABCD parameters of the two equivalent circuits, the equivalent values of the transmission line inverter shown in ***Figures 6*** and ***7*** can be obtained.

The ABCD matrix of an ideal transmission line and that of an ideal inverter with ideal transmission lines or immittances on both sides are given in Equations 2, 3 and 4, respectively.

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos\theta & jZ_g \sin\theta \\ jY_g \sin\theta & \cos\theta \end{bmatrix} \tag{2}$$

$$M \begin{bmatrix} 0 & jZ_g \\ jY_g & 0 \end{bmatrix} M,$$

where

$$M = \begin{bmatrix} \cos\frac{1}{2}\left(\theta - \frac{\pi}{2}\right) & jZ_g \sin\frac{1}{2}\left(\theta - \frac{\pi}{2}\right) \\ jY_g \sin\frac{1}{2}\left(\theta - \frac{\pi}{2}\right) & \cos\frac{1}{2}\left(\theta - \frac{\pi}{2}\right) \end{bmatrix} \tag{3}$$

$$M' \begin{bmatrix} 0 & j/J \\ jJ & 0 \end{bmatrix} M',$$

where

$$M' = \begin{bmatrix} 1 & 0 \\ jB/2 & 1 \end{bmatrix} \tag{4}$$

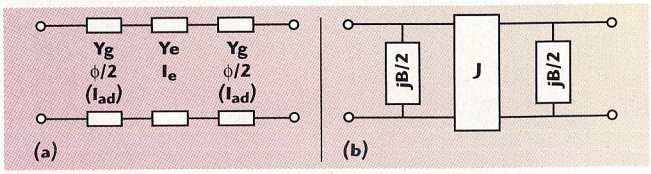


Fig. 8 An inverter with an evanescent waveguide (a), and its equivalent circuit (b).

Comparing Equations 3 and 4 gives the equivalent ideal inverter value, J, and the immittance of transmission line inverter, B, as

$$J = Y_g$$

$$B = Y_g \sin\frac{1}{2}\left(\theta - \frac{\pi}{2}\right) \tag{5}$$

For the first or last stage inverter, another equivalent circuit pair is used. The input admittances Y_{in1} and Y_{in2} can be easily obtained using

$$Y_{in1} = Y_g \frac{Y_0 + jY_g \tan\theta_0}{Y_g + jY_0 \tan\theta_0} \tag{6}$$

$$Y_{in2} = \frac{J_0^2}{Y_0} + jB_0 \tag{7}$$

Comparing these equations J_0 and B_0 are derived as

$$J_0 = Y_g$$

$$B_0 = Y_g \frac{Y_0^2 - Y_g^2}{Y_0^2} \cot\theta \tag{8}$$

The susceptance slope parameters b_0 and b for first (or last stage) and mid-stage inverters are determined from B_0 and B of Equations 5 and 8, respectively, by using the same definition as a resonator.

$$\underline{b} = \frac{\omega_0}{2}\left.\frac{dB}{d\omega}\right|_{\omega=\omega_0} = \frac{\pi}{8} Y_g \left(\frac{K}{\beta}\right)^2$$

$$\underline{b}_0 = \frac{\pi}{4} Y_g \frac{Y_0^2 - Y_g^2}{Y_0^2} \left(\frac{K}{\beta}\right)^2 \tag{9}$$

where

K = wave number
β = propagation constant

Similarly, equations for the same parameters are derived for an evanescent waveguide inverter shown in ***Figure 8***. The evanescent waveguide section (length l_e and characteristic admittance jY_e) with two propagating waveguide sections (length l_{ad} or $\phi/2$ and characteristic admittance Y_g) is a well-known and widely used inverter. First, the ABCD matrices of (a) and (b) are derived using the equivalent circuit parameters of the waveguide of ***Figure 9***.

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{(b)} = \begin{bmatrix} -\frac{B}{2J} & j\frac{1}{J} \\ jJ\left(1 - \frac{B^2}{4J^2}\right) & -\frac{B}{2J} \end{bmatrix} \tag{10}$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{(a)} = \frac{1}{Y_g} \begin{bmatrix} Y_g\left(\cosh\theta \;\; \cos\phi + \frac{1}{2}\varsigma\sinh\theta \;\; \sin\phi\right) & j\left\{\cosh\theta \;\; \sin\phi + \frac{1}{2}\sinh\theta\left(\xi - \varsigma \;\; \cos\phi\right)\right\} \\ j\left\{\cosh\theta \;\; \sin\phi - \frac{1}{2}\sinh\theta\left(\xi + \varsigma \;\; \cos\phi\right)\right\} & Y_g\left(\cosh\theta \;\; \cos\phi + \frac{1}{2}\varsigma\sinh\theta \;\; \sin\phi\right) \end{bmatrix} \tag{11}$$

where

$$\varsigma = \frac{Y_e}{Y_g} - \frac{Y_g}{Y_e}$$

$$\xi = \frac{Y_e}{Y_g} + \frac{Y_g}{Y_e}$$

From Equations 11 and 1, the electrical length ϕ and inverter value J have to be as Equations 12 and 13 in order to satisfy A=D=0 and the reciprocal condition AD-BC = 1 at center frequency.

$$\phi_0 = \tan^{-1}\left(\frac{2\coth\theta_0}{\frac{Z_e}{Z_g} - \frac{Z_g}{Z_e}}\right) \tag{12}$$

$$J = \frac{Y_g}{\cosh\theta_0 + \frac{1}{2}\left[\left(\frac{Y_g}{Y_e} + \frac{Y_e}{Y_g}\right) + \left(\frac{Y_g}{Y_e} - \frac{Y_e}{Y_g}\right)\cos\phi_0\right]\sinh\theta_0} \tag{13}$$

Comparing the matrices of Equations 10 and 11 gives the susceptance B as

$$B = Y_g \frac{-2\cos\phi - \varsigma\tanh\theta\sin\phi}{\sin\phi + \frac{1}{2}\left(\xi - \varsigma \;\; \cos\phi\right)\tanh\theta} \tag{14}$$

For the first stage inverter, the input impedances Y_{in1} and Y_{in2} in ***Figure 10*** can be also derived and compared. As a result, the inverter value J_0 and susceptance B_0 are given by

$$Y_{in1} = Y_0 \frac{\left(1 - \frac{Y_g}{Y_e}\tanh\theta\tan\phi\right) + j\frac{Y_g}{Y_0}\left(\tan\phi - \frac{Y_e}{Y_g}\tanh\theta\right)}{\left(1 + \frac{Y_e}{Y_g}\tanh\theta\tan\phi\right) + j\frac{Y_0}{Y_g}\left(\tan\phi + \frac{Y_g}{Y_e}\tanh\theta\right)} \tag{15}$$

$$Y_{in2} = \frac{J_0^2}{Y_0} + jB_0 \tag{16}$$

$$\phi = \frac{1}{2}\tan^{-1}\frac{2\xi_0\tanh\theta}{\varsigma_0\left(1 - \xi_0\right)\tanh^2\theta - \varsigma_0} \tag{17}$$

where

$$\varsigma_0 = \frac{Y_0}{Y_g} - \frac{Y_g}{Y_0}$$

$$\xi_0 = \frac{Y_0}{Y_e} - \frac{Y_e}{Y_0}$$

[Continued on page 160]

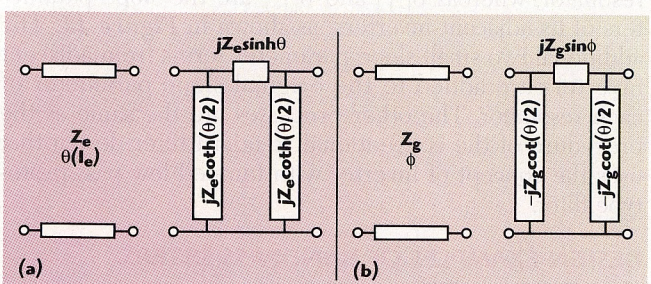


Fig. 9 WG equivalent circuits for below (a), and above (b) cutoff frequency.

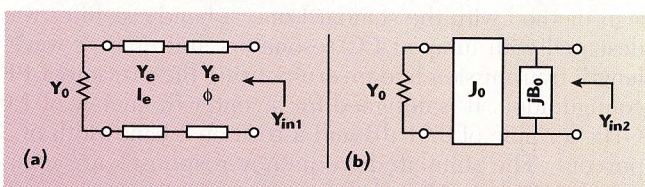
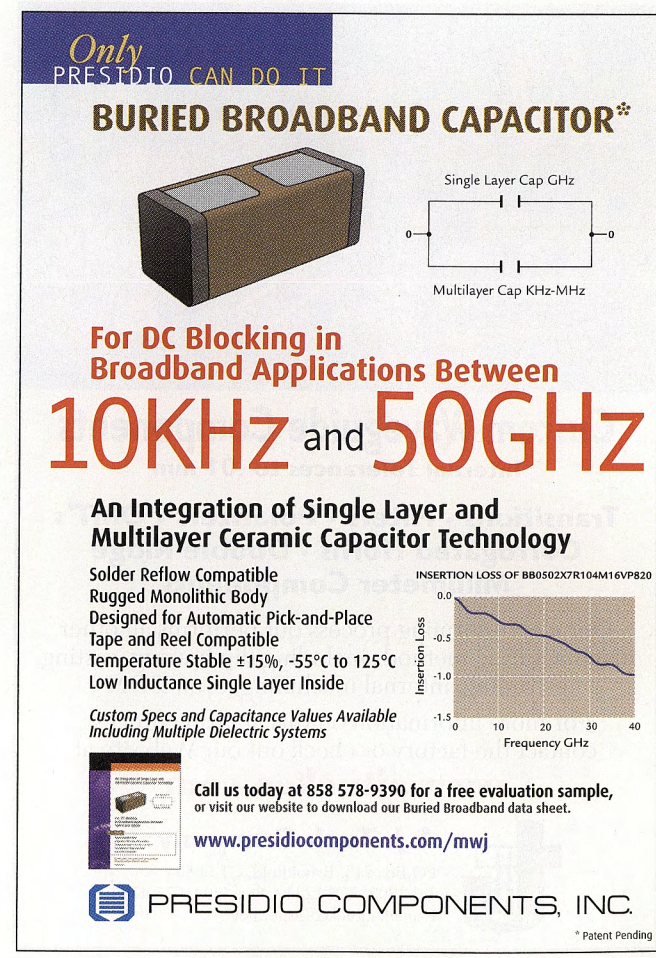


Fig. 10 The inverter for first-stage (a), and its equivalent circuit (b).



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$$\frac{J_0^2}{Y_0} = \frac{Y_0\left(1-\tan^4\phi\right)}{\tan^2\phi\left(\frac{Y_e^2}{Y_g^2}\tanh^2\theta+\frac{Y_0^2}{Y_g^2}\right)+2\xi_0\frac{Y_0}{Y_g}\tan\phi\tanh\theta+1+\frac{Y_0^2}{Y_e^2}\tanh^2\theta} \quad (18)$$

$$B_0 = Y_0\frac{\xi_0\left(\tan^2\phi-1\right)\tanh\theta+\tan\phi\left[\varsigma_0\left(1-\xi_0\right)\tanh^2\theta-\varsigma_0\right]}{\tan^2\phi\left(\frac{Y_e^2}{Y_g^2}\tanh^2\theta+\frac{Y_0^2}{Y_g^2}\right)+2\xi_0\frac{Y_0}{Y_g}\tan\phi\tanh\theta+1+\frac{Y_0^2}{Y_e^2}\tanh^2\theta} \quad (19)$$

The slope parameters for the first (or last) inverters and mid-inverters are calculated as

$$b_0 \approx \frac{f_0}{2}\frac{\Delta B_0}{\Delta f}$$

for the first inverter, and

$$b \approx \frac{f_0}{2}\frac{\Delta B}{\Delta f}$$

for mid-inverters (20)

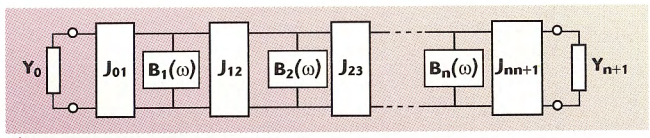
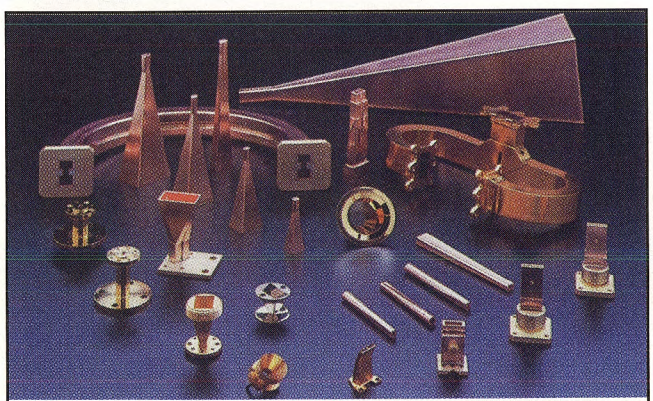


Fig. 11 A BPF with admittance inverters.[1]



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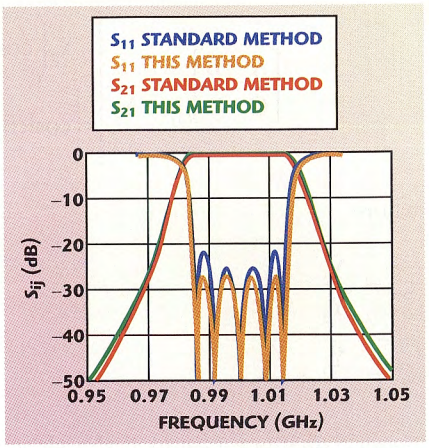

Fig. 12 A comparison of the five-pole bandpass filters.

where

Δ = incremental change in the parameters around the center frequency f_0

FILTER DESIGN METHOD

By using the inverter analysis of the previous section, bandpass filters can easily be designed with standard design equations modified slightly on the slope parameter $\underline{b}_j$ as

$$J_{0,1} = \sqrt{\frac{Y_0 W \underline{b}_1}{\omega_i g_0 g_1}} \quad (21)$$

$$J_{j,j+1} = \frac{W}{\omega_i}\sqrt{\frac{\underline{b}_j \underline{b}_{j+1}}{g_j g_{j+1}}} \quad (22)$$

$$J_{n,n+1} = \sqrt{\frac{Y_{n+1} W \underline{b}_n}{\omega_i g_n g_{n+1}}} \quad (23)$$

where

$$\underline{b}_j = b_{j-1,j} + b_{rj} + b_{j,j+1}$$

The parameters b_{rj} denotes the slope parameters of the jth resonator, whereas $b_{j-1,j}$ and $b_{j,j+1}$ are the slope parameters of its adjacent inverters, as shown in ***Figure 11***. The additional two small slope parameter terms from adjacent inverters are added to the original slope parameter of each resonator. The other processes are the same as the procedure of the conventional standard filter design that uses the concept of inverter with lumped low pass prototype filter.

DESIGN EXAMPLES OF BANDPASS FILTERS

(A) A Bandpass Filter with Quarter Wavelength Transmission Line Inverter

In order to compare the previously described filter design method with the standard one, a bandpass filter was designed with lumped LC resonators and quarter wavelength transmission line inverters using the previous BPF configuration. It is designed for a center frequency of 1.0 GHz, a ripple of 0.01 dB and a fractional bandwidth of 3 percent. The simulated frequency responses are compared in ***Figure 12*** and the designed inverter values are

[Continued on page 162]

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3201-1	dc-2.0	31/1	5	⌖	◆
3201-2	dc-2.0	120/10	5	⌖	◆
3201-4	dc-2.0	1.2/1	5		
3205-1	dc-2.0	70/10	5	⌖	◆
3205-2	dc-2.0	55/5	5	⌖	◆
3205-3	dc-2.0	1.5/1	5	⌖	◆
3206-1	dc-2.0	63/1	6	⌖	◆
3209-1	dc-2.0	64.5/0.1	10	⌖	
3250-63	dc-1.0	63/1	6	✱	
150-11	dc-18.0	11/1	4	⌖	➤
150-15	dc-18.0	15/1	4	⌖	➤
150-31	dc-18.0	0-31/1	5	⌖	➤
150-62	dc-18.0	62/2	5	⌖	➤
150-70	dc-18.0	70/10	3	⌖	➤
150-75	dc-18.0	75/5	4	⌖	➤
150-110	dc-18.0	110/10	4	⌖	➤
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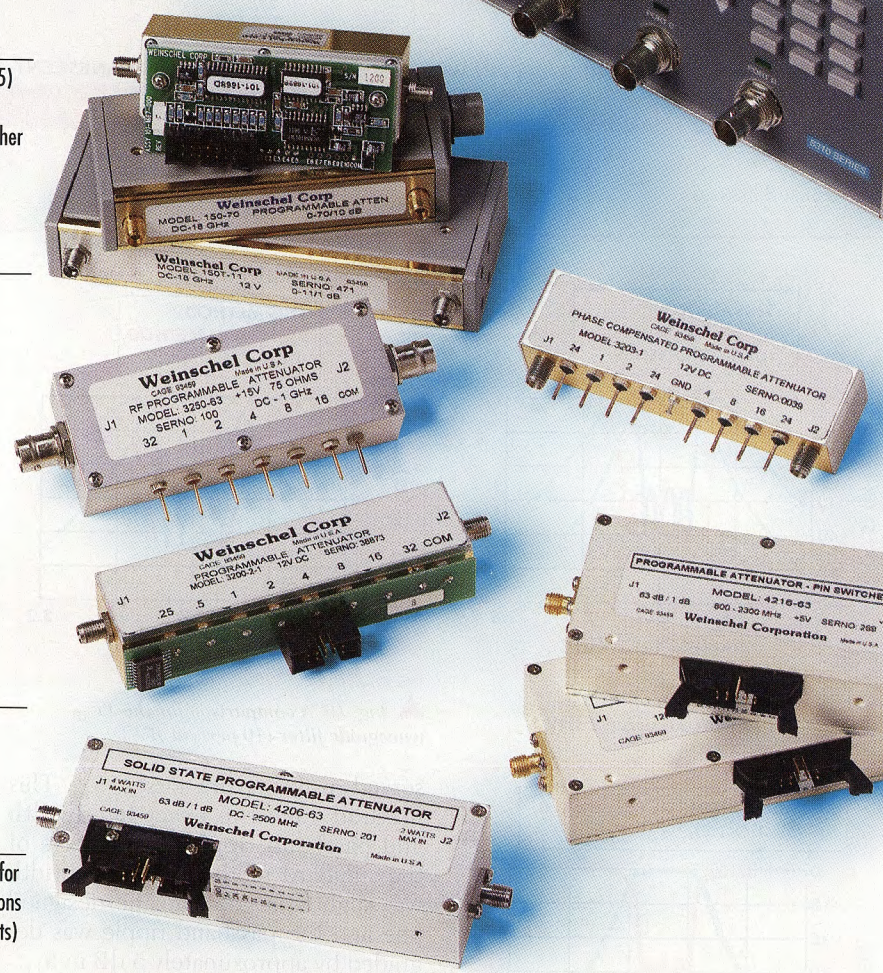

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TABLE I

FIVE-POLE BPFs USING SHUNT-PARALLEL RESONATORS AND QUARTER WAVELENGTH TEM LINE INVERTERS (Lr=2.533 nH AND Cr=10.00 pF FOR THE RESONATORS)

Method	$J_{01} \times 10^{-3}$	$J_{12} \times 10^{-3}$	$J_{23} \times 10^{-3}$	$J_{34} \times 10^{-3}$	$J_{45} \times 10^{-3}$	$J_{56} \times 10^{-3}$
Standard method	7.060	1/897	1.314	1.314	1.890	7.060
This method	7.378	2.003	1.339	1.339	2.003	7.378

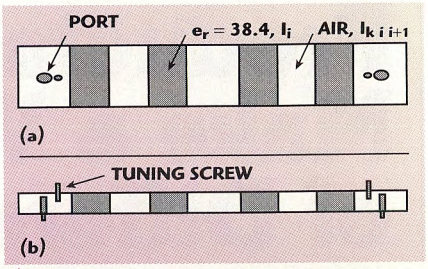


Fig. 13 The structure of the four-pole TE_{10} waveguide BPF; (a) top view and (b) side view.

TABLE II

TE_{10} WAVEGUIDE BPFs IN WHICH $\lambda_g/2$ RESONATORS AND EVANESCENT-GUIDE INVERTERS ARE USED

Method	l_{K01} (mm)	l_{K12} (mm)	l_{K23} (mm)	l_{K34} (mm)	l_{K45} (mm)	l_1 (mm)	l_2 (mm)	l_3 (mm)	l_4 (mm)
This article	10.02	22.00	24.06	22.00	10.02	3.14	3.10	3.10	3.14
Standard method	8.14	18.20	20.29	18.20	8.14	3.17	3.11	3.11	3.17

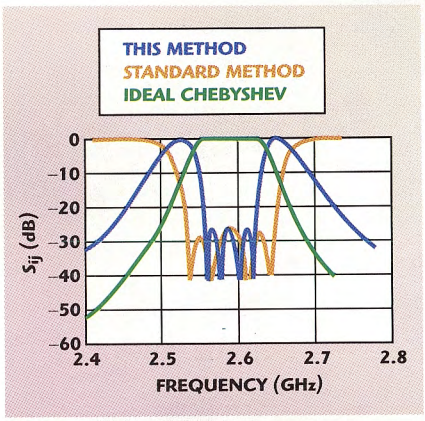


Fig. 14 A comparison of the TE_{10} waveguide BPFs with 2.5 percent BW.

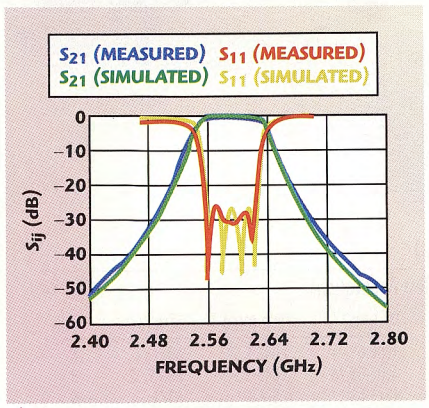


Fig. 15 The responses of the TE_{10} mode four-pole waveguide BPFs.

listed in ***Table 1***. The bandwidths are similar. However, the flat passband ripple is not obtained by the standard method but by the proposed method. Because the loss factors of the resonators and inverters are not considered, the passband ripples can be observed in the return losses, S_{11}. This method gave the exact bandwidth and passband ripple. In the case of the standard method, the bandwidth was slightly larger than the designed one and the passband ripple was degraded by approximately 5 dB in S_{11}.

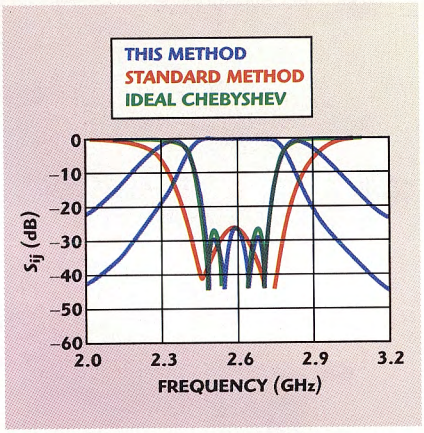


Fig. 16 A comparison for the TE_{10} waveguide filter (10 percent BW).

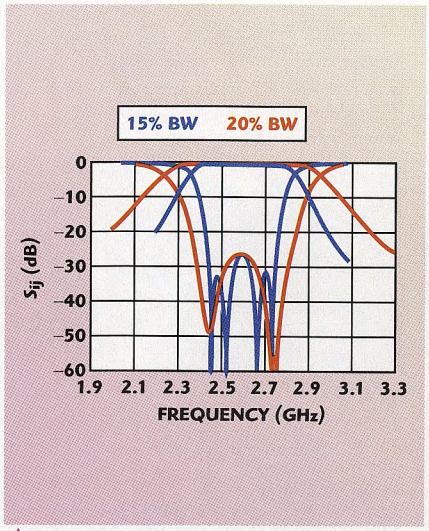
(B) A Bandpass Filter with Evanescent Guide Inverter

Another design based on the proposed method is a rectangular waveguide bandpass filter with evanescent waveguide inverters,[6] as shown in ***Figure 13***. At 2.59 GHz center frequency, bandpass filters with fractional bandwidths of 2.5 and 10 percent were designed using the same method. A rectangular waveguide (20 by 5mm) and ceramic materials (ε_r=38.4) were used in the filter construction. To calculate the inverter values, the equations for an inverter using arbitrary elements and transmission lines are used for the standard method, and Equations 13 and 18 are used for the proposed method. The designed parameters are given in ***Table 2***, in which l_{Kij} and l_i mean the lengths of evanescent sections and dielectric or propagating sections, respectively.

By the standard method, the designed filter response gives too wide a bandwidth (BW = 111 MHz, or result BW vs. wanted BW = 111/65 = 178 percent) and a bad ripple flatness (fluctuation of S_{11} approximately 2.5 dB), as shown in ***Figure 14***. On the other hand, the filter designed with this method gives excellent results in bandwidth (exactly 65 MHz) and passband ripples (S_{11} fluctuation within 0.5 dB).

The 2.5 percent bandwidth waveguide filter was designed using this method and the frequency response was measured. The loss terms are not considered in this method. There are no tuning screws in the constructed bandpass filter except at the input and output ports for matching of the transitions from coaxial to waveguide. The measured frequency response agrees well with the expected one except for the insertion loss, as shown in ***Figure 15***.

When a filter is designed for a 10 percent bandwidth with 0.01 dB ripple or SWR = 1.1, using this method, the SWR is from 1.10 to 1.07 in a passband, as shown in ***Figure 16***. The error is only 2.7 percent. The



▲ *Fig. 17 15 and 20 percent BW of the TE_{10} waveguide filter designed using this method.*

bandwidth error is about 3.5 percent (BW = 250 MHz and 250/259 = 96.5 percent). Therefore, this design method can be used for broader band filter designs. On the other hand, by the conventional standard method, the bandwidth error is about 46.7 percent (BW = 380 MHz and 380/259 = 146.7 percent). For bandwidths of 15 and 20 percent with 0.01 dB ripple, the resultant frequency responses designed by the proposed method show bandwidth errors of only –7.2 and –17.6 percent, respectively, as shown in ***Figure 17***.

CONCLUSION

One of the most serious factors that degrade the frequency response of bandpass filters designed by the standard method is the frequency dependence of the inverter immittance. In the proposed design method, the immittances of the inverters are considered as part of the adjacent resonators. The frequency-dependent terms of the inverters in the filters are treated as part of the resonator's immittance slope parameters. These parameters can easily be used to design filters by the conventional standard method with lumped low pass prototype filters. The frequency responses of the filters designed by this method are well matched with ideal Chebyshev responses, without any need for additional optimization or tuning. The proposed method is also applicable to wideband filters design to get better initial design values with ease. ■

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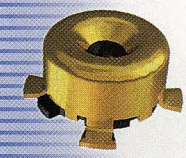

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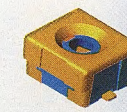

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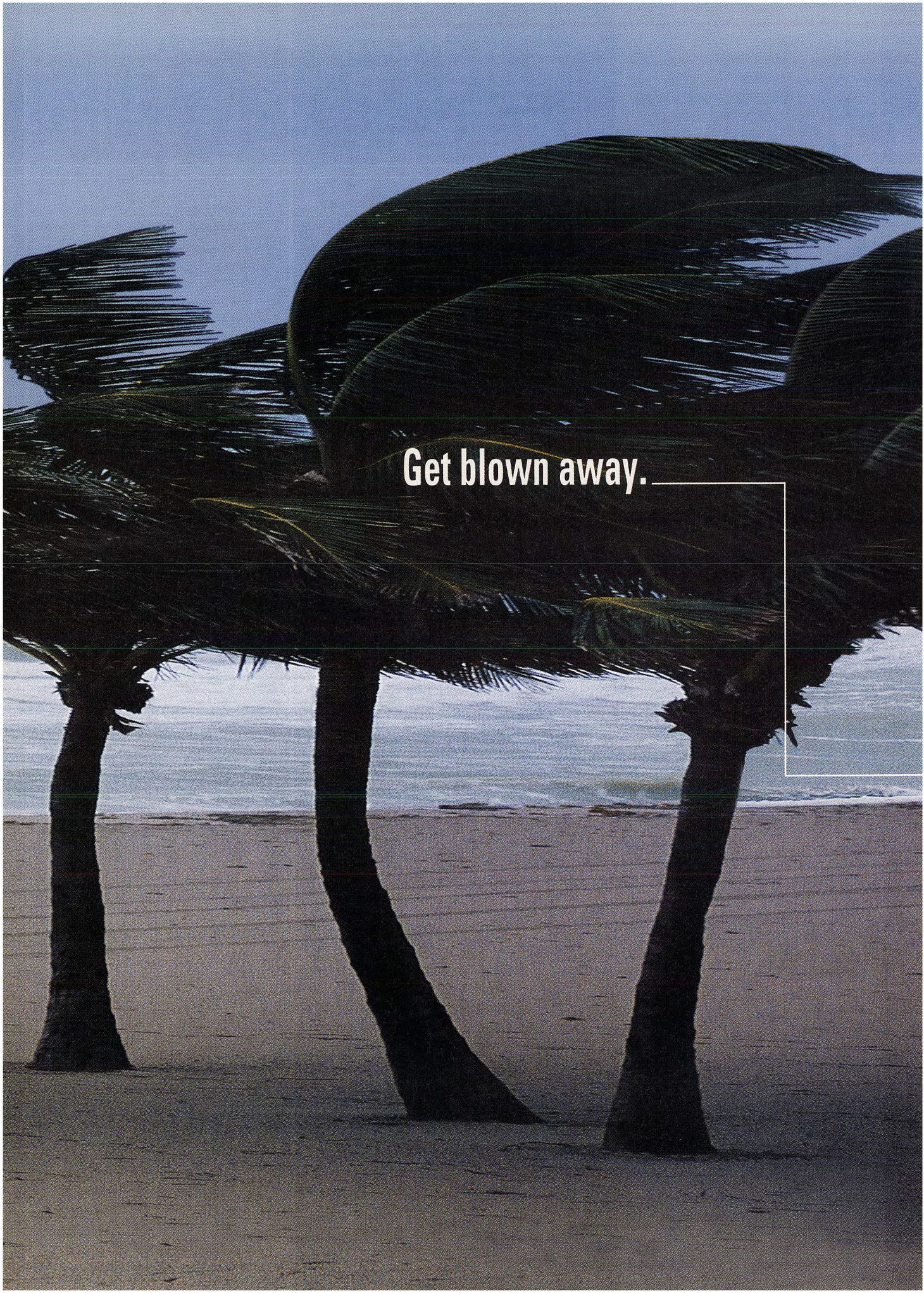
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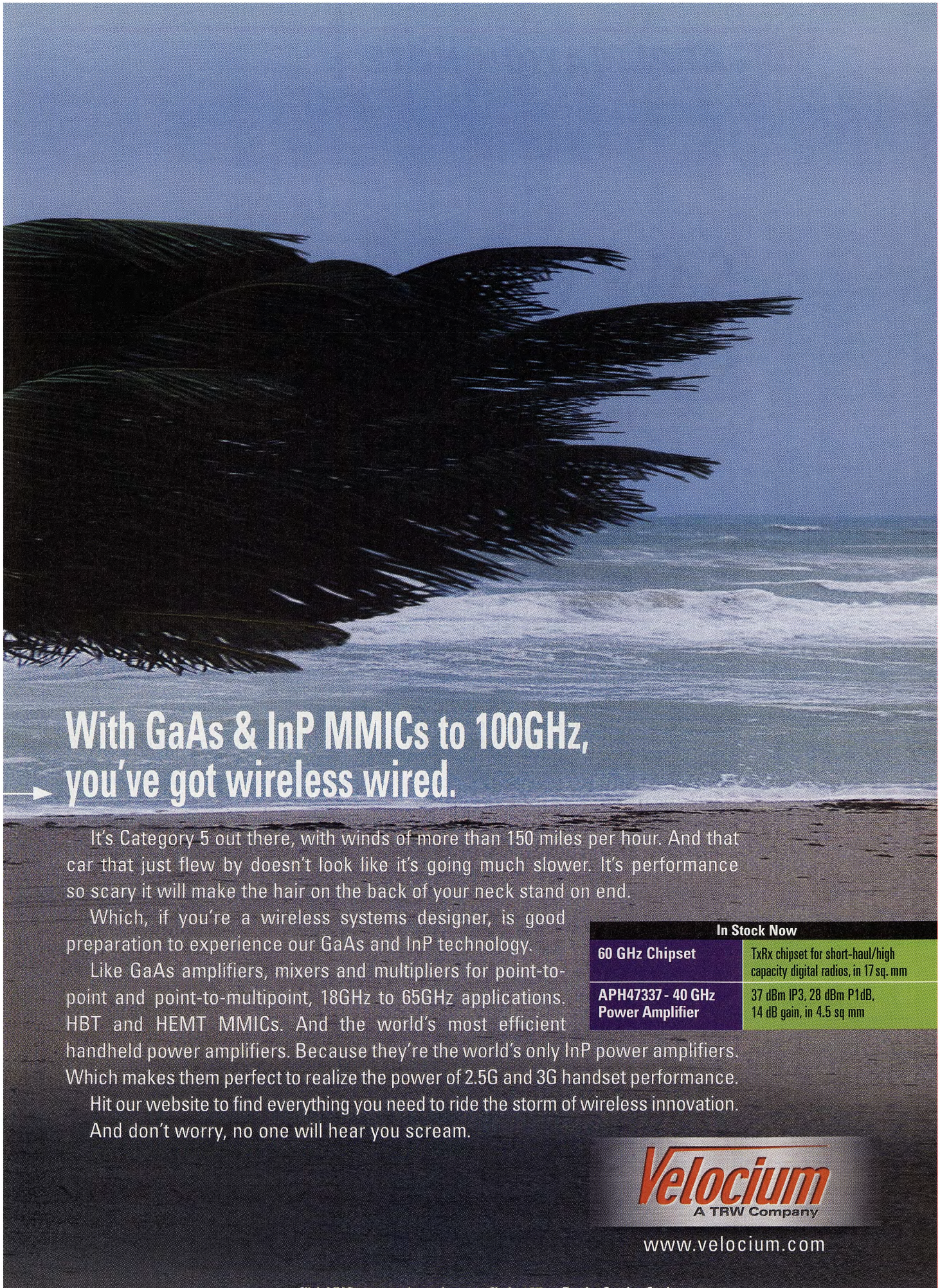

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SAW VOLTAGE-CONTROLLED OSCILLATORS

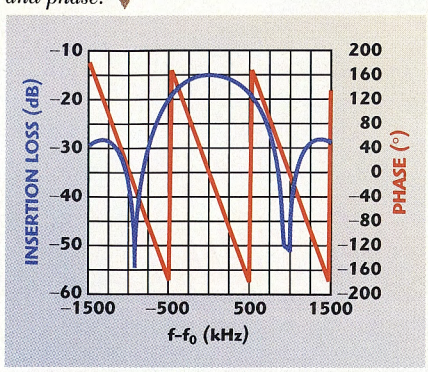
Voltage-controlled surface acoustic wave (SAW) oscillators (VCSO) have been used for many years in both commercial and military applications. The low phase noise allows frequency multiplication to higher frequencies for use as sources, such as local oscillators in radar and other microwave systems. The excellent tuning linearity provides outstanding performance in clock recovery applications in telecommunication systems. The small size, rugged construction and frequency stability offer significant advantages over other VCO technologies.

VCSOs do not offer the temperature stability of quartz crystal oscillators. However, they do provide higher fundamental output frequencies, lower phase noise and lower vibration sensitivity. Phase-locking a VCSO to a lower frequency crystal oscillator provides a method for obtaining the frequency stability of a crystal reference oscillator and the low noise performance of a SAW oscillator.

SAW DELAY LINE CHARACTERISTICS

The frequency-stabilizing element in a transmission type VCSO is the SAW delay line. The delay line is designed such that its –3 dB bandwidth is the inverse of its time delay ($1/\delta_d$), resulting in a linear 360° phase shift across the –3 dB bandwidth. A common design configuration uses a wideband transducer and a ladder transducer, and results in a sin x/x response. A typical response for a 1 µs SAW delay line is shown in ***Figure 1***. Note the sin x/x magnitude response and the linear phase. The insertion loss of the delay lines ranges from 5 to 20 dB depending upon design configuration and center frequency. The frequency range for SAW delay lines is 70 to 1200 MHz. The use of surface transverse wave (STW) delay lines increase the range to 2.5 GHz.

Fig. 1 One microsecond delay line amplitude and phase.



Delay line design parameters are determined by the oscillator performance requirements. The bandwidth is determined by the tuning range required. As a general rule, the bandwidth is at least twice the tuning range. The type of delay line, low loss and conventional SAW, or STW configuration, is determined by the phase noise specification and the oscillator center frequency.

All delay lines are packaged in hermetically sealed packages before being mounted in the oscillator. The use of a hermetic package is critical in achieving good long-term aging characteristics.

MEETING OSCILLATION CRITERIA

VCSOs are generally of the transmission type. In its simplest form, this type of oscillator consists of an amplifier with a SAW delay line as a feedback element connected from the amplifier output to the input. In order to sustain oscillation, the loop must meet two criteria — the loop

[Continued on page 168]

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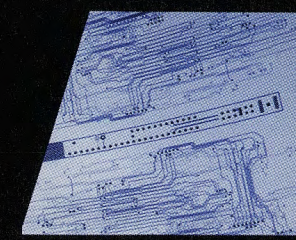

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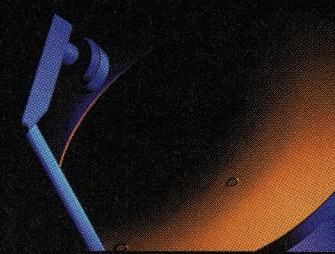

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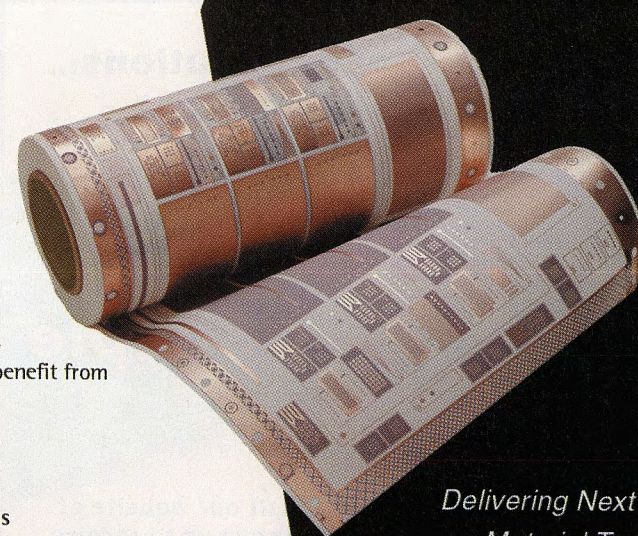

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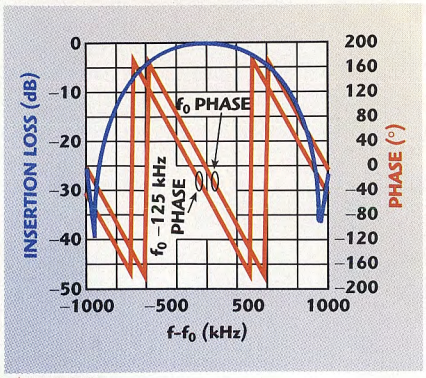

Fig. 2 Oscillator tuning.

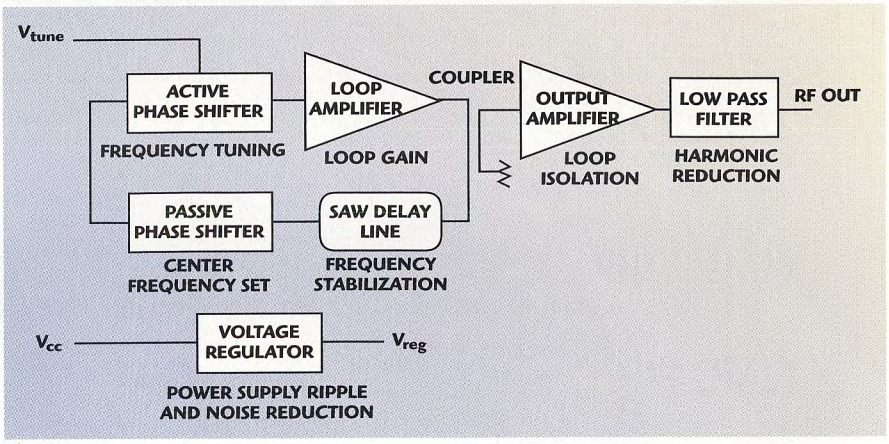

Fig. 3 VCSO block diagram.

gain must be equal to unity, and the phase shift at the desired frequency of oscillation must be equal to an integer multiple (n) of 360°. The unity gain requirement is met by selecting an amplifier having a gain greater than the delay line insertion loss. The loop gain will be set to unity by the amplifier limiting.

The phase shift requirement is met by controlling the phase in the loop. Assuming that the gain requirement is achieved, the loop will oscillate at the frequency meeting the n × 360° phase shift requirement. Changing the loop phase shift will cause the oscillator to change to a new frequency that provides the n × 360° loop phase shift. The effect of changing the loop phase shift is illustrated in ***Figure 2***. Note that as the phase shift is increased by 45°, the oscillator shifts to a different frequency that gives a loop phase shift of n × 360° (equivalent to 0°). The frequency is f_o – 125 kHz.

VCO BLOCK DIAGRAM

A block diagram of a VCSO is shown in ***Figure 3***. The VCO incorporates the transmission oscillator and an output amplifier used to isolate the oscillator from external influences. The oscillator loop consists of a SAW delay line, a passive phase shifter, an active phase shifter, a loop amplifier and a directional coupler.

The delay lines are typical of the one shown previously. The delays (δ_d) used range between 0.3 and 1.5 µs, depending upon the tuning range and modulation bandwidth specified. The delay line is designed such that the –3 dB bandwidth is approximately equal to $1/\delta_d$ to assure that the phase shift over the SAW delay line bandwidth is single valued.

The phase noise performance is generally an important characteristic of SAW oscillators. The best phase noise performance will be achieved using the longest delay (highest Q) and lowest insertion loss delay line design. However, this conflicts with wide tuning range and high modulation bandwidth. As in most designs, a compromise must be made. A general rule is to make the delay line bandwidth at least twice the required tuning range. This allows for center frequency adjustment and a guard band to prevent "wrap around." The oscillator cannot distinguish between n × 360° and (n+1) × 360°. When the oscillator frequency approaches the –3 dB frequency at one edge of the SAW delay line response, it will jump to the –3 dB frequency of the other band edge. This frequency discontinuity, or wrap around, must be avoided.

All oscillator delay lines are built on a quartz substrate. The frequency temperature coefficient of the quartz delay line is $-0.03(T-T_0)^2$ ppm. This

[Continued on page 170]



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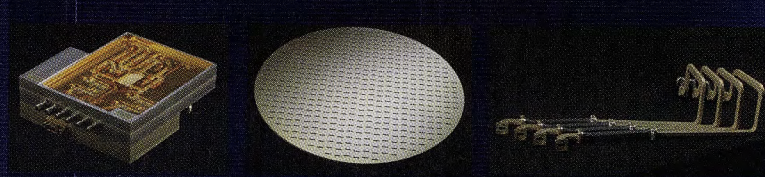

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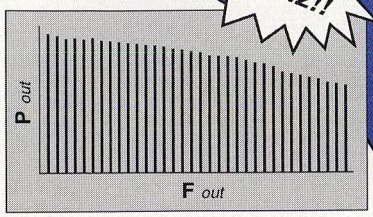

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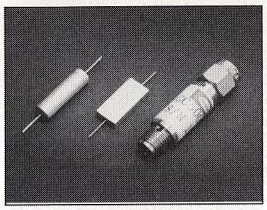

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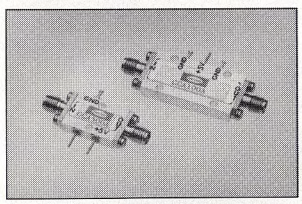

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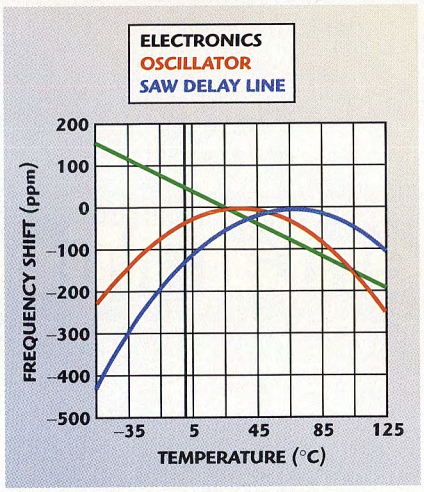

Fig. 4 Delay line and oscillator temperature performance.

characteristic is a negative parabolic function with the inflection point at T_0. T_0 is determined by the cut of the quartz crystal. In most cases, it is desirable to have the VCO inflection point at +25°C, or at the center of the operating temperature range, to minimize the frequency variation due to temperature.

The electronic components of a VCO have a nearly linear phase versus temperature characteristic with a negative slope. The linear phase shift added to the parabolic SAW characteristic results in a parabola having a lower temperature inflection point. The cut of quartz used for the delay line can be varied to change the inflection point. Thus, if the temperature characteristic of the electronic circuitry is known, the correct cut of quartz can be selected for optimum temperature stability. The delay line and oscillator temperature performance are illustrated in ***Figure 4***.

A passive phase shifter that allows the oscillator center frequency to be set during alignment follows the SAW delay line. The phase shift adjustment is necessary to compensate for variations in insertion phase of other loop components. The adjustment is made using "select-at-test" capacitors.

The active phase shifter provides the voltage-controlled tuning of the oscillator. The active phase shifter is similar in design to the passive phase shifter. The "select-at-test" capacitors are replaced by varactor diodes. The phase shifter provides approximately 180° of linear phase shift.

Both phase shifters are low insertion loss (2 dB) 50 Ω functional blocks. The values of the components used in the phase shifters are easily calculated for any oscillator frequency. Simple value changes allow the same design to function over the entire range of VCSO frequencies.

The loop amplifier provides a gain greater than the total loop insertion loss. In general, 6 to 10 dB of excess gain is desirable to allow for gain changes over the operating temperature range. The amplifier should be selected for the lowest noise figure possible, and an output power level to provide a +10 dBm input to the SAW delay line.

The amplifier phase shift as a function of temperature is important due to its effect on oscillator frequency stability. Most amplifiers are quite good when operated in their linear region. However, when used in a VCO, the amplifier is saturated. Since the phase shift data is rarely provided on a data sheet, the amplifier to be used must be characterized as part of the oscillator design.

Both MMIC RF amplifiers and discrete transistor amplifiers can be used. The MMIC amplifiers require little design effort and are space efficient. However, discrete transistor amplifiers are much more power efficient and allow the design to be optimized for a low power application.

A directional coupler is used to couple out of the loop. Couplings between 3 and 10 dB are used depending upon the oscillator loop insertion loss and the output power requirements.

The output amplifier is needed to isolate the oscillator loop and provide the necessary output power. Low pass filtering is incorporated in the output amplifier to reduce harmonic levels. When digital outputs are required, an appropriate logic interface circuit replaces the amplifier, and the filter is eliminated.

A low noise voltage regulator is used in most VCSOs. The regulator suppresses the external power supply ripple and noise, and provides frequency pushing of less than 2 ppm/V of power supply variation.

PHASE NOISE

The low noise provided by VCSOs is one of the parameters that dictate

[Continued on page 172]

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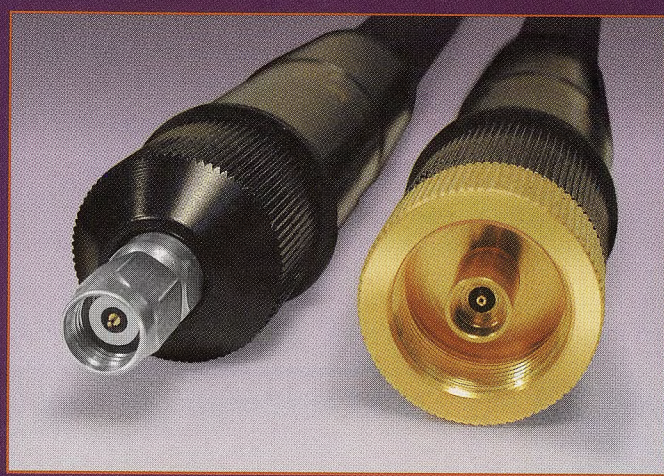

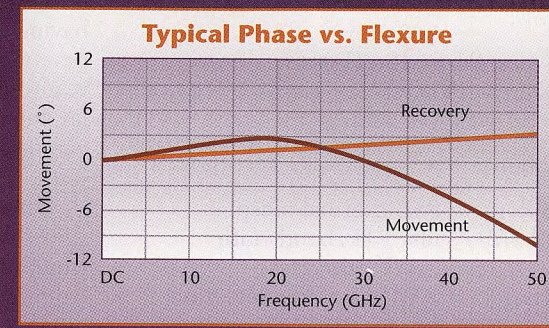

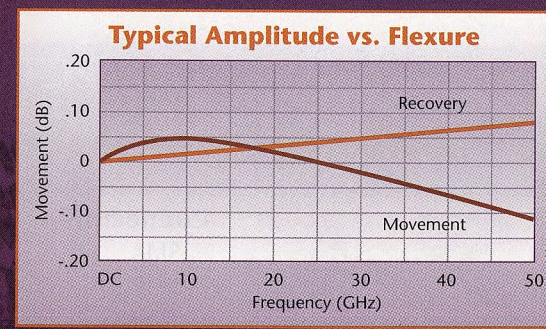

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their use in many applications. Although achieving low noise performance requires careful design and implementation, understanding and predicting phase noise performance is possible using just a few equations and oscillator parameters.

The first, and simplest, parameter to analyze is the noise floor. The noise floor of an oscillator is the ultimate white noise level, which the oscillator reaches at offset frequencies (f) outside the resonator bandwidth. It is a function of amplifier noise figure, amplifier output power and oscillator loop insertion loss. The noise floor can be calculated as shown below:

$$\text{Noise floor (dBc/Hz)} = K_{NF} = 10\log(kT/2) + IL_{SAW} + IL_{COUP} + IL_{PS} + NF_{AMP} - P_{0AMP} \quad (1)$$

where

$10\log(kT/2)$ = SSB thermal noise in a 1 Hz bandwidth (–177 dBm/Hz)
IL_{SAW} = SAW delay line insertion loss in dB
IL_{COUP} = coupler loss in dB
IL_{PS} = insertion loss of active and passive phase shifters in dB
NF_{AMP} = amplifier noise figure in dB
P_{0AMP} = amplifier ouptut power in dBm

The calculation for a typical 500 MHz VCSO is

$$K_{NF} = -177 + 15 + 1 + 4 + 3 - 10 = -164 \text{ dBc/Hz} \quad (2)$$

Equation 1 shows the circuit parameters that must be considered in the design of a low noise SAW oscillator. The insertion losses in the loop, including the SAW delay line, must be minimized. A low noise amplifier having as high an output power as is practical should be used. The power is ultimately limited by the SAW delay line. Power levels below 15 dBm can be considered safe for most delay lines.

Once the noise floor has been determined, the phase noise as a function of offset frequency can be calculated. Only two additional oscillator parameters are required for the calculation. The oscillator Q is simply the center frequency divided by the SAW delay line –3 dB bandwidth (f_0/BW). The $1/f$ or flicker noise corner frequency, f_c, is a characteristic of the loop amplifier or the delay line. In the case of SAW delay lines, the amplifier corner frequency dominates. The flicker noise adds an additional 10 dB per decade slope to the phase noise below the corner frequency. An empirical value of 4 kHz for the corner frequency has been determined for silicon bipolar transistors and MMIC amplifiers.

The equation for calculating the single-sideband (SSB) phase noise as a function of offset frequency, f_m, is

$$\mathcal{L}(f_m) = (10^{K_{NF}/10})[1+(F_0/(2f_mQ))^2](1 + f_c/f_m) \quad (3)$$

Converting to dBc/Hz

$$\mathcal{L}(f_m)_{dB} = 10\log\mathcal{L}(f_m)$$

[Continued on page 174]

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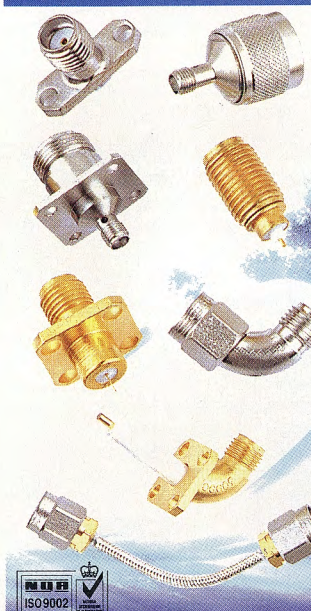

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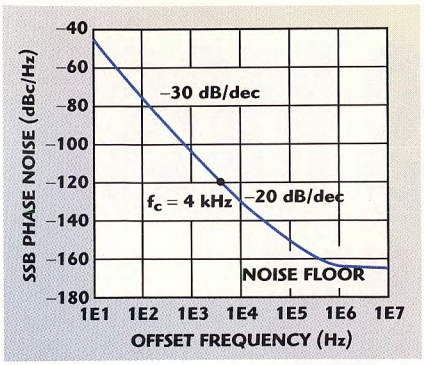


Fig. 5 Phase noise of a 500 MHz VCSO having a 1 MHz bandwidth.

where

K_{NF} = noise floor in dBm/Hz
F_0 = oscillator output frequency
f_m = offset frequency
Q = oscillator quality factor (f_0/BW)
f_c = 1/f noise corner frequency

Figure 5 shows a plot of the calculated phase noise for a 500 MHz VSCO having a 1 MHz bandwidth, –165 dBm noise floor and a 1/*f* noise corner frequency of 4 kHz. Note that the noise rises from the noise floor at a 20 dB/decade slope and changes to 30 dB/decade at f_c. Changes in the noise floor simply shift the entire phase noise curve either up or down.

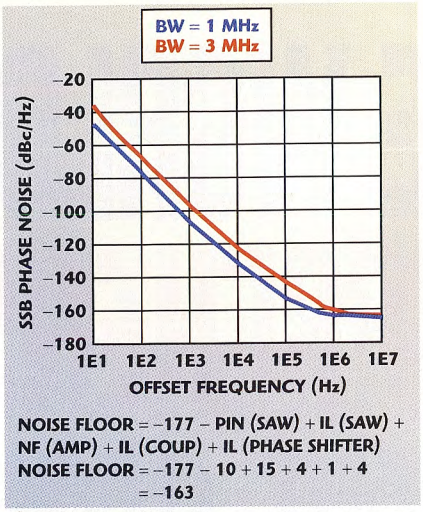


Fig. 6 Predicted phase noise of a VCSO with two delay line bandwidths.

Figure 6 illustrates the effect of changing the delay line bandwidth. Note that, with all other parameters remaining unchanged, increasing the delay line bandwidth from 1 to 3 MHz increases the phase noise by 10 dB.

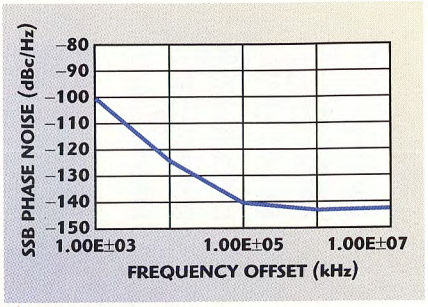
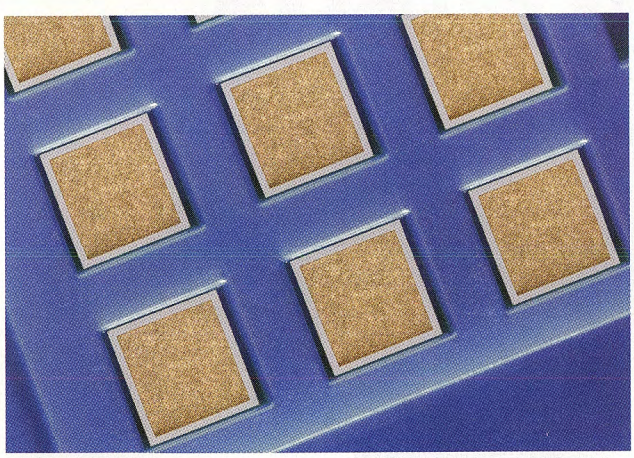


Fig. 7 Measured SSB phase noise of a VCSO at 622.08 MHz.

VCSO APPLICATIONS

Historically, VCSOs were built as discrete hybrid modules with a typical footprint of 1.0" × 1.5". New technology has made it possible to integrate ASICs and SAW technology to produce high performance VCSOs in small ceramic surface-mount packages. These VCSOs find large use in telecom applications such as low jitter clocks. A typical SSB phase noise for this type of VCSO having low voltage positive emitter coupled logic (LVPECL) outputs is shown in ***Figure 7***.

[Continued on page 177]



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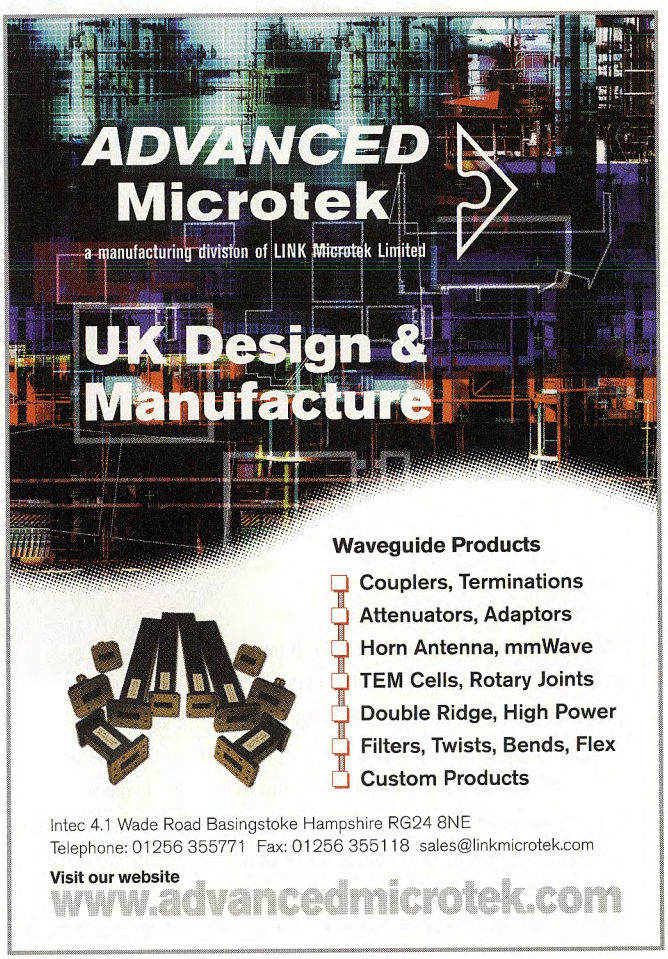

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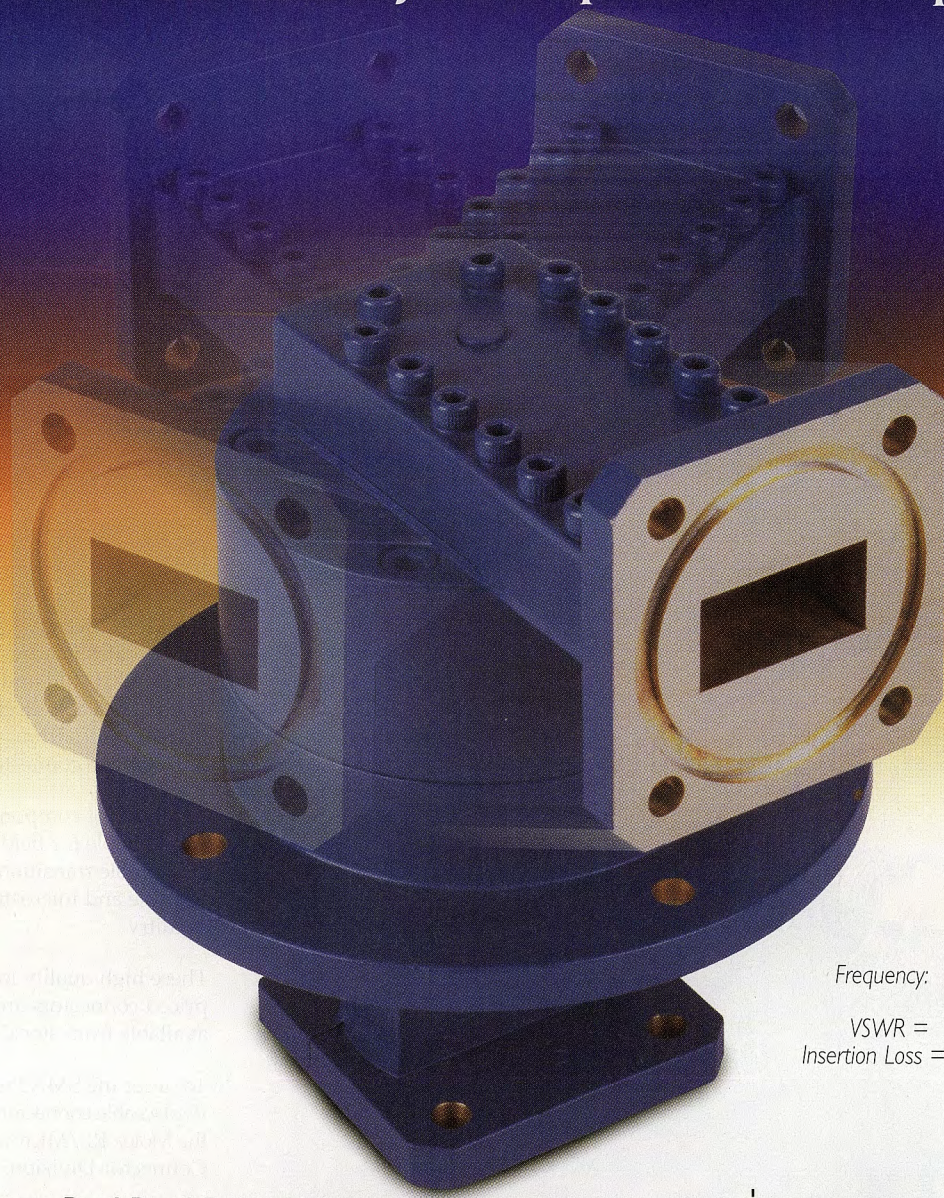

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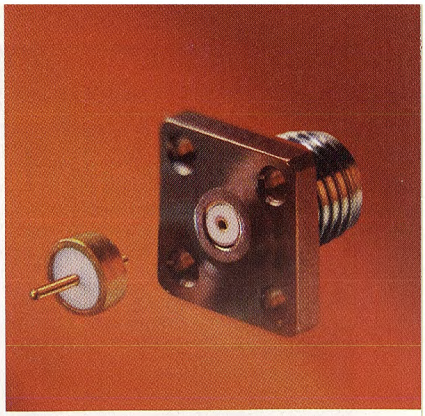

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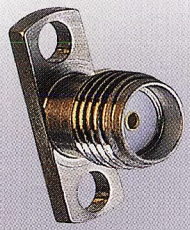

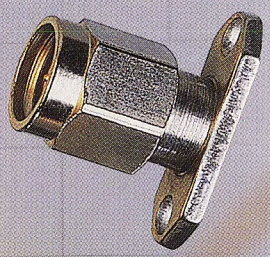

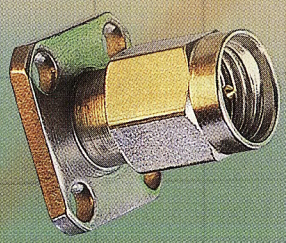

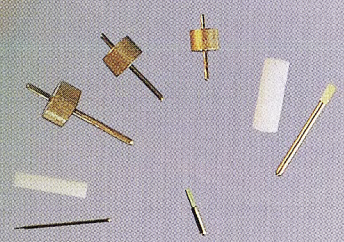

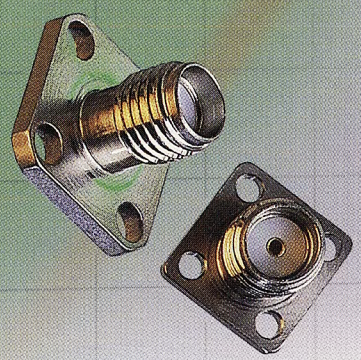

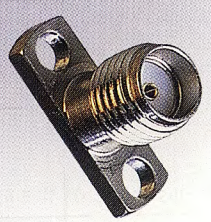

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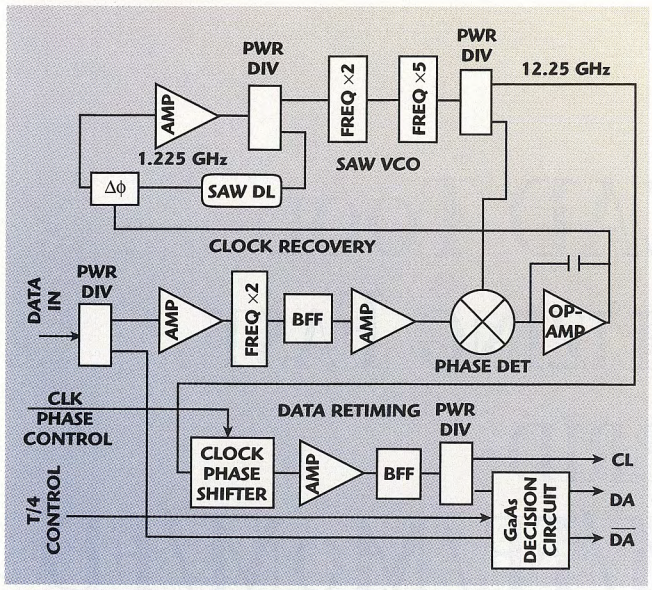
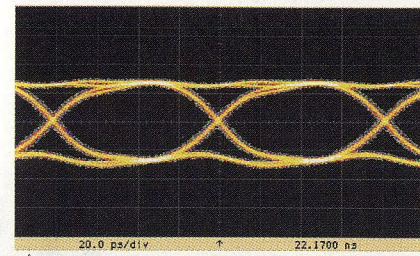


▲ *Fig. 8 CDR block diagram.*

VCSOs find application in high performance synchronous optical networks (SONET) and 10GE clock recovery applications. The clock data recovery circuits (CDR) use a frequency multiplied VCSO in a phase-lock loop (PLL) as a tracking filter to recover a low jitter clock from the incoming non return to zero (NRZ) data stream. The PLL loop bandwidth can be adjusted between 0.1 and 6 MHz to optimize jitter performance. The data is retimed by a high performance GaAs decision circuit. A block diagram of a VCSO-based CDR is shown in ***Figure 8***. An eye diagram at the OC-192 CDR data output with a 2^{31}-1 pseudorandom bit sequence (PRBS) is shown in ***Figure 9***.



▲ *Fig. 9 12 Gbps CDR data output eye diagram.*

CONCLUSION

The information presented in this article provides insight into the operation of a VCSO. Critical performance parameters and the design parameters affecting them have been discussed. In addition, two applications that make use of VCSO technology to provide high performance telecom solutions have been presented. ■

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3. A. Hajimiri and T. Lee, "A General Theory of Phase Noise in Electrical Oscillators," *IEEE Journal of Solid State Circuits*, February 1998, pp. 179–194.

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Due to its efficiency, the MM method has been widely employed for designing waveguide components, where modal expansions of electromagnetic fields can be derived analytically. For structures that are not separable in Cartesian or cylindrical coordinate systems, FE, MoM and FD techniques employ space- or surface-discretization techniques, which provide the desired flexibility. However, because of rather high requirements concerning central processing unit (CPU) time for the CAD of components using pure FE, MoM, or FD methods, for reasonably fast optimizations of typical industrial components, which often require a high number of iterations to meet given specifications, more advanced techniques are desirable.

The most effective approach for solving this problem is utilizing hybrid methods based on all four field simulators directly within the applied CAD technique, hence retaining the specific advantages of all proven EM methods while largely avoiding their disadvantages. WASP-NET fully exploits this efficiency and flexibility potential.

[Continued on page 180]

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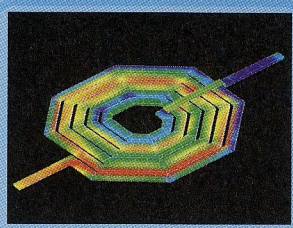

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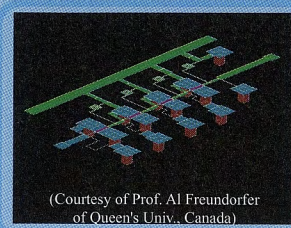

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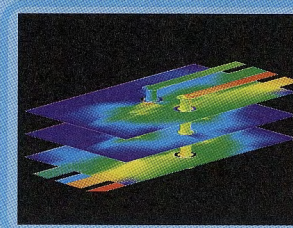

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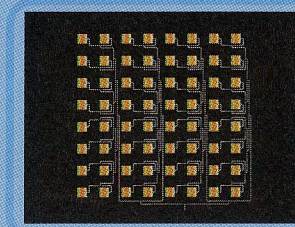

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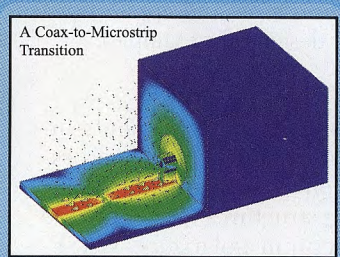

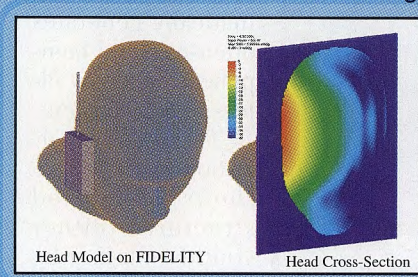

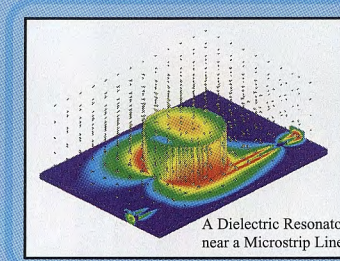

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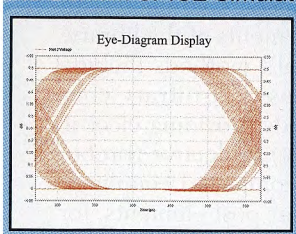

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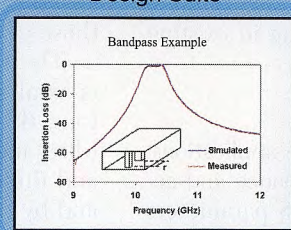

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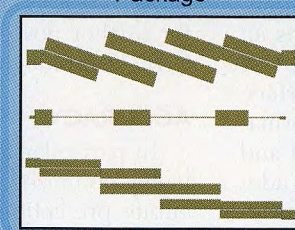

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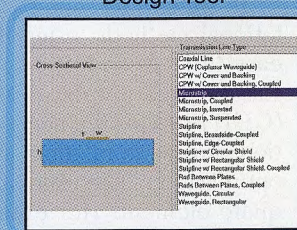

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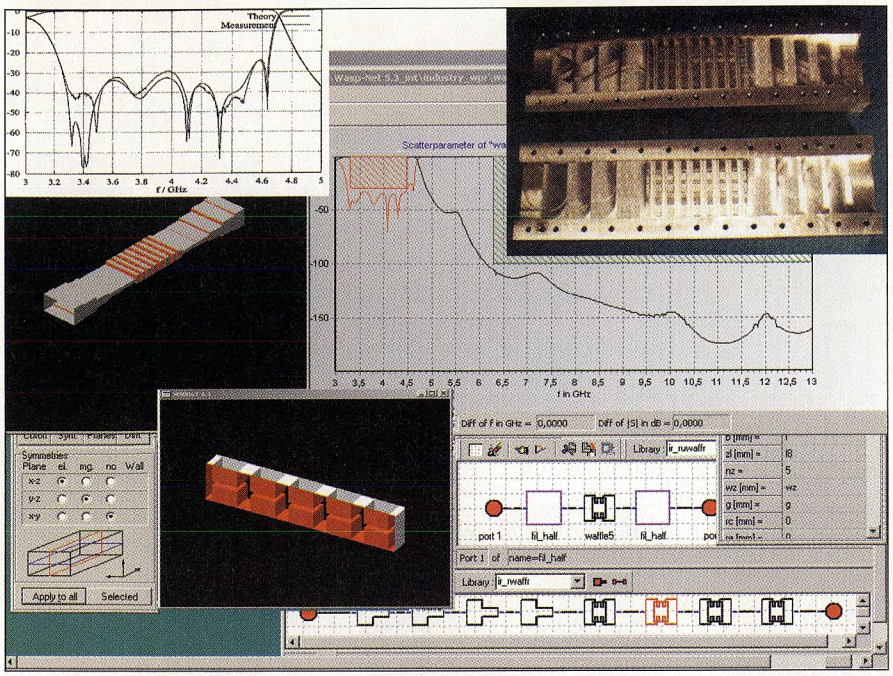

Fig. 1 C-band waffle-iron filter (photograph and measurements courtesy of Bosch SatCom and multipacting tested at > 1 kW by ESA).

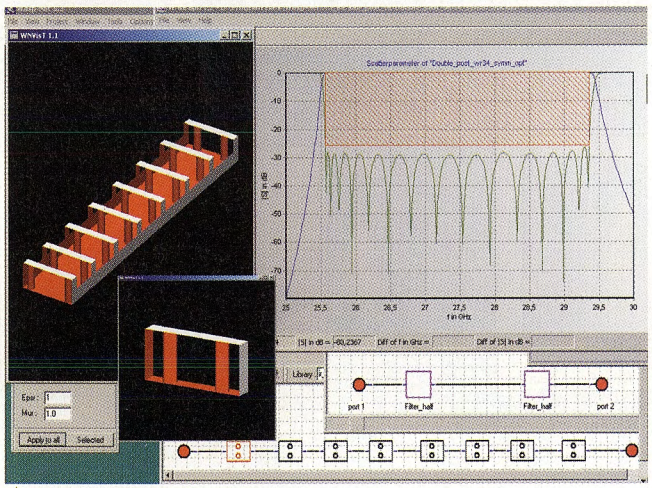

Fig. 2 WR-34 double-post filter (15 resonators).

In spite of its sophisticated computational methods, using the tool is an easy task. An intuitive Windows- or Linux-based graphical user interface (GUI) provides the necessary information during simulation, synthesis and optimization. The user can select adequate elements (for example, waffle-iron and step elements) from an element library currently comprising over 130 elements. These include irises, junctions, steps, bends, corners, crosses, apertures and coax-feeds. The desired components are built by combining the elements concerned — also via subcircuits — using sections of (rectangular, circular, coaxial and ridged) waveguides of any length (including zero). A synthesis wizard starting simply from desired specifications automatically generates often-required components, such as filters or transformers.

The new visualization tool WNVisT shows the created structures (either single elements, subcircuits, or as a whole) immediately on the screen. Common 2D and 3D output formats (DXF, OFF, STL, SAT) are suitable for further postprocessing in existing CAD environments.

ACCURACY

In particular for space applications, highly optimized performance and accurate prediction of all S-parameters (often spread across large limits) are of paramount importance. Therefore, a full-wave generalized S-matrix (GSM) combination of all individual elements taking into account all required higher order modes yields high accuracy and the necessary high dynamic range. This is demonstrated with the example of a waffle-iron filter (***Figure 1***), which has been fabricated without any tuning screws (optimizing efficiency: ca 0.12 s/fp, 209 modes, using a 2 GHz P4 PC).

Furthermore, the user-friendly full-wave filter wizard provides synthesis results for all typical cavity coupled waveguide filters with all common kinds of coupling structures, such as metal insert, single and multiple posts, all irises, and also with finite radii either in the H- or E-plane, according to given specifications. The procedure is to enter the specifications, select filter type, run the wizard and get the results (structure macro, geometries, S-parameters, output files for further postprocessing), which will typically be done within a few minutes.

Figure 2 shows the application example of a double post-coupled filter (with identical post diameters for low cost fabrication). The half filter is visualized (ca 0.4 s/fp, 27 modes). The posts are modeled by a new fast and flexible hybrid MM/TransFE method, that is, the combination of MM with a 2D FE method, which yields the solution for the complete class of planar waveguides of arbitrary contour. The created filter can be stored in subcircuits for further optimization and applications (for diplexer designs, for example).

ARBITRARY STRUCTURES

Many waveguide components involve structures of arbitrary cross-section, such as waffle-iron, cross-iris/coupling structures for dual-mode filters, or septum polarizers. WASP-NET solves the cross-section eigenvalue problem numerically by a specialized 2D FE method. Matching the transverse fields at the discontinuities produces the rigorous generalized S-matrix to be combined with those of other elements of the library.

The CAD tool's methods include coaxial structures of arbitrary contour. By coax-feeds providing electric (disc, metal sheet), inductive (probe) and direct post connected couplings, and by rectangular post elements, for example, it achieves the fast CAD and optimization of rectangular combline filters/diplexers, which can be fabricated by low cost milling techniques. Combinations with typical elements such as irises, corners and bends, provide the necessary high flexibility for realistic designs.

[Continued on page 182]

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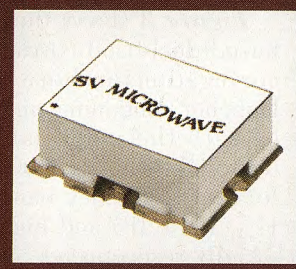

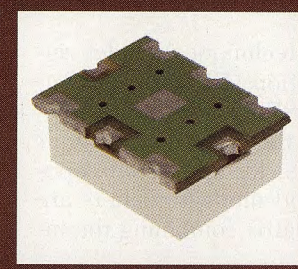

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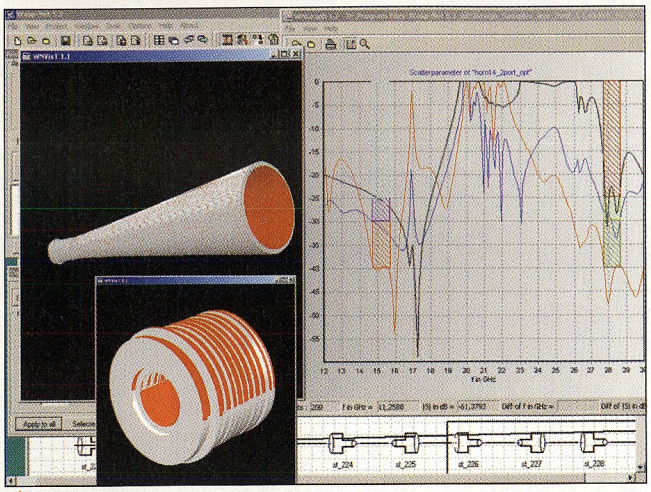

Fig. 3 S-parameter results of a corrugated circular horn with mode-launcher.

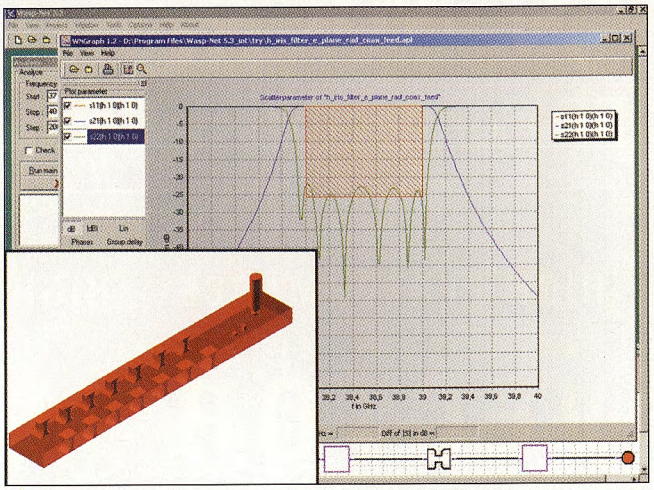

Fig. 4 Lateral coax-fed Ka-band H-plane iris filter with radii in the E-plane.

CORRUGATED HORNS

The hybrid MM/FE/MoM/FD technique includes rigorous electric field integral equation (EFIE) and combined source integral equation (CSIE) algorithms for accurate horn calculations, involving the outer horn contour (with aperture chokes, for example) for precise cross-polarization predictions. Complicated mode-launchers are optimized via the generalized S-matrix combining the inner and outer horn structures.

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Figure 3 shows the S-parameter results of an optimized dual-band corrugated horn structure (about 140 corrugations in horn taper) together with a mode-launcher containing ring-loaded slots. The horn, together with the mode-launcher, have been optimized (overnight run, ca 5000 iterations, 12 hours, 44 modes) for two frequency bands concerning the fundamental H_{11c} (–40 dB) and higher order E_{11s} modes (–30 and –25 dB, respectively).

For 3D microwave structures, such as dielectric resonator filter elements, round partial height posts, interdigital filter circular resonators, lateral coax-feeds and waffle-iron filter sections with round posts, adequate finite difference time domain (FDTD) elements are included, which are combined via the generalized scattering matrix with other WASP-NET elements.

The FDTD method applies advanced subgrid techniques combined with a locally conformal algorithm and a modified intersection approach for the efficient inclusion of arbitrarily shaped metal and dielectric surfaces. ***Figure 4*** shows a lateral coax-fed H-iris filter cut in E-plane with finite radii, where the degradation in return loss caused by the feed can be accurately taken into account (ca 5 min., 500 fp for feed, ca 0.3 s/fp for filter, 52 modes).

CONCLUSION

Current challenges for EM-based CAD software for microwave components relate to a new quality of efficiency and speed. The direction that CAD tools are taking is towards hybrid methods. The latest WASP-NET CAD and optimization tool addresses these challenges by utilizing fast hybrid methods and employing all four common solvers in one single tool, thus exploiting the benefits of using the efficiency of the mode-matching method together with the flexibility of the FE/MoM/FD techniques.

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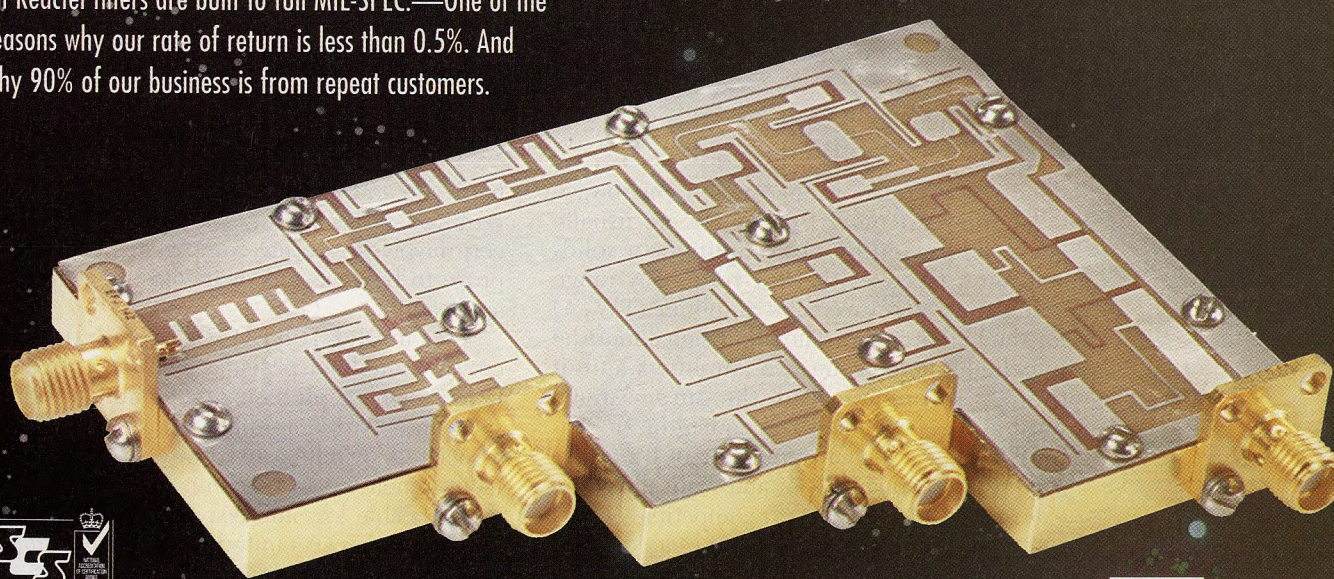

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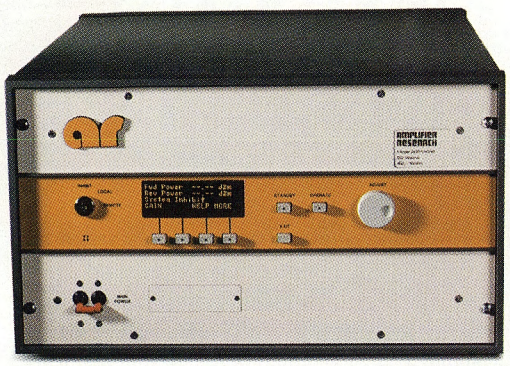

A BROADBAND HYBRID SOLID-STATE AND TWT AMPLIFIER

Test applications that require microwave power from 1 to 18 GHz are usually addressed by two amplifiers, a solid-state unit to cover the low frequency range and a traveling-wave tube amplifier (TWTA) for the higher range. The input signal must be switched between the two amplifiers and, if there is a common load, the output signal must also be switched. Depending on the nature of the test, this manipulation of RF cables is either done manually or automatically via an external GPIB (IEEE-488) compatible coaxial switching matrix and associated cables. The manual approach is very painstaking and can lead to system errors and repeatability problems due to repetitive attachment and removal of the precision high frequency RF connectors. The automatic approach corrects these problems, but there are a few issues to consider. First, the cost of the system must increase to account for the additional hardware. Secondly, the user must specify the external hardware and method used to accomplish the required system integration. A further concern involves external components that could prove to be awkward or inconvenient for the application.

The model 10ST1G18 broadband microwave amplifier provides a cost-effective solution to these problems by combining solid-state and TWT amplifiers, along with all the associated switching hardware in one convenient bench-top instrument. System variables such as cable loss and coaxial switch insertion loss have been accounted for. The new amplifier is a totally self-contained, forced air cooled, broadband hybrid solid-state and TWT microwave amplifier designed for applications where low harmonic content is re-

[Continued on page 186]

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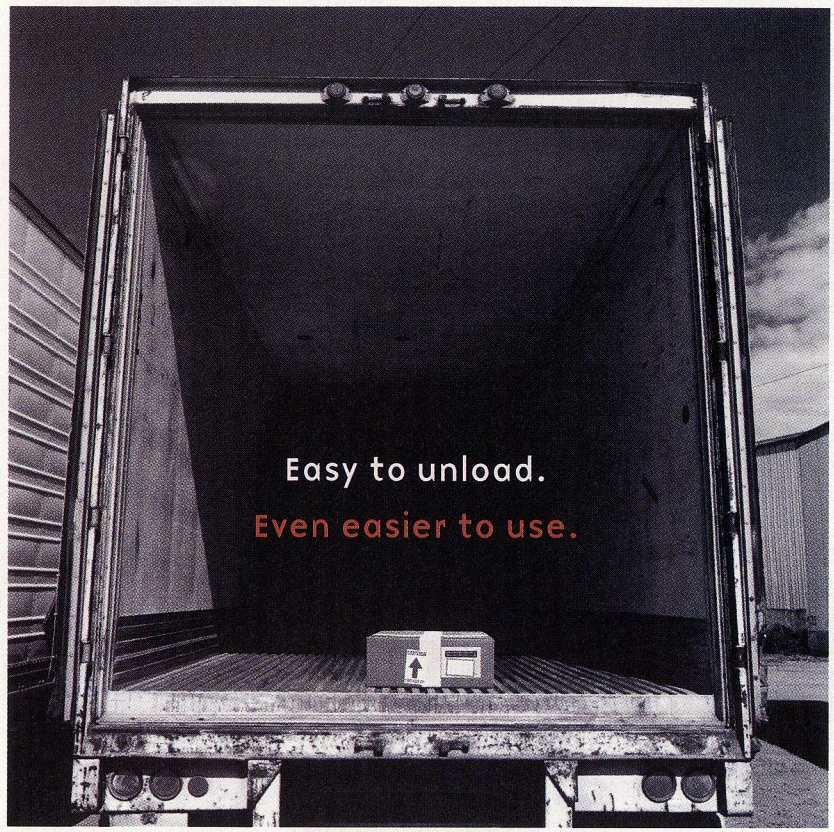
Souderton, PA





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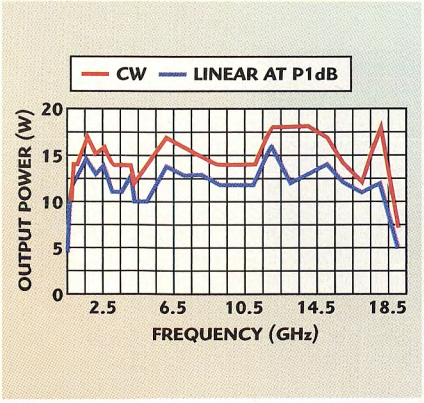

Fig. 1 Typical output power.

quired in sub-band ranges, and high gain and moderate output power are needed. This reliable amplifier system provides a conservative 10 W minimum power output with low harmonic content. ***Figure 1*** shows the amplifier's typical power output vs. frequency. ***Table 1*** lists the unit's performance specifications.

The amplifier's front panel digital display shows forward and reflected output plus extensive system status information accessed through a series of menus via soft keys. Status indicators include power-on, warm-up, standby, operate, faults, excess reflected power warning and remote operation. Standard features include a built-in IEEE-488 (GPIB) interface, 0 dBm input for rated output, gain control, RF output sample port, VSWR protection for the TWT only (not required for the solid-state unit), plus monitoring of the TWT helix current, cathode voltage, collector voltage, heater current, heater voltage, base-plate and cabinet temperature. The appropriate sub-band is user selected from either the front panel menu or the GPIB interface. Modular design of the RF assemblies and power supplies allow for easy access and repair. Use of switching mode power supplies results in significant weight reduction.

The standard model 10ST1G18 amplifier is supplied with a removable enclosure that measures 19.8" × 11.7" × 27.0" and weighs 55 kg. The unit may also be shipped without an outer cabinet or with the enclosure removed for rack mounting with slides and front handles installed. Self-contained fans provide forced air cooling with air entry and exit in the rear. All RF connectors are in the rear as well. The RF input and RF output sample ports are type N female connectors, while the RF output is a type TNC female.

Typical applications include a variety of electromagnetic compatibility immunity standards that have test requirements above 1 GHz, telecommunications testing and immunity testing to the rigorous Bellcore GR-1089 standard.

TABLE I

PERFORMANCE SPECIFICATIONS

Output power (fundamental) CW, (W) nominal minimum linear @P1dB	 15 10 8 (min)
Flatness (dB)	±2 (max), 0.8–4.2 GHz ±8 (max), 4.2–18 GHz
Frequency response (GHz)	0.8–18 instantaneously in one of four selectable sub-bands
Input for rated output (mW)	1.0 (max)
Gain (at maximum setting) (dB)	40 (min)
Gain adjustment (continuous range) (dB)	10 (min) (0.8–4.2 GHz) 35 (min) (4.2–18 GHz)
Input VSWR at 50 Ω	2.0:1 (max)
Output VSWR at 50 Ω	2.5:1 (typ)
Mismatch tolerance*	100% of rated power without foldback from 0.8–4.2 GHz. Output power foldback protection above 4.2 GHz at reflected power exceeding 10 W.
Modulation capability	Will faithfully reproduce AM, FM or pulse modulation appearing on the input signal. AM peak envelope power limited to specified power.
Noise power density (4.2–18 GHz) (dBm/Hz)	–80 (max) –90 (typ)
Harmonic distortion (in user selectable sub-band at 10 W) (dBc)	–20 (max) –30 (typ)
Primary power	99–260 V AC, 50/60 Hz single phase, 900 VA max

*Will operate without damage or oscillation with any magnitude and phase of source and load impedance. May oscillate if the RF output connector is left unterminated due to coupling to the input. Proper operation requires that the input and output ports be terminated.

CONCLUSION

The model 10ST1G18 broadband microwave amplifier has been developed to address testing needs in the 800 MHz to 18 GHz frequency range. This broad range, along with the low levels of harmonic distortion, places this new amplifier in a class by itself.

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A COMPACT MONOPULSE FEED FOR TRACKING ANTENNAS

With the steady improvements in tracking radar technologies over the past twenty years, the diameter requirements for antennas has been reduced to match the improvements in transmitter power and receiver sensitivity. This has led to a need for shorter feeds for use in Cassegrain configurations.

Antenna feeds have recently been developed for use at C-band, which are fabricated from cast waveguide components and optimized to tight phase characteristics. As a long-standing manufacturer of monopulse comparators, the development of an antenna feed was the next logical step in the extension of the product range. The choice of horn design was crucial to achieving a compact feed design.

The first C-band feed was developed for a nine-foot reflector and used a four-horn arrangement directly on the outputs of the comparator. This gave a small footprint to the feed that reduced blockage of the main reflector; however, the beamwidths in the elevation and azimuth difference patterns were excessive, resulting in high sidelobe levels.

The next generation feeds incorporated two auxiliary horns each in both the azimuth and elevation planes resulting in an eight-horn design. The sum pattern was unaffected by the new arrangement and gave similar performance to the earlier design. The delta patterns were significantly narrower giving reduced sidelobe levels, even though the footprint was increased.

The company's compact comparator uses four waveguide tees connected via four extension waveguides to the central four horns. The overall waveguide section is tuned to achieve less than ±1° phase imbalance between ports. The C-band version is capable of handling up to 1MW peak power at normal atmospheric pressure. It is designed for operation up to 30 PSIA, and should be pressurized to maintain a dry atmosphere inside the waveguide.

Sum, elevation and azimuth ports are provided as waveguide flanged interfaces. Isolation between any two ports is 35 dB minimum. When fitted to an antenna, cross polarization ratios of 30 dB minimum and an error channel null stability of less than 0.1 mil across the frequency range are achieved.

The auxiliary horns are connected to a power combiner network that includes the tees that are part of the central comparator. The two horizontal horns are combined with the azimuth signal from the comparator while the two vertical horns are combined with the

[Continued on page 191]

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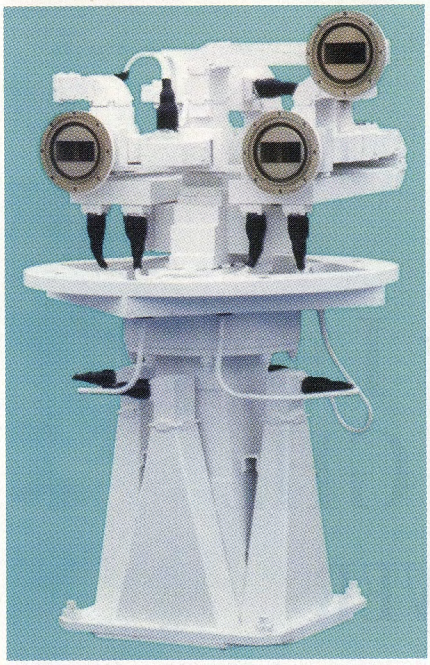

Fig. 1 The eight-horn feed from an eight-foot antenna.

elevation signal. All the interconnecting waveguide are phase matched during manufacture. A final test in an anechoic chamber allows the beam patterns from the main and auxiliary horns to be set coincident, thus providing accurate combining to give the maximum possible null depth. When fitted to an antenna, null depths of 35 dB minimum are achieved with typical values greater than 50 dB.

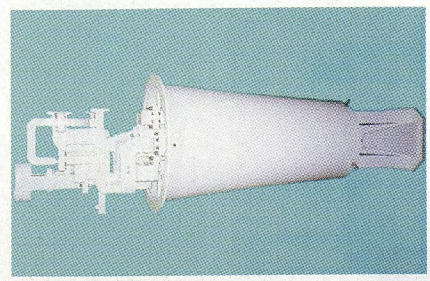

Fig. 2 An all waveguide 16-foot antenna feed.

The first eight-horn feeds used coaxial cables to connect the auxiliary horns to the power combiners. This resulted in a very compact feed, especially in the version fitted to the eight-foot reflectors, as shown in ***Figure 1***. Further development has replaced the cables with waveguides, which, in addition to providing lower insertion loss, also provide better protection against the environment. Although the earlier feeds were exclusively for C-band operation, versions have been developed for X-band using the company's range of precision investment castings.

Compared to a multimode horn the eight-horn array is much shorter in overall length. This allows the C-band version to be fitted in antennas with reflector diameters down to eight feet, without the comparator protruding far behind the dish. When fitted into a 12- or 16-foot reflector, as shown in ***Figure 2***, extension waveguides are fitted to increase the overall feed length. These are used to improve the phase balance of the comparator, resulting in improved antenna performance.

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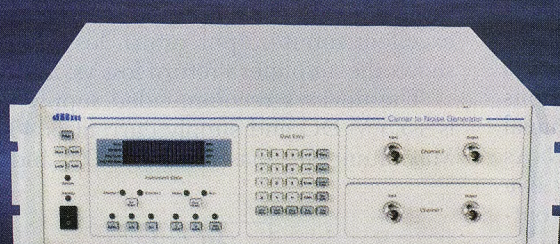

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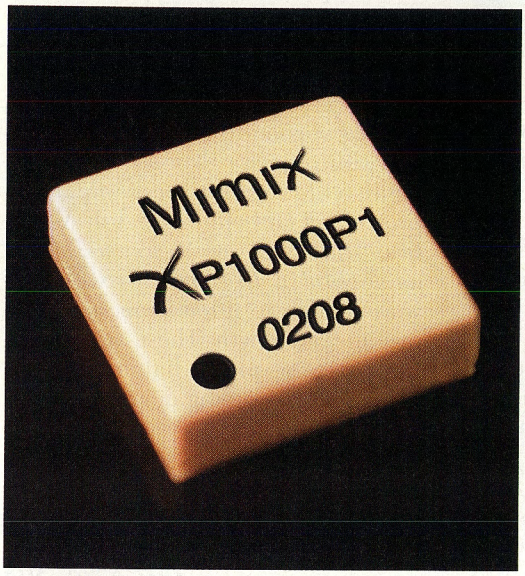

A HIGHLY LINEAR 17 TO 24 GHz SMT POWER AMPLIFIER

A new surface-mount technology (SMT)-packaged power amplifier has been introduced for wireless communications applications, including millimeter-wave point-to-point radio, local multipoint distribution services (LMDS), satellite communications (SATCOM) and very small aperture terminal (VSAT) use. The model XP1000P1 GaAs MMIC surface-mount power amplifier is a two-stage amplifier optimized for linear output operation over the 17 to 24 GHz frequency range that features an output third-order intercept point of +36 dBm and a small-signal gain of 18 dB. Using a 0.15 µm gate length GaAs pseudomorphic high electron mobility transistor (PHEMT) device model technology, the chip has been specifically designed to provide excellent linearity for applications utilizing high index modulation schemes. ***Figure 1*** shows the XP1000P1 device's typical gain vs. frequency.

The device is supplied in a surface-mount leadless chip carrier compatible with high volume SMT processing and includes an on-chip temperature-compensated output power detector and excellent input/output return loss. ***Figure 2*** shows the amplifier's return loss vs. frequency.

The device's recommended supply voltage is +5.5 V DC and supply current is 430 mA. Maximum gate bias is +0.3 V DC and maxi-

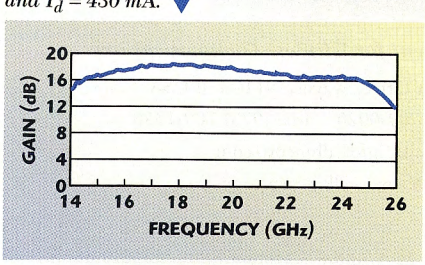

Fig. 1 Typical gain vs. frequency at V_d = 5.5 V and I_d = 430 mA.

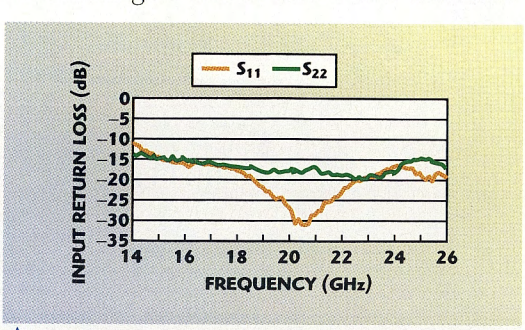

Fig. 2 Typical return loss at V_d = 5.5 V and I_d = 430 mA.

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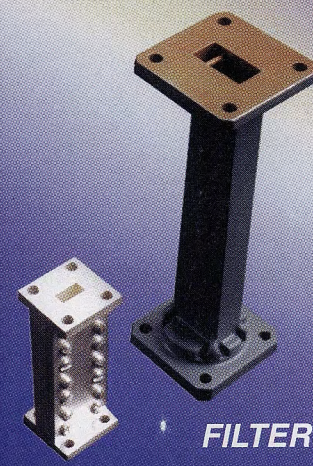

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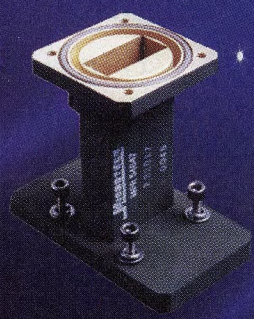

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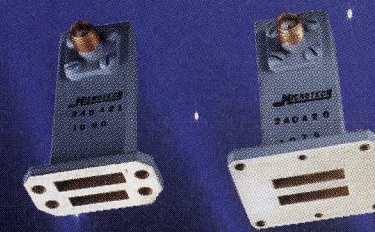

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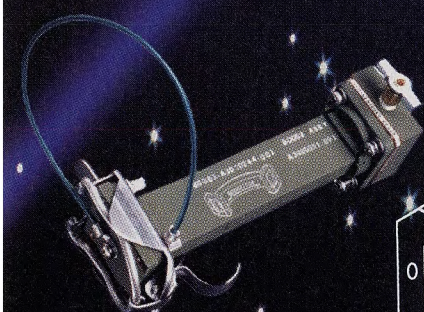

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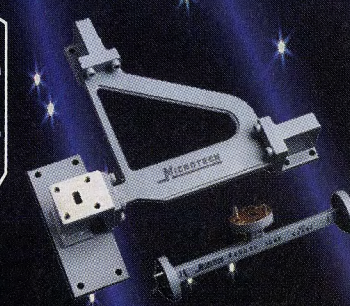

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TABLE I

ELECTRICAL CHARACTERISTICS (AMBIENT TEMPERATURE T = 25°C)

Parameter	Min	Typ	Max
Frequency range (GHz)	17	–	24
Input return loss (S_{11}) (dB)	14	17	–
Output return loss (S_{22}) (dB)	14	17	–
Small-signal gain (S_{21}) (dB)	15	18	20
Gain flatness (ΔS_{21}) (dB)	–	±2	–
Reverse isolation (S_{12}) (dB)	35	40	–
Output power for 1 dB compression (P1dB)[1,2] (dBm)	22.0	+24.5	–
Output third-order intercept point (OIP3)[1,2] (dBm)	33.0	+35.5	–
Drain bias voltage (Vd1,2,3,4) (Vd5 [Det], Rd=3–6kΩ) (V DC)	–	+5.5	+5.6
Gate bias voltage (Vg1,2,3,4) (V DC)	–1.0	–0.5	0.0
Supply current (Id) (Vd=5.5V, Vg=–0.5V Typ) (mA)	–	430	650
Detector (diff) output at 20 dBm[3] (V DC)	0.21	0.28	0.35

[1]Measured at 16 dBm per tone output carrier level at 22 GHz
[2]Measured using constant current
[3]Measured with either Vd5=1.0V, or Vd5=5.5V and Rd=5.6kΩ

mum input power is +9.0 dBm. Operating temperature is –55° to +75°C and storage temperature is –65° to +165°C. ***Table I*** lists the XP1000P1 amplifier's electrical characteristics at an ambient temperature of 25°C.

The XP1000P1 device has a broadband response that closely matches die performance with good thermal conductivity, providing a reliable SMT power amplifier. The SMT package permits assembly using standard SMT processes with no specialized die attach or wire bonding requirements, thus leading to a more rugged assembly for tuning and testing.

Engineering samples of the XP1000P1 device are available in limited quantities from stock and production quantities are available on order within eight weeks. Additional information may be obtained from the company's Web site and technical support is available from the company's application engineers at the number below.

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

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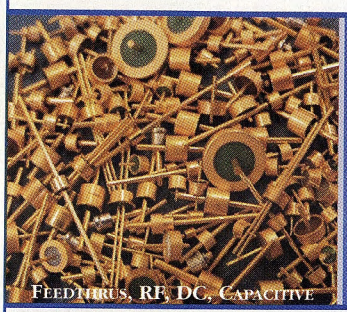
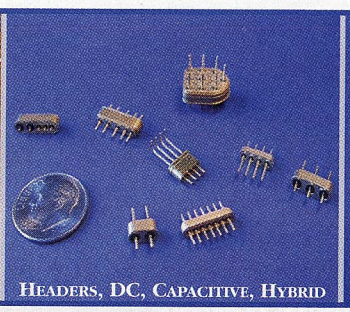

Feedthrus, RF, DC, Capacitive


Headers, DC, Capacitive, Hybrid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Hi-Rel By Design

39 Souhegan St. • P.O. Box 269 • Wilton, NH 03086
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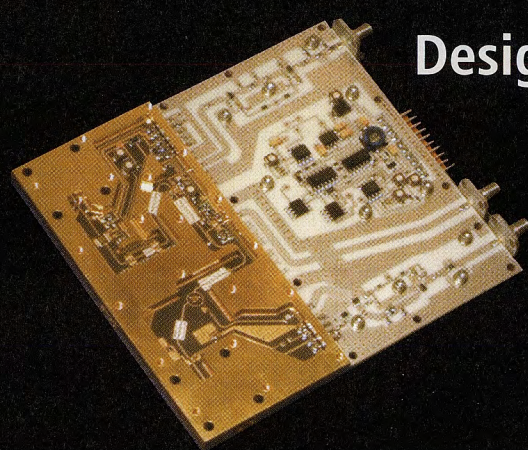

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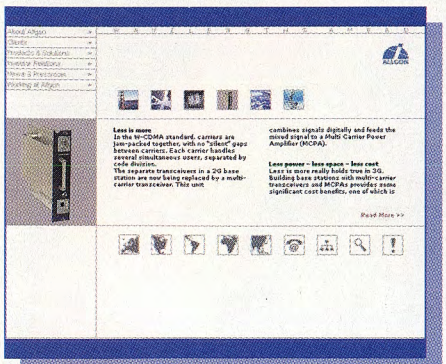


Radio-based Infrastructure Solutions

This new Web site highlights customer benefits and communicates the company's dedication to customer relations. The new customer-oriented Web site features product usability and promotes customer benefits, as well. The site is user-friendly and improves the company's on-line product information on the company's radio-based infrastructure solutions.

Allgon System AB,
SE-187 80, Täby, Sweden

www.allgon.com

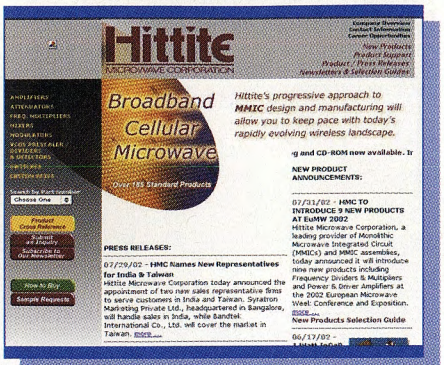


Resistive Products

This Web site offers a complete line of resistor products for the wireless markets for both commercial and military applications. Included on this site are high power terminations, resistors and attenuators. Also offered are cable load assemblies, precision chip resistors, and custom thick film circuits. All products are available in an array of materials that include BeO, AlN, BeO free ceramic and Alumina. Tech/sales support, on-line RFQs and sample requests are available.

Barry Industries,
60 Walton St., Attleboro, MA 02703

www.barryind.com

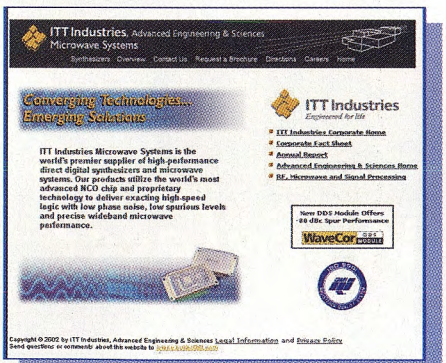


Expanded Quality and Product Support Section

The newly expanded quality and product support section of this Web site provides customers with new information on the company's DC to 40 GHz RFIC/MMIC products including: qualification test reports, package, layout, tape and reel drawings and a tour of the complete reliability and qualification laboratory. The Application Engineering Support section has also been updated with new application notes and a direct link to the product cross reference search engine.

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

www.hittite.com



Synthesizers

ITT Microwave Systems has added details of the latest low spurious, high speed, modular synthesizers to the company Web site at www.ittmicrowave.com. The WaveCor™ synthesizer line gives EW and radar system designers the utmost performance and flexibility. WaveCor's modular architecture supports critical applications requiring the fastest, high resolution synthesizers. Spurious performance is as low as –80 dB.

ITT Microwave Systems,
59 Technology Drive, Lowell, MA 01851

www.ittmicrowave.com



Simplifying Sensing

This site features the company's design and development of Hall sensor integrated circuits. A wide range of magnetic sensor ICs is offered for applications such as position sensing, dented wheel position sensing, electronic motor speed regulation and antilock braking systems. Products such as interface ICs, integrated silicon pressure sensor chips, ASICs and contactless identification ICs are also offered.

Melexis Inc.,
41 Locke Road, Concord, NH 03301

www.melexis.com



Waveguide Assemblies and Passive Microwave Components

This redesigned Web site features a new layout with ease of navigation throughout and an enhanced online product catalog. The site also adds a new and extended level of service and customer support.

Microtech Inc.,
1425 Highland Ave.,
Cheshire, CT 06410

www.microtech-inc.com

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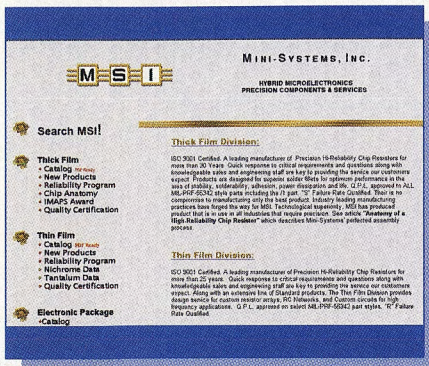


Passive Components

This site features the company's hand-crafted quality, extraordinary reliability, passive components. Product line consists of precision thin/thick film chip resistors, MOS capacitors, networks, attenuators, inductors, metallized/patterned substrates, hermetic packages and hybrids within four divisions. Applications include medical, military, aerospace, microwave and telecommunications.

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

www.mini-systemsinc.com

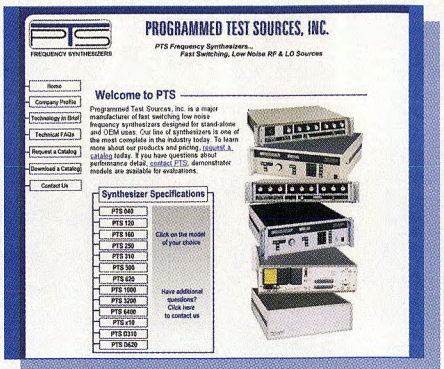


New Web Site

This newly launched Web site includes a product search capability, a simple to use 'request for quotation' facility, and a local representative identifier by selection from a map. Designed for ease of use, visitors to the new Web site can also request literature, ask for help from an applications engineer and receive new product alerts.

OPHIR RF,
5300 Beethoven Street,
Los Angeles, CA 90066

www.ophirrf.com



Agile Precision Frequency Sources

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

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

www.programmedtest.com



High Power RF Research Tools

This Web site describes radar system 10 kHz to 35 GHz RF sources, 1 kW to 25 MW modulators, microwave components, tracking pedestals, parabolic dishes to 60' diameter, microwave tubes and many more products available from stock (completely tested). A free 28-page catalog is also available.

Radio Research Instrument Co.,
584 North Main St.,
Waterbury, CT 06704

www.radioresearch.thomasregister.com



Power Components and Power Systems

This new Web site features comprehensive product information and design selection capabilities for the company's power distribution units and remote/local power management systems. The newest technology of the Web site includes application configuration capabilities whereby the user may design his/her own AC/DC power distribution unit directly on the site for immediate shipment. The site also incorporates online catalog, check stock and design/customer support features.

Spectrum Control Inc.,
8031 Avonia Road, Fairview, PA 16415

www.specpower.com

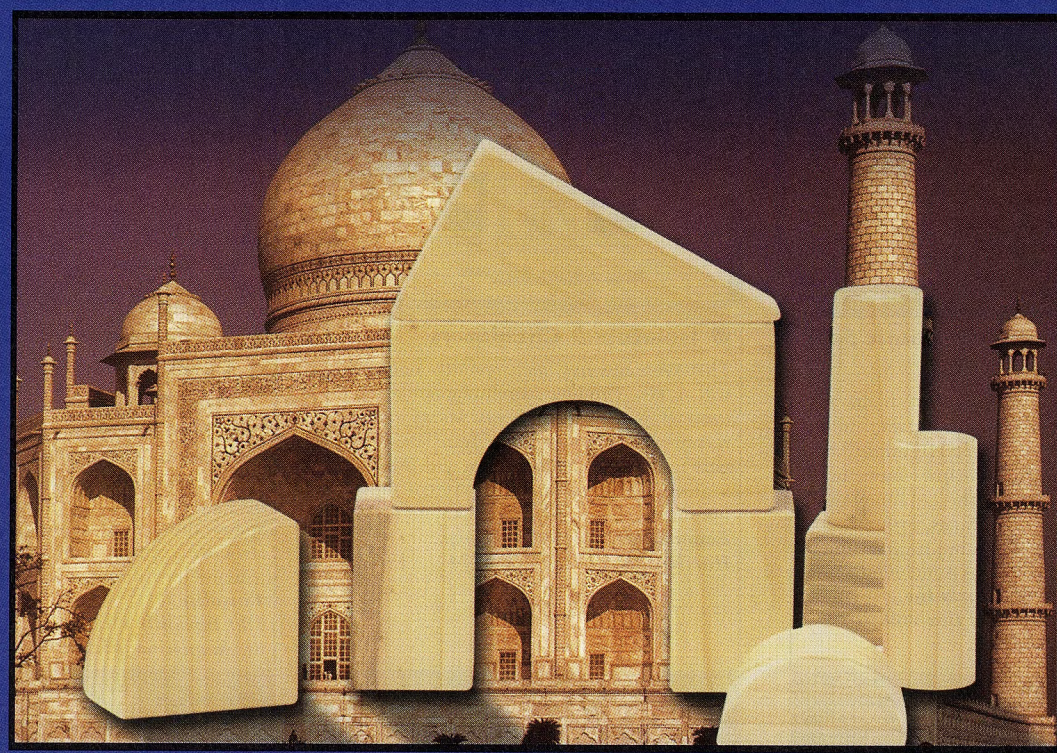


Connectors and Cable Assemblies

This new Web site offers telecom, wireless semiconductor and military designers a wide variety of standard and custom connectors and cable assemblies to choose from. In addition to a completely redesigned user interface, visitors can use the company's "Build Your Own Connector" tool that takes them through a step-by-step specification process and allows for submittal directly to the technical sales team for price and delivery.

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

www.tru-con.com



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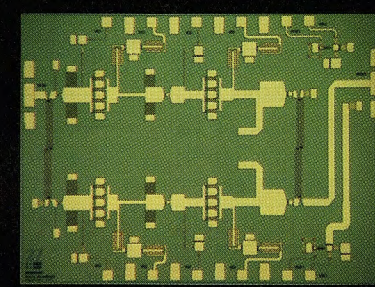

Mimix Broadband provides high performance MMICs for applications operating at 17 to 44+ GHz. Learn more about us at mimixbroadband.com.

Mimix BROADBAND

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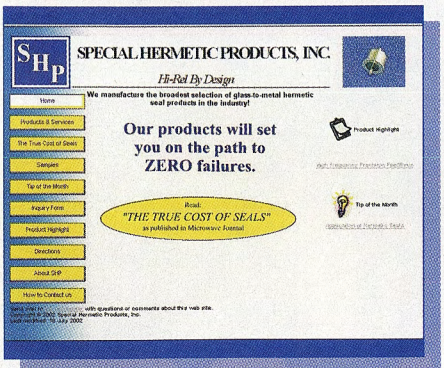

Glass-to-metal Hermetic Seal Products

This completely re-designed Web site features the company's full-line catalog. In addition, monthly "Product Highlight" and "Tip of the Month" features have been added. Information on the company's RF, DC and capacitive feedthrus, ground pins, solderable and weldable multi-pin connectors, headers and packages is included.

Special Hermetic Products Inc.,
39 Souhegan Street, PO Box 269,
Wilton, NH 03086

www.shp-seals.com



Isolators & Circulators

This Web site has been recently upgraded with a new product search engine and .pdf product specification sheets. Users' specific requirements will quickly translate into a part number and description, and from this a quote on price and delivery can be requested.

Renaissance Electronics Corp.,
Harvard, MA (978) 772-7774

www.rec-usa.com



Wire, Cables, RF/microwave Connectors and Cable Assemblies

This Web site features the company's high performance wire and cables, RF/microwave connectors and cable assemblies. The products are targeted at applications in the aerospace, defense electronics, wireless infrastructure, optical telecommunications, and test and measurement industries.

Tensolite,
100 Tensolite Drive,
St. Augustine, FL 32092

www.Tensolite.com

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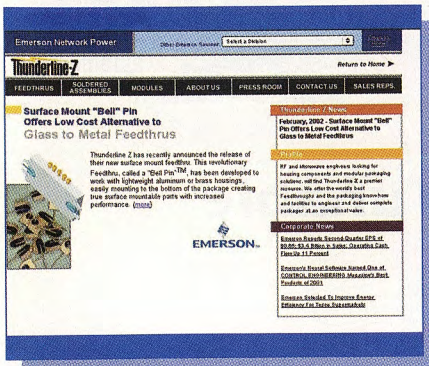
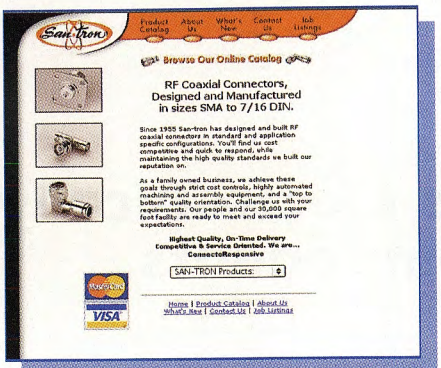


Housing Components and Modular Packaging Solutions

This new Web site is a resource for engineers looking for housing components and modular packaging solutions. The company, which was recently acquired by Emerson Electric, engineers and delivers complete soldered and direct sealed packages. A rep locator will guide users quickly to the closest sales office.

Thunderline Z,
a division of Emerson Electric,
11 Hazel Drive, Hampstead, NH 03841

www.thunderlinez.com



Adapters On-line

This site has added e-commerce capability, allowing connectors and adapters to be purchased direct from the manufacturer, using Mastercard or Visa, worldwide. Adapters are the first products available in the web store, with type N connectors to be added next.

San-tron Inc.,
4 Newburyport Turnpike,
Ipswich, MA 01938

www.san-tron.com



Packaging, Circuitry and Materials

The company has added a parametric search engine tool to the packaging section of its Web site. This feature provides another avenue for customers to use when selecting RF and microwave packages to match their application. Users simply enter key specifications into the search engine, then view the corresponding results from over 30 standard packages.

Zentrix Technologies,
6100 S. Tucson Blvd., Tucson, AZ 85706

www.zentrix.com

online catalog
www.pulsarmicrowave.com

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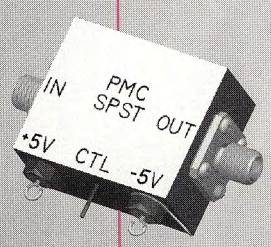

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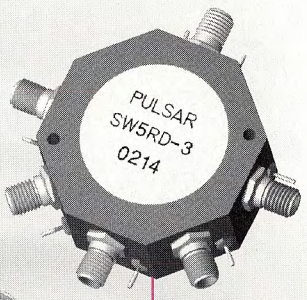

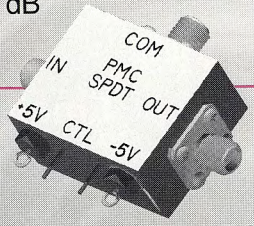

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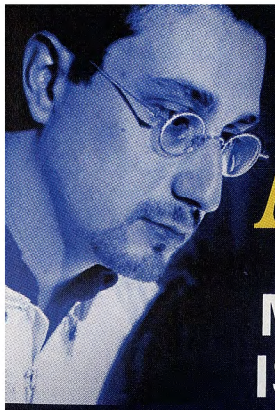

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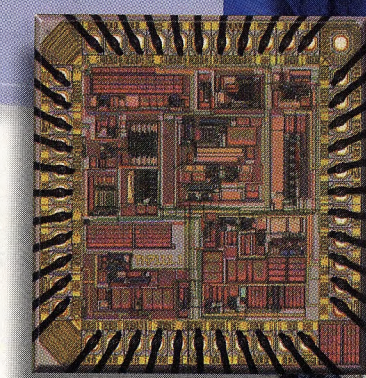
Melexis' receivers have a high large-signal handling capability, a high degree of image rejection, and a low spurious signal emission. Our transmitters have an adjustable RF output power range, fully integrated PLL synthesizer, high frequency stability over temperature and power supply variations, and automatic power amplifier turn-on after PLL lock. No external RF oscillator components are required for either transmitters or receivers and all are in low-profile surface mount packages built to rigorous QS9000 standards.

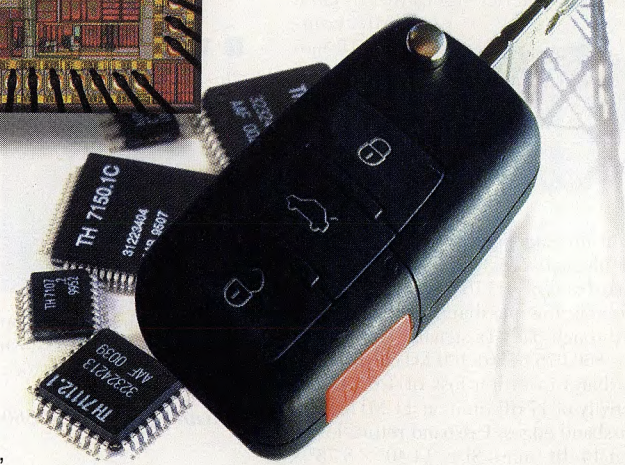
ASK, FSK - Even FM

Melexis' family of low-cost, high performance 300 to 950 MHz RF transmitters and receivers both simplify and speed your design by perfectly matching each RF system's frequency range, modulation scheme, blocking, and channel requirements. Employing highly integrated, RF-optimized 0.6 and 0.8 micron BiCMOS processes, Melexis has created highly efficient RFICs with low current consumption, a wide supply voltage range, and very low standby current.

Under Your Control

Melexis' RFIC family can be used in virtually any system where the designer wants to eliminate wired hardware to form a completely wireless communications link for **car remote keyless entry, immobilizers, remote tire pressure control, alarm systems, security monitoring, telemetry, garage door openers, baby monitors, wireless door bells, walkie talkies** - anywhere your imagination can take you. When comparing Melexis' RFIC family to discrete solutions, there can be as much as a 50% savings, and this doesn't include benefits derived from ease of design-in, higher levels of integration for enhanced reliability, or space savings.







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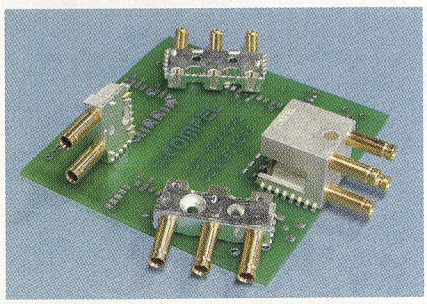
COMPONENTS

SMT Compatible Multi-interface Connector Series



This 1.0/2.3 multi-interface connector series features an SMT design that facilitates PCB assembly and also accommodates tight packaging density. These connectors are available with 2, 3 and 4 coaxial interface combinations in the same housing. Frequency coverage is from DC to 2 GHz in standard 75 Ω impedance value and DC to 10 GHz in optional 50 Ω impedance. Custom variants are available upon request. Standard housings are cast from a lightweight alloy and a liquid crystal polymer housing is also available in the 4-coax version. Units are available in tape-and-reel packaging.

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

Circle No. 215

Dual Duplexer

The model WSDD-00009 dual duplexer is designed to suppress interference caused by close proximity commercial SMR mobile serives to in-service public safety radios. In many cases the interference causes receiver desensitization resulting in messages and dispatches being missed or blocked. The duplexer provides a transmit passband of 811.075 to 816.100 MHz with extremely low passband loss of 0.4 dB (max) for through path Tx signals. The receive passband is 856.075 to 861.100 MHz with maximum passband insertion loss of 1.6 dB and high selectivity of 17 dB (min) at ±1 MHz from receive passband edges. Passband return loss is specified at 14 dB (min). Size: 14.40" × 8.75" × 3.25". Delivery is 8 to 10 weeks (ARO).



K&L Microwave Inc.,
Salisbury, MD (410) 749-2424.

Circle No. 218

Power Limiters

The UX series of PIN diode power limiters for UHF and SHF bands is designed to prevent failure of the input amplifying stages of low noise receivers when radio pulse power up to 5000 W is applied in the frequency range up to 12 GHz. The series has the following characteristics: input pulse power of 5 kW at 2 µs pulse duration and frequency range of 0.8 to 1.0 GHz, input pulse power is 1 kW at 3 µs pulse duration and frequency range of 2.0 to 2.5 GHz, input pulse power of 1 kW at 26 µs pulse duration and frequency range of 2.9 to 3.4 GHz, and input pulse power 100 W at 100 µs pulse duration at frequency range 7.0 to 8.3 GHz. The limiters can be supplied as functionally independent units operating without a power supply or as controlled switches, enabling the input power to be considerably increased.

ELSYS, Poltava, Ukraine +380532501372.

Circle No. 216

Mixers

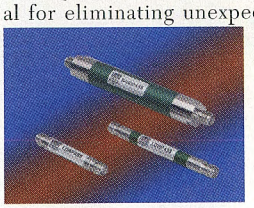
This family of GaAs MMIC mixers with LO amplifiers is designed for cellular/PCS/3G applications. These mixers are ideal for low cost infrastructure applications where a combination of small size, low LO drive and high linearity/isolation is required. The 1.3 to 2.5 GHz model HMC421QS16 is a high linearity down converter RFIC coupled with a high dynamic range IF amplifier that achieves an output IP3 of +29 dBm. The RFIC provides 8 dB of gain while operating from a single 5 V, 60 mA supply and a LO drive of +10 dBm. The HMC422MS8 and HMC423MS8 both provide 30 to 35 dB of RF/LO isolation and input IP3 of +15 dBm. The HMC422MS8 covers application between 1.2 to 2.5 GHz band while the HMC423MS8 covers 0.6 to 1.3 GHz. A single positive supply voltage biases the on-board LO amplifiers with the HMC422MS8 requiring 3 V at 30 mA and the HMC423MS8 requiring 3 V at 15 mA. These mixers can be used as up or down converters.

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

Circle No. 217

Tubular Filters

The "Quick Pick" series of tubular filters is ideal for eliminating unexpected spurious response when fastest delivery is required. Frequency range is 60 MHz to 20 GHz, and the filters are available in low pass and bandpass configuration (up to 50 percent 3 dB BW). Diameters are 0.25 and 0.50 with SMA-F connectors. Delivery: stock to two weeks.



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

Circle No. 219

Single Sideband Mixer

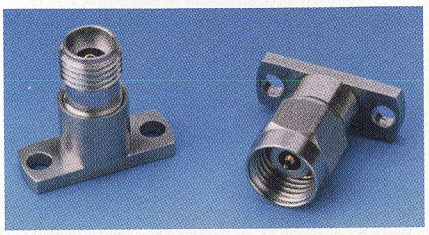


The model SSB-0218 single sideband mixer covers 2 to 18 GHz with numerous IF bands available from 30 to 500 MHz. Designed for broadband applications requiring carrier and sideband suppression, the SSB-0218 is double-balanced single sideband mixer design, available in SMA connectorized and pin-package outlines. Local oscillator drive levels from +13 to +19 dBm are available. Typical conversion loss is 7.0 dB, with a typical carrier and sideband suppressions of 22 dB.

Marki Microwave Inc.,
Morgan Hill, CA (408) 778-4200.

Circle No. 220

DC Blocking Connector



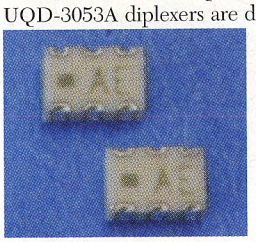
The model 8537 DC blocking connector integrates broadband DC blocking functionality into both the 2.92 and the 2.40 mm, 2-hole flange, female or male connectors. Operating frequency is 7 kHz to 45 GHz. Insertion loss is < 1.0 dB (typ), SWR is 1.15 and DC blocking voltage is 25 V. With the DC block built into the connector it has eliminated the need to buy these two components separately, which minimizes parts count, reduces assembly and test times, reduces size, increases reliability and lowers cost.

MCE/Inmet Corp.,
Ann Arbor, MI (734) 426-5553.

Circle No. 221

Diplexers

The model LDG0UQD-3051A and LDG0-UQD-3053A diplexers are designed to be used in forthcoming 2.4/5 GHz dual band W-LAN applications. The lower passband is 2.4 to 2.5 GHz and the upper bands are 5.15 to 5.725 GHz (-3053A) and 5.15 to 5.825 GHz (-3015A), which are covering any 5 GHz frequency band plan in the US, Europe and Japan. The attenuation at 4.8 to 5.0 GHz on 2450 MHz port is 20 dB (max). The application note to enhance the attenuation at 2 f_0 is available. Size: 2.00 × 1.25 × 0.95 mm.



NTK Technologies,
Arlington Heights, IL (847) 788-9795.

Circle No. 222

Connectors

The MMBX connector series has been developed particularly for board-to-board connection in second- and third-generation telecommunication systems. The series enables quick and easy connections with minimum space re-

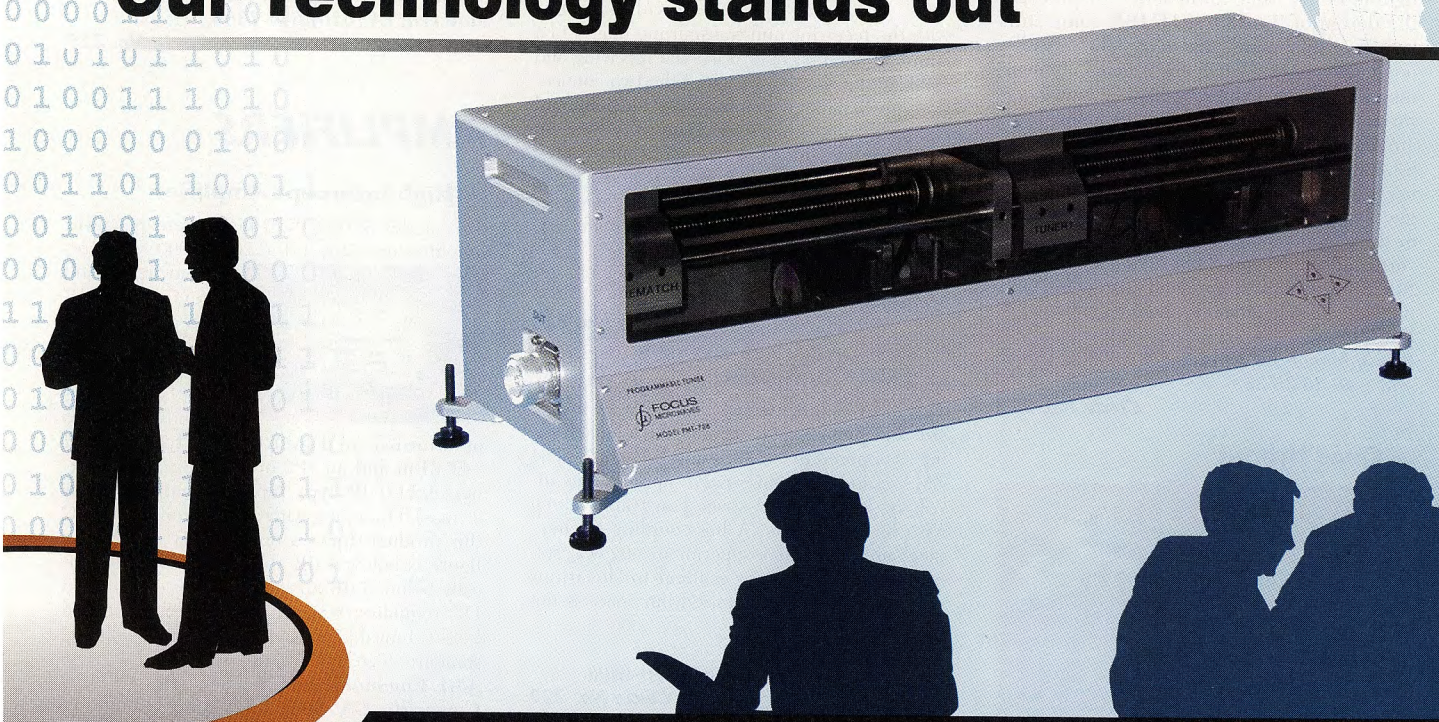
[Continued on page 206]

Patent Protected Technology

- Harmonic Tuners
- High SWR (Prematching) Tuners
- Low Loss Test Fixtures
- On Wafer Solutions

Focus microwaves

Our Technology stands out



Our People stand behind it

At Focus, we have been developing and manufacturing Load Pull and Noise measurement systems since 1988. ***Nearly 1000 Focus tuners are serving in various R &D and production labs worldwide.***

We use proprietary, patented designs and software. Our fundamental and harmonic programmable tuners reach from 0.2 to 110 GHz and have gained a reputation of precision and dependability. Over 120 application, product and technical notes support our products.

Focus is recognized for our Innovative Technology and Dedication to our Customer's needs. Because of our specialization in Load Pull and Noise metrology we closely pursue our customer's requests and have always succeeded in providing solutions to their requirements.

Our staff of Engineers and Technicians will assist you through the entire process from the procurement to the installation and successful operation of your measurement system.

Focus system users tell us that our customer support has been a key selling feature when choosing our products.

Detailed information about Focus and its products can be found at:

www.focus-microwaves.com

Focus Microwaves Inc.
1603 St. Regis Dollard-Des-Ormeaux, Montreal, Quebec H9B 3H7
Tel: 1(514) 684-4554 Fax: 1(514) 684-8581 Email: info@focus-microwaves.com

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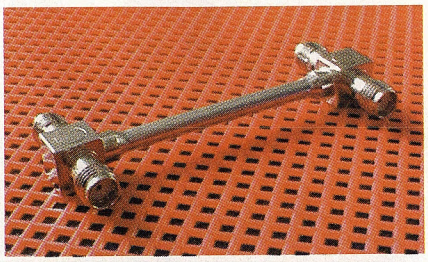
NEW PRODUCTS

quirements. The connectors permit a minimum board-to-board height of 7 mm. This offers a good alternative to an MCX or SMB configuration. By using an in-series adapter and the design of the series, MMBX connectors handle an axial misalignment of 0.6 mm with a nominal value of 6.7 mm and a radial misalignment of 0.4 mm. Exhibiting high electrical performances, these microminiature connectors are designed for 50 Ω applications from DC to 6 GHz. The series offers a large range of connectors, which includes straight and right-angle plugs, female or male receptacles in SMT or thru-hole version, edge-card receptacles, in-series adapters and SMA-MMBX adapters. MMBX products are supplied in standard bulk packages or in tape-and-reel offering.

Radiall,
Rosny Sous Bois, France
+33 1 49 35 35 35.

Circle No. 223

Quad Hybrids



The Slimline series of low package volume, formable 3 dB quadrature hybrids operate at incremental bands between 100 MHz and 2 GHz. These new devices are available with SMA female connectors standard and alternate interfaces upon request. They offer typical insertion loss of 0.4 dB, isolation of 20 dB (typ) and SWR of 1.1 (max). Power handling of up to 200 W CW is available. These new packages can be formed or meandered in order to accommodate system architectures where space is a premium. Connectors can be configured in T or L format to provide for desired cabling access. Additional benefits in weight reduction make this an attractive approach for tower-top or airborne requirements.

Response Microwave Inc.,
Framingham, MA (508) 231-8787.

Circle No. 224

Thin Film Wideband Termination

The model FMITN0100500XENFGG thin film wideband termination is ideal for applications (hybrid circuits) requiring high frequency performance in a small form factor. An AlN substrate supports 20 W power dissipation with the appropriate heat sink, and the thin film technology insures optimum performance over time and temperature. The high reliability device features a wire bondable top pad and the ground wrap back contact eliminates the need for ground wire. It features high frequency response of DC through 20 GHz with 50 Ω impedance.

SatCon Electronics,
Marlborough, MA (508) 485-6350.

Circle No. 225

Star Point Combiner

The star point combiner principle was chosen to implement a suitable filter combiner to



achieve low attenuation loss with acceptable mechanical dimensions in combining the uplink and downlink ranges with the receiving and transmitting ranges in a common antenna field. First the receiving and transmitting ranges of each of the two connections are separated in a two-way star point and routed through the filters. Then they are recombined in a four-way star point and routed to the antenna. The combiner is made up of four temperature-compensated, eight-cavity filters. They are combined in a star point network with strip line technology.

Spinner GmbH,
Munich, Germany +49 89 12601-0.

Circle No. 226

ZMA Connector

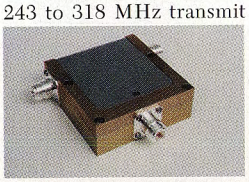
The ZMA connector matches the SMA in line size and provides easy quarter turn hand mating as opposed to torquing and lockwiring. The ZMA is ideal for microwave applications involving location and space constraints along with high vibration. A lug coupling latching mechanism provides superior mechanical stability. This connector is ideal for locations where blindmating is desired but space is not available.

SV Microwave,
West Palm Beach, FL (561) 840-1800.

Circle No. 227

VHF High Power, Low Loss Circulator

The model CT-1645-N circulator covers the 243 to 318 MHz transmit band and handles

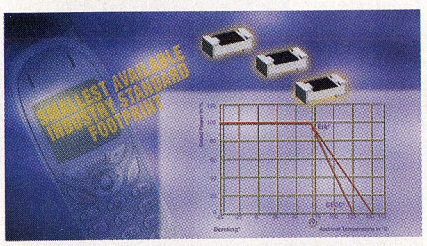


500 W CW power with very low loss. Specifications include 20 dB (min) isolation, 0.3 dB (max) loss and 1.25 SWR. Type N connectors are standard. Size: 3.500" × 3.625" × 1.250".

UTE Microwave Inc.,
Asbury Park, NJ (732) 922-1009.

Circle No. 228

Thick Film Rectangular Chip Resistor



The model CRCW0201 thick film rectangular chip resistor is designed with a small footprint to enable downsizing in applications where board space is critical. It is well suited for compact end products including memory modules, cell phones, PCMCIA cards, hearing aids, sensors, frequency control devices and notebook computers. The device features a power rating of 50 mW, a maximum working voltage of 30 V, and a standard TCR value of ±200 ppm/°C. The chip offers a broad resistance range from 10 Ω to 1 MΩ, including E24-range values, and a tolerance of ±5 percent. With flow-solderable terminations featuring a nickel barrier layer, the CRCW0201 is compatible with automatic placement equipment for easy integration into complex systems. Size: 0.600 × 0.300 × 0.009 mm.

Vishay Intertechnology Inc.,
Malvern, PA (610) 644-1300.

Circle No. 229

AMPLIFIERS

High Intercept Amplifier

The model BP60070120 high intercept power amplifier operates in the 20 to 2000 MHz frequency range and provides 23 dB gain and 30 dBm output power at 1 dB gain compression. High linearity and low orders of distortion are delivered with a typical IP3 of +41 dBm and an IP2 of +65 dBm. Gain flatness is ±1.0 dB (typ). Input and output SWR is 2 (max). Operating with a voltage of +15 V DC this product draws a nominal 550 mA. Noise figure is below 4 dB above 50 MHz and typically below 3 dB above 100 MHz. An internal DC regulator, reverse voltage protection and field removable SMA (f) connector shells are standard. Size: 1.5" × 1.1".



AML Communications Inc.,
Camarillo, CA (805) 388-1345.

Circle No. 230

20 W AMPS Band MCPA

The model BWTL-900-20W AMPS band multi-channel feedforward power amplifier is designed for small base station and repeater applications. This 20 W unit operates from 869 to 894 MHz and has a gain of 50 dB with a flatness of ±0.5 dB, a noise figure of 8 dB and includes an output isolator for protection. The amplifier produces < –65 dBc IMDs with two 10 W CW tones and < –60 dBc with any number of tones with random phases at 20 W average power. It is IS-97 compliant with a single 20 W CDMA signal and 15 W average power with 8 or more CDMA channels while drawing 6 A (max) at 28 V. Size: 4.80" × 8.00" × 2.15". Price: $1500.

Broadband Wireless Technologies,
Sparks, NV (775) 345-0411.

Circle No. 231

SDLVA

The model SDLVA-2020-50 option 26 INDRA successive detection log video amplifier (SDLVA) operates from 2.4 to 5.4 GHz (other frequencies are available) with RF gain of 60 dB (min), SWR of 3.0 (max) and the limited RF power output is +14 dBm (typ) and +10 dBm (min). The dynamic range is –45 dBm to +5 dBm for video output. Output video load is 100 Ω ±10 percent as desired. Frequency flatness is ±2.0 dB at 2.4 to 5.4 GHz. Size: 3.5" × 3.0" × 0.5".

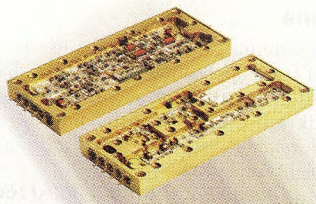
Planar Monolithics Industries (PMI),
Frederick, MD (301) 631-1579.

Circle No. 232

[Continued on page 208]

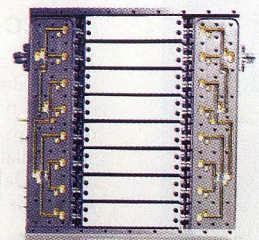
THINK OUTSIDE THE BOX...

ULTRA MINIATURE SDLA



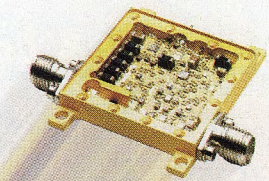
1.0 - 2.0 GHz
Limited RF Output
70 dB dynamic range
0 dBm ±2.0 dB from
-65 dBm to +5 dBm
0.6 cubic inches

SWITCH FILTER BANK



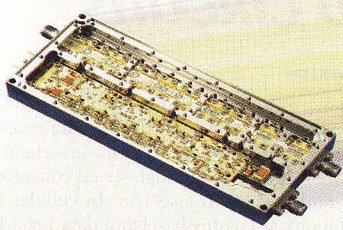
6.0 - 18.0 GHz
60 dBc; 15% from band edges
Modular construction

ULTRA MINIATURE DLVA (0.2 CUBIC INCHES)

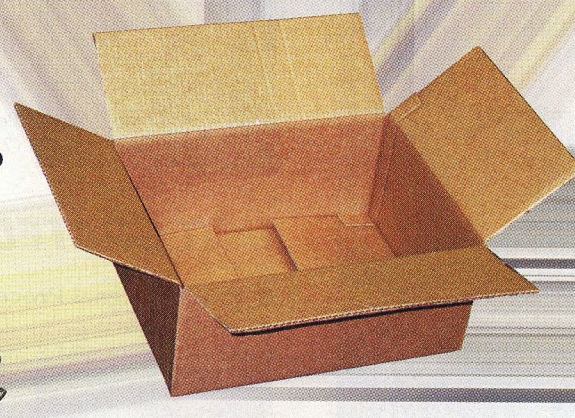


2.0 - 18.0 GHz
40 dB usable range
1.25"x1.25"x0.15"

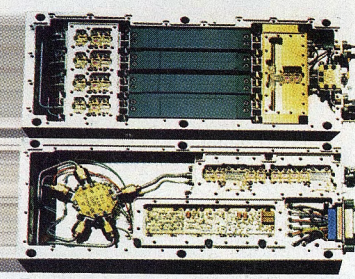
HIGH SPEED MULTIOCTAVE SDLA WITH LIMITED RF OUTPUT



0.5 - 2.0 GHz
2.0 - 6.0 GHz
6.0 - 18.0 GHz
Logging Range: -70 dBm to 0 dBm Video Output
Recovery Time: 60 nano seconds (60 dB drop)
T.S.S.: -73 dBm - Linearity: ±1.0 dB Nom.
Rise Time: 10 nano seconds
2nd/3rd Harmonic: -9 dBc
Limited RF Output:
-60 dBm to +10 dBm input &
+10dBm to +14dBm output



CHANNELIZED ESM RECEIVER



2.0 - 6.0 GHz
6.0 - 10.0 GHz
10.0 - 14.0 GHz
14.0 - 18.0 GHz
70 dB Dynamic Range
-65 dBm to +5 dBm

THINK...

INSTANTANEOUS FREQUENCY MEASUREMENT RECEIVER DIFM RECEIVER 0.5 TO 18.0 GHz

High Sensitivity: -60 dBm (6 - 18 GHz)
Accuracy: 2.0 MHz RMS @ 18.0 GHz
Resolution: Up to 14 BITS
Multiple Signal Handling: Pulse, Pulse on CW, CW and Pulse on Pulse
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Triggering: External or Internal
Built-in Limiting: -10 dBc 2nd & 3rd Harmonic

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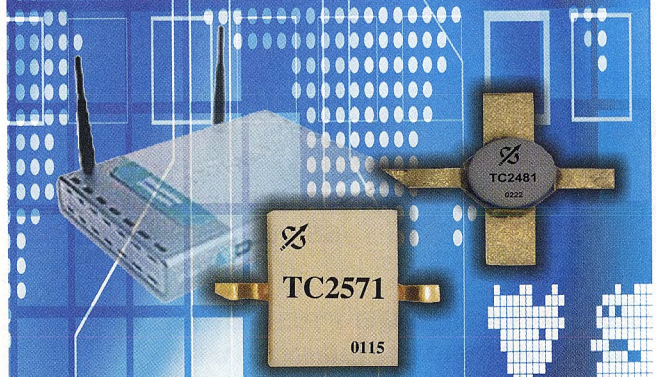
MMICs Devices

Part Number	TC3511	TC3535	TC3539
Frequency (GHz)	5~6	4.8~6	5~6
P-1 dB (dBm)	24	29	29
Gain (dB)	20	21	19
BIAS Condition (mA)	200 mA @ 3.3V	400 mA @ 8V	400 mA @ 8V
Application	WLAN Card	Access Point	Access Point

Note : Specifications are typical.



Discrete Devices

Part Number	TC2481	TC2571
P-1 dB (dBm)	27 @ 6 GHz	30 @ 6 GHz
Gain (dB)	11 @ 6 GHz	11 @ 6 GHz
Application	Access Point	Access Point

Note : Specifications are typical.

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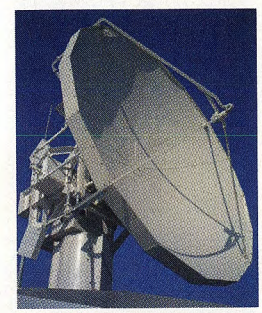
ANTENNAS

LTCC Chip Antenna

This high frequency chip antenna is designed for use in Bluetooth, WLAN and 2.45 GHz ISM band applications. This LTCC-based device provides typical gain figures of 3.0 dBi peak and 1.0 dBi average, while return loss is kept to 9.5 dB (min). These compact antennas also exhibit good radiation pattern performance. Size: 9.5 × 2.0 × 1.2 mm. Price: 45¢ (1000). Delivery: stock to eight weeks (ARO).
Johanson Technology Inc., Camarillo, CA (805) 389-1166.
Circle No. 233

C-band Weather Radar Antenna



The model 0132-800 4.5 M C-band weather radar antenna is a high performance, low side-lobe antenna that provides excellent cross polarization to enhance the performance of modern Doppler radars. The antenna operates over the 5.25 to 5.35 GHz frequency range with 43 dBi (min) gain, 27 dB (max) sidelobes, co-pol, 550 kW peak power handling and 1.2 (max) SWR.
Seavey Engineering Associates Inc., Pembroke, MA (781) 829-4740.
Circle No. 234

INTEGRATED CIRCUITS

Receive Signal Processor



The model AD6634 receive signal processor (RSP) is a member of the company's Versa-COMM™ family of RSPs and transmit signal processors (TSPs), which serve as the interface between the DSP and high speed converter in a multi-carrier transceiver. In cellular base stations, it creates baseband data for a DSP from high bandwidth data provided by an A/D converter and is compatible with SoftCell high performance IF sampling ADC converters. The AD6634 is a highly integrated, multi-mode, four-channel digital receive signal processor capable of processing up to two W-CDMA channels or four GSM/EDGE or IS-136 channels. Each of the AD6634's channels consists of four cascaded signal-processing elements: a frequency translator, two fixed coefficient decimating filters, and a programmable-coefficient decimating filter. Price: $42.50 (1000).
Analog Devices, Wilmington, MA (800) 262-5643.
Circle No. 235

Half-duplex Transceiver

The model HRF-ROC094XC half duplex transceiver is for use in digital data applications. Direct microprocessor connection for control and data transfer eliminates the need for additional ICs, while integrated data code-decode reduces the instruction set requirements on the microprocessor. It is ideally suited for use in battery powered wireless applications in conjunction with microprocessors for data communication. Adjustable data rates, filter bandwidths and detection levels allow the IC to be used in a wide variety of high sensitivity/high EMI environments.
Honeywell, Plymouth, MN (800) 323-8295.
Circle No. 236

MATERIAL

Copper Clad Laminate

Model GML 2032 copper clad laminate was designed for the RF/wireless communications market. With electrical performance similar to PTFE, it is an excellent candidate for applications in the high frequency market. The low loss makes GML2032 a very cost-effective option. The laminate features Dk stable from –55° to +125°C and in humid and dry environments. It also meets UL 94 V-0 flammability rating. There is no

[Continued on page 210]

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added RF or synergist and no special plated thru-hole treatments required. The material features fabrication and assembly in standard PWB operations and standard RF4 feeds and speeds for drilling and routing.
GIL Technologies, Collierville, TN (901) 853-5070.

Circle No. 237

SOFTWARE

Amplifier Compression Test Automation Program

CTAP™ (Compression Test Automation Program) provides a valuable and convenient tool for the design engineer to quickly measure the compression characteristics of an amplifier device over frequency, using a vector network analyzer. CTAP is designed to increase accuracy and throughput, while reducing repetitive procedures and utilizing the familiar look and feel of the Windows™ interface. CTAP offers flexibility in the measurements of amplifier compression characteristics and is very easy to use. It is designed to measure an amplifier's gain characteristics vs. input power, specifically locating the 1 dB compression point. It can also perform this measurement at a signal frequency or over a specified range of frequencies.
CorNic Technologies, Ellicott City, MD (410) 627-0795.

Circle No. 238

3D EM Software

QUICKWAVE-3D version 2.1 is a full-wave 3D electromagnetic software kit allowing fast and accurate industrial design of microwave and millimeter-wave devices with no need for 3D drawing. The software's advanced features such as conformal meshing and multi-modal wide-band S-parameter extraction result in a good accuracy to computer resources ratio. This new version brings a system of parameterized element libraries.
QWED Sp. Z o o., Warsaw, Poland +48 601 38 64 84.

Circle No. 239

PULSED CONSTANT CURRENT GENERATORS

AV-156 SERIES OF MEDIUM-CURRENT PULSERS

Laser Diode Driving ~ Air Bag Inflator Testing ~ Semiconductor Testing Electromigration Studies ~ Actuator Tests

The AV-156 series of user-friendly, general-purpose instruments are ideal for test applications where well-defined pulses of current of up to 10 Amps are required.



All models include IEEE-488.2 GPIB and RS-232 interfaces, for easy incorporation into automatic test systems!

★ AV-156B-B, 1 Amp, 40V compliance, 10 us - 10 ms pulse width, 4 us rise time
★ AV-156C-B, 2 Amps, 20V compliance, 1 us - 1 ms pulse width, 0.2 us rise time
★ AV-156A-B, 5 Amps, 15V compliance (25V opt.), 10 us - 10 ms, 4 us rise time
★ AV-156G-B, 10 Amps, 15V compliance (25V opt.), 10 us - 10 ms, 4 us rise time

Dual-channel models are also available - ideal for airbag squib testing and other tests requiring two current pulses with variable time delay:

★ AV-156E-B, Dual-channel 5A, 25V, 1 - 100 ms, 10 us rise time, 0 - 1000 ms delay
★ AV-156F-B, Dual-channel 10A, 25V, 1 - 100 ms, 4 us rise time, 0 - 1000 ms delay

For the full details on these models and other Pulsed Constant Current Generators, visit: **http://www.avtechpulse.com/current/**

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SOURCES

Crystal Oscillators



The model F4107 and F4109 miniature surface-mount crystal oscillators offer tighter stabilities for all operating conditions. The F4107 offers a stability of ±15 ppm and the F4109 offers a stability of ±10 ppm. The new oscillators maintain these stabilities inclusive of operating temperature range, input voltage change, load change, aging, shock and vibration. They are typically used in applications requiring stabilities tighter than ±20 ppm. Specific applications include wireless communications and networking where better stability and noise characteristics are needed. The two new 3.3 V HCMOS oscillators have a standard operating temperature range of –10° to +70°C, with an optional –40° to +85°C range available for the F4107.
Fox Electronics, Fort Myers, FL (888) 438-2369.

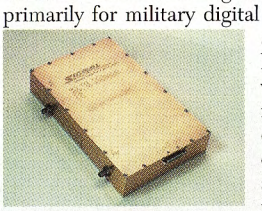
Circle No. 240

LO Synthesizer

This programmable signal source is completely self-contained with an internal TCXO reference. The synthesizer can be either serially loaded through the RS-232C control port or set up to power on at a pre-determined frequency. The primary output can be configured for output frequencies up to 2.5 GHz, while the secondary output can be configured for frequencies up to 510 MHz. The step size can also be specified. Narrow step sizes will affect the phase noise and spurious output of the synthesizer. This source is suitable for use in dedicated test setups or as a component of a production system. Typical applications include serving as a local oscillator (LO) source for single or dual conversion up/down converters, a stimulus for CW transmitter or a signal generator for bench testing or production test setup.
Praxsym Inc., Fisher, IL (217) 897-1744.

Circle No. 241

Digitally Tuned Oscillators



This standard line of digitally tuned oscillators (DTO) was developed primarily for military digital receiver front ends for radar applications and for electronic warfare simulator markets. These super components standout when speed, broadband jamming, and fast frequency hopping are required. The DTO design incorporates a new custom integrated assembly architecture using a dual source approach with hybrid and monolithic multi-function microwave and control component circuitry to achieve the broadband tuning and stability required. Robust designs with continuous frequency coverage from 2 to 18 GHz with 2 to 6 GHz, 2 to 9 GHz and 6 to 18 GHz options covering full military temperature ranges are available.
Signal Technology Corp., Arizona Operations, Chandler, AZ (480) 940-1655.

Circle No. 242

C-band VCO



The model V910ME13 C-band voltage controlled oscillator (VCO) is geared for the terrestrial radio market. It optimizes the performance and quality of a terrestrial radio PLL by delivering low phase noise performance in a compact low profile package. This VCO covers 4200 to 4400 MHz within only 2 to 10 V DC of control voltage. The model further realizes a clean spectral signal of –86 dBc/Hz (typ) at 100 kHz from the carrier and covers the 200 MHz with an average tuning sensitivity of 44 MHz/V. The V910ME13 features 1.1:1 linearity over frequency and temperature and suppresses the second harmonic to better than –20 dBc. It conserves energy by operating off a 5 V DC supply while drawing only 27 mA and provides the end user 0.5 ±3.5 of output. It is designed to operate over an extreme temperature range of –40° to +85°C. Size: 0.50" × 0.50" × 0.13".
Z-Communications Inc., San Diego, CA (858) 621-2700.

Circle No. 244

Clock Smoother

The CS-300 series ultra low jitter clock smoothing device is designed to be used in telecommunications applications. It is a SAW-based product that offers output frequencies between 155.52 and 800.00 MHz. The devices act as both a clock smoother and a frequency translator and can lock to virtually any input frequency between 10 and 700 MHz. The CS-300 series is not limited to integer multiplication and, for example, can translate 622.08 to 669.3266 MHz, which is ideal for FEC applications. The series is available with either +3.3 V DC or +5 V DC supply voltages and operates over the temperature range of –40° to +85°C. Size: 1.000" × 0.800" × 0.250".

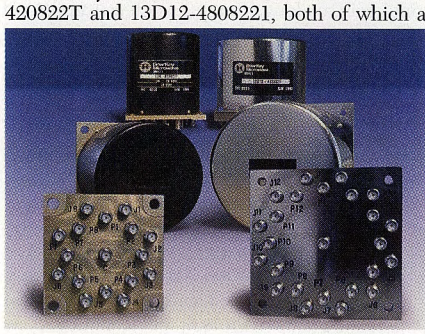
Vectron International, Norwalk, CT (888) 328-7661.

Circle No. 243

SUBSYSTEMS

CANBUS-based Switch Matrices

This family of CANBUS-based switch matrices consists of model 9D8-420822T and 13D12-4808221, both of which are equipped with built-in Ethernet control. They are based on the standard design of the SP8T and the SP12T internally terminated switches. Access to the termination port, via SMA connectors, allows for the utilization of the remotely mounted high power 50 Ω termination, increasing the power handling of these units. The access to the termination ports via SMA connectors make these switch matrices suitable as building blocks for redundancy solutions, specifically where insertion of multiple redundant units into any of the 8 or 12 main network lines is required. This new dual-use technology is implemented with a focus on the wireless market needs, especially in the area of satellite ground stations and wireless networking solutions.



Dow-Key Microwave Corp., Ventura, CA (805) 650-0260.

Circle No. 245

RF/Microwave Switch Matrix

The model TR10 switch matrix provides complete switching control through GPIB/RS232 in a 19", 3U, rack mountable enclosure. The unit displays complete status of all switches via a clear 4 × 20 lines of characters LCD display module. It provides local control of switches through a rugged 16-keypad or remotely through GPIB/RS232. The matrix can store up to 10 pre-set conditions for the switches. Users can select desired preset condition via remote or local controls. The unit can also be tailored to customer's specifications to provide desired signal conditioning, meaning passive and active components can be added internally.

Trilab Inc., Gaithersburg, MD (301) 519-3660.

Circle No. 246

TEST EQUIPMENT

Satellite Simulator

This tri-band satellite simulator covers the C-, X- and Ku-bands. The box provides simulation of the complete link including the transmit and receive antennas. Band selection is realized through an external select switch. The simulator is very compact with self-contained antennas and the ruggedized enclosures allow for outdoor deployment. Weight: less than 20 lb.



Tampa Microwave, Tampa FL (813) 855-2251.

Circle No. 250

[Continued on page 212]

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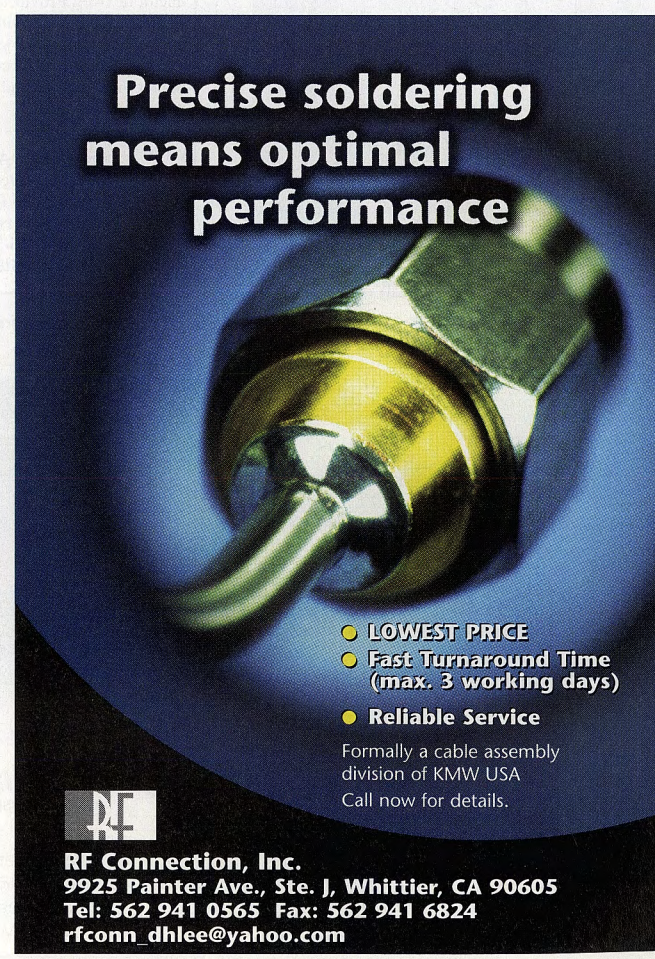

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NEW PRODUCTS

Spectrum Analyzer

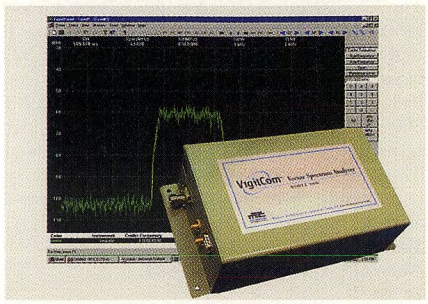


The model 2394 spectrum analyzer is lightweight and portable with a large color LCD display. It includes a fast processor and a large memory capable of storing up to 1000 screen traces and 2000 operational states. The 50 Ω output can accept signals between +30 and –110 dBm while providing protection up to 50 V DC. The 2394 includes a comprehensive marker system that allows as many as nine markers to be displayed at one time, together with a marker table showing the frequency and level of each marker selected. This feature allows multiple signals to be evaluated simultaneously. Applications for the 13 GHz spectrum analyzer include mobile handset production test, handset repair verification and base station transmitter testing. Price: $20,000. Delivery: eight weeks.

IFR, an Aeroflex company,
Wichita, KS (800) 835-2352
or (316) 522-4981.

Circle No. 247

Vector Spectrum Analyzer



The model VC900 vector spectrum analyzer improves quality of service by monitoring intermittent sources of interference. Equipped with the spectrum logging option, the model can periodically log the spectrum of signals in the vicinity of the base station. A remote operator can then view the logged data against a time axis, making it easy to detect trends and intermittent conditions resulting in improved quality of service. The VC900 gives a service provider continuous true real-time monitoring™ of important base station parameters such as adjacent channel power ratio, channel power and statistical power measurements, as well as standard spectrum analyzer functions. The analyzer can also perform modulation domain measurements such as polar plots, eye diagrams, rho, code channel power, etc. The unit covers the 800 to 1000 MHz cellular bands, and can be configured with three inputs for monitoring three sectors of a base station. Size: 6.75" × 9.75" × 3.125".

Morrow Technologies,
Largo, FL
(727) 531-4000.

Circle No. 248

Spectrum Analyzer

The model R&S FSH3 spectrum analyzer features an upper frequency limit of 3 GHz and numerous measurement functions. The analyzer has been specifically designed for wide-base customer applications where the focus is on portability and mobility. This includes areas of mobile communications, such as installation, maintenance, servicing and field-strength measurements, as well as use in labs and universities or by electronics hobbyists. The R&S FSH3 comes in two basic versions: as a pure spectrum analyzer from 100 kHz to 3 GHz and as a spectrum analyzer with a tracking generator for scalar network analysis. When equipped with an SWR bridge the analyzer can be used for scalar network analysis or for distance-to-fault measurements on cables.



Rohde & Schwarz GmbH & Co. KG,
Munich, Germany
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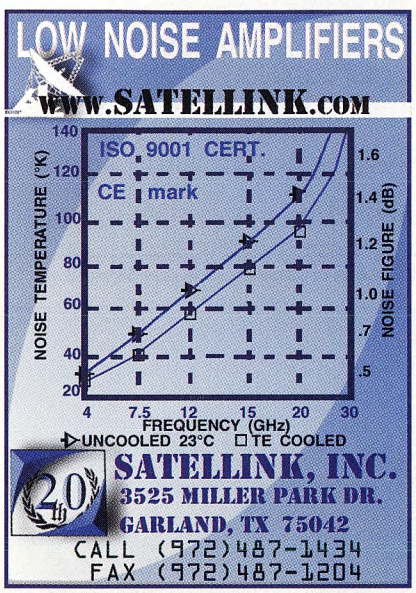

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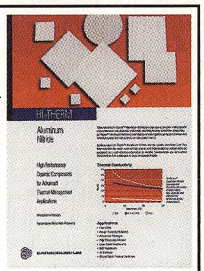

Literature details Hi-Therm™ Aluminum Nitride high performance ceramic components for thermal management applications such as RF/microwave components, optoelectronics, microelectronics packages and power semiconductor devices. Provides information on Hi-Therm™ Aluminum Nitride's excellent thermal conductivity and electrical properties. Hi-Therm™ ceramics have thermal conductivities eight times higher than alumina and approaching beryllia at higher temperatures.

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www.hithermaln.com

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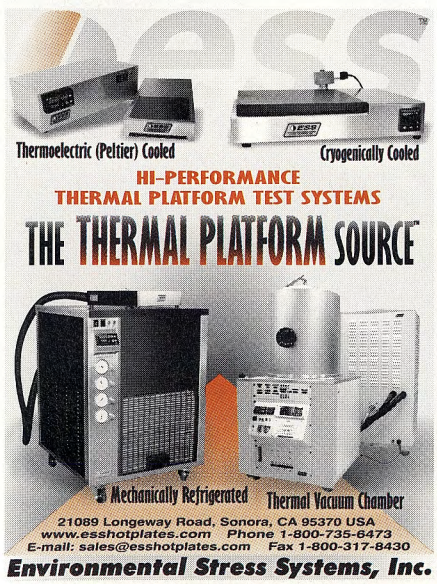

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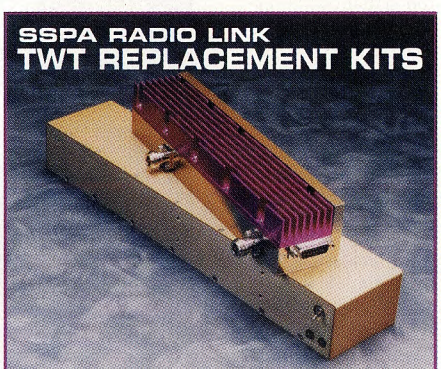

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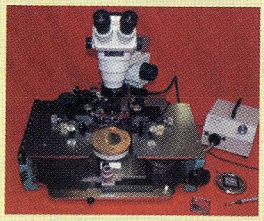

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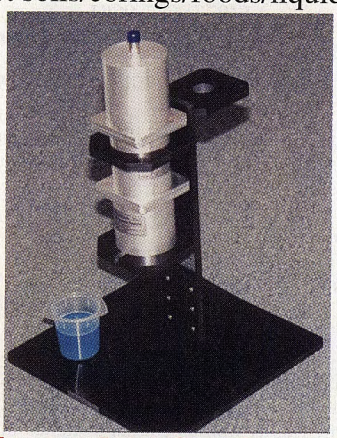

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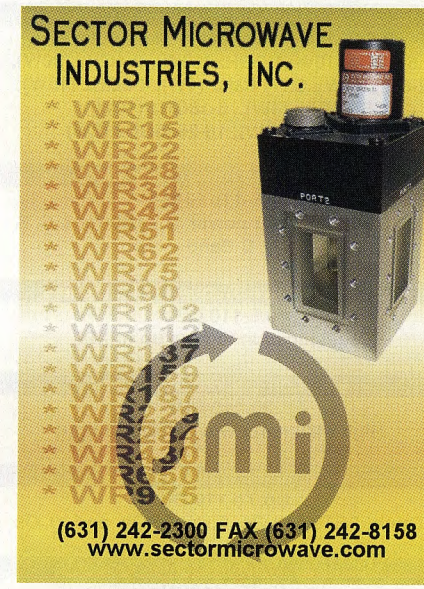

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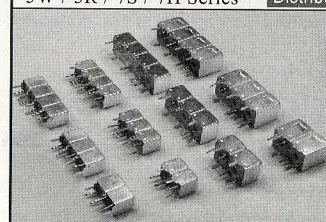

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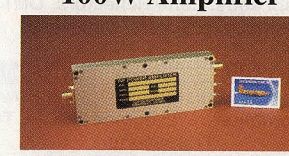

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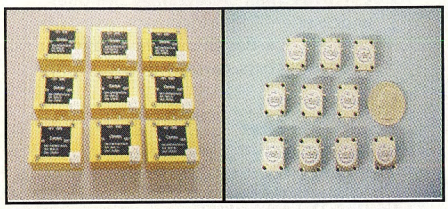

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NEW LITERATURE

Inductor Products Catalog

This 10-page catalog features the company's WL series of wire wound chip inductor products, designed to provide excellent performance at competitive prices. Product descriptions, features, applications, specifications, circuit applications, outline drawings and selection guides are provided.
American Technical Ceramics,
Jacksonville, FL (631) 622-4700.
Circle No. 200

GPIB Microwave Switch Products Brochure

This four-page brochure details the series 8000 GPIB microwave switch products. These products can be customized to meet individual needs of users. Product drawings, descriptions, features and key specifications and graphs are provided.
Ascor Inc., a Giga-tronics company,
Fremont, CA (510) 490-2300.
Circle No. 201

Company Brochure

This brochure features a corporate profile with an emphasis on the company's unique customer service programs and passive coaxial products. Innovative components, including power dividers, directional couplers, fixed attenuators, terminations and test accessories are briefly described.
BroadWave Technologies Inc.,
Franklin, IN (317) 346-6101.
Circle No. 202

Communications Antennas

This catalog features communications antennas for wireless LAN, ISM band and small cell applications. The company also features products in RFID data collection, land mobile radio, specialized mobile radio, cellular, security, wireless MAN, amateur radio and other applications.
Cushcraft Corp.,
Manchester, NH (603) 627-7877.
Circle No. 203

EMI/RFI Shielding Solutions Brochure

This brochure features an electromagnetic spectrum chart designed to assist in product selection for industrial shielding applications, including military power, radio and television, cellular and wireless communications, radar, and satellite. It also offers a brief description of the company's extensive shielding product line.
ETS-Lindgren,
an ESCO Technologies company,
Glendale Heights, IL (630) 307-7200.
Circle No. 204

Technical Brochure

This six-page technical brochure details the expanded range of options for the company's JITO-2® Just-in-Time oscillators. These options include ±220 ppm stability, and the division of the second HCMOS output by two, four or eight. This divide by output allows the use of one oscillator to drive two chips at different speeds without the need for a second oscillator or onboard divider.
Fox Electronics,
Fort Myers, FL (888) 438-2369.
Circle No. 205

New Product Catalog

This 20-page product catalog features IF/RF/microwave filters and multiplexers for commercial and military applications. A wide range of filter technologies is available, including ceramic, lumped element, cavity, combline and interdigital in frequencies from 1 MHz to 20 GHz. Other products include low cost, custom ceramic filters, diplexers and resonators for wireless applications.
Integrated Microwave,
San Diego, CA (858) 259-2600.
Circle No. 206

RF and Microwave Signal Control Product Catalog

This 51-page product catalog features all of the company's high performance RF and microwave signal control products covering the frequency range from DC to 18 GHz. Many new products are featured in this catalog, including fixed attenuators, directional and hybrid couplers, power divider/combiners, and terminations.
MECA Electronics Inc.,
Denville, NJ (973) 625-0661.
Circle No. 207

Isolators and Circulators Catalog

This 32-page catalog features the company's drop-in isolators and circulators, microstrip isolators and circulators, coaxial isolators and circulators, custom applications, and waveguide isolators and circulators. A company profile as well as general product information is also provided.
Renaissance Electronics Corp.,
Harvard, MA (978) 772-7774.
Circle No. 208

Full-Line Catalog

This edition includes a number of new products, including both PIN diode and waveguide switches, as well as coaxial switches up to 65 GHz. The filter section includes a range of Bessel filters, both absorptive and reflective, as well as cable filters. Other products include programmable attenuators, high power couplers, 40 GHz power dividers, detectors and 40 GHz bias tees.
RLC Electronics Inc.,
Mount Kisco, NY (914) 241-1334.
Circle No. 209

Materials Catalog

This catalog features the company's complete line of Rulon® higher performance fluoropolymer materials. An explanation of materials and processes, a material selection guide, and a typical product and application description is outlined for the most common 15 grades of material.
Saint-Gobain Performance Plastics,
Hoosick Falls, NY (800) 962-2666.
Circle No. 210

Product Brochure

This 12-page brochure features technical capabilities and product offerings. Information on tungsten dispenser cathodes and samarium cobalt (rare-earth) magnets for the microwave tube industry and other industries is provided.
Semicon Associates,
Lexington, KY (859) 255-3664.
Circle No. 211



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RF Technologies for Low Power Wireless Communications

Tatsuo Itoh, George Haddad and James Harvey, Eds.

John Wiley & Sons Inc.
468 pages; $84.95
ISBN: 0-471-38267-1

Several years ago a program in low power electronics initiated by the Army Research Office focused on addressing the issue of RF and microwave systems with a major concern for the prime power required for wireless transmitters. About the same time, DARPA initiated a program to address the reduction of power in digital and computing systems. As a complement to these programs, the Office of the Secretary of Defense initiated a multidisciplinary university research initiative (MURI) program to augment the Army program in RF and microwave systems. This program ran for five years and involved researchers in four universities: the University of California at Los Angeles (UCLA), the University of California, San Diego (UCSD), the University of Michigan and the University of Colorado at Boulder. The principal investigators from that MURI are the authors of this book, which presents the results of the sponsored research. The material in the book is presented to the design community in order to take advantage of the research in reducing power consumption in RF systems. The MURI effort focused primarily on communications systems. However, most of the research concepts can be applied to other RF systems, such as radar or target seekers in missiles.

"The goal of this research program was to develop techniques to accomplish the RF function at the lowest expenditure of energy."

The goal of this research program was to develop techniques to accomplish the RF function at the lowest expenditure of energy. The resulting comprehensive approach requires a highly interdisciplinary effort involving device and semiconductor science, circuit engineering, electromagnetics, antenna engineering and communications systems engineering. It is not possible in this book to go into as much technical detail in each topical area as is contained in the many technical publications resulting from the research. The book attempts to present the concepts and conclusions in an understandable manner and to allow the reader to reference the detailed publications for more in-depth information, as required.

To order this book, contact: John Wiley & Sons Inc., One Wiley Drive, Somerset, NJ 08875 (800) 225-5945.

Advanced Techniques in RF Power Amplifier Design

Steve C. Cripps

Artech House Inc.
320 pages; $99, £69
ISBN: 1-58053-282-9

By the author's own admission, this book is a sequel to his previous publication *RF Power Amplifiers for Wireless Communications* (Artech House Inc., 1999). It offers a more in-depth understanding of the theory of RF power amplifiers and covers some topics that were barely mentioned previously, such as bipolar junction transistors (BJT) and others that deserve a more detailed treatment.

With the advent of heterojunction bipolar transistor (HBT) and silicon germanium (SiGe) technology, interest in these devices has increased. Chapter 1 revisits the basics of class AB operation with higher emphasis on BJT applications. Chapter 2 is devoted to the Doherty and Chireix techniques, which still appear to be rooted in history and vacuum tubes. This chapter addresses their potential role in modern applications. This includes a more generalized analysis of the Doherty PA and some simulation results on practical implementations. The Chireix method continues to be a talking point and not much else. The chapter attempts to explain why it should be so. Chapter 3 takes up the theme of nonlinear effects in PAs, with particular emphasis on the problem of asymmetrical IM distortion, its causes and possible remedies. The chapter also has some tutorial material on the behavioral modeling of PAs and attempts to show that there is still much useful life left in polynomial and Volterra series modeling methods. Chapters 4, 5 and 6 cover the three main linearization topics of feedback, pre-distortion and feed-forward. Microwave power amplifier applications also get a chapter of their own, Chapter 7, in which an attempt is made to pull together some of the techniques which were developed in the 1970s and 80s for higher frequencies (> 2 GHz) broadband amplifier design and which could easily come back on stream again as wireless communications run out of bandwidth at the low end of the microwave spectrum.

"With the advent of heterojunction bipolar transistor (HBT) and silicon germanium (SiGe) technology, interest in these devices has increased."

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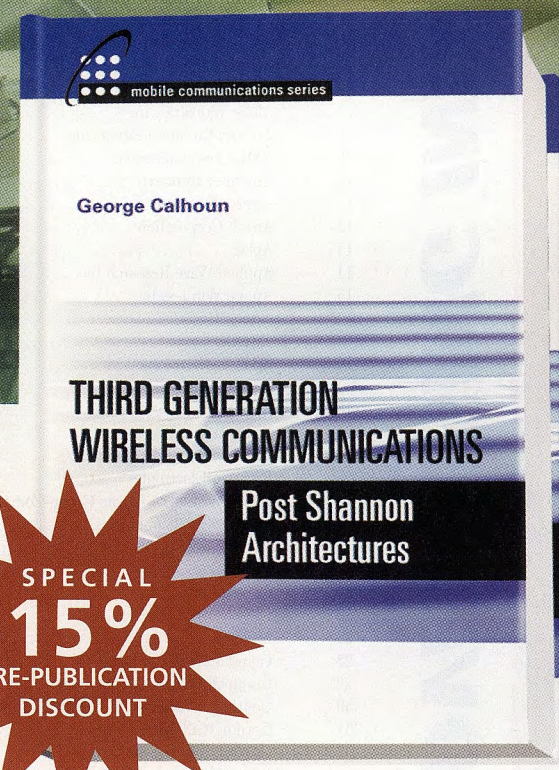

Third Generation Wireless Communications: Post Shannon Architectures

George Calhoun

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Contents: Preface. Acknowledgements. The Golden Age 1890-1940. Shannon. Wireless Systems Design: Problems & Parameters. Third Generation Systems: Technology Strategies. Signal Hardening Techniques. Signal Shaping Techniques. Signal Recovery Techniques. Signal Expansion Strategies. Epilogue: The Red Queen & Kitten.

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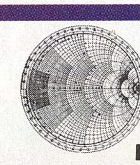

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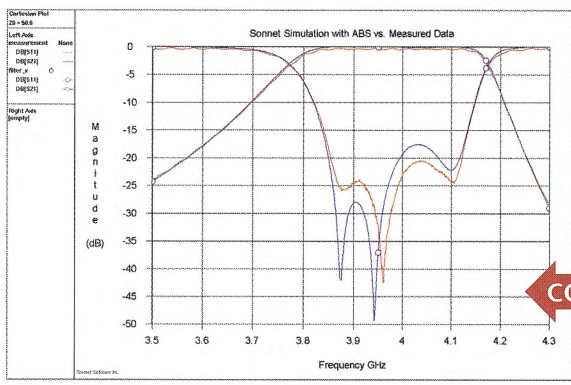
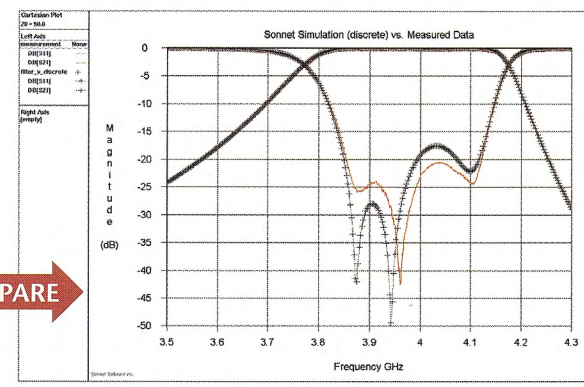
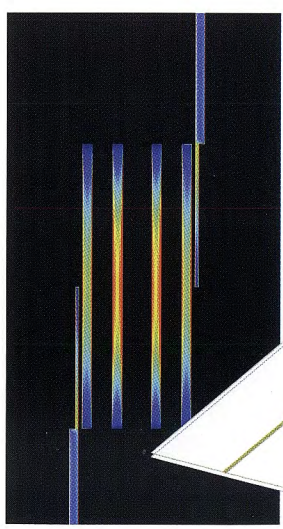


ABS simulation data based on 4 discrete EM analysis frequencies and measured data

COMPARE



300-point Discrete EM analysis and measured data



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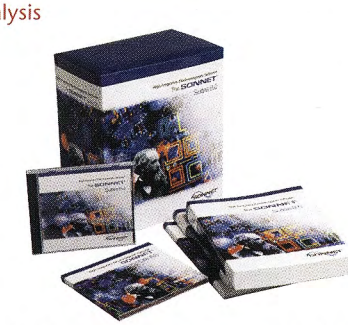

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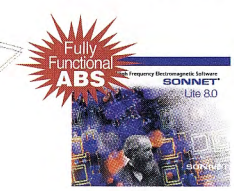

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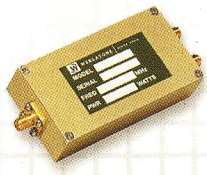

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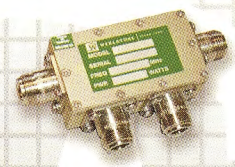
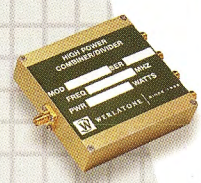
75 W CW





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Model C3910
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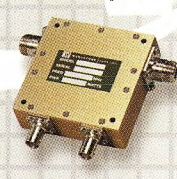



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Model C3063
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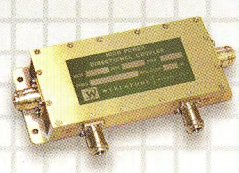

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