16 YRS WIRELESS LEADERSHIP

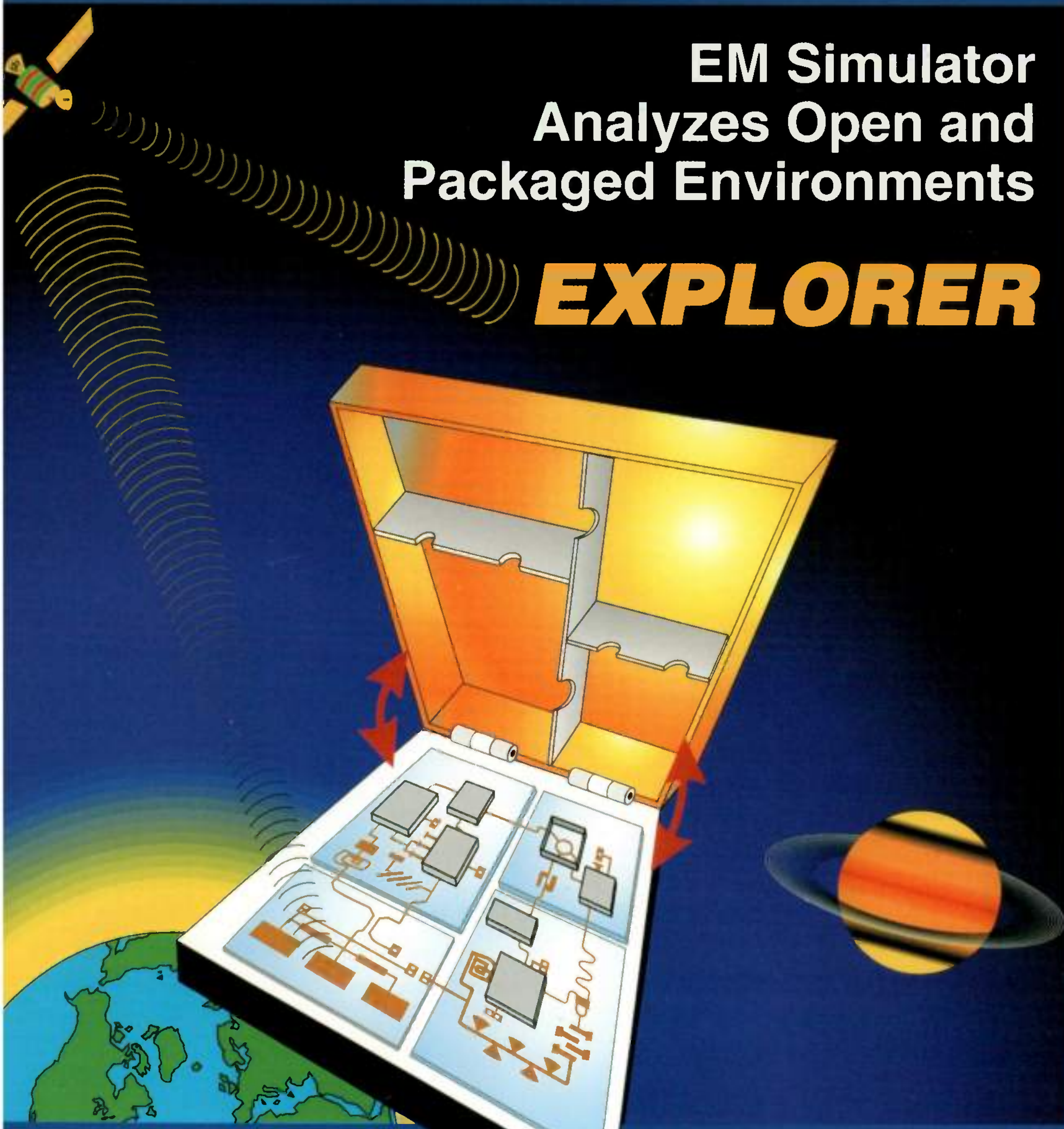
RF design™

engineering principles and practices

February 1995

EM Simulator Analyzes Open and Packaged Environments

EXPLORER



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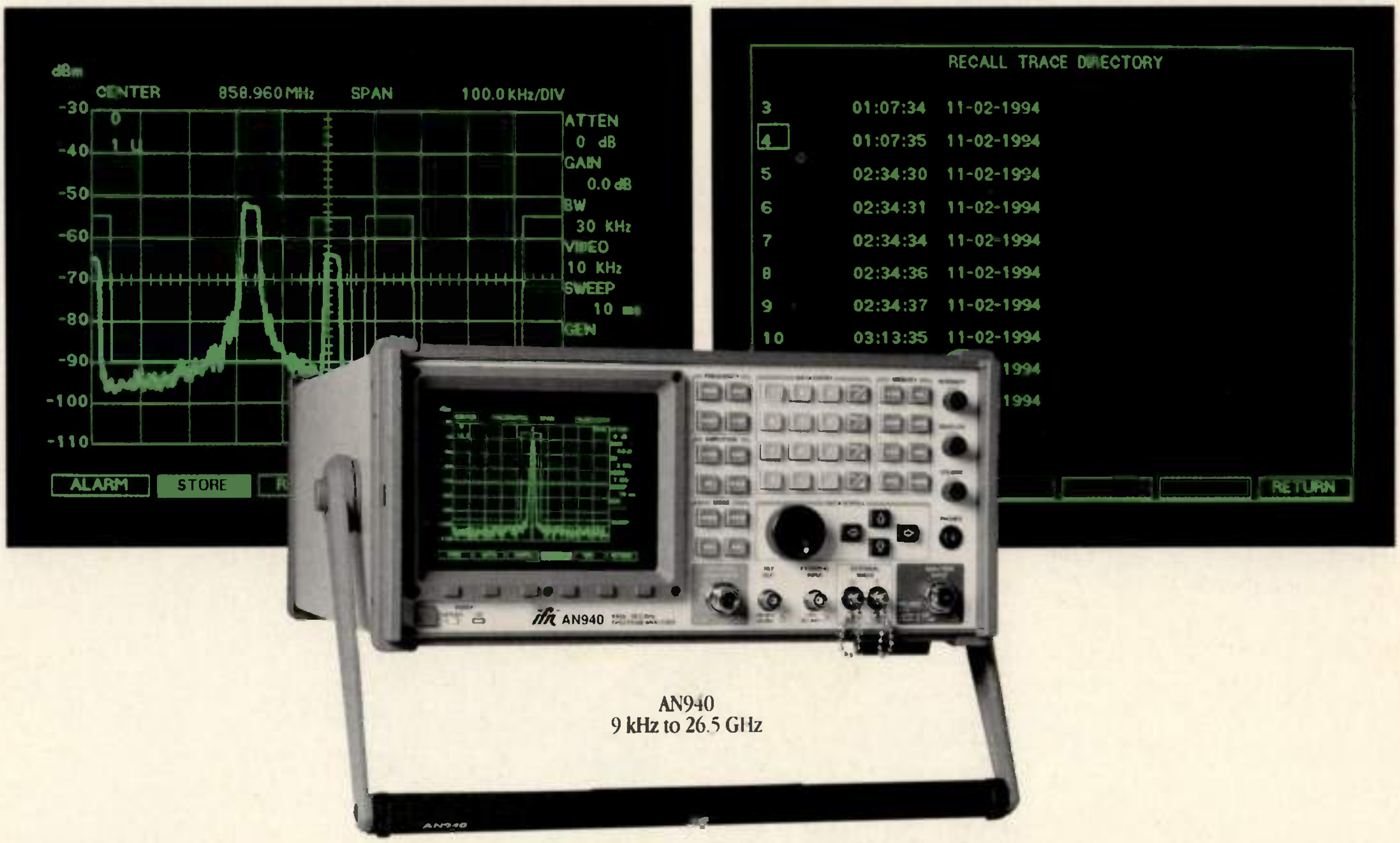

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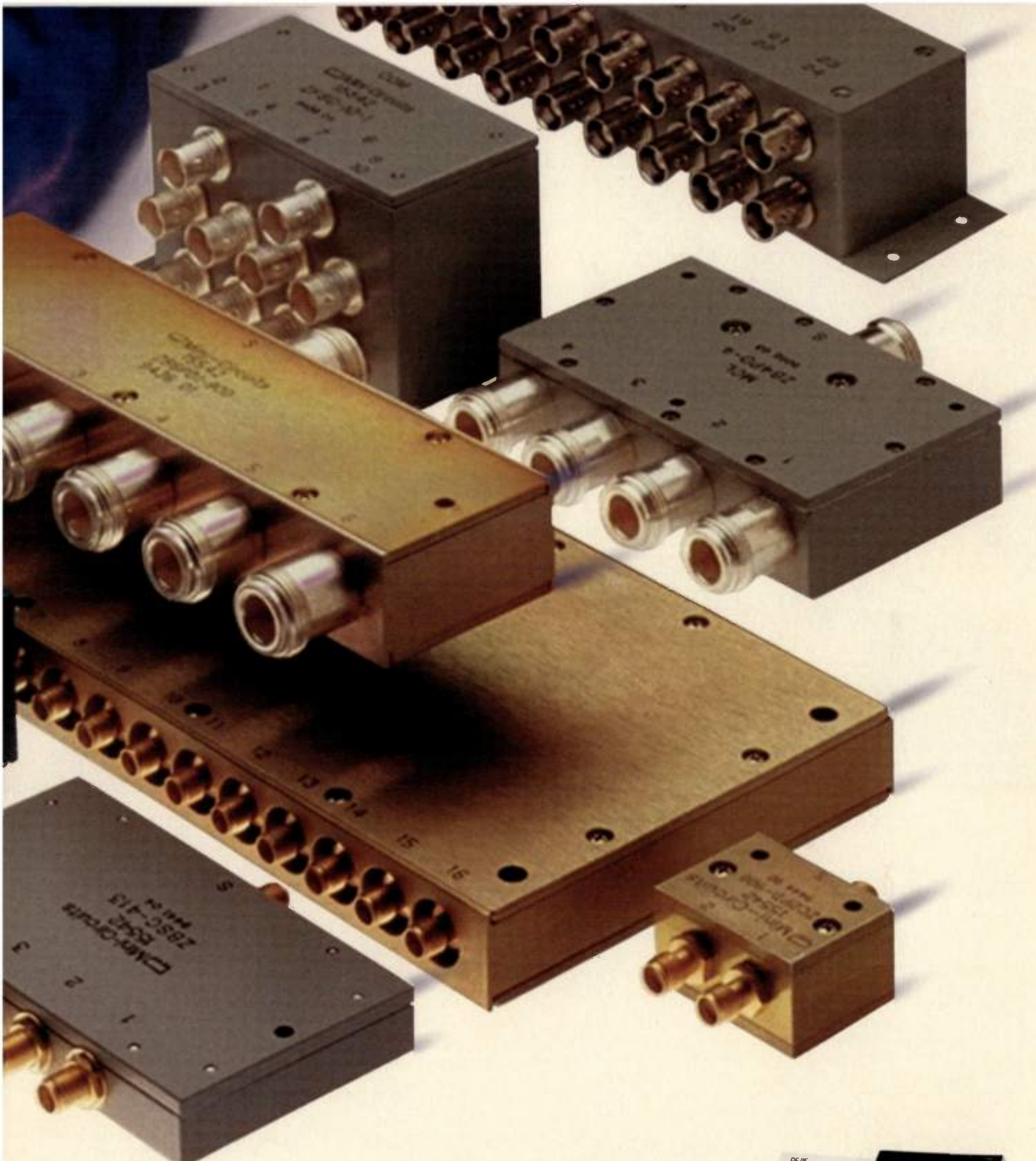

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INFO/CARD 3

RF design

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February 1995

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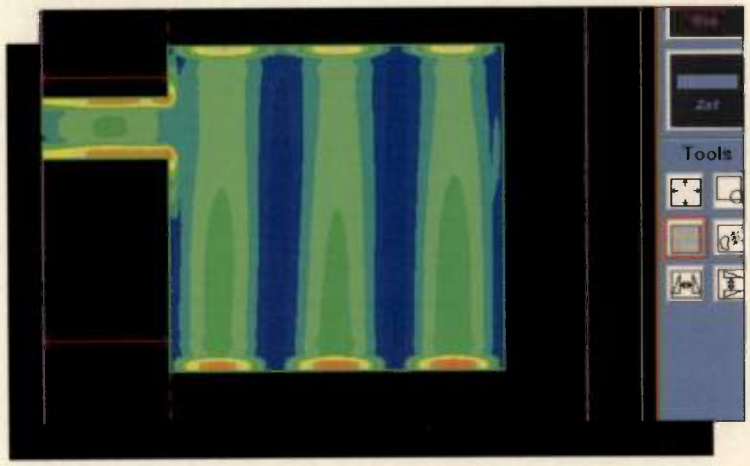

cover story

tutorial

departments

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RF editorial

Computer Engineering and Electromagnetics

By Gary A. Breed
Editor

Wireless communication products, perhaps using the spread spectrum systems featured in this issue, are a marriage of computer technology with radio communications. I was reminded of this recently in a letter from my friend and *RF Design* Editorial Board member Bob Zavrel. Bob managed to supply some specifics for an idea that I have long held — most computer designers don't have a good "feel" for electromagnetics, a problem that now needs to be addressed with some urgency.

Cellular radio equipment hasn't had many problems with computer/radio compatibility. I'll bet that success has come because traditional *radio* companies are making the equipment! However, many of the next generation of wireless products simply add a miniature radio to existing computing equipment — a very different situation!

Many of these new applications are for small, portable equipment which use a PCMCIA card (or IC card) slot for extra memory, applications programs, or connections to peripherals. These companies are beginning to request that the radio "peripheral" also be in a PCMCIA card form factor. Imagine the problems that must be solved to put a radio in a slot intended for memory or telephone modem applications. That's just what the computer companies are asking for.

Electromagnetic naivete is nothing new for the computer industry. Most early PCs, and many current products, simply use lots of sheet metal, aluminum foil, and EMC consultants' time to "fix" radiated emissions problems to meet FCC requirements.

The problem with integrated radio and computer products is far more serious. To quote Bob, "...the unit must perform the paradox of effective *antenna* and *shield*." FCC requirements require that unwanted emissions be suppressed, while at the same time, the desired signals must be transmitted. Add the potential for self-interference from the radio into the computer and you can see the magnitude of the problem.

I really didn't intend to pick on computer engineers so severely — the problem of new features that are simply tacked onto existing equipment is a common occurance. I once had a car where the headlight, wipers, high-beam, heater, cruise and turn signal controls bore little relationship to each other or to the driving position. Whoever designed that vehicle must have put them in any available empty place on the dashboard or steering column.

If we are going to design successful products for the increasingly competitive wireless market, such thinking must be avoided. Computer designers must add *wireless communications* to the generic functions of *computation*, *memory*, *I/O* and *data storage* that they have been accustomed to. The same effort that goes into a fast, efficient bus structure must be applied to the radio section, as well.

To you digital designers who haven't thrown this issue in the trash after my "attack," welcome to the world of RF! You will find new and fascinating challenges as you combine computing and communications in a single package.

Note: The "layman's" explanations of RF concepts I requested in my November 1994 editorial are presented on page 34 of this issue — I think you will find them quite interesting!

INFO/CARD 31

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LIFD-3010-080	30	10	-70 to +5	110	1
LIFD-3010P-80	30	10	-80 to 0	100	0.5
LIFD-6010-70	60	10	-70 to 0	65	1
LIFD-6020P-80	60	20	-80 to 0	50	0.5
LIFD-12020-80	120	20	-80 to 0	50	1
LIFD-16040P-70	160	40	-65 to +5	25	0.5
LIFD-16040-70	160	40	-70 to 0	30	1
LIFD-300100-60	300	100	-60 to 0	10	1

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Model Number	Center Frequency (MHz)	Bandwidth (3 dB) (MHz, Min.)	Dynamic Range (dB, Min.)	Rise Time (ns, Max.)	Linearity (±dB, Max.)
MLIF-500/100-70	500	100	-70 to 0	10	1
MLIF-750/500-62	750	500	-65 to 0	2	1
MLIF-1000/250-60	1000	250	-60 to 0	2	1
MLIF-1000/500-65	1000	500	-65 to 3	5	1.5
MLIF-1500/1000-60	1500	1000	-60 to 0	1.25	1
MLIF-1575/20-40*	1575	20	-38 to 3	N/A	1.5

* 1.25" x 1" package available for RSSI module used in GPS applications

Frequency Discriminators

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FMDM-21.4/4-5	21	4	1000	150	2
FMDM-30/6-8	30	6	1000	120	2
FMDM--60/10-15	60	10	250	75	2
FMDM-160/35-15	160	35	100	30	3
FMDM-160/50-25	160	50	20	17.5	5
FMDM-300/100-20	300	100	20	20	2.5
FMDM-1000/300-70	1000	300	10	5	5

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LCPM-30/10-70	30	10	-70 to 0	4	10
LCPM-60/20-70	60	20	-70 to 0	5	10
LCPM-60/14-65	60	14	-70 to -5	2.5	10
LCPM-160/40-65	160	40	-70 to -5	5	10
LCPM-160/40-70	160	40	-65 to 5	3	10
LCPM-300/50-55	300	50	-55 to 0	5	3
LCPM-500/100-45	500	100	-45 to 0	5	3

Variable Gain Control Linear Amplifiers

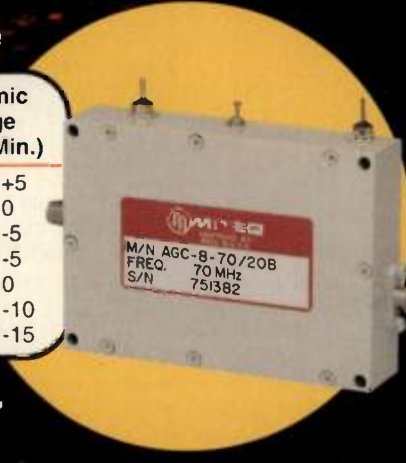
- Operating frequencies from 21 to 850 MHz
- Standard models up to 75 dB of gain control range

Model Number	Center Frequency (MHz)	Bandwidth (3 dB) (MHz, Min.)	Dynamic Range (dB, Min.)	Noise Figure (dB, Max.)	P Out @ 1dB Compr. (dBm, Min.)
VGC-7-30/10	30	10	-80 to -10	4	10
VGC-7-60/20	60	20	-85 to -10	6	10
VGC-7-70/10	70	10	-60 to -10	4	10
VGC-6-70/20	70	20	-50 to +10	5	10
VGC-7S-140/40	140	40	-75 to -10	7	10
VGC-6-160/40	160	40	-65 to -5	6	1
VGC-7-250/100	250	100	-70 to -10	6	10
VGC-4-720/100	720	100	-40 to 0	6	0
VGC-4-850/100	850	100	-40 to 0	6	0

Automatic Gain Control Linear Amplifiers

- Operating frequencies from 21 to 850 MHz
- Standard models up to 75 dB of gain control range

Model Number	Center Frequency (MHz)	Bandwidth (3 dB) (MHz, Min.)	Output Power (dBm, Min.)	Power Variation (dB, Max.)	Dynamic Range (dBm, Min.)
AGC-7P-30/15	30	15	10	2	-60 to +5
AGC-8-70/20	70	20	10	2	-75 to 0
AGC-6-70/30	70	30	3	2	-65 to -5
AGC-6-140/30	140	30	4	2	-65 to -5
AGC-4S-140/55	140	55	5	2	-40 to 0
AGC-5S-370/100	370	100	5	2	-60 to -10
AGC-5-387/175	387.5	175	3	1	-60 to -15



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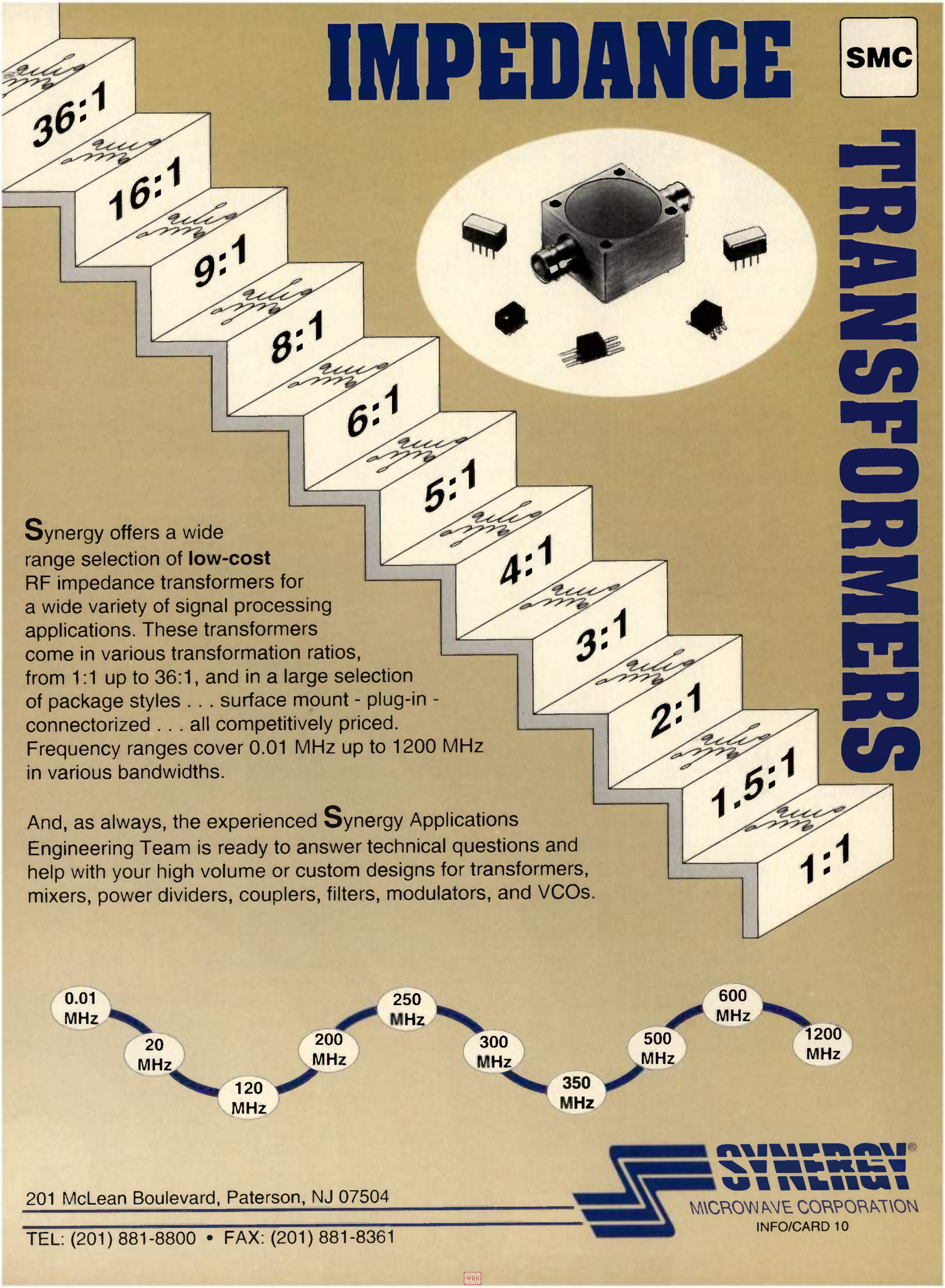
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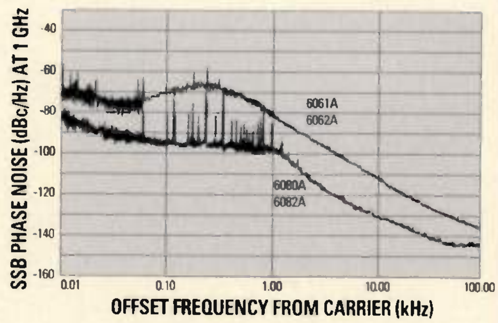

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Frequency Range Switching speed	.01 to 1050 MHz <100 ms	.1 to 2100 MHz <100 ms	.01 to 1056 MHz <100 ms	.1 to 2112 MHz <100 ms
Spectral Purity* Spurious Subharmonics	<-60 dBc None	<-54 dBc <-45 dBc	<-100 dBc None	<-94 dBc <-45 dBc
Phase Noise* @ 20 kHz offset	<-117 dBc/Hz	<-110 dBc/Hz	<-131 dBc/Hz	<-125 dBc/Hz
Residual FM* (Bandwidth)	<12 Hz (.5 to 3 kHz)	<24 Hz (.5 to 3 kHz)	<1.5 Hz (.3 to 3 kHz)	<3 Hz (.3 to 3 kHz)
Output Range* Accuracy Reverse Power Protection	+13 to -147 dBm ±1 dB >127 dBm 50 Watts/50 Vdc	+13 to -147 dBm ±1.5 dB >-127 dBm 25 Watts/25 Vdc	+17 to -140 dBm ±1 dB >127 dBm 50 Watts/50 Vdc	+13 to -140 dBm ±1 dB >-127 dBm 25 Watts/25 Vdc
Amplitude Modulation Depth Distortion @ 30%	0–99.9% <3%	0–99.9% <3%	0–99.9% <1.5%	0–99.9% <1.5%
Frequency Modulation Max. Deviation* Distortion	100 kHz <1%	400 kHz <1%	4 MHz <1% @ 50% Dev.	8 MHz <1% @ 50% Dev.
Phase Modulation Max. Deviation*	NA	40 Rad.	40/400 Rad.	80/800 Rad.
Pulse Modulation On/off Rise/fall time Minimum Pulse Width	NA	>80 dB <15 ns <2 µs	>40/60 dB <15 ns (Typ 7.5 ns) <30 ns	>80 dB <15 ns (Typ 7.5 ns) <30 ns
Internal Modulation Source Level Range Waveforms Programmable	400, 1000 Hz NA Sine Yes	400, 1000 Hz NA Sine Yes	0.1 Hz to 200 kHz 0 to 4 Vpk Sine/Sq/Tri/Pulse Yes	0.1 Hz to 200 kHz 0 to 4 Vpk Sine/Sq/Tri/Pulse Yes
Memory Locations (NVM)	50 Full Function	50 Full Function	50 Full Function	50 Full Function

*Specifications for the 6061A and 6080A are at 1 GHz, and specifications for the 6062A and 6082A are at 2 GHz. Phase noise is typical for the 6061A and 6062A.

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INFO/CARD 11

Letters should be addressed to: Editor, RF Design, *6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Letters may be edited for length and clarity.*

Broadband Impedance Matching Update

Editor:

My article "Broadband Impedance Matching – Fast and Simple" in November's *RF Design* used a frequently referenced matching problem to illustrate my three different solutions (pg. 50). Since then, I have discovered that the best of those solutions previously has been published by Dr. Steven Sussman-Fort in "The Computer-Aided Design of Microwave Matching Circuits", Intl. J. Microwave and Millimeter-Wave Computer-Aided Engineering, Vol. 1, No. 3, pp. 288-305, 1991, example 2.

Your readers may wish to know that Dr. Sussman-Fort's CiAO (Circuit and Analysis Optimization) program obtained this result using two direct-search strategies, a special objective function, and initial values from a Butterworth filter. Dr. Sussman-Fort may be reached at (516) 689-6582.

Direct-search optimizers explore matching element values in initially wide-ranging adaptive patterns which eventually reduce in size. Many of my associates over the years reported better matching results by those methods than by the more efficient and precise gradient optimizers. Indeed, I finally concluded from those reports that an exhaustive grid search (GRABIM) would provide the best chance of locating the (presumed) global solution, to be followed by a precise bounded, minimax gradient optimization.

Finally, the 2-3 minute running times for each GRABIM search on 486DX2-66 PCs were recently observed to be only one fourth as long on the fastest Pentium PC currently available, a trend that encourages more thorough exhaustive grid searches.

Thomas R. Cuthbert, Jr.
Plano, TX

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RF calendar

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15-17 **IEEE Solid-State Circuits Conference**
San Francisco, CA
Information: Electronic Industries Association, EIA Components Group, 2001 Pennsylvania, Avenue N.W., Washington, DC 20006-1813. Tel: (202) 457–4930.

22-23 **Radar/EW Conference**
McLean, VA
Information: Association of Old Crows Convention Department, The AOC Building, 1000 North Payne St., Alexandria, VA 22314-1696. Tel: (703) 549–1600.

27-1 **Second International Conference on Data Transmission**
London, UK
Information: DT 95 Secretariat, IEE Conference Services, Savoy Place, London WC2R 0BL, UK. Tel: 44–071–344 5478/5477. Fax: 44–071–497 3633.

March

8-15 **CeBIT 95 Hannover**
Hannover, Germany
Information: Mette Fisker Petersen, Project Manager, Hannover Fairs USA, Inc., 103 Carnegie Center, Princeton, NJ 08540. Tel: (609) 987–1202. Fax: (609) 987–0092.

20-24 **The 11th Annual Review of Progress in Applied Computational Electromagnetics**
Monterey, CA
Information: Ray Luebbers, Department of Electrical Engineering, Pennsylvania State University, University Park, PA 16802. Tel: (814) 865–2362. Fax: (814) 865–7065.

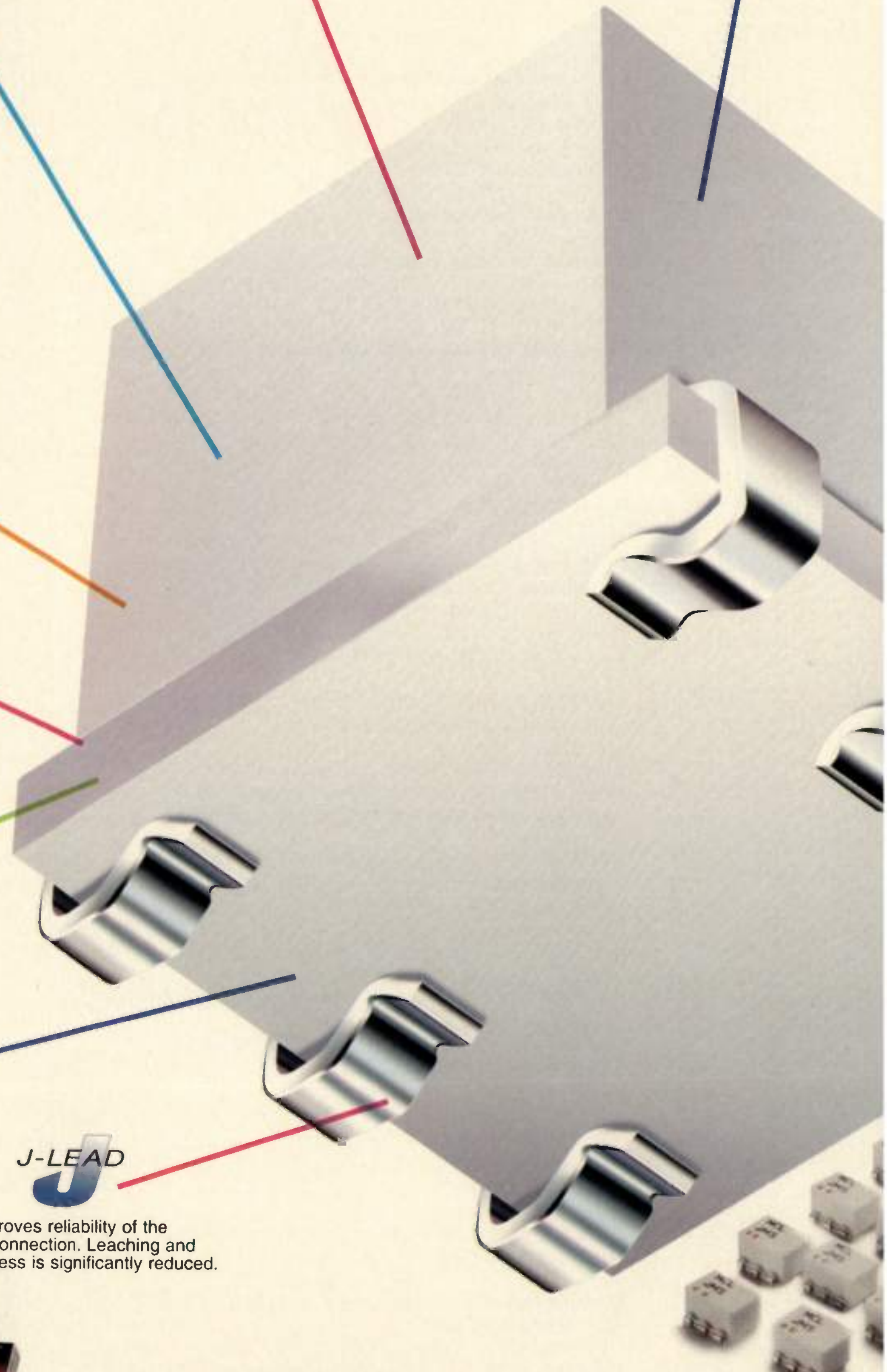
26-29 **Fifth IEE Conference on Telecommunications**
London, UK
Information: ICT 95 Secretariat, IEE Conference Services, Savoy Place, London WC2R 0BL, UK. Tel: 44–071–344 5478/5477. Fax: 44–071–497 3633.

28-29 **95 Mid-Lantic Electronics Show and Conference**
King of Prussia, PA
Information: Judith Ginsberg, Show Manager. Tel: (610) 828–2271.

April

3-8 **Hannover Fair 95**
Hannover, Germany
Information: Hannover Fairs USA, Inc. 103 Carnegie Center, Princeton, NJ 08540. Tel: (609) 987–1202. Fax: (609) 987–0092.

19-21 **Fourth International Conference & Exhibition on Multichip Modules**
Denver, CO
Information: International Symposium on Multichip Modules 95, Conference Management, ISHM- The Microelectronics Society, 1850 Centennial Park Drive, Suite 105, Reston, VA 22091. Tel: (800) 535–ISHM or (703) 758–1060. Fax: (703) 758–1066.



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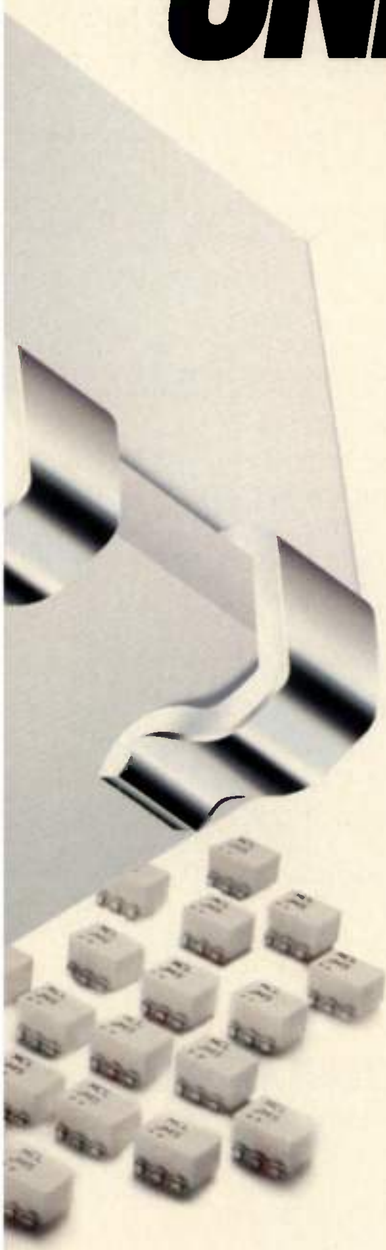

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JMS-2L	+3	800-1000	DC-200	7.0	24	20	7.45
JMS-2	+7	20-1000	DC-1000	7.0	50	47	7.45
JMS-2LH	+10	20-1000	DC-1000	6.5	48	35	9.45
JMS-2MH	+13	20-1000	DC-1000	7.0	50	47	10.45
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RF courses

Analog and Digital Cellular Networks: CDMA versus TDMA
March 6-8, 1995, Washington, DC
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March 13-16, 1995, Washington, DC
Information: The George Washington University, Continuing Engineering Education, Academic Center, Room T-308, 801 22nd Street, N.W., Washington, DC 20052.
Tel: (202) 994–6106 or (800) 424–9773. Fax: (202) 872–0645.

RF Component Modeling
February 20-24, 1995, Middletown, NJ
Applied RF Techniques, I/B,
February 22-24, 1995, Middletown, NJ
RF/MW Circuit Design I
March 6-10, 1995 Switzerland
RF/MW Circuit Design II
March 13-17, 1995 Switzerland
Information: Besser Associates, 4600 El Camino Real, Suite 210, Los Altos, CA 94022. Tel: (415) 949–3300.
Fax: (415) 949–4400.

High-Resolution Microwave Imaging: Principles and Applications
February 21-24, 1995, Los Angeles, CA
Information: UCLA Extension, Engineering Short Courses, 10995 LeConte Ave., Ste. 542, Los Angeles, CA 90024.
Tel: (310) 825–1047. Fax: (310) 206–2815.

DSP Without Tears
February 20-22, 1995, Ft. Lauderdale, FL
April 5-7, 1995, San Jose, CA
Information: Z Domain Technologies, Inc., 325 Pine Isle Court, Alpharetta, GA 30202. Tel: (800) 967–5034, (404) 587–4812. Fax: (404) 518–8368.

High-Speed Communication Networking
February 20-24, 1995, Tempe, AZ
Information: Arizona State University, Center for Professional Development Box 877506, Tempe, AZ 85287–7506. Tel: (602) 965–1740. Fax: (602) 965–8653.

Inherently Conductive Polymers: An Emerging Technology
February 15-17, 1995, Boston, MA
Information: Dr. M. Aldissi, Advanced Polymer Courses, P.O. Box 463, Winooksi, VT 05404-0463. Tel: (617) 479–5587.

Wireless and Mobile Networks: From Theory to Practical Implementation
February 23-24, 1995, Chicago, IL
February 27-28, 1995, Baltimore, MD
Information: Lori Milhaven, Project Leader, International Institute for Learning, 110 East 59th St., Sixth Floor, New York, NY 10022-1380. Tel: (800) 325–1533 or (212) 758–0103. Fax: (212) 909–0558.

Virginia Tech on the "Smart Road" to IVHS

The Mobile and Portable Radio Research Group (MPRG) and Virginia Tech's Center for Transportation Research (CTR) are developing the communications architecture for the Virginia Tech Smart Road, a six-mile section of highway designed and built from the ground up to incorporate intelligent vehicle highway system (IVHS) technology.

Construction on the Smart Road, which will connect Blacksburg with I-81 south of Roanoke, VA will begin in 1996, with the first phase tentatively scheduled for completion in 1997. The project is expected to last four and a half years.

The goal of the Smart Road is to provide a national test bed for infrastructure-based IVHS technologies, and to give both vendors and end users an opportunity to communicate needs and solve technological problems that does not currently exist. Now, vendors testing IVHS technology are repeating their efforts, since vendors must comply with the test requirements for each individual state. "In Virginia alone, I know of at least three cases where there's been repeated testing." says Robert James, of the Center for Transportation Research. "We will help vendors develop their products, and offer a service to end users, to help marry those two sets of needs."

The Road will be used to test vehicle-to-vehicle, vehicle-to-roadside, and roadside to traffic management center communication. Testing of IVHS sensors, automated commercial vehicle weigh stations, traffic management models, and automated highway system concepts will be possible, in addition to the testing of advanced IVHS communications systems.

The Smart Road is a beacon-based approach. Information passes between a command center and vehicles via beacons along the highway. Roadside-to-vehicle and vehicle-to-vehicle communications must be wireless, while roadside-to-command center communications will utilize fiber optics, cellular, and cable technologies.

Vendors will be able to have their technologies tested and evaluated based on a common set of standards developed by MPRG and the CTR. Technologies will be evaluated on the basis of their price, compatibility and upgradability, with emphasis on helping vendors meet their end user's needs.

The Smart Road represents an excellent opportunity for vendors to shorten the time-to-market of their IVHS technologies. For more information on the Smart Road, contact Dr. Jeff Reed at the MPRG, (703) 231–2972, or Robert James at the Center for Transportation Research, (703) 231–7740.

The International Academy of Broadcasting Opens

The International Academy of Broadcasting opened September 23 in Montreux, Switzerland. The IAB is an independent institution of higher education offering post-graduate studies in broadcasting. The IAB teaches its students how to manage a broadcasting organization, foster its survival, its evolution, and its expansion. Students are taught by experts in broadcasting and the academic world, who share their experience and their vision of the broadcast media. Two years of studies are concentrated into one single academic year. Information of the International Academy of Broadcasting may be obtained from The International Academy of Broadcasting, 11, avenue de Florimont, CH-1820 Montreux (Switzerland), tel: +41 21 961 16 60, telefax: +41 21 961 16 65.

New NIST Optoelectronics Division

The Optoelectronics Division of the Electronics and Engineering Laboratory will provide its industry customers with comprehensive and technically advanced measurement capabilities, primary standard, and traceability to those standards. Four groups make up the Optoelectronics Division: Sources and Detectors, Fiber and Integrated Optics, Optical Components, and Optoelectronic Manufacturing. For more information, contact Div. 815, NIST, Boulder, CO 80303-3328, tel: (303) 497–5342, fax: (303) 497–3387.

Call for Articles

The Applied Computational Electromagnetics Society announces a special issue of the ACES Journal on Applied Mathematics, meeting the challenges presented by computational electromagnetics. The deadline for papers is June 30, 1995. Suggested topics are integral equation and integro-differential equations, Eigenfunction expansions, selfadjoint and non-selfadjoint operator approximation, singularity expansion method, diffraction and asymptotics, variational principles, finite element methods, the radiation boundary problem, solution of large scale linear systems, Eigenvalue estimation, optimization, conjugate and biconjugate gradient methods, GMRES, and numerical evaluation of integrals with oscillatory or singular integrands. Mail one hard copy to each Guest Editor: Eugene Tomer, Applied Mathematics and Computing, 150 Hernandez Avenue, San Francisco, CA 94127, tel (415) 665–9555, Fax: (415) 731–3551, E-mail: etomer@netcom.com; and Andrew F. Peterson, School of Electrical Engineering, Georgia Institute of Technology, Atlanta, GA 30332, tel: (404) 853–9831, fax: (404) 853–9171, E-mail: ap16@prism.gatech.edu.

Call For Papers

The Technical Program Committee of Surface Mount International 95 is seeking papers for presentation at its fifth annual conference to take place August 27-31, 1995. The committee invites papers that present new developments in microelectronics packaging, manufacturing processes, soldering technology, manufacturing test, ball grid array, and PCMCIA cards. Abstracts are due by February 15, 1995. For information on presenting a paper at Surface Mount International, contact Martin Barton at (214) 424–8805.

New Areas in NIST Advanced Technology Program

NIST announced six new areas of technology for which companies and consortia can propose projects to receive nearly $800 million in support under the Advanced Technology Program. The new programs include digital video information networks, a five year $120 million program to help develop interoperable digital video capabilities for emerging information networks through techniques for encoding, converting, and transcribing video data. The program will help firms use the information network to allow any video-based information product to travel via wire, optical fiber, satellite, or broadcast seamlessly into TVs and information appliances.

Business Briefs

Bell Atlantic Delivers Real-Time Two-Way Interactive Video Over Existing Phone Lines – Bell Atlantic achieved a technology milestone with the delivery of interactive real-time, high-quality, full-motion encoded video over existing telephone lines at a distance of over 450 miles. The interactive video used off-the-shelf routing equipment, and commercially available hardware and software. Previously, interactive video had only been sent using higher bandwidth facilities.

Motorola Creates New Mobile Software Organization – Motorola's Wireless Data Group (WDG) introduced Mobile Software Products, an organization within WDG that delivers advanced software development tools, mobile communications servers, and applications for wireless communications. The products will be distributed as AirMobile products, and will be based on a common architecture that allows them to work on all major wireless wide-area data networks.

Oak Industries Expands McCoy Joint Venture – Oak Industries, Inc. and the SURAL Group announced that they have expanded their McCoy International joint venture, which manufactures quartz crystal blanks used in pagers and cellular phones. Oak will invest additional capital to increase production capacity and will receive a 50 percent equity position in the operation.

Cadence Introduces Silicon Synthesis – Cadence Design Systems, Inc. unveiled the details of Silicon Synthesis™, the industry's first technology to merge placement and logic optimization algorithms into a single-step process for logic designers. The system eliminates iterations typically incurred using methodologies based on estimation for deep submicron design.

Tektronix Announces Comprehensive PCS Measurement Solution – Tektronix now has available a broad range of measurement solutions critical to rapid development and deployment of personal communication services (PCS) in the US and Canada. PCS mobile phone and base station manufacturers can design and verify compliance with the upbanded global system for mobile communications (GSM) standard, which extends GSM to the 1800-2000 MHz band being auctioned by the FCC.

Siemens to Underwrite IEEE Award for Engineering Excellence – Beginning in 1995, Siemens will underwrite the Institute of Electrical and Electronics Engineers (IEEE) medal for Engineering Excellence over the next 10 years. Total funding for the award is expected to reach $180,000. The award may be conferred by the Institute's Board of Directors each year, and consists of a gold medal, bronze replica, certificate, and $10,000; funding is administered by the IEEE Foundation.

R & D Circuits Goes On-line with BBS – R & D Circuits has gone on-line with its own electronic bulletin board. The bulletin board will make it easier for R & D Circuits customers to order prototype printed circuit boards. The bulletin board runs 24 hours a day by modem or via an Internet E-mail link. The modem telephone number is (908) 549-7332.

Proxim and LXE Form Wireless Alliance – Proxim, Inc, and LXE, Inc. have entered into a strategic alliance. The two companies will work together on a variety of joint product efforts as well as initiating a broader alliance to achieve interoperability among 2.4 GHz frequency hopping LAN systems.

Motorola Sets Sail as Official Supplier to America³ – Motorola has signed on as an official supplier to America³, the first all female sailing team to compete in the 143-year history of the America's cup, sailing's most coveted prize. Motorola will provide America³ with cellular and radio communications equipment for transmitting real-time information from the race yachts to the team's headquarters and support vessels during the actual races.

Contracts

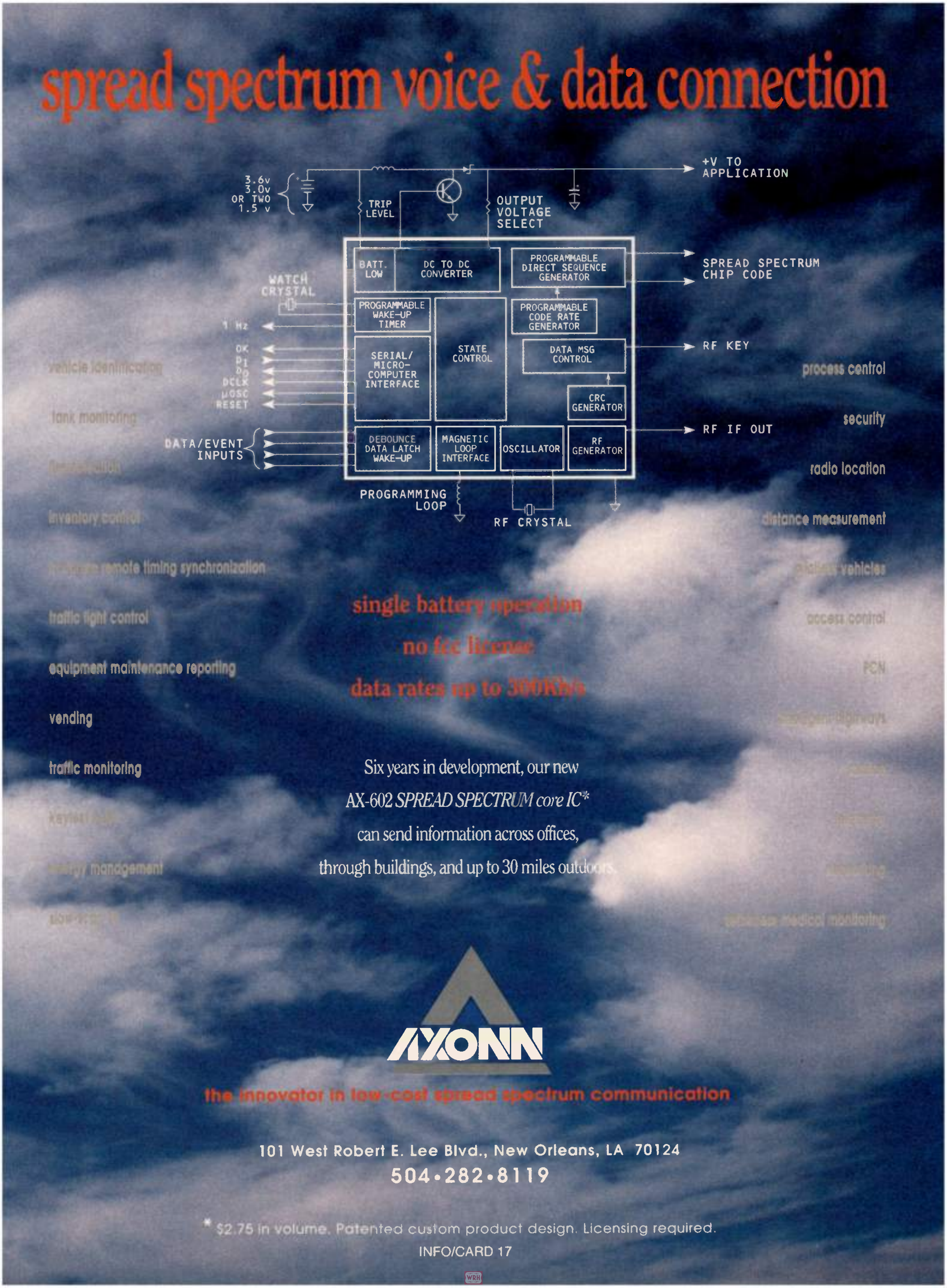
Andrew to Build Digital System for Hong Kong Mass Transit – Andrew Corporation has been awarded a contract in excess of $45 million by the Mass Transit Railway Corporation of Hong Kong to design and build an underground cellular and paging system extension for the Hong Kong Metro. Work will be completed by 1997.

Telecom Analysis Systems and Motorola Join Forces – Telecom Analysis Systems has signed an agreement with Motorola to incorporate Motorola's R-2600 communications systems analyzer with TAS Equipment and software for wireless communications test applications. TAS and Motorola are also exploring engineering enhancements to address additional wireless testing applications.

MFS Network Technologies to Supply AVI Subsystem – MFS Network Technologies, Inc. has been selected by Lockheed Information Management Services Company, Inc. to supply Automatic Vehicle Identification (AVI) technology for electronic toll collection in Orange County, CA. The agreement is worth $7 million.

Harris Wins UK Radio Order – Harris Corporation has won a $1.5 million order to supply the United Kingdom's newest independent national radio network with advanced broadcast transmitters and other equipment. Harris' Broadcast Division will provide Talk Radio UK with transmitters featuring advanced digital modulation technology that improves AM broadcast quality and efficiency.

Advance Circuits Licenses Form-Factor Technology – Advance Circuits has signed a licensing agreement for FormFactor's proprietary technologies for interconnecting semiconductors and laminate packages to printed circuit boards. The agreement grants Advance Circuits rights to manufacture laminate-based semiconductor packages using these processes.



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Radio Engineering Education

By Andy Kellett
Technical Editor

Companies are combing universities and their competitor's ranks to find RF engineers. At the same time, few EE department cover RF at the undergraduate level, and many graduate programs face reduced funding. For industry, trying to find RF design engineers, and for students, looking for RF design instruction, it is catch as catch can.

Graduate Education

Graduate programs have traditionally been the place where RF engineers get the bulk of their formal training. Funding for research is spotty – in some fields researchers see very little money flowing towards them, while people in other fields have to turn research projects away.

Dr. Ted Rappaport of the Mobile Portable Radio Research Group at Virginia Polytechnic Institute has been "deluged with requests" to do research in RF propagation. Meanwhile another professor states that, "funding has gone down the tubes."

Much of the decline in university research funding has been the result of Department of Defense cutbacks. "By and large we are going towards more funding from industry," says Dr. Majid Belkerdid, Associate Professor of Electrical Engineering at the University of Central Florida (UCF). However, Belkerdid says that industry funding is at low levels and the requirements are high.

At the Georgia Institute of Technology (Georgia Tech), David Hertling, Professor of Electrical and Computer Engineering, says that the number of grad students studying RF topics is increasing, even though funding has decreased. Hertling says the presence of university-linked labs like the Georgia Tech Research Institute and Lincoln Labs at MIT help. At these facilities, industry can find research partnerships suited to industry needs, and graduate students can get experience.

Undergraduate Education

The number of EE undergraduate programs offering series of classes covering RF design has never been large, and that is still a fact today. Until late in their undergraduate careers, most EE students are busy studying the basics of electricity and are blissfully unaware of RF engineering as a sub-field. However, there are more reasons for the lack of RF engineering programs at the undergraduate level.

Part of the reason, according to UCF's Belkerdid, is the cost of equipment. "To get a network analyzer, you are talking 50K, so very few schools have that equipment," says Belkerdid. Another reason could be the student's apprehension about studying a field where laws held near and dear to their heart no longer apply. "In RF there is no ground, and Ohm's law doesn't work any more," says Belkerdid explaining what might scare some students away from RF.

Nevertheless, there are certain schools where undergraduates can take RF engineering courses. Georgia Tech is probably the best known school for RF education at the undergraduate level, but Georgia Tech's Hertling points out that one- and two-course RF design "programs" can be found in universities across the country. "All it takes is one good person who teaches a good course at any school," says Hertling. "At the University of Illinois there was a professor Albright who got me and a number of other people started," says Hertling.

Education and Employment

The people who hire RF engineers help shape the RF educational system. When asked where her company got RF engineers, Rebecca Shaw, Manager of Recruiting for Harris RF Communications said, "Wherever we can."

Companies do recruit at various universities. Often individual students are targeted for recruitment, says Tony Coleman, Personnel Manager for the Communication Components Division at Hewlett-Packard. "We set up fairly good relationships with the instructors of the schools where we recruit, and the faculty ends up recommending people to us."

Belkerdid says companies are willing to hire someone with problem solving abilities and train then on RF and microwaves later. "They can send them to short courses, like [the courses offered] at RF Expos, or a lot of people will send them to a course by someone like Les Besser," says Belkerdid. "You always set aside six months to a year for the learning curve, even if they are experienced," says Harris' Shaw.

Students are increasingly aware of the demand for RF engineers, and more are looking for RF programs, particularly at the graduate level. "Students right now are very practical," says Dr. Jeff Reed, Assistant Professor and Associate Director of the Mobile Portable Radio Research Group at Virginia Tech, "They are very concerned about getting a job."

Companies seeking RF engineers and students interested in learning about RF have to do the same thing to find what they want – look around. However, if more schools help students find what they want, industry will get get more of what they want. *RF*

A Low Cost CDMA Transmitter Using the AX602 ASIC, Microcontroller and Minimal RF Circuitry

By David J. Beal and Gerard J. Hill
Axonn Corporation

As competition increases in the wireless markets, engineers are increasingly attempting to find low cost, FCC Part 15.247 compliant transmitter designs for high volume consumer applications including fire and security, remote monitoring, and point of sale. The following describes the control and RF elements of such a design (shown in Figure 1) which is comprised of three primary elements: the AX602 spread spectrum core ASIC, a microcontroller, and associated RF circuitry.

The AX602 custom IC is a mixed analog/digital full custom design optimized for low-cost small-size full-performance direct sequence spread spectrum systems; it provides the core functionality of such system. A block diagram of this ASIC and required external components is shown in Figure 2.

Since the ASIC performs all of the processing functions required to implement chipping, data modulation, cyclic redundancy check (CRC) calculation and up-converted voltage output control, as well as providing a divided external clock signal, the microcontroller may be one of many available low-cost slow-speed devices depending on the product application.

The RF circuitry consists of up-conversion, modulation, amplification and filtering stages as required to generate the desired signal from the RF square wave output of the AX602. Figure 3 illustrates one possible RF configuration utilizing the AX602 square wave output.

The schematic shown in Figure 4 is an implementation of the block diagram shown in Figure 3. Transmitters at a parts cost of approximately \$6.00 are currently finding high volume commercial applications; these designs incorporate a proprietary BPSK modulator, which replaces the level shifter and mixer shown below, at a cost of approximately \$0.50. This modulator design has been made available to a number of licensees.

The circuit essentially performs a multiplication and modulation transfer function on the AX602 RF output. The 14.X MHz clock output provided by the AX602 on pin 22 is bandpass filtered to select the seventh harmonic (≈ 100 MHz) which is input to a multiplier and filtered to yield ≈ 300 MHz. This signal is input to the LO port of a mixer; BPSK modulation is applied by passing a pseudo-random, 20 mA signal into the IF port of the mixer. From the mixer's RF output port, the 300 MHz spread signal is multiplied to ≈ 915 MHz, amplified, and again filtered to meet FCC emissions requirements. Other output frequencies (e.g. 2.4 GHz) may be produced by other combi-

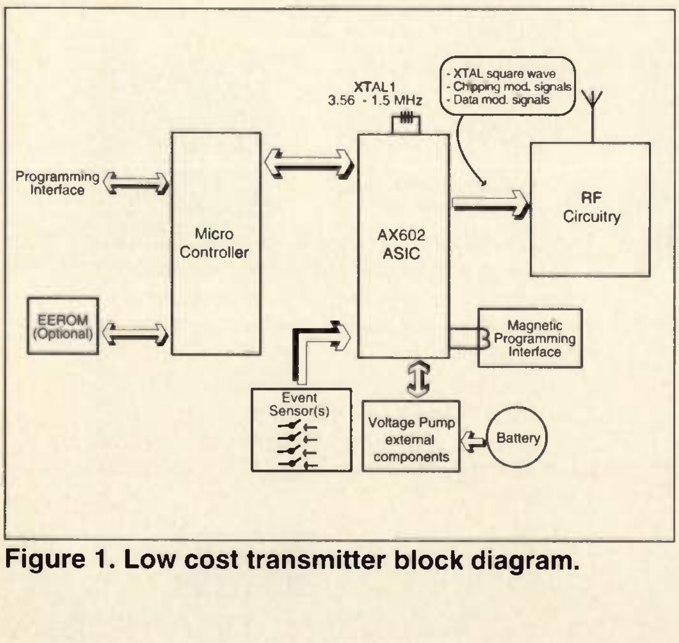

Figure 1. Low cost transmitter block diagram.

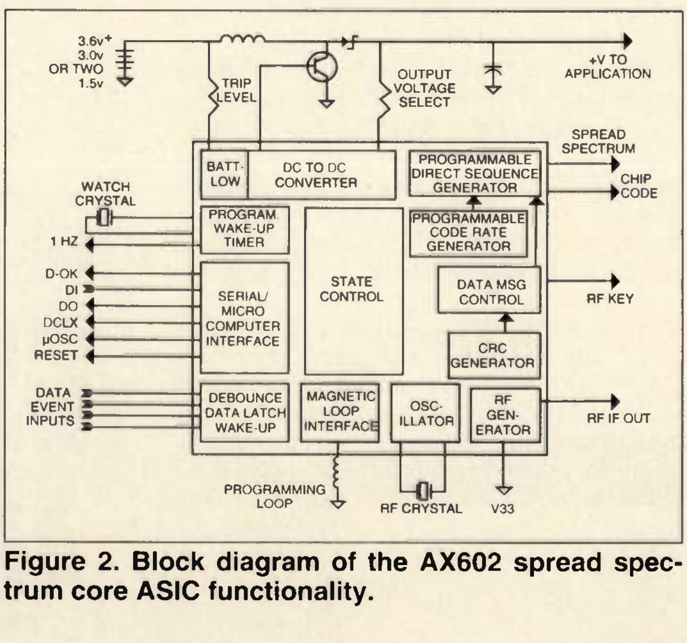

Figure 2. Block diagram of the AX602 spread spectrum core ASIC functionality.

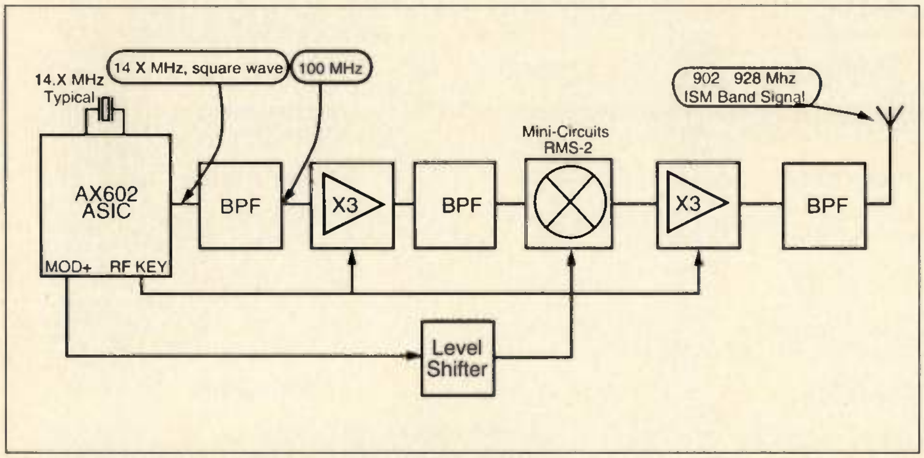

Figure 3. Low cost RF circuit configuration.

nations of base clock frequency and odd multiplication values.

The AX602 allows the transmitter to modulate data by either a modulo-2 addition of data bits to the pseudo-random sequence generated by the AX602 and applying the combined output to the BPSK modulator; or by applying only the pseudo-random sequence to the BPSK modulator and modulating data by on/off keying (OOK) of subsequent amplifier stages. The ASIC provides complementary Mod+ and Mod- outputs to control the BPSK modulator, an RF key output for OOK control of amplifier stages, and an RF enable signal for overall RF circuitry enable.

Transmitter Modes of Operation

A typical transmitter will operate in four modes: programming, sleep, active, and transmit. The following paragraphs describe each of these modes as they apply to an event detector transmitter with a design based on the block diagram in Figure 1.

After initial AX602 and microcontroller reset, the microcontroller programs all operational parameters including transmit data rate, data modulation type, CRC enable, voltage pump operational characteristics, and event input enable. Only the individual transmitter specific parameters remain to be programmed into microcontroller RAM or optional external EEROM.

Programming Mode

Following manufacturing and test, but prior to installation at the end-user location, the transmitter must be programmed with transmitter-specific parameters which generally include transmitter family ID, transmitter individual ID, transmitter type, chipping sequence selection, supervisory transmission period, and alarm parameters (burst interval and number of transmissions in each burst).

The AX602 may be programmed through either a direct serial input connection or through the magnetic programming interface. The ASIC contains circuitry that wakes-up the microcontroller when a programming device has been directly connected, or detected through the magnetic programming interface. Once activated, the microcontroller controls the transfer of data (transparently through the AX602) from the programming device at a data rate up to 9.6 kBaud. Following programming and on every subsequent wake-up, the microcontroller reads the stored transmitter specific datafrom on-board RAM or, in the event of power failure, external EEROM.

The direct serial connection provides a two way communications path between the programming device (e.g. an IBM PC) and the transmitter. Typically implemented as a three-pin connector, this path allows access to both command and status registers and is often used by programming software to display battery status and CRC byte information.

The ASIC's magnetic programming interface supports one-way communication and allows field service personnel to enter parametric and local data via an electrically and physically isolated magnetic loop. This facilitates tamper- and moisture-proof housings by eliminating openings needed to access a programming connector. This interface provides both gain and data detection and yields logic level data output to the microcontroller. The interface is transparent, allowing any data format to be used with data modulation by OOK at any data rate up to 9.6 kBaud.

The sensitivity of the AX602 to the magnetic input has been intentionally set to a low level to prevent accidental wake-ups due to stray magnetic fields or nearby, high-power transmitters. The system can also differentiate between a real programming signal and noise on the pick-up loop to avoid the possibility of being misprogrammed by an EMI source. The operational distance from the magnetic programming device is a function of the strength of its magnetic field; for small +9V cell operated programmers, this equates to several inches.

The magnetic programming interface draws less than 1 μA when not active and can be completely disabled by the microcontroller after initial programming is complete.

Sleep Mode

In a typical transmitter application, sleep mode is invoked between transmissions in order to reduce average current consumption and extend battery life. During the active cycle immediately prior to the sleep mode, the microprocessor programs a wake-up timer value into the AX602 which decrements when the device is asleep. When the counter reaches zero, it initiates an internal wake-up which then initiates a microcontroller wake-up and reset.

Sleep mode is managed by a low power, programmable clock divider and on-chip oscillator utilizing an external 32 kHz miniature watch crystal. Wake-up intervals may be programmed from 50 ms to 15 minutes. The current consumption of the wake-up oscillator and its associated divider chain is less than 3 μA at 2.7 volts.

While the chip is in its low-power sleep mode a 1 Hz, 50 percent duty cycle output is provided for use as an external real time reference or as a trigger for an external data sample.

The sleep mode is normally exited through any one of three events: the programming input senses an incoming message (if enabled); the programmable wake-up timer reaches zero; or any of the four external event inputs (as enabled) transition from high-to-low, or low-to-high (as programmed).

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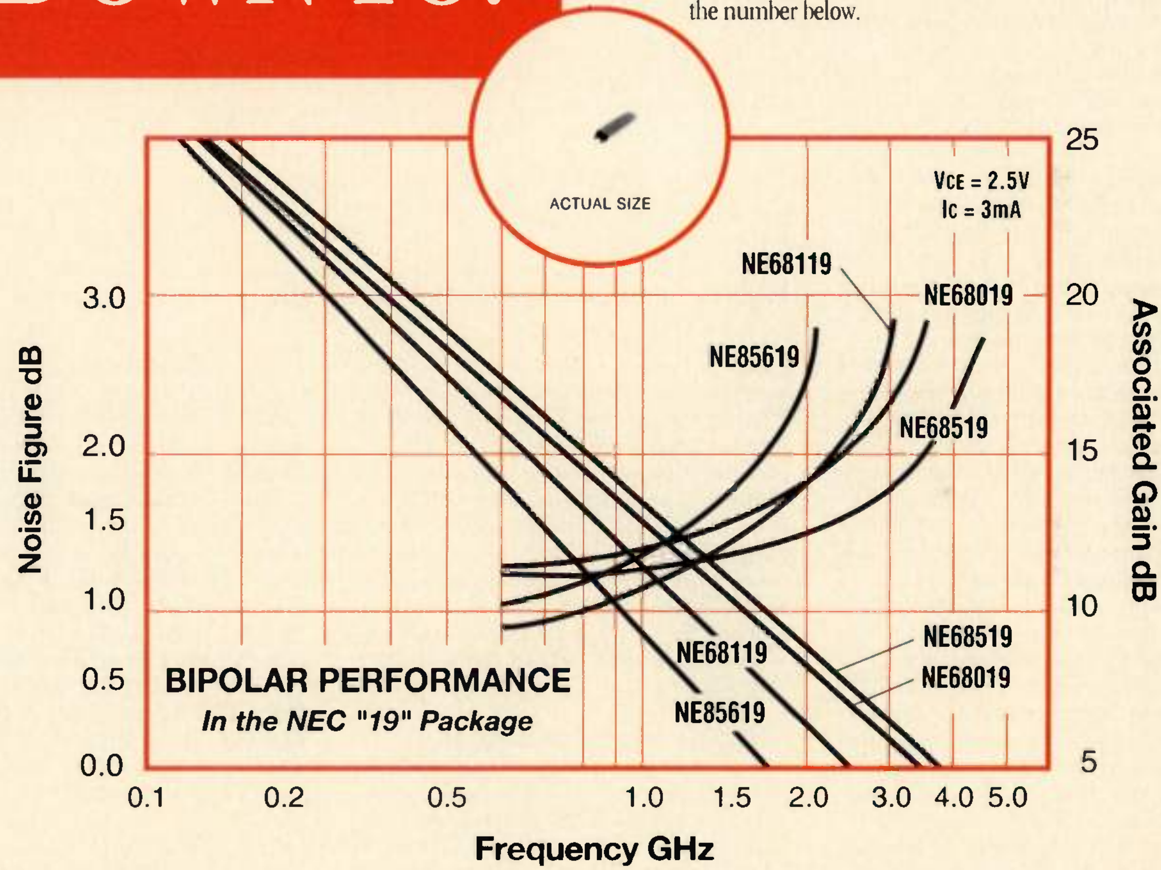

NEC Bipolars are available in these packages (shown approx. 2X size)

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INFO/CARD 20

Wake-up States (Active and Transmit Modes)

Once sleep mode is exited, the state control generator enables the DC to DC converter which pumps the output voltage up to the desired level. Next, the state control generator enables the RF oscillator; once this oscillator has stabilized, the AX602 generates an external reset pulse which is used to wake-up the microcontroller (and any other attached device). After the microcontroller is reset, the transmitter enters active mode at which time the microcontroller polls the AX602 status registers to determine what prompted the wake-up and to determine what action is required according to programming.

During all wake-up modes, the microcontroller directs transmitter operation through the AX602 interface with polls for information from status (read) registers, and with operations and configuration commands sent to any of the command (write) registers.

If the transmitter is activated because the AX602 programming input senses an incoming message, it will go into programming mode.

If the transmitter is active because the programmable wake-up timer has reached its terminal count, it broadcasts a periodic general status (supervisory) message to assure the system (receiver) that the transmitter is functional. This message generally includes family and individual ID, general status information, and may include a transmission sequence number which helps the host system to determine if a transmission has been missed. The supervisory message is important to ensure that the transmitter is functional and would broadcast an alarm burst transmission if an event occurs, and to monitor the status of the battery via a battery low detection circuit.

If the transmitter is active because an event detector has closed, it will broadcast an alarm burst consisting of the programmed number of transmissions at the specified time interval. The alarm burst generally includes family and individual ID, alarm state information, and general status information, and may also include a transmission sequence number.

During transmit mode, the microcontroller will set the control parameters and enable the RF output block. The AX602 synchronizes the data supplied by the microcontroller with the desired chipping sequence; simultaneously, a 16 bit CRC is generated for error detection/error correction. This CRC is appended to the input data stream for broadcast as part of the on-air data packet. These signals (data, chipping modulation, and CRC) are then output for routing to an external RF modulator.

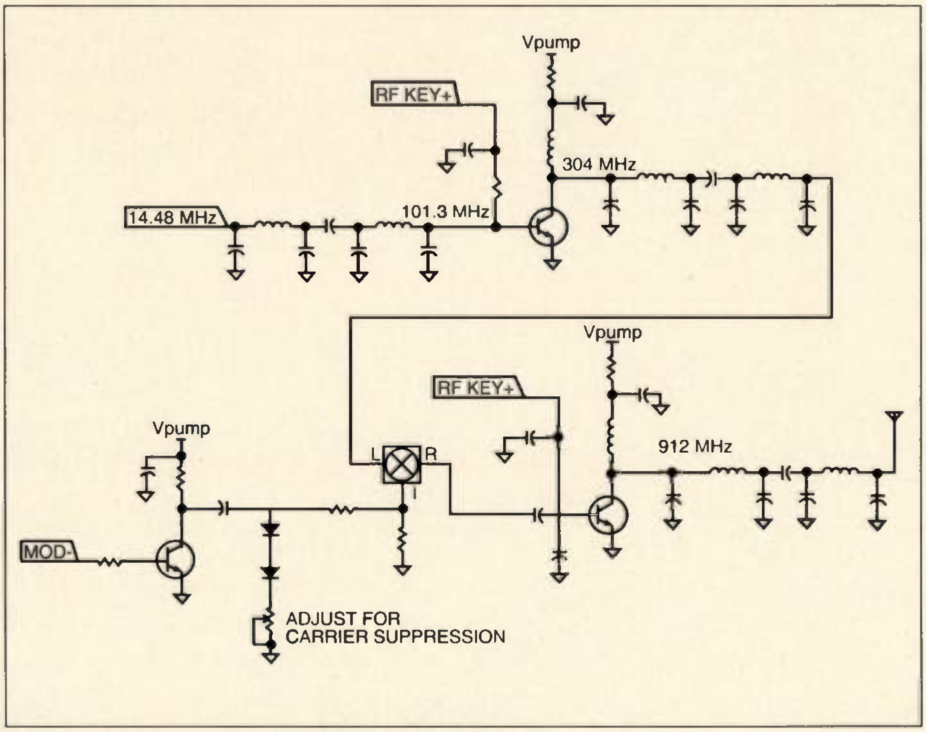


Figure 4. Low cost transmitter schematic.

Once the transmission is complete, the microcontroller typically re-programs the wake-up timer and re-enters the sleep mode to conserve battery life.

Direct Sequence Generator

Full implementation of code division multiple access "multi-channel" operation is supported by the transmitter. The ASIC generates direct sequence linear maximal length sequence chip codes (LMLS) using an eight position linear recursive shift register with programmable feedback taps and initial states supporting programmable code lengths up to 255 chips.

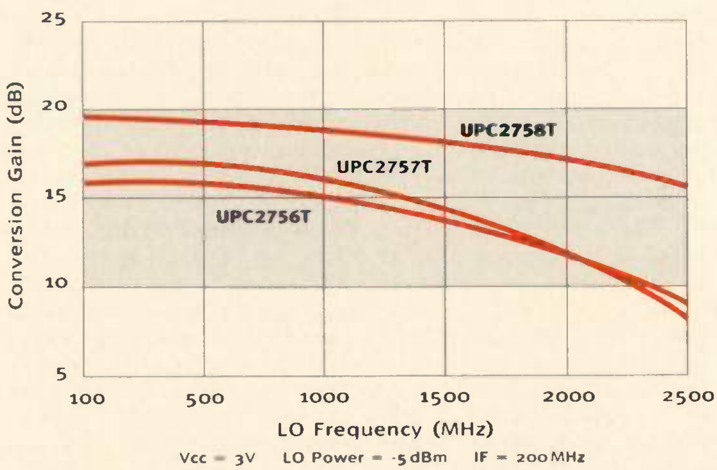
The clock for the direct sequence block is programmable from 1/3 to 1/32 of the high frequency RF oscillator, resulting in a selectable code rate of up to 5 megachips per second. Incoming data bits from the microcontroller are synchronized to a fixed position in the chip code sequence.

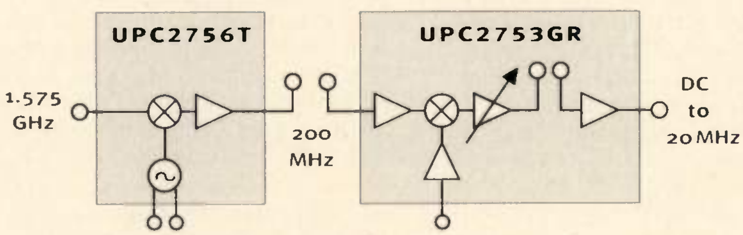
Two types of data modulation are supported by the AX602: on-off keying (OOK) and binary phase shift keying (BPSK). Each of these two methods supports data rates from approximately 1 kb/s to 320 kb/s.

For OOK data modulation, RF energy is transmitted during periods when the data bit being sent is a "1", and shut off when the data is a "0". The AX602 IC performs this function by enabling the RF KEY signal during "1" bit times, and disabling the RF KEY signal during "0" bit times. The CHIP CODE lines actively generate the programmed chipping code during "1" bit times, and are set to the key rest state during "0" bit times.

For BPSK data modulation, RF energy is transmitted continuously from the beginning to the end of a complete message transmission by enabling the RF KEY signal at the beginning of a transmission until the transmission is complete. The AX602 performs BPSK modulation by exclusive-oring the chipping code sequence with the data bits and outputting the result on the CHIP CODE lines. The CHIP CODE signal lines generate the BPSK stream continuously until a transmission is complete, at which time they return to the programmed key rest state.

New 3 Volt Downconverters: From RF to IF for 99¢





TYPICAL SPECIFICATIONS

PART	OPERATING VOLTAGE	Icc	CONVERSION GAIN	OUTPUT IP3
UPC2758T[1]	3V	11mA	17dB	+5dBm
UPC2757T[1]	3V	5.6mA	13dB	0dBm
UPC2756T[2]	3V	5.9mA	14dB	0dBm

1. Measured at 2.0GHz 2. Measured at 1.6GHz

NEC miniature downconverters are the latest addition to CEL's growing family of 3 Volt RF ICs.

Need low distortion? Our new *UPC2758T* delivers +5dBm output IP3. Low current application? Choose the *UPC2757T*. It provides 13dB of conversion gain from only 5.6mA. Both feature a mixer, LO and IF buffer amplifier, and a *Power Down* function to prolong battery life.

Another low current device, the *UPC2756T*, helps simplify your designs by combining mixer, IF amplifier and oscillator — all on a single chip.

All three feature 3dB RF bandwidth to 2.0GHz, with 3dB IF bandwidth of 10 to 300MHz.

Housed in miniature packages no bigger than a SOT-143, these devices are available now on tape and reel and priced in quantity from only 99¢.

Best of all, they can be combined with CEL's other MMICs and discretes to provide complete GPS, PCN or 2.4GHz wireless LAN solutions.

Need a higher level of integration? The 3 Volt *UPC2753GR* IF downconverter combines an RF input amplifier, Gilbert cell mixer, LO input buffer, IF amplifier with AGC, external filter port, and IF output limiting amplifier — all in a miniature 20 pin SSOP package. This device features DC to 400MHz RF response, DC to 20MHz IF response, and typical overall conversion gain of 79dB.

For data sheets and a Silicon MMIC Product Selection Guide, call your nearest CEL Sales Office, or circle the number below.

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RF Oscillator

The RF oscillator is the source for the external RF output, chip code generator, microcontroller clock divider, and voltage pump clock source. This oscillator is designed to minimize drift over temperature and voltage variations and uses an external parallel resonant, fundamental mode crystal which can range in frequency from 3.58 MHz to 15 MHz.

The AX602 external RF output provides a clean square wave from which the desired odd harmonic may be selected using a bandpass filter for later modulation and upconversion to the desired RF output frequency.

The RF oscillator is disabled during the sleep mode.

Microcontroller Clock

The microcontroller clock signal is generated by the AX602 as a sub-multiple of the RF oscillator crystal frequency. The divider can be programmed to divide by 1, 2, 4, or 8, but upon first power-up or reset is initially set to 8 to allow slower external devices to function; after initial reset the microcontroller can command the AX602 into a lower divide ratio to accelerate operations as required.

DC to DC Converter (Voltage Pump)

The AX602 includes on-board DC to DC converter control circuitry. This voltage pump is used to provide external components such as the microprocessor, RF circuitry, and sensors with regulated voltage. The V-pump offers the designer flexibility with respect to battery selection by allowing any input voltage from 2.0 to 5.5 VDC.

The V-pump configuration requires five principal external parts: one resistor; one NPN switching transistor; an axial lead iron core inductor; a Schottky diode; and a low ESR capacitor. Depending on the ambient temperature, battery chemistry, value and type of external components selected, a regulated voltage can be provided from 3.7 V to 5.5 V to a load ranging from 40 mA to 150 mA.

The DC-DC converter is a pulse width modulation based design utilizing a digital control loop for voltage regulation. The switching frequency is internally synchronized with the transmit data rate in order to minimize potentially harmful harmonically related byproducts. On-time duty cycles greater than 70 percent are prevented in order to avoid latch-up under low input voltage and high output current conditions. Typical efficiencies range from 65 percent to 91 percent depending on input and output voltage, output load, and the type of external components utilized.

Optimizations for Battery Operation

The AX602 incorporates optimizations for battery operation including a proprietary programming scheme which is used to optimize V-pump operations during transmission.

Battery-low detection is especially critical in applications involving security or fire detection and monitoring. The battery-low detection circuitry informs the system device (receiver and associated processor or control panel) when the transmitter's battery should be replaced. The battery-low detection circuit samples the battery voltage 2 ms after the start of each transmission (since the transmitter's maximum current drain typically occurs during data transmission) and indicates a low battery on the following transmission if the sampled voltage is below 2.0 VDC, or optionally at any higher value as set by an external resistor.

Data/Event Inputs

Data/event inputs are used to interface the transmitter to the sensing device (e.g. door SPST switch, smoke detector, door bell, motion detectors, photoelectric switches, tamper switch, etc.). An active data/event alarm input line, which is not locked out, will cause the AX602 IC to wake from sleep mode and start the microcontroller.

Four data/event inputs are available on the AX602N28 (28 pin SOIC), and two inputs are available on the AX602N20 (20 pin SOIC). These inputs are low leakage CMOS, independently Schmidt triggered, and static protected. Each input is readable and configurable through the microcontroller interface and can be individually programmed to initiate a wake-up sequence upon detection of either a low or a high input level, or can be completely disabled (lock-out).

The data event lockout feature allows the user to block alarm states on any of the four data/event alarm input lines. If the lockout is enabled for a given alarm input, then an active state on the alarm line will be blocked from causing a wake-up.

Watchdog Timer

The watchdog timer will reset both the AX602 and the external microcontroller in the case of system failure, and is applied if the ASIC is active for a period longer than two seconds (i.e. an error condition).

Conclusion

Devices and technologies currently exist which enable the designer to produce CDMA transmitters which are low cost, high performance and compact in size. The AX602 ASIC performs the processes and calculations required for chipping and data modulation, sleep counter and supervisory maintenance, and CRC calculation as well as RF circuit control, voltage multiplication, and low battery detection. When combined with a low cost microcontroller, RF circuitry, and a small number of discrete components, a full performance direct sequence spread spectrum transmitter operating over the commercial temperature range may be produced for less than $6.00 in parts cost. Units operating over the full industrial temperature range may be produced for slightly more.

Acknowledgement

The authors would like to thank Mr. Britton Sanderford, John Souvestre, Micah Wilson, David Dunbar and others who performed top level design, development and test of the AX602, and who provided review and comment to this manuscript. *RF*

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Technical Specifications for *ARRL Radio Designer 1.0* Analysis:

Maximum number of nodes per circuit block*	250
Range of node-number values	0 through 999
Maximum number of ports per circuit block	30
Maximum number of frequency steps	512
Maximum number of statistical histograms	20

* The number of circuit blocks allowed depends on their complexity; generally, 50 or more circuit blocks may be defined in a single *ARRL Radio Designer* netlist.

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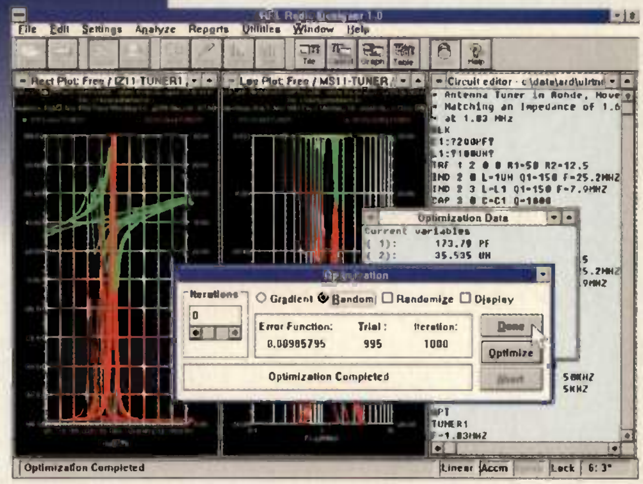

***ARRL Radio Designer* simulates and reports**

- S, Y, Z, group delay and voltage probe parameters for *n*-port networks;
- Chain (ABCD), hybrid (H), inverse hybrid (G), gain, voltage gain, and stability parameters for two-port networks;
- Magnitude of reflection coefficient, phase of reflection coefficient, VSWR and return loss parameters for one-port networks;
- Gain, gain matching and noise parameters; and
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- 386, 486 or Pentium™ IBM PC or 100% compatible (math coprocessor strongly recommended)
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A Layman's Guide to RF

As promised in the November 1994 Editorial, here are our readers' suggestions for explaining RF to non-engineers. Here are excerpts from the faxes and letters submitted. They have been edited for length, and in some cases only one of several analogies was selected for publication. Unfortunately, there isn't room to publish all of them.

Also as promised, we selected one name at random from all the suggestions submitted. Thomas Webb of Texas Instruments is the winner of a set of nine RF Design *handbooks.*

What is RF?

Radio frequency energy is a type of AC, or altenating current, electricity. It differs from the electricity in your electrical outlet only in that its frequency is much higher. That is, it alternates (changes direction) much more frequently.

Its utility lies in the fact that it can bridge the gap between two points without the help of wires. It leaps from one antenna to another much like light waves travel from a flashlight to the object at which it is pointed. When it leaves the antenna it is an invisible field, like the one that surrounds a magnet.

Thomas W. Webb
Texas Instruments

Circuit Analogy

I use the old standby of a water pipe for the circuit with the water being the RF. Resistors are like faucets that can let less or more water through, capacitors are like selective gates that can let water through but keep out trash (DC), and inductors are also like faucets. For modulation I use a big oar causing waves in the water which can mean something to an expert. Demodulation is like a wall with a series of tubes at various levels getting their share of the water depending on the height and strength/duration of the wave. They then use the water they received to turn wheels, etc.

John W. Frank
Millersville, MD

AM, FM and Broadcasting

I have to explain principles of RF to laymen when they come through our radio stations on a tour. I find that the explanation must be simple, not necessarily 100 percent correct. Here are some things people can relate to:

The antenna transmits radio energy like the speakers of a stereo system. The radio energy can not be seen or heard, but it can be received on a piece of wire and fed into your radio.

AM goes up and down (moving your hands closer and further apart in a vertical direction). FM goes side to side (Again move your hands closer and further apart, but horizontally).

If you could see radio waves, AM would look like a single color that gets brighter and weaker in time with music being played. FM would look like a light that is always the same brightness, but changes color in time with the music.

John Marocchi
Franklin Communications

RF Interference

Many of the problems involved in radio technology center on the fact that we all share the same pond in which waves are transmitted. Transmitters must be designed to send out waves only on the frequency they are licensed to operate. If they accidentally send out waves, even small ones, on other frequencies they can cause inter-

The Wonder of RF

In 1936 I became fascinated by the phenomena of radiation and propagation. But, in this day of instant worldwide radio and TV coverage, cellular telephones and pagers, it is hard to describe the wonder of being able to build a crystal set and listen to music and news that was not accessible to the general community. Can you explain RF to non-engineers? No, I can't, and I don't think anyone can — you sorta have to "be there."

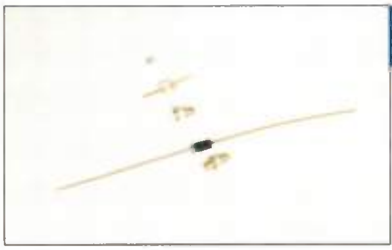
I was fortunate enough to hear Richard Feynman speak, and he gave an explanation that comes pretty close to my view:

Almost all things in nature emit some form of waves. Whether ocean waves, sound waves or light waves, they are defined by the distance between successive peaks, called wavelength. Waves have a most interesting property in that a number of waves can pass through the same environment and not disturb other waves. For example, your eyeball receives light that bounces off a person across the room, and your brain sorts it out so you can identify that person. At the same time, a person on your left can receive light reflected off a person standing on your right, from these tiny waves that passed through the same space without distorting the image of the person you are looking at.

All the time that you are receiving these light waves, other waves are passing through the same space. Infrared waves are longer wavelengths; they can help a pit viper find warm-blooded mice at considerable distance, yet we can only detect them at very short distances (as heat). At still longer wavelengths, radio frequency waves are also there all the time. If you don't believe it, all you have to do is stick a short wire in this space, attach a small box with a couple of knobs on it (a radio receiver) and adjust it until it matches the wavelength of these electromagnetic waves that come "sloshing" across the wire — the BBC, Radio Moscow or a local NOAA weather broadcast. The amazing thing is that they are all really there, and we don't know it until we turn on the box and find the right wavelength.

Quoting from my notes, Feynman said, "We all know this is happening, but you have to stop and think about it to really get the pleasure about the complexity, the inconceivable nature of nature."

Daniel McMillin
Greensboro, NC



Chips and Diodes

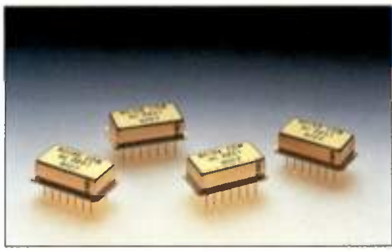
All Noise Com diodes deliver symmetrical white Gaussian noise and flat output power versus frequency. Noise Com diodes are available in a wide variety of package styles, and in special configurations on request.

TYPICAL STANDARD MODELS	
MODEL	FREQUENCY RANGE
NC 204	0.1 Hz – 500 MHz
NC 302	10 Hz – 3 GHz
NC 401	100 MHz – 18 GHz
NC 406	18 GHz – 110 GHz

Drop in Modules for BITE

The NC 500 series drop-in noise modules in TO-8 cans are an economical solution for built-in test requirements. These devices contain complete biasing networks and need no external components. Also available are TO-39 and surface mount packages.

TYPICAL STANDARD MODELS		
MODEL	FREQUENCY RANGE	OUTPUT ENR
NC 501/15	0.2 MHz – 500 MHz	31 dB
NC 506/15	0.2 MHz – 5 GHz	31 dB
NC 511/15	0.2 MHz – 500 MHz	51 dB
NC 513/15	0.2 MHz – 2 GHz	51 dB



Broadband Amplified Modules

The NC 2000 series amplified noise modules are an excellent choice when a high level noise output is desired and the noise source is to be mounted on a circuit board. 24 pin packages are standard, 14 pins are available.

TYPICAL STANDARD MODELS		
MODEL	FREQUENCY RANGE	OUTPUT
NC 2101	100 Hz – 20 kHz	0.15 Vrms
NC 2105	500 Hz – 10 MHz	0.15 Vrms
NC 2201	1 MHz – 100 MHz	+5 dBm
NC 2601	1 MHz – 2 GHz	-5 dBm

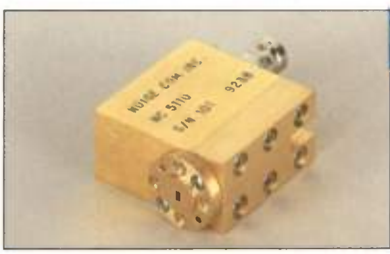
The NC 1000 series amplified noise modules produce white Gaussian noise from -14 dBm to +13 dBm at frequencies up to 6 GHz. They are designed for coaxial test systems, and are available with several bias voltages and connector options.

TYPICAL STANDARD MODELS		
MODEL	FREQUENCY RANGE	OUTPUT
NC 1101A	10 Hz – 20 kHz	+13 dBm
NC 1107A	100 Hz– 100 MHz	+13 dBm
NC 1112B	20 MHz – 2 GHz	0 dBm
NC 1126A	2 GHz – 6 GHz	-14 dBm

Broadband Precision, Calibrated Coaxial

Noise Com's NC 346 series is designed for precision noise figure measurement applications. These products are available with coaxial or waveguide outputs. For OEM applications, the NC 3200 series provides high performance in a small ruggedized package.

TYPICAL STANDARD MODELS		
MODEL	FREQUENCY RANGE	OUTPUT ENR
NC 346A	0.01 GHz – 18 GHz	6 dB
NC 346B	0.01 GHz – 18 GHz	15 dB
NC 346D	0.01 GHz – 18 GHz	25 dB
NC 346Ka	0.1 GHz – 40 GHz	15 dB



Broadband Calibrated Millimeter-wave

The NC 5000 series noise sources feature outstanding stability and convenience in waveguide bands up to 110 GHz.

TYPICAL STANDARD MODELS		
MODEL	FREQUENCY RANGE	WAVEGUIDE
NC 5142	18 GHz – 26.5 GHz	WR-42
NC 5128	26 GHz – 40 GHz	WR-28
NC 5115	50 GHz – 75 GHz	WR-15
NC 5110	75 GHz – 110 GHz	WR-10

Coaxial with Built-in Isolators

The NC 3400 series are precision calibrated noise sources for extreme accuracy and flatness enhanced by their low VSWR 1.25:1.

TYPICAL STANDARD MODELS		
MODEL	FREQUENCY RANGE	OUTPUT ENR
NC 3404	2 – 4 GHz	30–36
NC 3405	4 – 8 GHz	30–35
NC 3406	8 – 12 GHz	28–33
NC 3407	12 – 18 GHz	26–32

BER Testing Equipment

The UFX-BER accurately sets and displays Eb/No, C/N, C/No, or C/I between a user supplied signal and internally generated white Gaussian noise. The UFX-BER can be used for back to back or IF loop-back testing with extreme precision over a broad range of input or output power. Eb/No values can be entered directly from the front panel or by IEEE-488 bus.

TYPICAL STANDARD MODELS		
MODEL	FREQUENCY RANGE	APPLICATION
UFX-BER-70	50 MHz – 90 MHz	General
UFX-BER-IBS/IDR	50 – 90; 100 – 180 MHz	IBS/IDR
UFX-BER-836	824 MHz – 849 MHz	CDMA
UFX-BER-1850	1800 MHz – 1900 MHz	DCS–1800

Amplifier Test Station

The UFX-NPR series instruments perform automatic distortion measurements in mobile telephone (CDMA and FDM) base stations, satellite communications systems, CATV, and other equipment operating in multi-signal environments. Some models are available with tunable measurement frequency or with multiple measurement frequencies.

TYPICAL STANDARD MODELS	
MODEL	FREQUENCY RANGE
UFX-NPR-70	50 MHz – 90 MHz
UFX-NPR-CATV	50 MHz – 1.0 GHz
UFX-NPR-1700	1.6 GHz – 1.9 GHz
UFX-NPR-2400	2.2 GHz – 2.6 GHz
UFX-NPR-11900	10.95 GHz – 12.8 GHz

Broadband Noise Generators

The NC 6000 and NC 8000 series noise generating instruments are designed for applications on the test bench or incorporated with other equipment to provide a wide variety of functions. Each instrument contains a precision noise source, amplification, and step attenuators to provide repeatable symmetrical white Gaussian noise with variable output power.

TYPICAL STANDARD MODELS		
MODEL	FREQUENCY RANGE	OUTPUT POWER
NC 6107	100 Hz – 100 MHz	+13 dBm
NC 6110	100 Hz – 1500 MHz	+10 dBm
NC 6124	2 GHz – 4 GHz	-10 dBm
NC 8107	250 kHz – 100 MHz	+30 dBm

The new UFX-7000 series noise generating instruments are extremely easy to use, combining dedicated keys for control of operations and programming, with a large 4 x 20 character LCD display. Control of output power, filter settings, and attenuator step size for both the noise and the signal (for units with internal combiners) is performed from the front panel or remotely using the IEEE-488 interface.

TYPICAL STANDARD MODELS		
MODEL	FREQUENCY RANGE	OUTPUT POWER
UFX-7107	10 Hz – 100 MHz	+13 dBm
UFX-7108	100 Hz – 500 MHz	+10 dBm
UFX-7110	100 Hz – 1500 MHz	+10 dBm
UFX-7218	2 GHz – 18 GHz	-20 dBm
UFX-7909	1 MHz – 300 MHz	+30 dBm

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ference to receivers trying to operate on that other frequency. Likewise, receivers must be carefully designed to accept only signals on the desired frequency while rejecting other signals that may be very close to the same frequency, and very much stronger.

Other interference problems are caused by the fact that all circuits that have electrical vibrations will produce and receive radio waves, even if we don't want them to. Computers switch electrical currents on and off very quickly, generating radio waves that can interfere with nearby receivers. Even a hair dryer creates radio waves. Likewise, non-radio equipment can be disrupted by nearby radio transmitters even if they are operating correctly. The radio waves can be so strong that vibrating currents are set up in the circuits even though we have no desire for them to receive radio signals. Shielding and filtering is needed to contain the unwanted radio waves.

Mark Kolber

Shielding Attenuation

"Why does high frequency energy penetrate apertures more easily than low frequency energy" Suppose you had a chain link fence surrounding your property, and from your home a dozen children had a countless number of balls of random sizes (e.g., marbles, ping pong balls, tennis balls, beach balls, basketballs). All of the children throw the balls at the same speed toward the fence.

Now, suppose that the smaller size of the ball corresponds to higher frequency (smaller ball = shorter wavelength). Obviously, as the ball gets smaller, the chance of the ball passing through the fence increases. The ratio of the number of balls thrown that actually pass through is analogous to the attenuation of the fence as a function of ball diameter. Therefore, the attenuation of beach balls is infinite, and the attenuation of marbles and BBs is very low.

If this analogy doesn't help bring home the concept that electromagnetics are as real any any visible phenomenon, I proceed with second, slightly more poignant response: "Sure you can't see it, but 50 bucks says you won't stick your head in a microwave oven for five seconds."

Allan D. Pincus
W.L. Gore & Associates

Frequency Conversion

Most people are familiar with the spinning wheel effect, where the spokes on a wheel appear to "stand still" when the spins at just the right speed (rotational frequency). This is because of a sampling process performed by the human brain. Also familiar is the same effect, even more dramatic, when a strobe light is used to "freeze frame" a wheel. A rapidly clockwise rotating wheel can be made to appear to rotate slowly clockwise or slowly counterclockwise as the strobe flash is adjusted slightly faster or slower that the speed of the wheel. (This also demonstrates why "negative frequencies" are real!)

Robert Tso
S. San Gabriel, CA

ERP

Imagine in the center of a round table there is a 60 watt light bulb. Anywhere you sit around the table you will see the same amount of light (power). Now, put a reflector on the bulb. Behind the reflector you will see less light, and in front of the reflector you will see more light. Notice that we did not change the size of the light bulb. ERP is the same, we are talking about keeping the energy the same, but focusing it to where we need it.

Bill Unger
TVOntario

AM Modulation

The principle of a variac is easy to comprehend for most laymen, perhaps easier than a potentiometer. A demonstration with a light bulb will cinch the idea. Hang a pendulum on the variac knob and watch the brightness of the bulb vary sinusoidally. If a "microphone diaphragm" could be placed on the end of the pendulum, ignoring the acousto-mechanical problems, the concept of sound modulation would be demonstrated. A photocell will "demodulate" the light bulb's modulation.

Ralph Burgess
MIT

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INA-51063	DC-2400	5	12	3.0	20.5	+ 6	SOT-363
INA-52063*	DC-1600	5	30	3.5	20	+17	SOT-363
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Next Generation EM Simulator Provides Open and Packaged Environment Analysis

By Peter Petre, Krishnamoorthy Kottapalli, Ali Sadigh, and Todd Westerhoff
Compact Software

Electromagnetic (EM) simulators let designers analyze complex RF/microwave circuits and antennas to predict EM field distribution and extract S parameter data. EM simulations can also accurately predict electromagnetic effects such as inter-trace coupling, radiation and package resonance. The term "electromagnetic simulator" is used because the tool predicts electromagnetic fields and current density within the circuit by solving Maxwell's equations.

In practice, simple forms of electromagnetic coupling are handled by models in popular circuit simulators. For example, the Super-Compact MCPL model can be used to predict EM coupling between adjacent, parallel transmission lines. However, all such circuit simulator models have inherent limitations for supported geometries, the frequency at which they can be used, conductor width, height, etc. In contrast, EM simulators accurately model circuits and antennas of arbitrary shape and size, and are not limited by circuit parameters.

Electromagnetic simulators model design behavior under two different sets of conditions. Closed environment simulations model the behavior of the circuit within its IC package. This is important for high frequency circuits because resonances that affect the circuit's behavior can occur within the package. Open environment simulations model the behavior of the circuit without the package. These simulations predict the energy radiated by the circuit into free space and are often used to predict the behavior of antenna designs. This aspect of EM simulation is important because antenna radiation cannot be analyzed without the use of an EM simulator.

Full-wave EM simulators solve Maxwell's equations by enforcing various boundary conditions and developing integro-differential operator equations for the unknown EM fields or current density. Network input ports are excited by known incident fields or voltage/current sources. The simulator then solves the operator equations numerically for the unknown electric and/or magnetic fields and induced current density on the metallization. The operator equation is solved by discretizing (meshing) the unknown electric/magnetic fields or current density. By solving the operator equation at each frequency, the simulator determines the way electromagnetic fields or currents are distributed, where and how much electromagnetic coupling will occur, and what, if any, energy will be radiated by the circuit.

An EM simulator generates a mathematical model based on a physical (layout) description of the circuit. A detailed description of the layered substrate is extracted and passed to the EM simulator for analysis. This description includes the complex permeability and permittivity of the substrate layers, the metallization pattern on the different layers, and the location of vias and vertical strips. The layout circuit description is usually obtained from a layout program in standard file formats such as GDS II.

Once the simulation is complete, designers can view current density plots and extract equivalent S parameters for use with circuit simulators. Using this technique, layout data can be extracted for EM simulation and analysis, with the resulting S parameters plugged back into a circuit simulator as a "black box" model.

A commercial EM simulator should be able to analyze microwave circuits in both open and closed environments. Packaged environment analysis is used to analyze the effects the package top cover and sidewalls have on the design. This helps ensure that a circuit will not resonate within its final environment. Open environment analysis is used for predicting the behavior of antennas and also analyzing circuits without considering the effects of the package. Most commer-

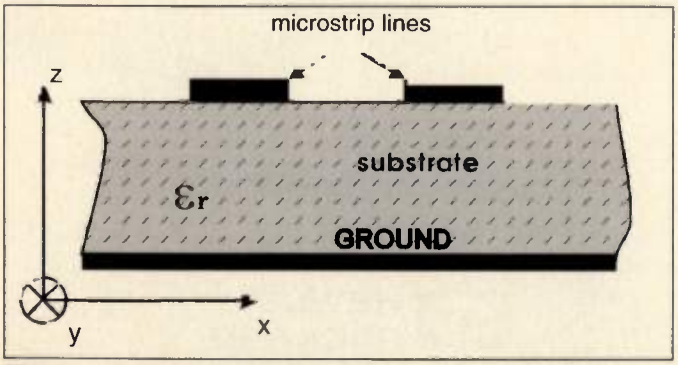

Figure 1. Typical circuit suited for 2D analysis.

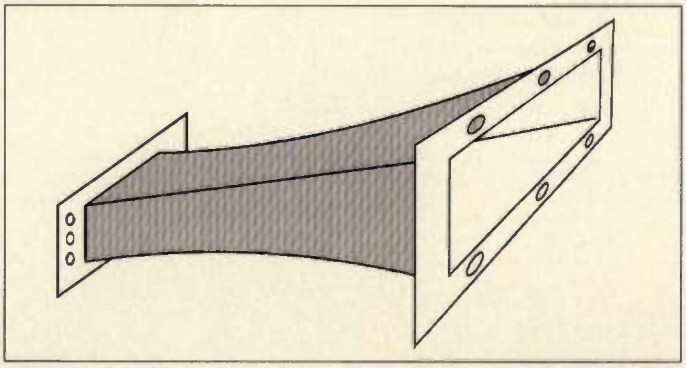

Figure 2. Microwave horn example requiring full 3D analysis.

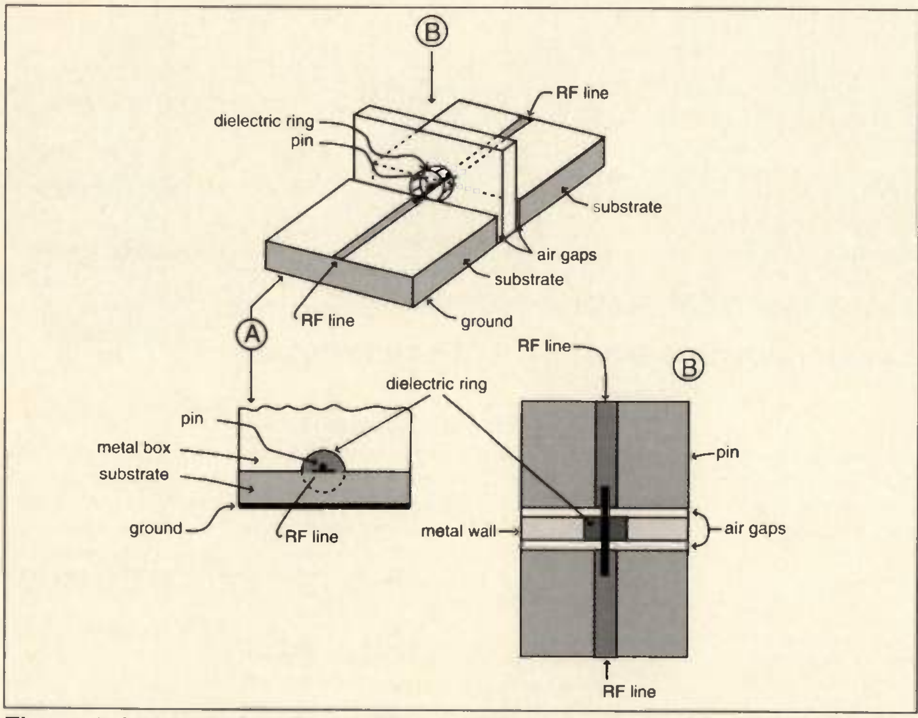

Figure 3. Hermetic bead transition in MMIC circuit requiring 3D analysis.

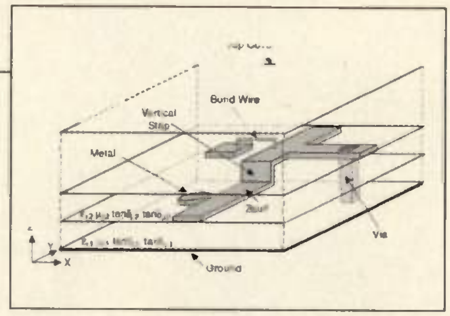

Figure 4. MMIC circuit suited to 2.5D analysis.

cial implementations of EM tools analyze only a single environment; some tools model open environments while others model closed environments, because the mathematical formulations and treatments of boundary conditions for open and closed environments are different. Simulators that analyze only closed environments have been used to approximate open environment conditions. However, this method is unsatisfactory because the result is always only an approximation and the associated accuracy is unpredictable.

Compact Software's Microwave Explorer 3.0 is a full-wave EM simulator that includes two different simulation engines. One engine is dedicated to open environment analysis and the other is dedicated to closed environment analysis. The two engines run from a common graphical user interface and access a common netlist. The user is able to switch between the different engines at the touch of a button. Explorer 3.0 is uniquely suited for analyzing both open and packaged arbitrary planar microwave circuits as well as microstrip antennas. Microwave Explorer can also be used efficiently for EMI/EMC analyses, characterizing effects such as cross-talk, inter-element coupling, and radiation.

Types of EM simulation

Full-wave EM simulation can be carried out as a two dimensional (2D), three dimensional (3D), or 2.5 dimensional (2.5D) analysis, depending upon the geometrical complexity of the circuit being modeled. The decision to use 2D, 2.5D, or 3D analysis is made based on the dimensionality of the actual circuit or antenna. Although every fabricated circuit or antenna has three actual dimensions, certain applications can be accurately analyzed with a 2D or 2.5D mathematical model. The advantage from the user's standpoint is that 2D and 2.5D analysis are substantially faster than a full 3D analysis. To clarify this point, we will review the geometric models for 2D and 2.5D analysis noting the geometry restrictions.

Figure 1 shows a typical 2D geometry consisting of a coupled microstrip line above a grounded dielectric substrate. This structure has 2D geometry because it is assumed that the lines are uniform along the y-axis (perpendicular to the plane of the cross-section). No discontinuities in the line can be modeled since the cross-section is constant. This circuit can be readily analyzed using 2D full-wave techniques. The 2D operator equation can be derived for the unknown EM field components or unknown surface current density. The 2D meshing algorithm is used to discretize the cross-sectional area of the structure for both the field and current.

2D EM simulation is often used to analyze trace coupling of microstrip lines with arbitrary metallization cross sections. This type of analysis is common in PCB layouts and high speed digital circuit design. An example of 2D analysis is the multiple coupled line (MCPL) model in the Super-Compact linear frequency-domain simulator. This model is actually a miniature self-contained 2D EM simulator.

The most general type of electromagnetic simulator is the 3D simulator, which can model any arbitrary 3D geometry. Because 3D simulators model the electromagnetic fields or the equivalent volume currents in the complete 3D volume, they provide accurate results, but require long computation time and large amounts of computer memory. A typical example requiring 3D analysis is the microwave horn shown in Figure 2. A 3D simulation would be used to determine the electromagnetic field distribution inside and outside the structure, from which the radiation pattern and efficiency can be determined. A full 3D analysis is required because this structure has varying dimensions in the X, Y and Z directions.

3D electromagnetic simulators are also used to examine microstrip circuits with inhomogeneous substrates, waveguide discontinuities, and various 3D connectors and transitions. An example of a MMIC structure requiring 3D analysis is the hermetic bead transition shown in Figure 3. This structure requires 3D EM simulation because the dielectric substrate is not homogeneous (there are air gaps in the substrate), and there is a discontinuity in the vertical direction (the dielectric ring is located in the vertical metal wall).

2.5D electromagnetic simulators represent a tradeoff between 2D and 3D electromagnetic simulation and are targeted for a specific class of circuits. 2.5D electromagnetic simulators take advantage of the fact that microstrip circuits and antennas are usually planar in nature. Although the planar geometries in MMIC circuits are arbitrary, these circuits are fabricated in "planes" of regular thickness and spacing. Novel EM analysis techniques can be used to characterize planar circuits. These techniques have the advantage

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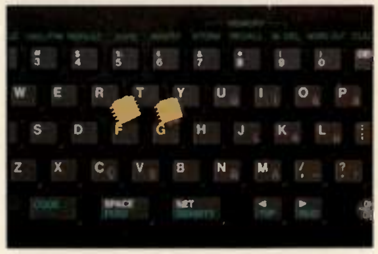

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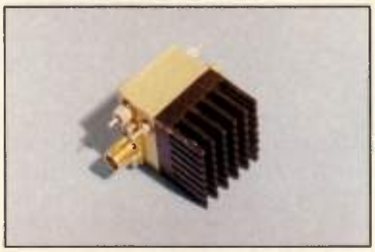

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SMM-210	1.5-2.5	25	+30	+39	+5.0	10-pin ceramic
SMM-280-2	1.5-2.5	25	+33	+42	+7.0	0.6 x 1.0" flange
SMM-280-4	1.5-2.5	25	+36	+45	+7.0	0.6 x 1.0" flange
SMM-610	5.9-6.4	27	+33	+42	+5.0	10-pin ceramic
SM-680-2	5.9-6.4	27	+36	+45	+7.0	0.6 x 1.0" flange
SMM-1820-1	6.0-18	11	+27	+36	+8.0	0.6 x 1.0" flange
SMM-1820-2	6.0-18	11	+30	+39	+8.0	0.6 x 1.0" flange

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SMM-010	0.1-4.0	18	2.2	+5.0	+15	10-pin ceramic
SMM-108	0.5-2.0	18	3.5	+5.0	+12	plastic so-8
SMM-110	0.5-3.0	19	3.2	+5.0	+12	10-pin ceramic
SMM-808	2.0-7.0	13	5.0	+12	+17	plastic so-8
SMM-810-1	2.0-8.0	14	5.0	+12	+17	10-pin ceramic
SMM-810-2	2.0-8.0	27	5.0	+12	+17	10-pin ceramic
SMM-1810	6.0-18	12	5.0	+5.0	+12	10-pin ceramic
SMM-2010	2.0-18	7	5.5	+5.0	+20	10-pin ceramic

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Part Number	Ga @ 1 GHz (dB)	Nf @ 1 GHz (dB)	Ga @ 2 GHz (dB)	Nf @ 2 GHz (dB)	P1dB (dBm)	Package
SPF-284	18	0.5	16	0.8	+10	85 mil plastic
SPF-484	18	0.3	16	0.5	+10	85 mil plastic

Part Number	Ga @ 4 GHz (dB)	Nf @ 4 GHz (dB)	Ga @ 12 GHz (dB)	Nf @ 12 GHz (dB)	P1dB (dBm)	Package
SPF-684	15	0.7	9	1.5	+10	85 mil plastic
SPF-884	15	0.5	9	1.2	+10	85 mil plastic
SPF-1076	16	0.4	11	1.1	+15	70 mil ceramic
SPF-1276	16	0.4	11	1.0	+10	70 mil ceramic
SPF-1376	15	0.3	10	0.8	+9	70 mil ceramic
SPF-1476	15	0.3	10	0.7	+9	70 mil ceramic
SPF-1576	15	0.2	10	0.6	+9	70 mil ceramic

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of providing 3D accuracy in a fraction of the time typically required for 3D analysis. To differentiate between circuits which can be analyzed by this 2.5D technique and the circuits which can only be analyzed by a 3D simulator, a new type of geometry has been introduced, called 2.5D geometry.

2.5D geometry consists of a planar layered substrate with arbitrarily shaped metallization on the surfaces of the various layers. Vertical connections, such as vias and vertical strips, run between the different metal layers. The substrate can be a set of homogeneous dielectric and/or magnetic, lossy/lossless layers. Advanced 2.5D EM simulators can also accurately model the finite thickness of the metallization, bond wires, air bridges, and arbitrarily shaped via holes. A typical 2.5D structure is shown in Figure 4.

2.5D EM simulation is the most popular form of simulation, since it can model most practical MMIC circuits and microstrip antennas. One of the biggest advantages of 2.5D simulation is that it uses a 2D meshing algorithm, which greatly simplifies the meshing required to analyze the circuit. The use of 2D meshing generates the operator equation with fewer unknowns, thus providing fast results (typically several orders of magnitude faster than full-wave 3D analysis) with no loss of accuracy.

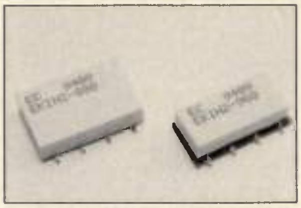
EM Algorithms and Tradeoffs

From the designer's point of view, one of the most important issues is the numerical technique implemented by the EM simulator being used. This is important because the numerical technique determines the accuracy and speed of the calculations. The most common numerical techniques implemented in commercially available EM simulators are the finite difference (FD) technique, the finite element method (FEM), the various forms of the integral equation (IE) technique, the finite difference time domain (FDTD) technique, and the mode matching technique.

The FEM, FD and FDTD methods can be used for 2D, 2.5D, and 3D analysis. These methods are well suited for closed environment analysis where the package size is not significantly greater than the circuit size. Metal sheets are used to form the shape of the metal package and the "perfect electric conductor" condition is enforced on these surfaces. The efficiency of the analysis is heavily dependent on the ratio between the circuit and package size. If the package is much bigger than the circuit inside, large numbers of unknowns are created and the numerical solution requires large amounts of memory and computational time. The "small circuit in large package" problem is often manageable for 2D analysis, but not for 2.5D and 3D analysis.

The FEM, FD and FDTD methods cannot be used to accurately and efficiently model an open environment, although considerable research effort is being directed towards this problem. Various techniques have been developed to terminate the volume of the analysis as close as possible to the circuit of interest by enforcing proper boundary conditions. These are usually the first- and second-order absorbing boundary conditions and other numerically derived conditions. Keeping the analysis volume close to the circuit size is critical, because this determines the necessary number of unknowns and therefore the required memory and computational time.

Integral equation (IE) techniques usually formulate the operator equation for the electric, magnetic or combined fields in either the space or spectral domain. IE techniques are efficient for 2D and 2.5D analysis, although applying the IE technique to 3D problems requires excessive amounts of memory and computational time. For 2.5D EM simulation, the two most popular formulations of IE are the electric field integral equation (EFIE) formulation in the space domain and the EFIE formulation in the spectral domain. The space domain EFIE can be used efficiently for the analysis of open microstrip circuits and antennas, while the spectral domain EFIE can be used efficiently for the analysis of packaged microstrip circuits.The EFIE formulation in the space domain calculates the surface electric current density on the metal portion of the circuit, assuming that the EM waves can propagate into free space above the circuit. Modeling the effect of the package on the circuit performance using the space domain EFIE is difficult and inefficient, because additional equivalent surface currents must be set up all over the metal package. This increases the necessary number of unknowns to the point where memory and computation-



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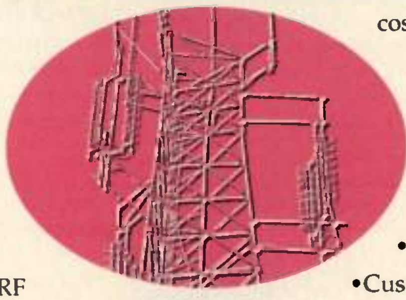

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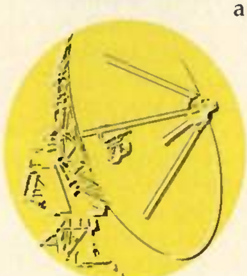

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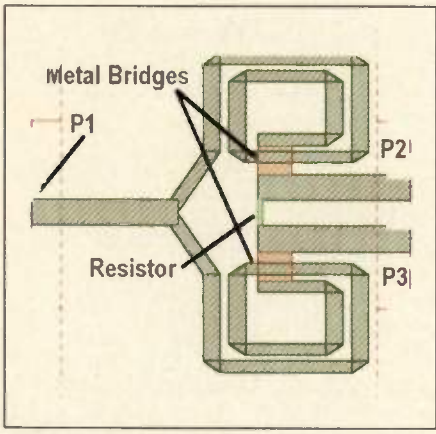

Figure 7a. Layout of Wilkinson power divider.

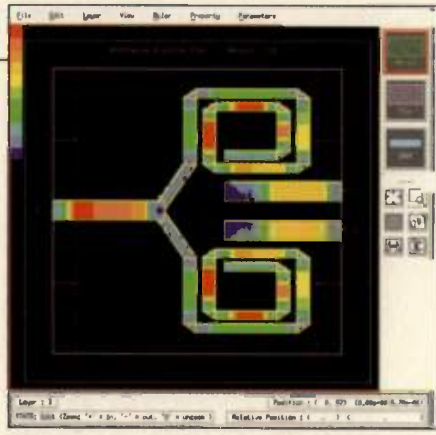

Figure 7b. Current distribution at 16 GHz.

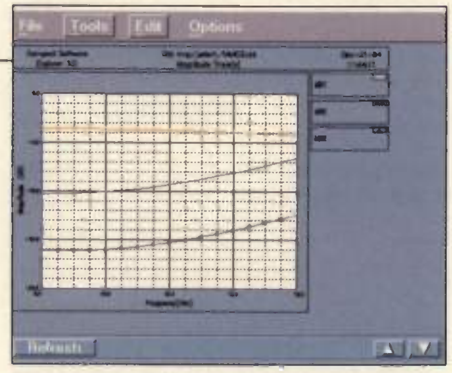

Figure 8. S parameters of power divider.

al time requirements become unacceptable.

The EFIE formulation in the spectral domain is very efficient for analyzing packaged microstrip circuits, as this technique was specifically developed to solve these type of problems. The original technique was not well suited for the analysis of open circuits and antennas. In the 3.0 release of Microwave Explorer, Compact Software has extended the spectral domain technique for efficient analysis of open environments. The key issue was extending the formulation to accurately and efficiently analyze microstrip antennas. These antennas are very sensitive to the simulation accuracy, especially for the value of the input impedance.

Microwave Explorer

Microwave Explorer version 3.0 introduces a unique feature among EM simulation tools that allows the user to select whether the circuit should be analyzed inside its metal package or in an open environment. Closed environment analysis includes the effects of package resonances and side walls while open environment analysis models EM waves radiating into free-space or into a user definable homogeneous half space.

Developing a single simulation engine to provide both open and closed environment analysis is difficult and involves tradeoffs in speed and accuracy. Rather than compromise accuracy or performance, Microwave Explorer 3.0 employs two different simulation engines, one tuned for closed environment analysis, the other for open environment simulation. The use of two simulation engines creates its own set of technical challenges. Both simulator engines must produce exactly the same S parameters for low frequency simulations, independent of the circuit being analyzed. Another challenge is maintaining the same level of efficiency for both open and closed simulation. Both of the simulation engines in Microwave Explorer 3.0 are based on the periodic structure approach. Compact Software has extended the basic periodic structure approach to support packaged environment analysis and the analysis of single circuit elements in the open environment. Various novel methods including averaging techniques combined with efficient fast Fourier transforms, and an open excitation/de-embedding procedure have been implemented in the open environment simulation engine. The use of two simulation engines provides a good compromise between open and closed environment analysis, allowing each engine to provide accurate results without sacrificing performance.

The open environment simulation engine models EM effects such as surface wave losses and parasitic radiation. This helps designers optimize the size and shape of microstrip antennas. This also allows designers to verify and modify circuits containing sensitive microwave circuit elements such as filters, phase bridges and meander lines. The simulator can accurately predict the parasitic radiation of and the coupling between circuit elements.

The closed environment simulation engine predicts the effects of side walls and package resonance. The top and bottom package covers can be lossy, allowing designers to examine the effects of the device package on the circuit performance and to redesign the package, if necessary. Microwave Explorer lets designers optimize the locations of the circuit elements within the package to obtain maximum circuit performance. A unique "Box Mode Pre-Processor" quickly determines if the package is resonant in the frequency range and, if so, the Q of the package. This lets designers quickly determine if a potential problem exists, without requiring a full simulation.

Both the open and packaged simulation engines perform accurate full-wave EM analysis of any arbitrarily shaped 2.5D structure. There is no limit on the frequency range that can be analyzed, nor is there a limit on substrate parameters such as thickness, permittivity, loss tangent, bulk resistivity, or permeability. Designers can analyze circuits with an unlimited number of layers and ports, limited only by the computer hardware. Microwave Explorer has a unique and accurate de-embedding procedure to remove the port discontinuities and/or compute the S parameters from a user-defined reference plane.

The graphical user interface plots the circuit's current distribution using a color graphic current visualization in different resolutions. After simulation, resultant S parameters for the circuit can be extracted and output to a file in Super-Compact or Touchstone format.

Application Examples

To illustrate the capability of the open and closed environment simulation engines in Microwave Explorer 3.0, this section reviews various application examples, including microstrip antennas, microstrip power dividers and coplanar waveguide filters.

Power Divider

This microstrip compact two-way Wilkinson power divider is designed on a GaAs substrate. The layout of this circuit is shown in Figure 7a. This circuit takes the input power at P1 and evenly divides the power delivered to output ports P2 and P3. Metal bridges are used to connect each inductor to its respective output port. The isolation resistor is used to isolate ports P2 and P3 from each other. Figure 7b shows the current distribution on metal 1 at 16 GHz. Figure 8 shows

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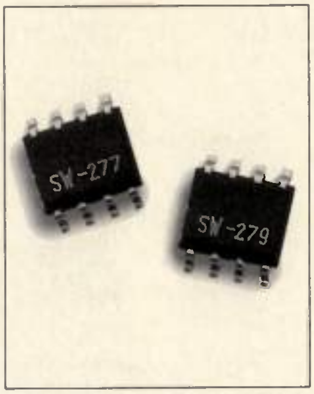
CIRCLE READER SERVICE NO. 50



GaAs MMIC Switches for Mobile and Portable Radios

Low cost, high power (4W), GaAs MMIC single-pole, double-throw switches designed for maximum power dissipation. Applications include T/R switching, antenna diversity and changeover functions. Wide bandwidth (DC-2.5 GHz), for voice, data and LAN applications. P/N SW-277 / SW-279

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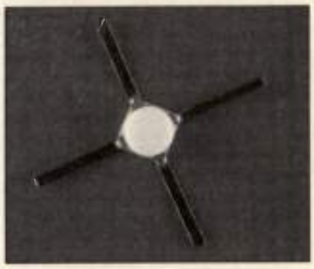

Low Voltage, Low Noise Transistor

This high f_T, low noise transistor operates on a 3-5 volt supply. Noise figure is < 1.5 dB @ 1.5 GHz. This transistor family is designed for any battery powered RF communication system including wireless subscriber applications.

P/N MA4T6365

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CIRCLE READER SERVICE NO. 52

OSMT: Microwave Surface Mount Interconnect System

The OSMT has a mated height of 4.2 mm, and a VSWR of 1.2:1 at 2 GHz, and 1.4:1 max at 6 GHz. Applications include Cellular, GPS and WLAN. Plugs are supplied in tape and reel packages and cable jacks are available in pigtails or jumpers.

OSMT Plug Receptacle
P/N 2367-0000-54
Right Angle Jack Cable Pigtail
P/N 9950-2200-23

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In the race to the marketplace, it's easy to spot people using our wireless data transmission solutions.

In today's intensely competitive wireless environment, the race goes to the swift (and the smart). That's why so many smart companies are turning to M/A-COM to help make their wireless applications a reality. After all, we've been leaders and innovators in RF, microwave and millimeter wave technology for more than 40 years. Successful companies have learned that M/A-COM has proven, cost-effective solutions that work today—across the spectrum.

You'll find our products are already hard at work around the world in both LANs and WANs. Connecting everything from pen-based computers to bar code scanners to personal communicators. And while today we're helping you with data and voice transmission, we're also ready to take you into the realm of integrated data, voice and video applications.

So if you're looking for more than a supplier, if you're looking for a strategic partner that will help you with product development, innovative solutions and high-volume low-cost manufacturing, look to M/A-COM. We'll give you such a competitive advantage, it'll almost be unfair.

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INFO/CARD 6

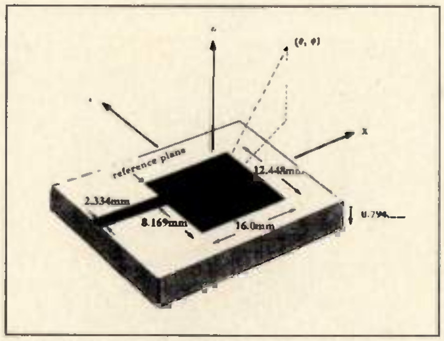

Figure 9. Layout geometry of patch antenna.

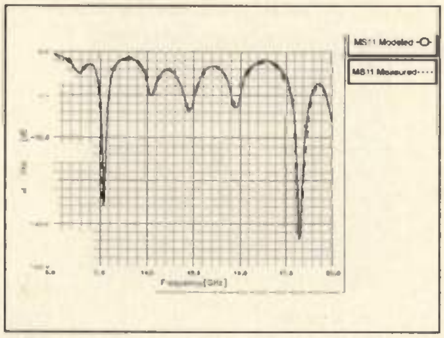

Figure 10. Input match of patch antenna.

the transmission coefficient between port 1 and 2 (S_{12}), and the input reflection coefficients at ports 1 (S_{11}) and port 2 (S_{22}) in the frequency band f = 8-16 GHz. The divider was originally designed to give –3 dB transmission between port 1 and 2, also between port 1 and 3, while the calculated S_{12} parameter shows a variation between –3.4 dB and –4.4 dB.

Patch Antenna

This edge-fed rectangular microstrip patch antenna is 16.0 mm × 12.448 mm. The microstrip patch antenna is asymmetrically fed by a microstrip line of width 2.334 mm. The substrate has a thickness of 0.794 mm with relative dielectric constant = 2.2. Figure 9 shows the geometry input to Microwave Explorer. Figure 10 shows the measured and calculated input impedance of the antenna in the 5.0 - 20.0 GHz frequency range. There is excellent agreement between the measured and simulated input impedance all over the frequency band. Figure 11 shows the current distribution on the microstrip antenna at the second resonant mode (the current has a maximum at the center of the shortest edge of the antenna). For this mode there is a reasonable impedance match between the feeding line and the antenna (–18 dB). Figure 12 shows the current distribution on the antenna at

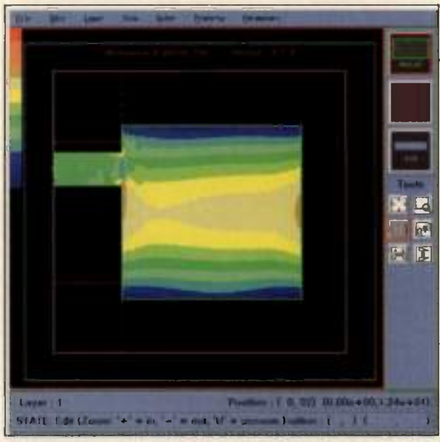

Figure 11. Current distribution at second resonance mode.

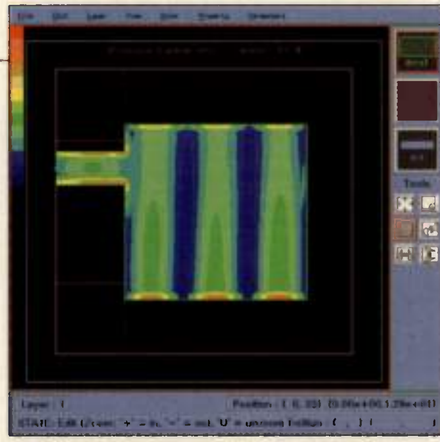

Figure 12. Current distribution at 18.3 GHz.

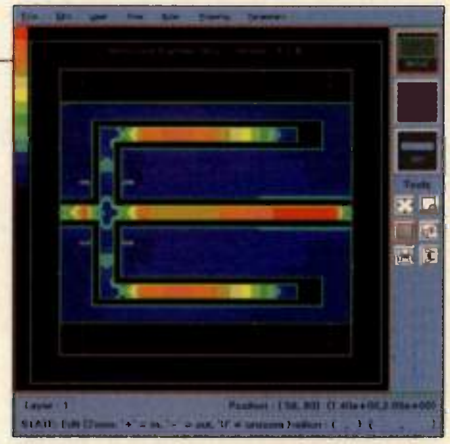

Figure 13. Current distribution in coplanar waveguide at 36 GHz.

the resonant mode which occurs near the frequency f = 18.3 GHz. From the current plot it is easy to conclude that this mode is a higher order mode where the longest edge of the antenna has a resonant length at this frequency.

Coplanar Waveguide

This circuit is a coplanar waveguide (CPW) band reject filter. This filter was designed to have no transmission at 18 GHz and good transmission at 36 GHz. The main assumption behind this design is that the CPW line behaves as a unimodal transmission line. To eliminate the coupled slotline mode for the CPW shunt stub, air-bridges are used to equate the potential of the two ground planes. Under this assumption each stub acts as a short circuit at f = 18 GHz, thereby allowing no transmission between ports 1 and 2 at this frequency. The stub acts as an open circuit at f = 36 GHz thereby allowing good transmission. Figure 13 shows the current distribution on the metal portion of the CPW filter at f = 36 GHz. The current plot shows that the stub acts as an open circuit at this frequency, because the current has a maximum at the center of the stub and there is high current everywhere on the center line. Figure 14 shows the measured and calculated S_{11} parameter of the CPW filter with the air-bridges in the frequency band f = 10-40 GHz. The figure shows excellent agreement between the measured and calculated data.

Conclusion

Electromagnetic simulation is a valuable tool for the characterization of RF and microwave circuits. EM simulators allow designers to analytically characterize circuits to determine S parameters, EM coupling and radiation. By characterizing designs analytically rather than empirically, EM tools help shorten the overall design cycle and improve product quality.

MMIC circuits and microstrip antennas can be accurately analyzed with 2.5D EM simulation tools, which are orders of magnitude faster than traditional 3D analysis tools. While most 2.5D simulation tools restrict designers to either open or closed environment analysis, Microwave Explorer 3.0 provides two different simulation engines. This gives designers the choice of analyzing either type of environment without sacrificing simulation speed or accuracy. Compact Software's "Next Generation EM Simulator" provides open and packaged environment analysis. *RF*

Figure 14. Modeled and measured S_{11} CPW filter.

About the Authors

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Todd Westerhoff received his BEEE from the Stevens Institute of Technology in 1979, and has 12 years experience in the design and marketing of CAE/CAD systems for digital and analog electronics.

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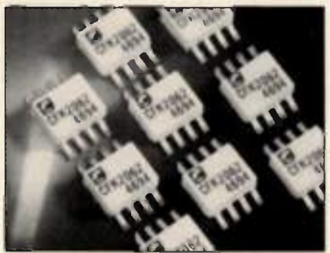
PCS, PCN, GSM Test Sets

Tektronix has announced the availability of a series of digital radio communications test sets, each of which can be used for PCS (DCS 1900), PCN (DCS 1800) and GSM applications. The CMD55 tests mobile phones by completely simulating the operation of a base station. Two transmitters are provided for true simulation of call setups and handoffs to different channels, time slots and powers. An autotest function allows initiation of complete testing routines with a single button for fast go/no-go testing of mobile telephones. The CMD57 base station test set provides a variety of operating modes and interfacing capabilities for complete base station verification and troubleshooting, with the functions of both a spectrum analyzer and a signal generator. The CTRP series provides full GSM-compliance test capability, and allows detailed analysis and control for testing the signaling and RF performance of mobile phones and base stations. A key application of the series is interoperability testing of mobile phones and base stations from different manufacturers. These products were developed with Rohde & Schwarz. All these products are available for ordering today. The CMD55 is U.S. priced at $28,440, The CMD57 at $32,800, the CRTP series begins at $238,700.

Tektronix, Inc.
INFO/CARD #220

1 W, 5 V Power Stage

Celeritek has announced a low-cost, 1 watt power stage that operates from a +5 V supply. The CFK2062 series is a family of high-gain FETs intended for driver amplifier applications in the 1.7 to 2.5 GHz range. The device is externally biased, allowing use in systems that require saturated or linear power stages, and as such can be used with all types of digital modulation. The device's high efficiency minimizes the need for heat sinking. For many wireless design applications, matching is very simple and can be achieved with as few as two capacitors. Manufactured with Celeritek's proprietary power FET process, the CFK2062 is assembled in an industry standard SOIC-8-compatible power package. Samples are available from stock. Production quantities of 1,000 are available in 30 to 45 days ARO and are priced at $26.00 per unit.



Celeritek, Inc.
INFO/CARD #219

Thin Film Chip Inductors

The KL73 series of thin film chip inductors from KOA Speer Electronics is designed to satisfy the high frequency and small size requirements common in wireless and telecommunications applications. The series has SRFs up to 3,000 MHz, and come in 0805 and 1206 sizes. KL73 inductors are manufactured to provide consistent performance characteristics within each lot and from lot to lot. These inductors are available in either ±2% or ±5% tolerances and are manufactured to impedance analyzer standards. The rugged construction and tape and reel packaging of the KL73 inductors are well suited for automated assembly operations using pick and place equipment.

KOA Speer Electronics, Inc.
INFO/CARD #218

SMD TCXO

The FOX789A, an SMD temperature compensated oscillator with an optional voltage control on pin 1, is now available through Fox Electronics. With its industry standard package size and footprint, this TCXO is useful in existing designs where cost effectiveness and high capacity are important. The oscillator is available in frequencies from 9.600000 to 20.000000 MHz. Supply voltage is 5.0 V ±5.0%, and operating temperature range is –40 to +85 °C. Frequency stability over –30 to +75°C is ±2.5 ppm, and over supply voltage change of 5.0 V ±0.3 V is ±0.3 ppm. The output wave form is a clipped sine wave with amplitude of 1.0 V peak-peak. The optional voltage control (FOX789E) adds ±5.0 ppm control with control voltage of 2.5 V ±2.0V. Maximum current consumption for the FOX789A is 2.0 mA.

Fox Electronics
INFO/CARD #217

RFID Kit

Deister Electronics has introduced the Minireader, a hardware package that will enable engineers to incorporate RF proximity technology into their automatic identification designs. The Minireader is available as a chip set or as a fully integrated proximity reader that measures less than 1.75 in^2. The m3394b ASIC reader chip can write data directly into the transponder, and contains a transmitter and all necessary drivers for activating the transponders, as well as a filtered receiver and amplifier for response signals. The transponders can store up to 106 bytes. The transponders operate at 125 kHz. A Minireader Design Kit, containing a complete reader, RS-232 serial interface, demonstration software, documentation and six different types of transponders is available for $200.00.

Deister Electronics USA Inc.
INFO/CARD #216

SIGNAL SOURCES

TCXO Replacement

The 210 OCXO series from MTI is available in frequencies from 1.2 to 80 MHz and can be used as a replacement for any 14-pin DIP clock oscillator or TCXO. Stability is better than ±0.25 ppm over a 100°C temperature range. The unit warms up in less than three minutes and consumes less than 0.7 W at 25°C. The device measures 18.3 × 13.2 × 12.0 mm (0.720 × 0.520 × 0.472 inches) and is available with either a 12 or 5 volt supply.

MTI - Milliren Technologies, Inc.
INFO/CARD #215

VCXOs

KVG offers a series of voltage controlled oscillators which are especially designed to meet the requirements of phase locked loops for clock recovery and frequency synthesis. The VCXOs have spurious suppression of up to 60 dB. Tuning ranges from ±50 ppm up to ±200 ppm, with excellent tuning linearity. The oscillators are manufactured in all ISDN and ATM standard frequencies up to 622 MHz.
KVG GmbH
INFO/CARD #214

Reduced EMI Oscillators

SaRonix' line of true bipolar TTL crystal clock oscillators and VCXOs reduce EMI because of their reduced voltage swing, reduced signal overshoot and lower power supply transients. The S1227 oscillator line is compatible with the AT&T 127-type oscillator family and is available from 0.5 to 34 MHz. The S1527 VCXO line corresponds to the AT&T 127-type VCXO family and is available from 2.5 to 33 MHz with ±100 ppm minimum pullability. Prices in the 1000 piece quantities are $1.50 to $4.00 for the S1227 series and $13.00 to $25.00 for the S1527.
SaRonix
INFO/CARD #213

1150 - 1520 MHz VCO

Z-Communications has introduced the V503MC01 miniature surface mount VCO for earthstation applications in the 1150 to 1520 MHZ region. The V503MC01 delivers 8.5 ±1 dBm into a 50Ω load while drawing less than 30 mA from a 12 VDC supply. Tuning is achieved with a control voltage from 1 to 11 V, with excellent tuning linearity. The VCO comes in Z-Communications' industry standard MINI surface mount package measuring 0.50 × 0.50 × 0.20 inches.
Z-Communications, Inc.
INFO/CARD #212

SIGNAL PROCESSING COMPONENTS

Coaxial Transfer Relay

Coaxial transfer function relay model RTL-SR004 require 40% less actuating current than conventional designs, offer a 30% reduction in height, and operate from a 28 VDC supply. Operating frequency is DC to 3000 MHz. Nominal impedance is 50 Ω, with VSWR less than 1.2:1, insertion loss less than 0.2 dB, and isolation better than 70 dB. The through-hole mounted devices are offered with type N connectors. Price is less than $225 in quantity.

RelComm Technologies, Inc.
INFO/CARD #211

3.0 GHz Attenuator

A new series of miniature 50 Ω coaxial attenuators from Elcom Systems can be used from DC to 3.0 GHz. They are available in SMA, SMB, BNC, and TNC connectors, in 1 dB steps from 1 dB to 10 dB, and in 2 dB steps from 10 dB to 20 dB. They have 0.5 dB accuracy from DC to 2.5 GHz, and 1 dB accuracy from 2.5 GHz to 3.0 GHz. Nominal VSWR is 1.2:1. Elcom Systems Model AT-53-dB/Conn costs $19.50 to $26.00 each in 1 to 24 piece quantities.
Elcom Systems, Inc.
INFO/CARD #210

Miniature CDMA Filter

Part number 854596 is a CDMA subscriber SAW filter measuring only 19 × 6.5 × 1.78 mm. The filter features low profile, surface mount packaging, quartz stability, excellent out-of-band rejection, low phase and amplitude variation, superior triple transit suppression, and low cost. The filter is hermetically sealed in a ceramic surface mount package. Impedance matching is done externally.
Sawtek, Inc.
INFO/CARD #209

Broadband 1P8T Switch

Model 3816-K12 operates over the frequency range of 0.5 to 18.0 GHz. This absorptive 1P8T switch offers minimum isolation of 60 dB, with max. VSWR of 1.8:1 in all states. Switching speed is < 2 μs with 0.5 W average CW power. Control is via 4-bit BDC TTL and operates off +5 and −12

VDC. Size is 4.0 × 1.5 × 0.40 inches. In quantities from 1 to 4, the switch sells for $1,600.00.
Robinson Laboratories, Inc.
INFO/CARD #208

AMPLIFIERS

Television Amplifier
Motorola has announced a high power, solid state class A amplifier, specifically designed for television transposers and transmitter applications. Offering instantaneous broadband capability, the MRFA2600 operates in the frequency range of 470 to 860 MHz. This device is specified at 26.5 V, with a minimum output power of 25 W at 1 dB compression and a minimum small signal gain of 10.5 dB. The amplifier measures 4.5 × 3.3 × 0.5 inches. Price is $1,254.40 in low volumes.
Motorola Semiconductor
INFO/CARD #207

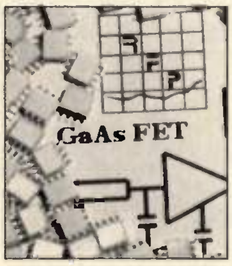
Drop-In Broadband Amps
A line of drop-in amplifiers from Microwave Solutions operate in popular broadbands. These miniature amplifiers have gains ranging from 6 to 11 dB, with output powers from +10 to +18 dBm. Typical current consumption ranges from 35 to 230 mA. The amplifiers are available in K-band, X-band, C-band, and S-band.
Microwave Solutions Inc.
INFO/CARD #206

CDMA Base Station Amp
Model SSPA8689-12/15191 is a low distortion amplifier designed for CDMA modulated carriers used in cellular systems. The amplifier delivers 25 W total average output power (150 W peak) with 32 dBc spectrum degradation in a 1.25 MHz CDMA channel. Gain is 30 dB ±1 dB, with gain flatness across 869 to 894 MHz of ±0.5 dB. Input and output VSWR are 1.5:1. DC power consumption is 9 A at 28 VDC. The air-cooled amplifier is housed in a 9 × 5 × 2.5 inch box.
Microwave Power Devices, Inc.
INFO/CARD #205

Board Mounted Log Amp
Miteq's LIFD series logarithmic amplifiers are now available for installation on printed circuit boards with a VME format. These logarithmic amplifiers utilize Miteq's successive detection logging circuits, providing up to 80 dB of dynamic range in bands from 10 to 350 MHz and linearity from ±0.5 dB. This amplifier supports rise times from 12 ns, making it well suited for most radar applications. The 0.4 inch height chassis meets the VME standard.
Miteq
INFO/CARD #204

SEMICONDUCTORS

2400 MHz GaAs FET
RF Products has announced a family of 2400 MHz, 6.0 V, class A GaAs FET transistors specifically designed for surface mount, wireless power amplifier applications. The GaAs-200-3 provides 2 W of class A output power with 10.0 dB of gain from a 6.0 V supply. Also available are 1 W, 0.5 W, and 0.25 W versions. The GaAs-200-3 is packaged in an economical, high dissipation, ceramic SO-8 surface mount package. Price is $38.00 each in 100 piece qty.



RF Products, Inc.
INFO/CARD #203

Spread Spectrum IC
The S20043 is a single IC transceiver that can send and receive data at rates to 2 Mbps with direct sequence chipping rates near 64 MHz. The programmable IC allows a wide variation of direct sequence psuedo-random noise (PN) codes in lengths from 3 to 2047 and can be programmed for data rates from less than 100 bps to 2 Mbps. Complete packet management is programmable, allowing the IC to independently handle the packet protocol, preamble, error checking, and scrambling. The IC can also control center frequency selection, gain settings, antenna selection, and other configurable characteristics of the radio. Samples will be available in 2Q95. Pricing for the S20043 is $23.50 in volumes of 10,000.
American Microsystems, Inc.
INFO/CARD #202

Tunnel Diode Detectors
Narrow or broadband tunnel diode detectors from Metelics are designed to work between 0.8 and 14.5 GHz. Tunnel diode detectors offer low temperature drift, high sensitivity, low VSWR and excellent flatness. Both positive and negative output polarities are available. These detectors are available in several epoxy sealed drop-in or surface mount packages.
Metelics Corp.
INFO/CARD #201

110 MHz Op Amp
Comlinear has announced the CLC405 and CLC407 op amps, offering low-cost, low-power, and 110 MHz 3 dB bandwidth. The CLC405 offers the standard op amp configuration, while the CLC407 features internal resistors, allowing gain settings of ±1 and +2 with no external resistors.The two op amps feature very fast TTL-compatible enable/disable (18 ns turn-off and 40 ns turn-on times) allowing them to be used in high-speed multiplexing. Differential gain and phase are 0.01%/0.25°, and frequency response is flat to 0.1 dB up to 50 MHz. Price begins at $1.59.
Comlinear Corp.
INFO/CARD #200

950 MHz Video Buffer
The MAX4005 high-speed video buffer provides a trimmed 75 Ω output resistor to minimize reflections while driving cables. A JFET input provides 10 pA input current and differential gain and phase of 0.11% and 0.03°. Gain is flat to within 0.1 dB up to 60 MHz. The MAX4005 is available in an 8-pin SO package. Prices start at $2.75 in quantities of 1000.
Maxim Integrated Products
INFO/CARD #199

TEST EQUIPMENT

Communications Test Set
Hewlett-Packard's HP 8920B can reduce test time by 15 to 30 percent of what it takes when using rack-and-stack equipment. With a 20 MHz μP and a 32-bit data link, the test set is optimized for manufacturers of cellular phones, trunked mobiles, pagers and cordless phones. Several features, including program storage on PCMCIA cards, are designed to speed test times. Performance specifications include: ±1 dB output level accuracy, 5% power measurement accuracy, and 4 to 7 Hz residual FM. Price for the HP 8920B begins at $19,000.
Hewlett-Packard Co.
INFO/CARD #198

VXIbus Chassis
Four major features have been added to Racal Instruments' VXIbus chassis model 1261A+. The enhanced features of the 13-slot, C-size mainframe were implemented to increase the effectiveness of the complete system, to boost reliability, and to reduce and simplify maintenance. The new features are plugable power supplies, cable access holes, occupied-slot-only cooling, and configurable system reset.
Racal Instruments, Inc.
INFO/CARD #197

4 Gsps A/D Board
Gage Applied Sciences has introduced the CompuScope 250 ETS, an 8-bit A/D card with up to 4 Gsps equivalent time sampling. The card is a state-of-the-art, IBM PC XT compatible ISA bus card capable of performing dual-channel, A/D conversion. As the sampling rate of the card is much faster than what the ISA bus can handle, the A/D data is stored in on-board memory, storing up to 8 million samples.

The card comes with GageScope software, which enables the card to be operated like an oscilloscope. CompuScope 250 ETS - 32k is available for $3,995.
Gage Applied Sciences Inc.
INFO/CARD #196

Fault Location Software

Wiltron announces an upgrade of the model 2300-12 distance-to-fault location software for the 68-Series synthesized generators. The software uses the frequency domain reflectometry technique. The software also compensates for cable attenuation.
Anritsu Wiltron Sales Co.
INFO/CARD #195

LabView® Instrument Drivers

Boonton Electronics has developed instrument drivers for LabView. The drivers can be used with the company's Model 4400 peak power meter, Model 4220 and Model 4300 power meters, Model 9200B RF voltmeter, Model 1121 audio analyzer, and Model 8201 modulation analyzer.
Boonton Electronics Corp.
INFO/CARD #194

CABLES & CONNECTORS

45° SMA Adapter

A SMA male to female 45° radius angle

adapter meets all requirements of MIL-C-39012. VSWR is less than 1.15:1 through 18 GHz. The adapter is available in passivated stainless steel.
United Microwave Products, Inc.
INFO/CARD #193

CrimpedCable Connectors

Trompeter Electronics has introduced the PL75MC tool crimp cable connector line. These connectors require only four steps for cable assembly, and the redesigned crimp results in higher cable retention. The connectors are offered with 2-lug, 3-lug, 4-lug, and threaded keyings. The PL75MC are designed to meet or exceed the requirements of MIL-C-49142; category G. Cost is $9.95 in 1000 piece quantities.
Trompeter Electronics, Inc.
INFO/CARD #192

Path Loss and Antenna Gain Elementary Calculations

By Frank L. Egenstafer
American Meter Co.

The path loss equations developed in this article are limited to free space functions, in the interest of simplicity. Including horizontal, vertical and complex path loss reflection equations severely limits the initial learning process. Equations utilized are held to simple, second-order algebraic expressions, though these are thoroughly manipulated. Measurements to confirm the accuracy of the equations were performed using an RF transponder and interrogator designed to comply with FCC regulations and a tape measure to measure path lengths. A few calibration measurements were performed at professional testing labs.

Automatic meter reading of utilities by means of radio waves requires a transmitter/receiver at both ends of the system. The transmitter/receiver at the utility is defined as a transponder and the transmitter/receiver at the other end is called an interrogator. The transponder is a low power, low cost, energy-starved device that encodes the meter readings for transmission to the interrogator and operates under the interrogator's control. The interrogator operates under control of a computer that contains the serial number of the transponders and the routing information pertinent to the location of the transponders.

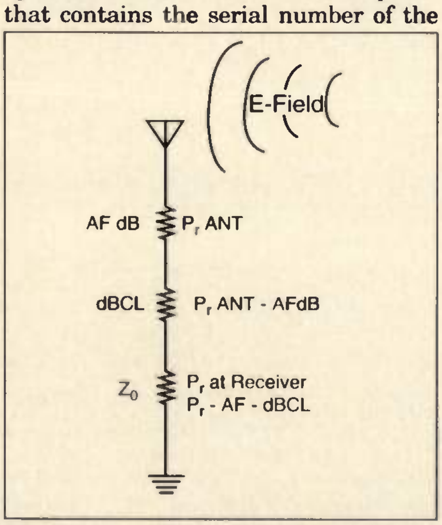


Figure 1. Receiving antenna chain.

An interrogator mounted on a vehicle of some sort is called a mobile interrogator unit, or MIU. Incorporated with the computer in the MIU is dead-reckoning system that uses magnetic wheel sensors and an electronic compass in conjunction with a geographical database of streets and highways to calculate vehicle position.

The transponder is interrogated by a coded transmission from the interrogator, which wakes up the transponder, and it, in turn, transmits the index settings, its serial number and system status codes to the receiver in the interrogator. These codes are then stored in the computer for eventual down loading and customer billing. All the transmitters operating in this system were designed to meet FCC requirements. On the other hand, the receivers and associated antennas were designed to meet system communication requirements and had to perform as well as physically possible.

Since utility meters are randomly located, the RF path from the interrogator to the transponders is rarely line-of-sight. However, since each communication would represent a special analysis and be too complex for usefulness we strive for maximum line-of-sight as a performance measure.

Definitions

Isotropic Antenna – Radiates uniformly in all directions. This is not a real, constructable antenna, rather, its easily calculated theoretical parameters are used as a reference for other antenna's performance. For example, the power gain of the isotropic antenna is defined as 1; a dipole antenna's gain is 1.64 above isotropic. Therefore, a dipole antenna with a gain of 1.64 isotropic has a gain "dB above isotropic"of 10 log 1.64 or 2.15 dB. The above distinction will become important when articles indiscriminately interchange the nomenclature.

The *power density* (Pd) at a point due to *power transmitted* (P_t) by a transmitting antenna with *power gain* (G_t) at a *range* (R) in *meters* is given by:

$$P_d = \frac{P_t G_t}{4\pi R^2} \qquad (1)$$

The effective *area* of an antenna (A) and it's *power gain* (G_r) (for a receiving antenna) is given by:

$$A = \frac{\lambda^2 G_r}{4\pi} \qquad (2)$$

The *power received* (P_r) by an antenna is:

$$P_r = P_d A \qquad (3)$$

Combine equations 1, 2 and 3.

$$P_r = \frac{P_t G_t}{4\pi R^2} \frac{\lambda^2 G_r}{4\pi} \qquad (4)$$

where:

$$\lambda = \frac{300}{f}$$

λ is wavelength in meters and f is frequency in MHz.

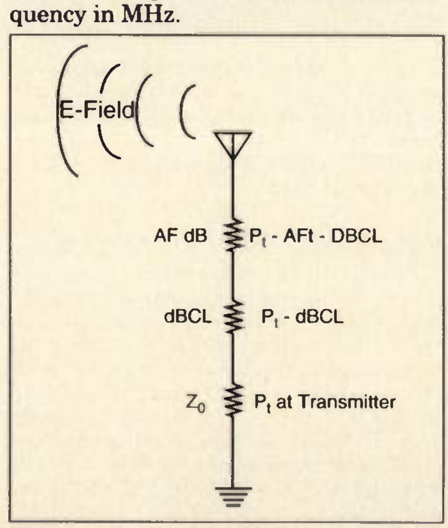


Figure 2. Transmitting antenna chain.

VNA!

VNA Amplifiers +17.5dBm, 0.5 to 2.5GHz only $2.95 (1000 qty.)

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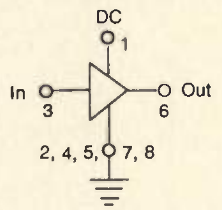

Freq.(GHz)	.5-.8	.8-1.0	1.0-2.0	2.0-2.5
Gain (dB) typ.	14.0	17.0	18.0	16.0
Max. Output (dBm) @1dB Comp. typ.	+18.0	+18.5	+17.5	+17.0
I P 3rd Order (dBm) typ.	+27	+27	+27	+27
VSWR Output typ.	1.5:1	1.7:1	1.7:1	1.5:1
VSWR Input typ.	6.4:1	2.8:1	2.0:1	1.4:1

DC Power.: +5.0V for specified performance.
Current,(mA): 85typ., 105 max.
Thermal Resistance. Junction-to-case: 125° C/W
Price ($) ea. : 2.95 (qty. 1000), 4.95 (qty. 10).

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INFO/CARD 36

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$$\frac{P_r}{P_t} = G_t G_r \left(\frac{300/f}{4\pi R}\right)^2 \qquad (5)$$

Collecting terms:

$$\frac{G_t G_r}{f^2 R^2}(300/4\pi)^2$$

$$\frac{P_r}{P_t} = G_t G_r \frac{569.9316}{f^2 R^2} \qquad (6)$$

The elements of equation 6 may be rearranged and solved for any term as required by the problem at hand.

The logarithmic form of (5) is defined as the *propagation loss*, (dBPL).

$$\text{dBPL} = 10 \log \frac{P_r}{P_t} = \qquad (7)$$

$$10 \log \frac{G_t G_r}{f^2 R^2} \left(\frac{300}{4\pi}\right)^2$$

$$\text{dBPL} = 10 \log G_t + 10 \log Gr - 20 \log f - 20 \log R + 27.558 \qquad (8)$$

The path loss is taken from the power output point of the transmitter to the signal input of the receiver and includes everything between these points, like the antennas, cables, space and any other losses encountered.

Equation 5 is an inverse square law with range. This means every doubling of range deceases received power by one-fourth and the electric field strength by one-half. The equation also shows that the transmission loss increases with the square of the frequency, so that higher gain antennas are required at higher frequencies.

If the antenna power gains in (8) were referenced to a dipole antenna instead of an isotropic antenna, one only has to multiply G_t and Gr in (8) by the power gain of a dipole over an isotropic antenna, which is 1.64.

The electric field strength in V/m and the *power density* , Pd, in W/m at any point are related by (9) where 120π is the resistance of free space (377 ohms).

$$P_d = \frac{E^2}{120\pi} \qquad (9)$$

Recall equation 1

$$P_d = \frac{P_t G_t}{4\pi R^2} \qquad (1)$$

Combine 9 and 1 and solve for R^2.

$$R^2 = \frac{P_t G_t 30}{E^2} \qquad (10)$$

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Combine 10 and 11 which eliminates P_t and G_t.

$$P_r f^2 = E^2 Gr\ 18.9977 \tag{12}$$

Solve equation 12 for each of the elements except f. All of the elements of (12) are associated with activity at the receiving antenna.

The E is the E field at both the receiving and transmitting antennas and will be identified as E_f. The following equations dc not include cable loss in antenna system.

The power received by the antenna as a result of E field generated is:

$$P_r = \frac{E_f^2 G_r\ 18.9977}{f^2} \tag{13}$$

Receiver antenna power gain is:

$$G_r = \frac{P_r f^2}{E_f^2\ 18.9977} \tag{14}$$

The electric field strength received by the antenna is:

$$E_f = f\sqrt{\frac{P_r}{G_r\ 18.9977}} \tag{15}$$

Recall (10) and solve for all the elements. All of the elements of (10) are associated with activity at the transmitting antenna. These equations also do not account for cable loss.

Given an electric field strength, the range can be calculated from:

$$R = \frac{\sqrt{P_t G_t 30}}{E_f} \tag{16}$$

The electric field at range R is given by:

$$E_f = \frac{\sqrt{P_t G_t 30}}{R} \tag{17}$$

The value of P_t based on G_t and the E field at range R is:

$$P_t = \frac{E_f^2 R^2}{30 G_t} \tag{18}$$

The power gain of the transmitting antenna is:

$$G_t = \frac{E_f^2 R^2}{30 P_t} \tag{19}$$

Recall equation 7.

$$10 \log \frac{P_r}{P_t} = \text{dBPL} \tag{7}$$

This expression for path loss is made more useful with a little manipulation. Change dB to the numerical value for calculation.

$$P_t = \frac{P_r}{\log^{-1}(\text{dBPL}/10)} \tag{20}$$

Receiver Antenna-Factor

The antenna-factor in dB is simply a measure of how many volts an antenna will output when placed in a defined electric field. The antenna factor value varies with frequency and is unique for every type of antenna. The antenna factor (AF) is also used to calculate the electric field intensity E_f by measuring the voltage at Z_0 of the receiver.

The antenna factor, in dB, is simply the loss created by the antenna in converting the E field to a voltage.

In developing the equation for the antenna factor, AF we can start by examining Figure 1 where we will convert the E field in V/m into power across the receiver input Z_0.

If you consider that the E field sets up a current in the antenna system which consists of the antenna (AF), the cable loss (dBCL) and the system load Z_0 and if you think of the AF and the cable as resistors, the initial value of the E field will decrease as you go down the system into Z_0, where we measure P_r, and conversely, if we start at Z_0 and go up the system, the value of E will tend to increase until we reach the E field value.

Development of the Receiver Antenna Factor Formula

In Figure 1 start at Z_0 and go up the system. Neglect the cable loss for now. Power received (P_r) is:

$$P_r = \frac{E^2}{Z_0},\quad E = \sqrt{P_r Z_0} \tag{21}$$

However, E is influenced by the antenna factor AF which is in dB, so convert AF(dB) to $\log^{-1}$(AFdB/20) for calculation purposes.

$$P_r = \frac{E^2}{Z_0 \log^{-1}(\text{AF}/20)^2} \tag{22}$$

$$\frac{P_r}{E^2} = \frac{1}{Z_0 \log^{-1}(\text{AF}/20)^2} \tag{23}$$

Recall equation 12 which is associated with activity at the receiving antenna and rearrange the terms as in (23).

$$\frac{P_r}{E_f^2} = \frac{G_r\ 18.9977}{f^2} \tag{24}$$

Combine (23) and (24) to eliminate P_r/E^2

$$\log^{-1}(\text{AF}/20)^2 = \frac{f^2}{Z_0 G_r\ 18.9977} \tag{25}$$

Since we are looking for power, multiply by 10 log and solve for AF.

$$\text{AF(dB)} = 20 \log f - 10 \log Z_0 - 10 \log Gr - 12.79 \tag{26}$$

Convert AF(dB) to the numeric form by applying $\log^{-1}$(AFdB/20).

$$\text{AF(numeric)} = \log^{-1}((20 \log f - 10 \log G_r - 12.79)/20) \tag{27}$$

$$\text{AFn(numeric)} = \log^{-1}(\text{AFdB}/20) \tag{28}$$

$$\text{dBi} = 10 \log G_r \tag{28a}$$

Therefore,

$$G_r = \log^{-1}(\text{dBi}/10) \tag{28b}$$

These are the equations for deriving AF when the antenna gain G_r is given in terms of power, numeric, or dBi gain. From (26) and (28):

$$\text{AF(dB)} = 20 \log f - 29.78 - \text{dBi} \tag{29}$$

This is the equation for deriving the antenna factor when the antenna gain is given in dBi.

There is another equation, not derived, that will give the AFn(numeric) when G_r is given in numeric terms.

$$\text{AF(numeric)} = (9.76/\lambda)\sqrt{G_r} \tag{30}$$

Power at the Antenna and Z_0

Referring to Figure 1 we may calculate P_r(at ant), P_r (at Z_0), AF, E, dBCL, E(at ant) or E(at Z_0) by either defining or measuring the required parameters and utilizing the formulas to follow shortly.

In many cases the system under test is calibrated, so that parameters Z_0, dBCL, and AF are known. In that case, the measurement of E(at Z_0) is an indirect measurement of the E field (E_f) generated by a transmitter under test, such as in the case of FCC measurements.

The analysis of this concept is the same as described in the "Receiver Antenna Factor Concepts" section where the E field sets up a current in the antenna system.

E(at Z_0) or E_f(at ant) are simply the sums of the voltage drops along the resistor strings indicated by Figure 1 and converting the dB values to their numerical form.

$$E(\text{at } Z_0) = E_f/\log^{-1}((AF+dBCL)/20) \quad (31)$$

$$E_f(\text{at ant}) = (E \text{ at } Z_0)\log^{-1}((AF+dBCL)/20) \quad (32)$$

The next set of equations were developed by using $P_r = E^2/R$.

$$P_r(\text{at ant.}) = \frac{E_f(\text{at ant.})^2}{\left(\log^{-1}(AF/20)\right)^2 Z_0} \quad (33)$$

$$P_r(\text{at ant.}) = \frac{\left(E(\text{at } Z_0)\log^{-1}\left(\frac{dBCL}{20}\right)\right)^2}{Z_0} \quad (34)$$

The power form

$$P_r(\text{at ant}) = P_r(\text{at } Z_0)(\log^{-1} dBCL/10) \quad (35)$$

$$P_r(\text{at } Z_0) = P_r(\text{at ant})/(\log^{-1} dBCL/10) \quad (36)$$

The last equation uses the whole antenna string because we are going from Z_0 to E_f to find $P_r(\text{at } Z_0)$.

$$P_r(\text{at } Z_0) = \frac{E_f(\text{at ant.})^2}{\left(\log^{-1}(AF + dBCL/20)\right)^2 Z_0} \quad (37)$$

Transmitter AF Formula

Examination of Figure 2 reveals that:

$$P_t = \frac{E_f^2}{Z_0} \quad (39)$$

The effects of the antenna on the power transmitted are contained in the antenna factor, AF_t. Convert AF_t from logarithmic form (dB) to a simple factor by remembering: $AF_t(\text{dB}) = 20\log(AF_t)$.

$$P_t = \frac{E_f^2}{\left(\log^{-1} AF_t/20\right)^2 Z_0} \quad (40)$$

$$\frac{P_t}{E_f^2} = \frac{1}{\left(\log^{-1} AF_t/20\right)^2 Z_0} \quad (41)$$

Recall equation 18, rearranging the terms as in equation 41:

$$\frac{P_t}{E_f^2} = \frac{R^2}{30G_t} \quad (42)$$

Combine equations 41 and 42

$$\frac{R^2}{30G_t} = \frac{1}{\left(\log^{-1} AF_t/20\right)^2 Z_0} \quad (43)$$

$$R^2(\log^{-1} AF_t/20)^2 Z_0 = 30\, G_t \quad (44)$$

Take the log of both sides and multiply by 10 to return to the decibel form:

$$-AF_t(\text{dB}) = 10\log G_t - 20\log R - 10\log Z_0 + 14.77 \quad (45)$$

The antenna factor is calculated by looking out through the antenna for both transmitting and receiving antenna factors. The signal level after the antenna is smaller than the signal level before the antenna, hence, AF_t is negative. The numeric form of AF_t(dB) is:

$$AF_{tn}(\text{numeric}) = \log^{-1}(-AF_t(\text{dB})/20) \quad (45)$$

These are the formulas for the transmitter antenna factor.

Calculating P_t and E_f from AF

In this case P_t sets up the current in

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Transponder		
Receiver sensitivity @ 451.15 MHz (AM) =		
-60 dBm	223.6×10^{-6} V	1.0×10^{-9} W
Power output @415 MHz (FM) =		
-5 dBm	125.7×10^{-3} V	316×10^{-6} W
Portable interrogator		
Receiver sensitivity @ 451 MHz (FM) =		
-100 dBm	2.236×10^{-6} V	100×10^{-15} W
Power output @415.15 MHz (AM) =		
$+31.6$ dBm	8.544 V	1.46 W
Mobile Interrogator		
Receiver sensitivity @ 451 MHz (FM) =		
-112 dBm	561.7×10^{-9} V	6.31×10^{-15} W
Power output @415.15 MHz (AM) =		
$+37$ dBm	15.8 V	5.0 W

Table 1. System component specifications.

the antenna and creates the E field (E_f). Remember the sign of AF_t is negative and that AF_t is in dB.

$$P_t(\text{at ant.}) = \frac{\left((E \text{ at } Z_0)(\log^{-1} - \text{dBCL}/20)\right)^2}{Z_0} \tag{46}$$

$$P_t(\text{at ant}) = P_t(\text{at } Z_0)(\log^{-1} - \text{dBCL}/10) \tag{47}$$

$$P_t(\text{at } Z_0) = \frac{P_t(\text{at ant.})}{\log^{-1} - \text{dBCL}/10} \tag{48}$$

$$P_t(\text{at } Z_0) = \frac{E_f(\text{at ant.})^2}{Z_0 \log^{-1}(AF_t - \text{dBCL}/20)^2} \tag{49}$$

$$Ef(\text{at ant}) = E(\text{at } Z_0)(\log^{-1} | AF_t - \text{dBCL}/20 |) \tag{50}$$

$$E(\text{at } Z_0) = \frac{E_f(\text{at ant.})}{\log^{-1}|AF_t - \text{dBCL}/20|} \tag{51}$$

When the terms are expressed in dBm, simply add the terms. P_t is dBm, AF is dB and dBCL is dB.

TRACE Automatic Meter Reading System

With the TRACE Automatic Meter Reading System we have three components that must be FCC certified; the transponder which transmits FM at 415 MHz and receives AM at 451 MHz, the portable interrogator (PI) which transmits AM at 951 MHz and receives at FM 415 MHz and the MIU which transmits AM at 451 MHz and receives FM at 415 MHz.

The equations we have acquired so far will permit us to calculate the antenna gains, path losses or the range in meters or feet between the elements of the system – but only for line-of-sight communications.

The information we have at hand is the sensitivity of each receiver, the output power of each transmitter, the distance used in FCC testing and the range of reliable line-of-sight communication between the various components of the system.

The determination of antenna gain and path loss values require both accurate field strength measurements and accurate distance measurements. However when working with transmitters and receivers, where only the upper limits are dictated by FCC regulations, and field tests are only carried out on a few units, predicting the communication range between any two units is only possible to within tens of feet or more, and only in an unobstructed straight line.

System Component Specifications

Table 1 shows the various devices' power outputs and sensitivities.

The transponder antenna is an integral part of the whole unit and simultaneously serves as both the receiving and transmitting element. The capacitance "top hat" is 3 1/2" by 2 1/4" mounted on a chassis and circuit board for an overall unit size of 4" wide x 2" deep by 3 1/4" high.

The PI antenna is a commercially available 1/4 wavelength whip selected for 415 to 451 MHz and serves as both the transmitting and receiving antenna.

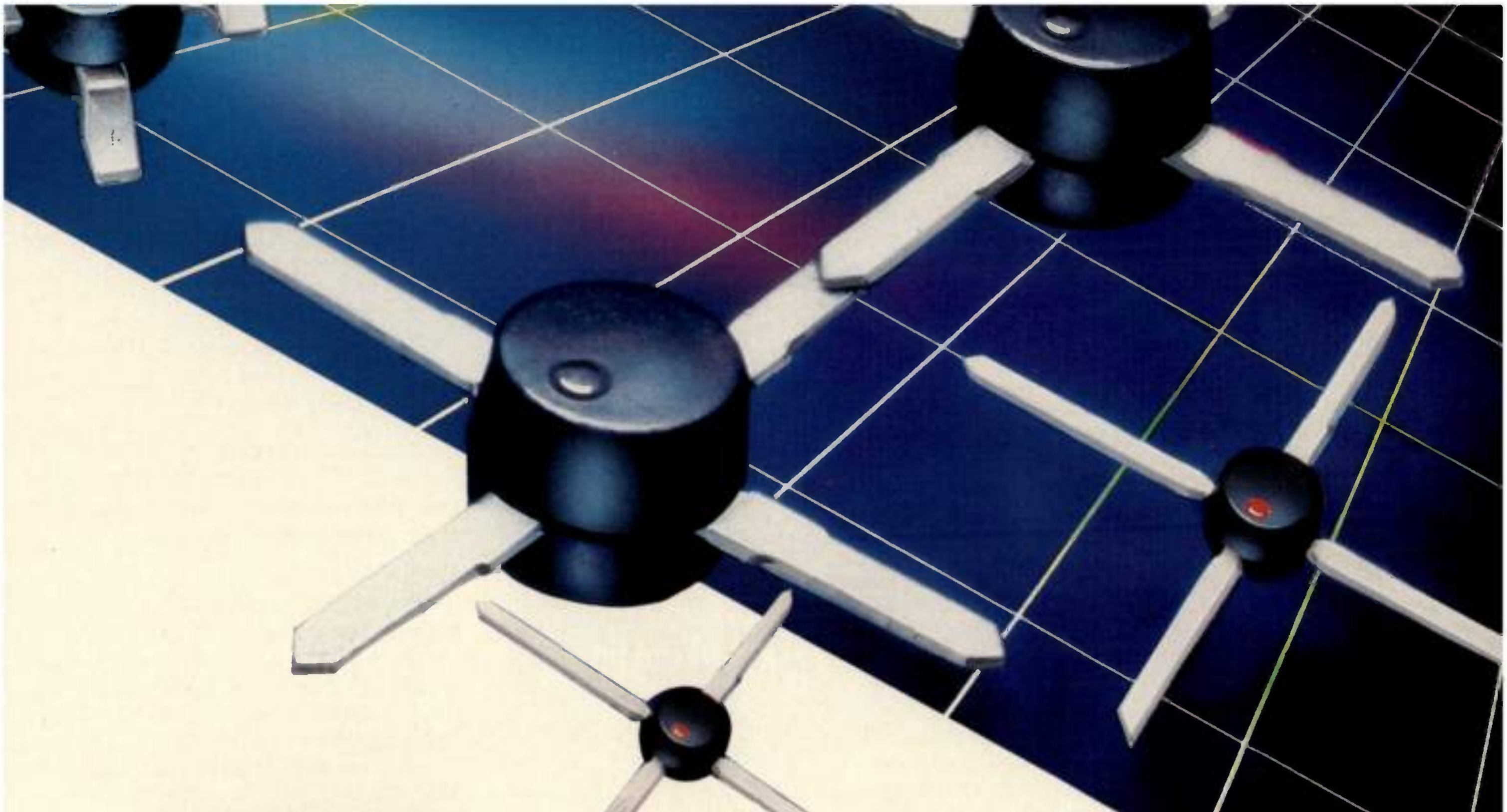
The MIU uses separate, roof mounted 1/2 wave receiving and transmitting antennas.

The first step in the testing program is to measure the field strength of the three transmitters in µV/m at 3 m. From that accurate information we then calculate the power gain (G_t) of the three transmitting antennas. The next step is to determine, by field measurement, the reliable line-of sight communication range in meters, between the portable interrogator (PI) and the transponder. From that information, we can then calculate the receiving antenna power gains of both units.

The reliable line-of-sight range of the MIU and transponder is then field tested. These three units were all tested to insure their compliance with applicable FCC regulations relative to either field strength at 3 m or RF power output.

Problems And Solutions

When using a calibrated receiving antenna to measure the E field at three meters, the G_t value of the transmitting antenna is very accurate because there are no reflections and



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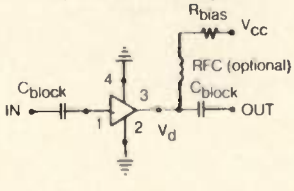
120x60	.022, .047, .068, .1 µf

Typical Circuit Arrangement



	MODEL	Freq. (MHz) DC TO	GAIN (Typ. dB) At 100MHz	MAX. Power (@ 1dB Compr.) dBm	NF dB (Typ.)	Price $ea. (Qty. 50)
MAR	MAR-1	1000	18.5	1.5	5.5	.99
	MAR-2	2000	12.5	4.5	6.5	1.35
	MAR-3	2000	12.5	10.0	6.0	1.45
	MAR-4	1000	8.3	12.5	6.5	1.55
MAR SM	MAR-6	2000	20.0	2.0	3.0	1.29
	MAR-7	2000	13.5	5.5	5.0	1.75
	MAR-8	1000	32.5	12.5	3.3	1.70
RAM	RAM-1	1000	19.0	1.5	5.5	*6.40
	RAM-2	2000	12.5	4.5	6.5	*6.40
	RAM-3	2000	12.5	10.0	6.0	*6.40
	RAM-4	1000	8.5	12.5	6.5	*6.40
	RAM-6	2000	20.0	2.0	2.8	*6.40
	RAM-7	2000	13.5	5.5	4.5	*6.40
	RAM-8	1000	32.5	12.5	3.0	*6.40
MAV	MAV-1	1000	18.5	1.5	5.5	1.10
	MAV-2	1500	12.5	4.5	6.5	1.40
	MAV-3	1500	12.5	10.0	6.0	1.50
	MAV-4	1000	8.3	11.5	7.0	1.60
MAV SM	MAV-5SM	50-1500	8.0	18.0	6.5	2.07
	MAV-11	10-1000	12.7	17.5	3.6	2.10
VAM	VAM-3	2000	11.5	9.0	6.0	1.45
	VAM-6	2000	19.5	2.0	3.0	1.29
	VAM-7	2000	13.0	5.5	5.0	1.75

*Qty. 10
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INFO/CARD 19

the effects of angle of propagation for the transmitting antenna are not apparent at three meters. However, measurements of the receiving antenna's G_r occur at some range R, which is much farther than three meters.

Since the transmitted wave is usually propagated at an angle above the horizon, one may increase the reliable range of communication, R, by raising the height of the receiver. It is easy to see that this measurement must have some physical rules or constraints in order to establish a repeatable or meaningful receiver antenna gain (G_r) value. Therefore, the receiver antenna gain formulas specify a range and height. It's apparent that the receiver gain (G_r) calculations are not as neat as the 3 meter transmitter calculations, but they are still very useful in evaluation of performance.

Testing Lab Receiving Antenna:
AF = 21, Gr = 1.4392 @ 415 MHz
Cable Loss, Receiving Antenna:
dBCL = 2.8 dB, 1.38 numeric
Transponder Output Power:
Pt = 316 x 10–6 W
Range Between Antennas:
R = 3 meters
Signal Level Received:
E = 0.032 V/m @ 3 m
System Impedance:
50 Ω

Table 2. Parameters for transponder transmitting antenna power gain measurement.

Example 1. Transponder Transmitting Antenna Power Gain

The transponder is put in constant transmit. The signal is measured via the test lab antenna. Table 2 shows the known parameters.

Equation 19 is the simplest approach to a solution. P_r in this example is the power received by the test lab antenna. The missing information required to solve (7) is P_r(at ant) of the receive antenna, that may be calculated by using either (12) or (33)

$$P_r = E^2 G_r (18.9977)/f^2 \qquad (12)$$

$$= \frac{0.032^2(1.4392)(18.9977)}{415^2}$$

$$= 162.6784 \times 10^{-9}\ \mathrm{W}$$

$$P_r = \frac{E^2}{Z_0 \log^{-1}(AF/20)^2} \qquad (33)$$

$$= \frac{0.032^2}{(\log^{-1}(21/20))^2 50}$$

$$= 162.6784 \times 10^{-9}\ \mathrm{W}$$

$$G_t = \frac{P_r f^2 R^2}{569.9316(P_t)(G_r)} = \qquad (7)$$

$$= \frac{(162.6784 \times 10^{-9})415^2 3^2}{569.9316(316 \times 10^{-6})(1.4392)}$$

$$G_t = 0.9728$$

To find P_r(at Z_0) of the test receiver use equation 36 which includes the effect of the cable (dBCL) in the receiving antenna listed previously as 2.8 dB.

$$P_r(\text{at } Z_0) = \qquad (36)$$
$$P_r(\text{at ant})/(\log^{-1} -\text{dBCL}/10)$$
$$P_r(\text{at } Z_0) = 162.6784/(\log^{-1} -2.8/10)$$
$$P_r(\text{at } Z_0) = 85.3748 \times 10^{-9}\ \mathrm{W}$$

However only the voltage at the

receiver was known, as in most real test situations, then P_r could be calculated by using equation 34.

$$P_r(\text{at ant}) = \left(E(\text{at } Z_0)\log^{-1}(\text{dBCL}/20)\right)^2 \Big/ Z_0 \qquad (34)$$

Convert P_r(at Z_0) to a voltage:

$$E = \sqrt{P_r Z_0}$$

From equation 34

$$E(\text{at } Z_0) = \sqrt{P_r(\text{at } Z_0) Z_0} = \sqrt{50\left(85.3748\times10^{-9}\right)} = \qquad (21)$$

2.066×10^{-3} V

which is the sensitivity of the receiver. This is 2066 µV; because we are only working 3 meters away, this is a reasonable value.

$$P_r(\text{at ant.}) = \frac{\left(2.066\cdot\left(\log^{-1}2.8/20\right)\right)^2}{50} = \qquad (33)$$

162.6784×10^{-9} W

Transmitting-Antenna AF and Electric Field

Since this is a transmitting antenna calculate AF_t using equation 44.

$AF_t(\text{dB}) = 10 \log G_t - 20 \log R - 10 \log Z_0 + 14.77$ (44)

$AF_t(\text{dB}) = 10 \log 0.9728 - 20 \log 3 - 10 \log 50 + 14.77$

$AF_t(\text{dB}) = -11.88$

AFt(numeric) = 0.25468

Close the loop by calculating E_f(at ant) from (32). Let dBCL = 0.

$E_f(\text{at ant}) = E(\text{at } Z_0)(\log^{-1} |AFt - dBCL/20|)$ (32)

Since P_t is given as 316×10^{-6} watts,

$$E = \sqrt{316\times10^{-6}(50)}$$

$E(\text{at } Z_0) = 0.1257$ volts

$E_f(\text{at ant}) = (0.1257)(\log^{-1} -11.88/20)$

$E_f(\text{at ant}) = 0.032$ volts,

which is the value of the E field measured at three meters.

Example 2. PI Transmitting Antenna Power Gain

The PI is put in constant transmit, and the signal is measured via the testing lab receiving antenna. Table 3 shows the known parameters. We again use equation 19

$$G_t = \frac{E_f^2 R^2}{30 P_t} \qquad (19)$$

$$= \frac{1.64^2 3^2}{30(1.46)} = 0.5527$$

The power gain of the PI transmitting antenna $G_t = 0.5527$

We now utilize (12) to find the power received (P_r) at the test lab receiving antenna and then use equation 33 to calculate P_r based on the antenna factor (AF=21.8 dB) and then use (7) to calculate G_t. The result will be equal to the value obtained from (19). P_r is the power received by the test lab antenna.

$$P_r(\text{at ant}) = \frac{E^2 G_r\, 18.9977}{f^2} \qquad (13)$$

$$= \frac{1.64^2 1.414(18.997)}{451.10^2}$$

P_r(at ant)= 355.05×10^{-6} watts at the receiving antenna.

Testing Lab Receiving Antenna:
AF = 21.8, Gr = 1.414 @ 451.1 MHz
Cable Loss, Receiving Antenna:
dBCL = 3 dB
PI Output Power:
Pt = 1.46W
Range Between Antennas:
R = 3 meters
Signal Level Received:
E = 1.64 V/m @ 3 m
System Impedance:
50 Ω

Table 3. Parameters for PI transmitting antenna power gain measurement.

Calculate P_r from the antenna factor using (33):

$$P_r(\text{at ant}) = \frac{E_f^2(\text{at ant})}{Z_0(\log^{-1} AF/20)^2} \qquad (33)$$

$$= \frac{1.64^2}{50(\log^{-1} 21.8/20)^2}$$

P_r(at ant) = 355.05×10^{-6} watts at the receiving antenna.

We now solve (7) to find G_t of the PI transmitter antenna:

$$G_t = \frac{P_r f^2 R^2}{569.9316(P_t)(G_r)} \quad (7)$$

$$= \frac{355.06 \times 10^{-6} 451.1^2 3^2}{569.9316(1.46)(1.414)}$$

G_t = 0.5527 PI transmitter antenna power gain.

Now find P_r(at ant) of the receiving antenna utilizing equations 36 and 34.

$P_r(\text{at } Z_0) =$ (36)
P_r(at ant)/(log^{-1} dBCL/10)
$P_r(\text{at } Z_0) = 355.05 \times 10^{-6}/(\log^{-1} 3/10)$
$P_r(\text{at } Z_0) = 177.9477 \times 10^{-6}$ W

Convert $P_r(\text{at } Z_0)$ to a voltage:

$$E(\text{at } Z_0) = \sqrt{P_r(\text{at } Z_0) Z_0} \quad (21)$$

$$= \sqrt{50(177.9477 \times 10^{-6})}$$

$$= 94.326 \times 10^{-3} \text{ V}$$

Include the 3 dB of cable loss:

$$P_r(\text{at ant}) = \quad (34)$$

$$\left(94.326 \times 10^{-3}\left(\log^{-1} \text{dBCL}/20\right)\right)^2 / Z_0$$

$$P_r(\text{at ant}) =$$

$$\left(94.326 \times 10^{-3}\left(\log^{-1} 3/20\right)\right)^2 / 50 =$$

$$355.05 \times 10^{-6} \text{ W}$$

This is the same value we calculated using equation 33

PI Transmitting Antenna AF and Electric Field

Calculate AF_t from equation 45:

$AF_t = 10 \log G_t - 20 \log R -$ (45)
$10 \log Z_0 + 14.77$
$AF_t = 10 \log 0.5527 - 20 \log 3 - 10 \log 50 + 14.77$
$Af_t = -14.3375$ dB
AF_t(numeric) = log^{-1} (–14.34)= 0.1918

Close the loop by calculating E_f(at ant) from 50:

Ef(at ant) = E(at Z_0)(log^{-1} | AF_t + dBCL/20 | (50)
Let dBCL = 0. Since P_t is given as 1.46 watts –

$$E = \sqrt{1.46(50)} \quad (21)$$

E(at Z_0) = 8.594 V
E_f(at ant) = (8.544)(log^{-1} | –14.3375/20 |

Specified and Measured Parameters:
PI Transmitter Output Power:
Pt = 1.46 W, 31.674 dBm
Transponder Receiver Sensitivity:
Pr = 1.0 × 10^{-9} W, –60 dBm
Range from PI to Transponder:
R = 457.4 m, 1500 ft.
Frequency:
f = 451.15 MHz
Calculated Parameters:
PI Transmitter Ant. Power Gain:
Gt = 0.5527

Table 4. Transponder receiver antenna power gain measurement parameters

E_f(at ant) of the PI = 1.639 V

Even though electric field at the transmitting and receiving antennas were calculated to be the same, the equations can still be considered accurate. This is because for measurements at a range of only three meters, a very accurate measurement would have to be made to see a difference in the calculated electric field strengths.

Example 3. Transponder Receiver Antenna Power Gain

In this situation the reliable communication range between the PI to the Transponder is established by field testing, and the range measured is used to calculate the power gain G_r of the transponder receiver antenna. Table 4 shows the known parameters.

Since the path loss is taken from the power output point of the transmitter to the signal input of the receiver, the P_r or power received element of (6) may utilize the sensitivity value of the transponder receiver, 1.0 × 10^{-9} watts.

$$G_r = \frac{P_r f^2 R^2}{569.9316(P_t)(G_t)} \quad (6)$$

$$= \frac{1.0 \times 10^{-9} 451.15^2 457.4^2}{569.9316(1.46)(0.5527)}$$

G_r = 0.0926, the transponder receiver antenna power gain.

Use equation 26 to calculate AF of the transponder receiver antenna.

AF(dB) = 20 log f – 10 log Z_0 (26)
– 12.79 – 10 log G_r
AF(dB) = 20 log 451.15 – 10 log 50 – 12.79 – 10 log 0.0926
AF = 33.64 dB
AF_n = log^{-1}(33.64/20) = 48.08

Now use equation 17 to calculate the E field (E_f) at 457.4 meters.

$$E = \frac{\sqrt{30(P_t)(G_t)}}{R} = \quad (17)$$

$$\frac{\sqrt{30(1.46)(0.5527)}}{457.4} = 0.00959 \text{ V}$$

Now calculate P_r(at ant) using equation 33 which should equal the sensitivity value assigned to the transponder.

$$P_r(\text{at ant}) = \frac{E(\text{at ant})^2}{50\left(\log^{-1} AF/20\right)^2} = \quad (33)$$

$$\frac{0.00959^2}{50\left(\log^{-1} 33.64/20\right)^2}$$

P_r (at Ant) = 7.967 × 10^{-10} W, which equals –60.987 dBm. The specification for the transponder sensitivity is –60 dBm.

Calculate E(at Z_0) using 21.

$$E(\text{at } Z_0) = \sqrt{P_r Z_0} =$$

$$\sqrt{50(7.967 \times 10^{-10})} = 199.58 \times 10^{-6} \text{ V}$$

Calculate E(at ant) using (32) to confirm the value found previously.

E_f(at ant) = Ef(at Z_0)(log^{-1} AF/20) (32)
E_f(at ant) = (199.58 × 10^{-6})(log^{-1} 33.64/20) = 0.00959 V

Example 4. Communication Range From Transponder To MIU

In this exercise we will use known antenna gains and circuit parameters (some measured, some specified, and others calculated) to determine the communication range from the transponder to the MIU. Table 5 shows the known parameters for the transponder and MIU.

The commercial receiving antenna on the MIU is specified for a gain of 5 dBi at 415 MHz. This converts to a power gain, from equation (48), of: G_r = (log^{-1} dBi/10) = 3.16.

If we use equation (16) to solve for R we will first have to calculate Ef which is by definition equivalent to the sensitivity of the receiver in volts. Since P_r has been specified we will convert it to a voltage, E_f, and solve (16).

$$E = \sqrt{P_r Z_0} = \quad (21)$$

$$\sqrt{50(6.31 \times 10^{-15})} = 5.62 \times 10^{-7} \text{ V}$$

However this is E(at Z_0) and we want E(at ant), the value of which will be increased by the AF in the direction

Transponder Parameters:	
Frequency = 415 MHz	specified
Pt = 316×10^{-6} W, –5 dBm	meas. or spec.
Gt = 0.9772	calculated
AFt = –11.88 dB	calculated
Ef(at ant) = 0.032 V	measured at 3 m
MIU Parameters	
Receiver Sensitivity = –112 dBm	measured
Gr = 3.16	specified
AF = 17.58 dB; AFn = 7.57	calculated

Table 5. Transponder and MIU parameters for range calculation.

we are going. Use equation 32 to solve for E(at ant).

$$E(\text{at ant}) = E(\text{at } Z_0)(\log^{-1}(AF + dBCL/20)) \quad (32)$$

$$E(\text{at ant}) = (5.62 \times 10^{-7})(\log^{-1} 17.58/20) = 4.25 \times 10^{-6}\ V$$

Now to equation 16.

$$R = \frac{\sqrt{30(P_t)(G_t)}}{E} = \quad (16)$$

$$\frac{\sqrt{30\left(316 \times 10^{-6}\right)(0.9772)}}{4.25 \times 10^{-6}}$$

Range = 22,674 meters (74,281 feet)

This range is optimistic because of various factors not covered in this article.

Try checking the answer by using (6) which uses all of the parameters.

Where are the Losses?

For this analysis we will use the information calculated in communicating from the PI to the transponder at 457.4 meters.

The total path loss between the PI and the transponder is taken from the power output point of the transmitter to the signal input point of the receiver.

In this discussion the path loss is given by equation 7:

$$dBPL = 10 \log \frac{P_r}{P_t} = \quad (7)$$

$$10 \log \frac{1.0 \times 10^{-9}}{1.46} = -91.64\ dB$$

Therefore if the total loss is –91 64 dB and we add the sum of the antenna factors for each antenna, which in this case is, AF(total) = –14.34 for the transmitter and –(+33.64) the receiver, we get an over the air 457.8 meter path loss of only 43.66 dB. The rest of the –91.64 dB or 47.97 dB is lost in the antenna system. If these antenna systems included cable losses the numbers get worse.

Conclusion

Look to improving your antenna for increased communication range. *RF*

Bibliography

Reference Data For Radio Engineers Howard W. Sams ITT

About the Author

Frank Egenstafer's background in electronics has been circuit design from DC to 2 GHz, and from relays and stepper switches to vacuum tubes and transistors. he has mostly worked on the "bench", even in the several managerial positions he has enjoyed. He attended Drexel Institute in Philadelphia. He can be reached at (304) 562-6582.

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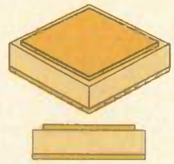

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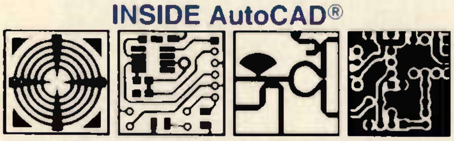

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RF Power Amplifiers Move from Defense into Commercial Markets

This month the product forum highlights the market changes affecting RF power amplifiers. Several manufacturers offer their opinions regarding today's marketplace and trends in the industry.

Milcom International

We at Milcom International of Irvine, CA believe the wireless marketplace will continue to grow at an accelerated pace spurred by the transition from analog to digital systems. Key technologies required are very linear amplifiers for TDMA, CDMA, Microcell and multichannel repeater applications, primarily for ESMR, cellular, and paging in the domestic, Pacific Rim, Eastern European and South American markets. The future is in PCN applications as the industry converts to wireless local area networks.

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Amplifier Research

Donald R. Shepherd, President of Amplifier Research (Souderton, PA), sees a strong market for at least the next five years, driven largely by the need for high-performance amplifiers in testing for RF susceptibility. "The sharp transition from military to commercial communications products has finally brought home the vital importance of keeping wireless products such as portable phones, pagers, even remote-actuated door locks in cars immune to interference from other mobile devices," he points out.

"The Europeans really forced the issue, setting standards of immunity for products which could be sold to the European market. We're happy about that, because other manufacturers will now have to scramble to catch up with the quality level we've imposed on ourselves for 25 years. You now have to prove that your amplifier will actually deliver the rated power across the bandwidth — a problem we've never had."

Amplifier Research's equipment "package": RF power amplifier, antenna, and field monitoring system.

"It's becoming increasingly important for a test-equipment supplier to provide a complete package that will deliver a field of 10, 50, 100, or 200 volts/meter for susceptibility testing in a shielded room. The supplier who can deliver the whole package — RF power amplifier, antenna, and field-monitoring equipment — will have a clear advantage."

Instruments for Industry

The market as we knew it has changed. In the 80s, the EMC market was defense driven (about 40 percent market share). Today the commercial side dominates. The companies who communicate with this new breed of EMC engineer should show moderate growth. The market as we know it today is 25 percent defense, 25 percent automotive, 35 percent commercial, and 15 percent other. There is only a 5 percent increase in the total market. Most of the growth in the commercial market has been offset by the 15 percent decline in the defense side.

The largest changes have been in off-shore sales compared with US sales. This ratio has reversed from 60/40 for US sales to 60/40 in favor of foreign sales, and is increasing. The other noticeable shift has been in amplifier wattage; there is now more interest below the 100 watt level than before.

The key application is IEC 801; this regulation dominates trade shows and publication seminars. I foresee moderate growth for the next two to three quarters, then a slight fall off as the requirement subsides. Real growth will come with the commercial market, plus additional defense spending, and the emergence of the medical market. IFI provides the customer with an amplifier that accommodates the broadest frequency range, and a product line that allows the customer to select very basic models or fully automated systems.

Kalmus Engineering, Inc.

For the past two to three years, we have noticed a definite increase in applications requiring RF power amplifiers. In fact, our records show an increase of more than double for this year over 92-93, in spite of the fact that the NMR/MRI business has fallen off sharply.

EMC (mostly in Europe) and communications are leading the pack and should continue to do so for at least the next three to five years. The new CE Marking directive has created a new demand for RF power amplifiers and associated hardware (antennas, field sensors, chambers, etc.), keeping the manufacturers of this equipment busy

for years to come. The MOSFET has just about replaced the vacuum tube in the 10 kHz to 220 MHz bandwidth up to a 1000 watts power output.

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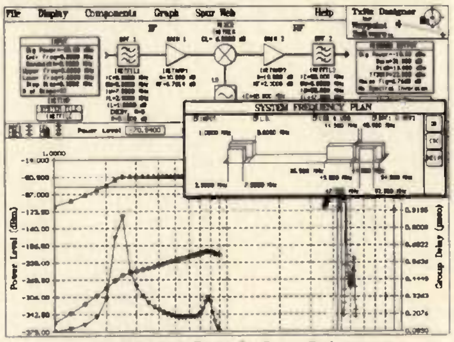

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Job Number: 94RTP-24.

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Job Number: 94RTP-68.

Sr. Audio/Acoustic Engineer

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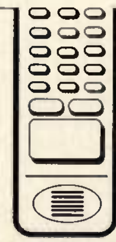

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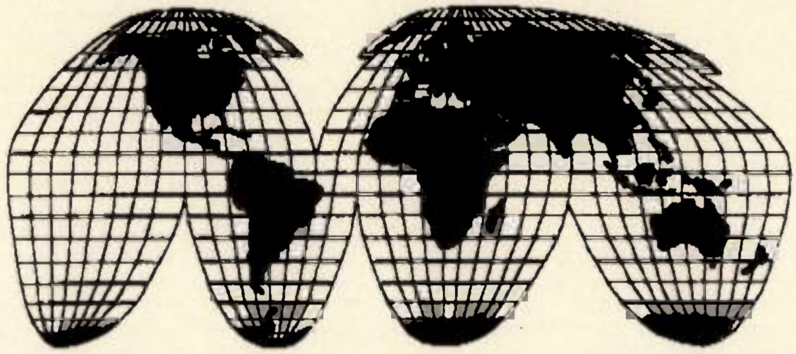

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DC TO LIGHT, P.O. Box 7140, Bozeman, MT 59771................. (406) 586-5399 Fax (406) 586-6556

SERVICES

ANTENNA MEASUREMENT SYSTEMS
Jef Consultants, Inc., 8501 Beck Rd., Bldg. 2227, Belleville, MI 48111-1254 ......(313) 482-5505

ANTENNA DESIGN & MEASUREMENT
Antenna Design Specialists, 1171 Melayn Dr., Lebanon, OH 45036..........................(513) 932-3385

CONSULTANTS
Management Recruiters of Boulder ....Fax (303) 447-9536 Tel (303) 447-9900
Windy Bradfield CSAM, Bob Sund ....
Goldman Research, 12705 Monfort, Dallas, TX 75230..........................(214) 788-1122
RF Design & Modeling – Spice, EEsof, Wireless ....WNJU80A@PRODIGY.COM

EMC/EMI TESTING
Liberty BEL EMC SVCS., P.O. Box 5431, MS20, Compton, CA 90224 ....(310) 537-4235
Above MS20 represents RF Design

EQUIPMENT CALIBRATION
Instrument Repair Labs, Inc., 2100 W. 6th Ave., Broomfield, CO 80020 ....(800) 345-6140

INSTRUMENT RENTAL/LEASING
Naptech, 12312 Hwy 175, Cobb, CA 95423..............................(800) 336-7723 Fax (707) 928-1963

OEM PRODUCTS
Locus, Inc., 1842 Hoffman St., Madison WI 53704..(608) 244-0500

TELEMETRY SYSTEMS & ENGINEERING
Telemetry Technologies, Inc., 3307 West St., Rosenberg, TX 77471 ....(713) 344-9000

DIGITAL SIGNAL PROCESSING

SYSTEMS DEVELOPMENT REAL TIME
Adaptive Technology, Inc., 309 Curtis St., Syracuse, NY 13208....(800) 724-6968 Fax (315) 472-3279

RF literature

Amplifier Catalog

A 66-page catalog from Microwave Solutions provides information on their low-noise, broadband, high and medium power, communications band, and special product amplifiers. Specifications listed include frequency range, noise figure, power and gain.
Microwave Solutions, Inc.
INFO/CARD #190

RF CAD System Brochure

Compact Software offers a brochure describing their PC/Windows-based Serenade 6.5 software for integrated RF, microwave and lightwave design. Serenade software includes schematic capture, linear or nonlinear frequency domain simulation, simulation libraries and optional physical design software tools. The eight-page, color document describes the different stages of the design process and how the different software tools are integrated.
Compact Software
INFO/CARD #189

Ceramic Capacitor Catalog

Republic Electronics' 33-page catalog gives electrical and mechanical specifications for their lines of ceramic capacitors, Ultra-Q ceramic capacitors, and single-plate Beta capacitors. Included in Republics' standard ceramic capacitor line are high-reliability, high-voltage, temperature compensating and NPO capacitors.
Republic Electronics Corp.
INFO/CARD #188

High-Frequency ASIC Development

Maxim's *High Frequency ASIC Development Handbook* introduces their high-frequency ASIC capabilities for semi-custom arrays, full custom, and multichip module designs. Maxim's high performance bipolar and complementary bipolar processes, with F_t's up to 27 GHz, are described. Sections covering Maxim's QuickChip and Full Custom IC design approaches are included, as are sections covering software design tools and hybrid design.
Maxim Integrated Products
INFO/CARD #187

PTFE/Composite Materials

A series of technical data sheets on its frequency-matched PTFE laminated circuit board materials is now available from Arlon. Full descriptions of composition, advantages, electrical and mechanical properties are available in the data sheets for DiClad®, CuClad®, IsoClad®, AR Series®, Epsilam 10®, and CLTE® materials.
Arlon, Materials for Electronics Div.
INFO/CARD #186

Standards Catalog

Global Engineering Documents offers the 1995 EIA/TIA catalog. The latest edition of the catalog has nearly 50 new and revised EIA and EIA/TIA Standards, Interim Standards, JEDEC Standards and related engineering documents and publications published by the Electronic Industries Association and the Telecommunications Industry Association.
Global Engineering Documents
INFO/CARD #185

DSP Reference

A 657-page DSP reference book published by Prentice Hall and Analog Devices is now available. *Digital Signal Processing Applications Using the ADSP-2100 Family, Volume 2* contains twelve chapters of new applications as well as useful information on how to use the ADSP-2100 family of 16-bit fixed-point DSPs. Analog Devices' retail selling price for the book is $30.
Analog Devices Literature Center
INFO/CARD #184

Capacitor Market Report

World Information Technologies has released its study, *Electronic and Electrical Capacitors U.S. Markets, Technologies and Opportunities: 1994-1999 Analysis and Forecasts*. The 136-page report, containing 91 tables, segments the U.S. market for all types of capacitors according to capacitor technology/product category, geographic area and end-use markets.
World Information Technologies, Inc.
INFO/CARD #183

Frequency Control Products

A six-page selection guide from SaRonix greatly facilitates the task of finding the best quartz crystal, oscillator or VCXO for the application, be it computer, networking, data/telecommunications or wireless communications. The guide covers a wide range of metal, ceramic and plastic packaged quartz crystals, oscillators and VCXOs, with frequencies from 32 kHz to 622.08 MHz.
SaRonix
INFO/CARD #182

SMT-Product Catalog

M-tron offers a 40-page catalog devoted exclusively to surface-mount products. Included are complete descriptions and specifications for: microprocessor crystals, AT strip crystals, high-frequency fundamentals, crystal products for extreme environments, microprocessor clock oscillators, clock oscillators utilizing strip crystal capabilities, and oscillators designed to withstand harsh environments.
M-tron Industries, Inc.
INFO/CARD #181

Crystal Oscillators

Vectron's 79-page handbook and catalog contains specifications for their lines of clock and sinewave oscillators, TCXOs, OCXOs, VCXOs/VCOs, and Sonet/SDH clock recovery devices. Also discussed are Vectron's capabilities, and a section describing phase noise and phase noise measurements.
Vectron Laboratories, Inc.
INFO/CARD #180

Keeping Up With Technology!

Call for Papers: RF Expo East 1995

August 21-23, 1995
Baltimore Convention Center
Baltimore, Maryland

Suggested Topics

Although any RF-related subject is a valuable addition to our technical program, the following areas are of special interest to RF engineers right now:

Wireless Data Communications
Low-Cost Design Techniques
Efficient Use of CAD Tools
Digital Modulation Methods
ISM-Band Applications
Design for PCS Systems
New Components for Wirelsss
Medical and Scientific Applications
Manufacturing Methods

Our format is in one-hour time slots, which allows plenty of time to cover a topics thoroughly and completely.

Session Chairs Wanted!

Session moderators are needed to introduce speakers and to guide the question-and-answer period. The benefits are the same as for speakers, and your contribution to a smoothly-running conference is especially valuable. When you offer your services, please indicate the areas of RF engineering you are most interested in.

Rewards and Benefits

All of our speakers receive free admission to the technical papers and exhibition, plus a copy of the Conference Proceedings. This does not include our full-day courses or any travel or lodging. A breakfast is held for each day's speakers and Session Chairmen.

The greatest benefit is in the appreciation of your RF engineering colleagues, as you share your particular expertise with them in our interactive presentation forum.

Submit a 150-word abstract by February 28 to:

RF Expo East 1995
RF Design Magazine
6300 S. Syracuse Way, Suite 650
Englewood, Colorado 80111
Fax: 303-267-0234

EM/CAE Integration

HP EEsof has announced that its most recent release of Momentum, HP's planar electromagnetic simulator, is now available completely integrated in its Series IV high-frequency computer-aided engineering (CAE) design suite. Release 2.0 contains many new features which are also available to users of Momentum for HP's Microwave Design System. New features of Momentum include adaptive frequency sampling, edge meshing, far-field plots, internal ports, and a SPICE model generator. HP Momentum 2.0 is priced from $24,000 and will be available in May 1995.

HP EEsof
INFO/CARD #175

Low-Cost RF CAD

The ARRL now offers the ARRL Radio Designer, a RF CAD package which models passive and small-signal linear circuits from audio to RF. The software allows users to enter circuits via a netlist editor, optimize circuit performance, and simulate component value variations using Monte Carlo analysis. Circuit elements include active devices; user-defined "black-box" elements; controlled sources; lossy capacitors, inductors, coaxial cables and transmission lines; and transformers. The ARRL Radio Designer 1.0 can be used on 386 or higher PCs, with 8 Mb of RAM, Windows™ 3.1 or higher, 3.5 inch HD drive, 5 Mb of hard drive space, and a mouse or other pointing device. Price is $150.

American Radio Relay League
INFO/CARD #174

Model Library

Compact Software has announced that it has released a new Nonlinear Device Library for use with its popular nonlinear frequency-domain simulators, Microwave Harmonica and Microwave Scope. The library contains extracted model information for over 87 popular GaAsFET and bipolar devices. All the models have been extracted an validated using Compact's in-house microwave laboratory. The Nonlinear Device Library is designed to be used with the 4.5 (workstation) and 6.5 (PC/Windows) versions of Compact's nonlinear circuit simulators, and is available for immediate delivery.

Compact Software
INFO/CARD #173

Mixed Mode Simulation

A new version of Intusoft's ICAP/4 Windows includes an expanded set of built-in SPICE models and a digital logic simulator capable of providing native mixed mode simulation. Current ICAP/4Windows owners may update to the new version for $295. Those that bought ICAP/4Windows after October can get the upgrade free-of-charge by sending in their free update card.

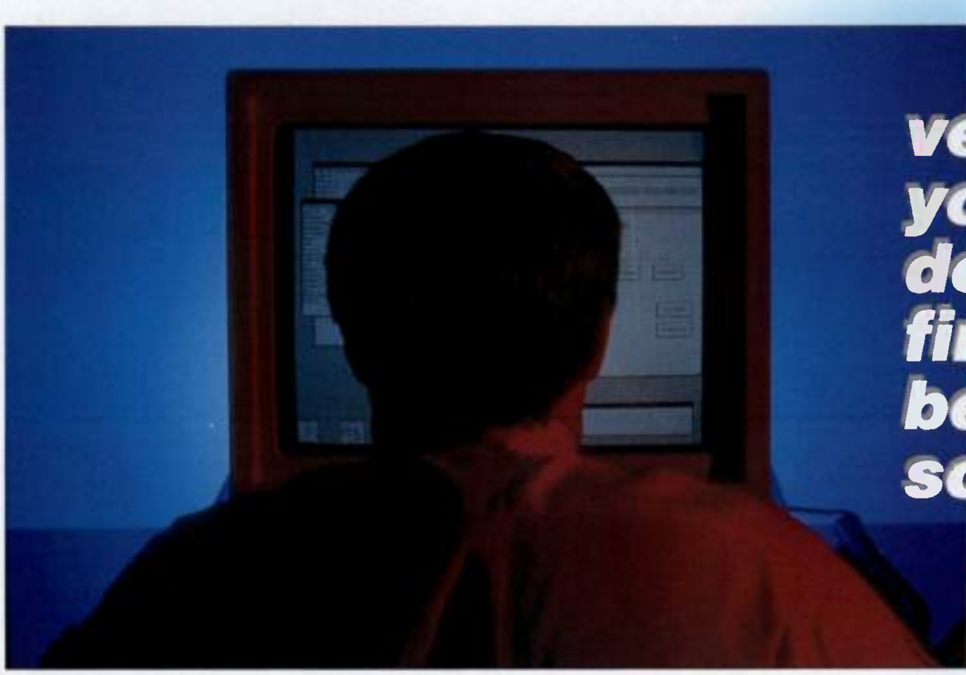
Intusoft
INFO/CARD #172

INFO/CARD 53

RF advertising index

RF guide to editorial coverage

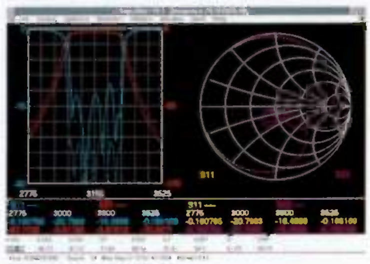
New System 32 Software...



verify your designs... find better solutions.

Typical design flow

Initial synthesis in =M/FILTER=



Tune or optimize in =SuperStar= simulator

Layout to plotter, printer, HPGL and DXF files

REAL-TIME CIRCUIT SIMULATION
- Accurate models
- Huge library
- Easy nodal entry
- Schematic entry
- Tune by tapping
- Super-fast optimization
- Unrestricted noise
- Statistical analysis
- 3-D plotting

CIRCUIT SYNTHESIS

=FILTER= (L-C filters)
- Coupled-resonator, zig-zag, symmetric, Blinchikoff, conventional, other structures
- All popular transfer shapes
- Group-delay equalizers

=M/FILTER= (microwave filters)
- End, edge, hairpin, combline, elliptic, interdigital, stepped-Z, lowpass, bandstop, highpass
- Microstrip, rod, stripline, coax, generic
- Layout generation

=OSCILLATOR=
- L-C, SAW, crystal, T-line
- VCOs
- Noise estimation

=MATCH=
- Multiple algorithms
- General synthesis & order
- Active or passive
- Arbitrary terminations

=A/FILTER= (active filters)
- Multiple structures
- All popular transfer shapes
- Non-ideal op-amps

=M/FILTER=
=OSCILLATOR=
=FILTER=
=MATCH=
=A/FILTER=
=SuperStar=
HIGH-SPEED SIMULATOR
=SCHEMAX=
UTILITIES

System 32 available for...

MS DOS
MICROSOFT WINDOWS
MICROSOFT WINDOWS NT

Windows versions are 32-bit
Complete packages from $695
Money-back guarantee
Free technical support
No annual fees

INFO/CARD 48

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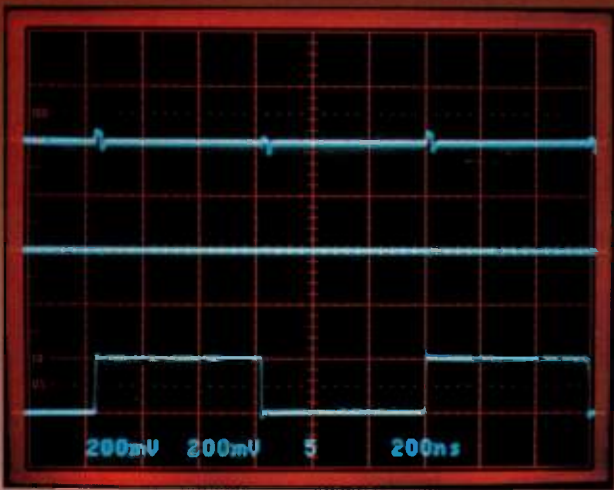
EAGLEWARE

Eagleware Corporation ★ 1750 Mountain Glen ★ Stone Mtn, GA 30087 ★ USA
TEL (404) 939-0156 ★ FAX (404) 939-0157

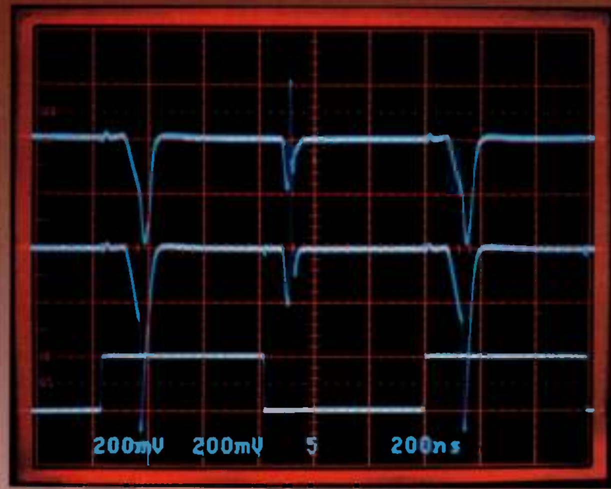
Switches Without Glitches.



Output

Input

Logic



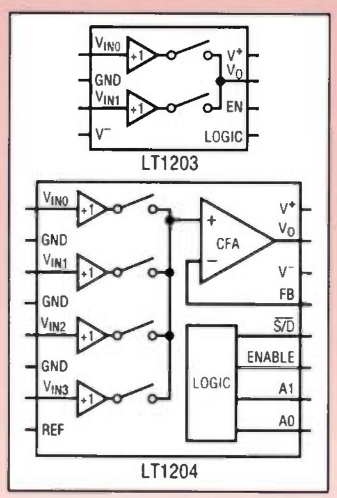
LT1203

CMOS MUX

LTC Video Multiplexers Have 90dB Isolation.

LTC's family of video multiplexers deliver professional quality solutions on your PC board without cascading switches to improve channel separation and isolation. The LT1203, LT1204 and LT1205 provide 90dB of isolation at 10MHz on real printed circuit boards. Forget those old switch buffers too, because all LTC multiplexers include buffers, are easily expandable and operate on ±5V to ±15V supplies. Switching glitches are almost invisible. The 2-input and 4-input LT1203/05 switch channels in only 25nsec and unlike CMOS switches, are virtually glitch-free at both output and input.

The LT1203/1205 are ideally suited for high speed graphics, multimedia, video routers or crosspoint applications delivering 150MHz bandwidth, 0.1dB gain flatness to 30MHz and Differential Gain/Phase of 0.02%/0.02° for true color fidelity.



For multiplexing where more output current is needed such as cable driving, the LT1204 4-input Video Multiplexer has an on-chip 75MHz Current Feedback Amplifier with 50mA output drive and 0.1dB gain flatness to 30MHz. A unique bootstrapping feature allows you to create larger multiplexers (8:1, 16:1) by just connecting the LT1204's outputs together, and you still get 90dB isolation at 10MHz on your PC board.

So, for multimedia, graphics or broadcast quality video, make LTC your first stop for ALL of your multiplexer needs. Pricing starts at $2.96 in 1000-piece quantities for the LT1203CS8. The LT1204CN is $4.78 and the surface mount LT1205CS starts at $5.06, both in 1000-piece quantities.

For details, contact Linear Technology Corporation, 1630 McCarthy Boulevard, Milpitas, California 95035/ 408-432-1900. For literature only, call **1-800-4-LINEAR.**

LINEAR TECHNOLOGY

FROM YOUR MIND TO YOUR MARKET
AND EVERYTHING IN BETWEEN.

INFO/CARD 49 - Call Me. I'm interested.

INFO/CARD 56 - Please send literature.