RF design

engineering principles and practices

July 1991

Mike Ellis and Charles Wenzel
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INFO/CARD 3

RF design

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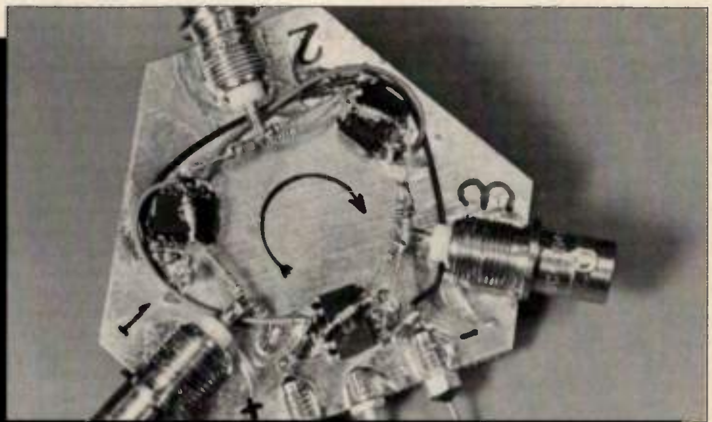

design awards

emc corner

departments

R.F. DESIGN (ISSN: 0163-321X USPS: 453-490) is published monthly plus one extra issue in September. July 1991. Vol. 14, No. 7.

Second-Class Postage paid at Englewood, CO and at additional mailing offices. Subscription office: *RF Design*, P.O. Box 1077, Skokie, IL 60076-9931. Domestic subscriptions are sent free to qualified individuals responsible for the design and development of communications equipment. Other subscriptions are: $38 per year in the United States; $48 per year in Canada and Mexico; $52 (surface mail) per year for foreign countries. Additional cost for first class mailing. Payment must be made in U.S. funds and accompany request. If available, single copies and back issues are $5.00 each (in the U.S.). This publication is available on microfilm/fiche from University Microfilms International, 300 Zeeb Road, Ann Arbor, MI 48106 USA (313) 761-4700.

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RF editorial

Engineering Productivity: It's People That Count

By Gary A. Breed
Editor

The last couple of months, I've talked about organizational concepts, plus hardware and software that are intended to help an engineer work as efficiently as possible. I left the most important issue for last — the engineer as a person.

Advanced hardware and software can definitely improve any engineer's work output. Of course, this improvement in *quantity* is valuable; production schedules must be kept, contract deadlines must be met, and other departments can't be kept waiting. Ultimately, however, the *quality* of work depends on the ability of individual engineers, and their attitude towards their work and their co-workers.

Engineering ability comes from several sources, including raw talent, a good education, and on-the-job training. A good attitude is developed from such things as lifelong upbringing, the influence of mentors, and the engineer's working environment. These factors are highly variable, and should be examined by every RF engineering manager who wants to hire and develop the best possible staff.

Companies wanting to get the most out of their engineers must use every tool within their control. Mentorship can be encouraged, a positive environment can be developed, and educational support can be offered. A good number of companies support nearby colleges and universities, improving their chances for hiring engineers with an appropriate education. These things can make the difference between developing an outstanding engineering staff, or having one that is merely adequate.

Special Individuals: Our Contest Winners

Two examples of outstanding ability and attitude are Mike Ellis, our first Software Contest winner, and Charles Wenzel, winner of our sixth Design Contest.

Mike is a graduate student at Mississippi State University, on leave from the U.S. Army Corps. of Engineers. Mike has gathered RF filter design data into a comprehensive program which grows every time he learns a new concept or technique. His filter "notebook" is his computer, where lessons learned are kept for the long term. His attitude concerning the value of extra effort has been rewarded with our Grand Prize.

Charles has a quite different position in the engineering community. As owner of his own oscillator company, he has a special interest in innovative and efficient engineering. His winning design was developed in response to his need to measure the output impedance of an operating oscillator. The relative ease of development, and the wide range of other applications prompted him to enter it in our contest and garner our other Grand Prize.

Dozens of engineers with the same kind of ability and attitude as these Grand Prize winners made a special effort to prepare contest entries (see the results on page 26). We are happy to have prize donors willing to reward this kind of enthusiasm. Recognition for a job well done definitely has a positive effect on an engineer's productivity!

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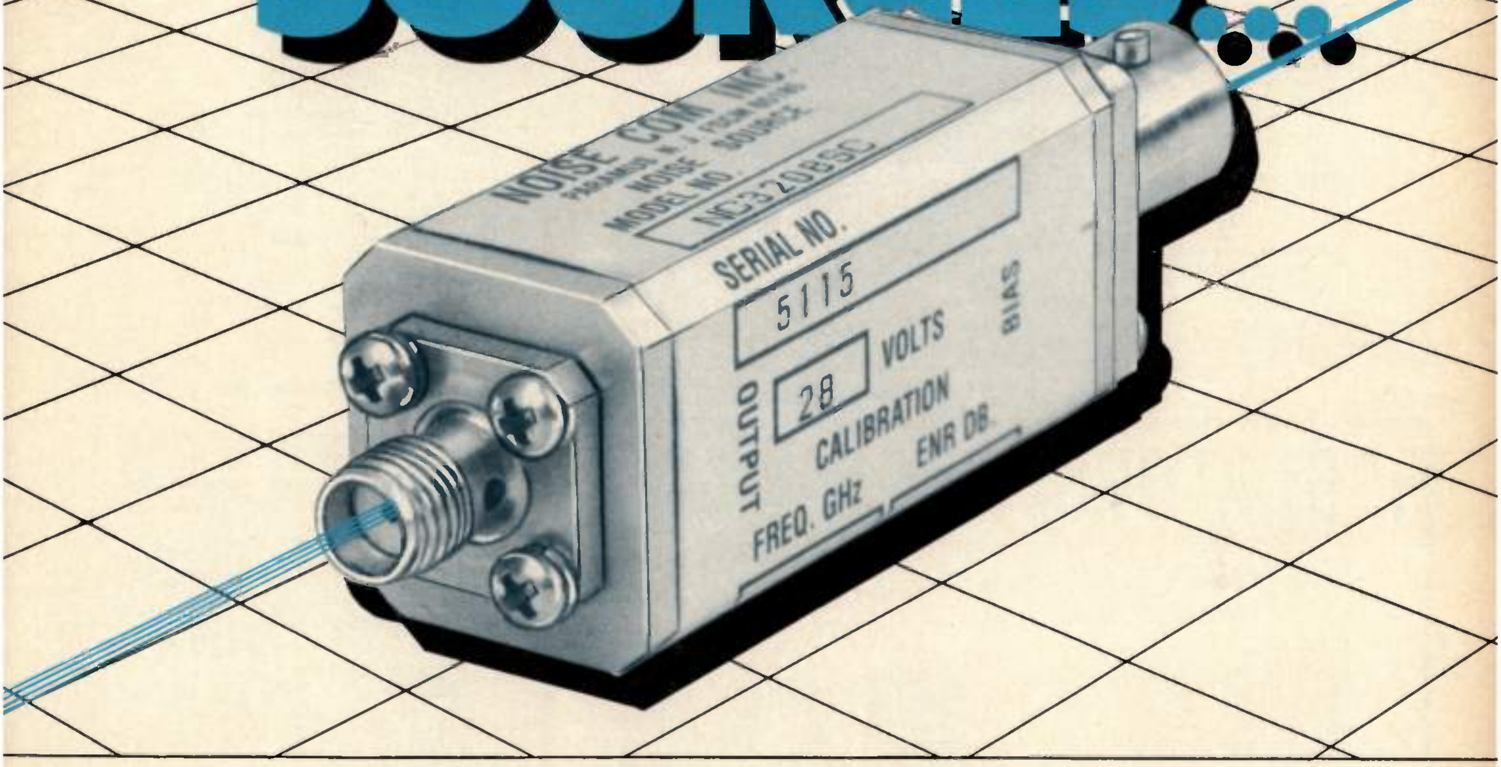

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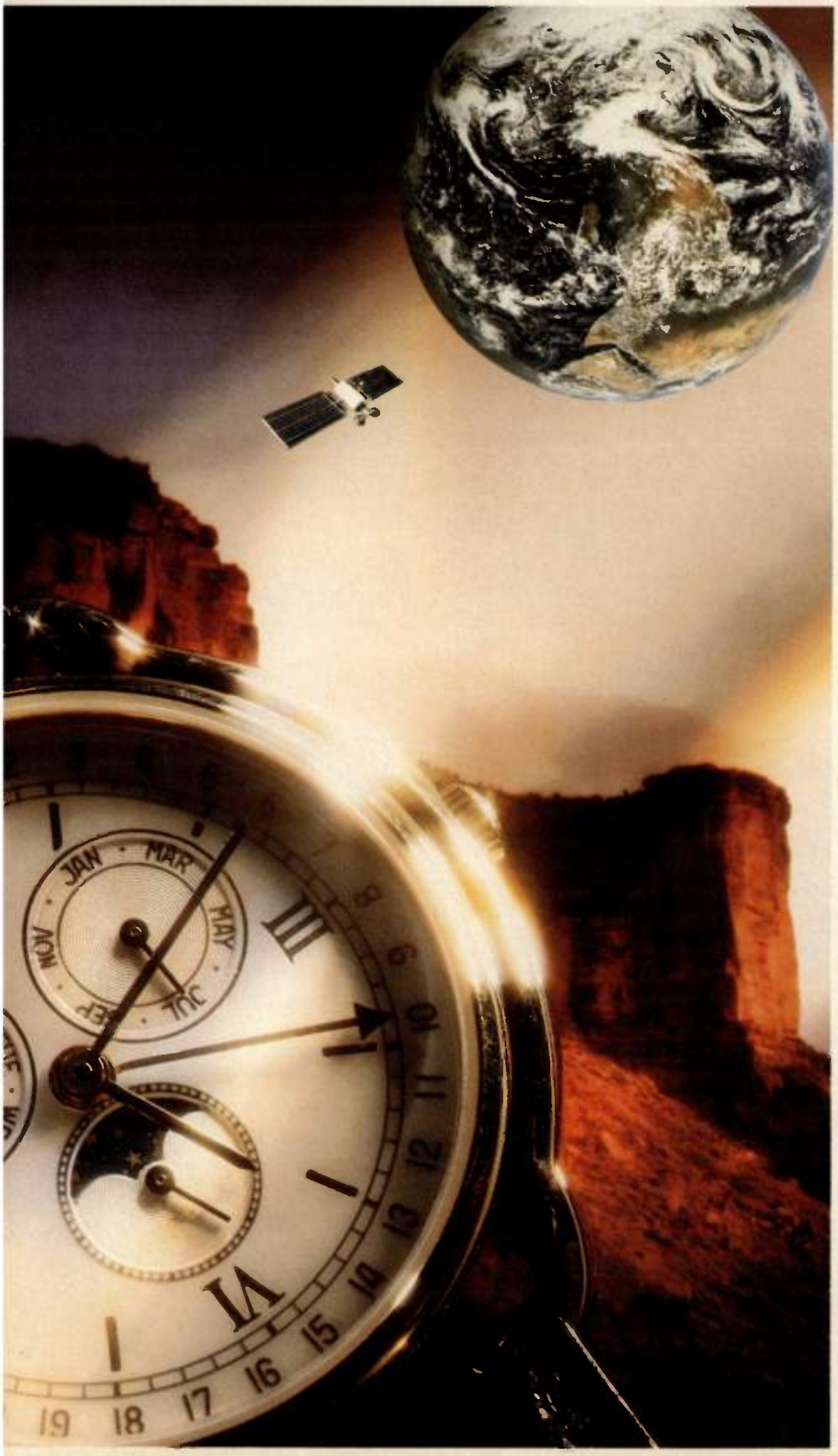
For those who dream of suspending time in the rush to the communications market.



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INFO/CARD 8

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IQ Demodulator Comment

Editor:

In his article, "IQ Sampling Yields Flexible Demodulators," in the April 1991 issue of *RF Design*, Thomas Hack describes well how to use a sampling analog-to-digital converter (ADC) to build a digital-output IQ demodulator.

Some designers may find that available ADCs are just a little too slow to use as demodulators. I wish to point out that the ADC sample rate can be reduced to 75 percent of the sample rate used by Hack, at the expense of additional digital calculation on the ADC output.

Hack uses one ADC to obtain I and Q signals. The ADC sample-clock frequency is four times the local oscillator frequency. Thus, the ADC samples four times each local-oscillator cycle. If these four samples are labeled a, b, c and d, then:

(1) $I = a - c$
(2) $Q = b - d$

The same result can be obtained by making the ADC sample-clock frequency three times the local oscillator frequency. Thus the ADC samples three times each local-oscillator cycle. If these three samples are labeled A, B, and C, then:

(3) $I = 2A - B - C$
(4) $Q = (B-C) \times \sqrt{(3)}$

Equations 3 and 4 require more calculations than Equations 1 and 2. Thus, four samples per local-oscillator cycle are usually preferable to three samples per local-oscillator cycle. If the ADC is not fast enough to do four samples, but is fast enough to do three samples, then three samples are preferable to four.

For example, the local-oscillator frequency is 3 MHz, and the available ADC can be sample-clocked at 10 MHz. Four times the local oscillator frequency is 12 MHz, too high for the ADC. Three times the local-oscillator frequency is 9 MHz, within the ADC capability.

Peter Traneus Anderson
Burlington, VT

Solid State VHF Transmitters

Editor:

In your "Industry Insight" column in the April 1991 issue you dealt with RF technology in broadcasting. You briefly mentioned that several companies offer VHF transmitters with solid state aural amplifiers but that the video amplifiers "remain a challenge." I would like to point out that LDL Communications, Harris Corporation and Toshiba all manufacture and sell 100 percent solid state VHF television transmitters. Prior to pulling out of the US market, NEC also offered a 100 percent solid state VHF transmitter. The technology is so well proven and reliable that I doubt if any VHF television station currently considering replacing their transmitter is looking seriously at tube models. I just thought I'd point this out since from the article I was left with the impression that there is still a way to go before a solid state VHF transmitter is available.

William T. Hayes
Manager of Engineering
WSAZ Television

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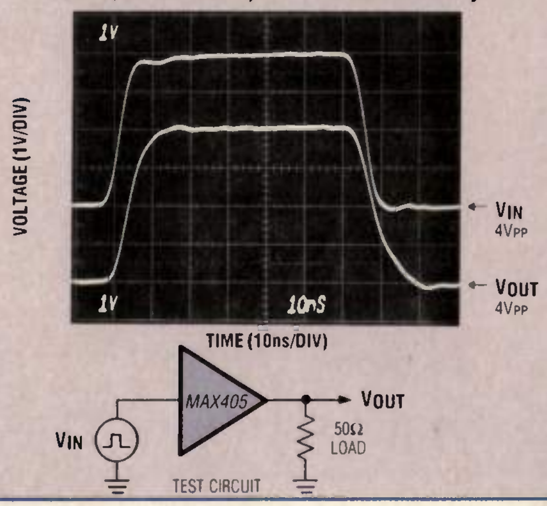

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RF calendar

July

15-18 **Communication Networks West '91**
Moscone Center, San Francisco, CA
Information: Conference Sales, Tel: (800) 225-4698.

22-24 **Fifth International Conference on HF Radio: Systems and Techniques**
Edinburgh Conference Centre, Edinburgh UK
Information: Secretariat, Conference Services, IEE, Savoy Place, London WC2R OBL, United Kingdom. Tel: 071 240 1871 ext. 222.

August

13-15 **IEEE 1991 International Symposium on Electromagnetic Compatiblity**
Cherry Hill, NJ
Information: IEEE International Sympsium on EMC, PO Box 609, Lincroft, NJ 07738. Tel: (201) 386-2378.

18-21 **The 3rd International Symposium on Recent Advances in Microwave Technology**
Reno, Nevada
Information: Banmali Rawat, Chairman, Technical Program Committee, Electrical Engineering and Computer Science Department, University of Reno, Nevada, Reno, NV 89557-0030. Tel: (702) 784-6927. Fax: (702) 784-1300.

25-29 **Surface Mount International**
San Jose, California
Information: Surface Mount International, 1050 Commonwealth Ave., Boston, MA 02215 or Miller Freeman Exhibitions, Tel: (800) 223-7126 or (617) 232-3976.

September

2-5 **Sixth International Conference on Digital Processing of Signals in Communications**
Loughborough, United Kingdom
Information: Secretariat, Conference Services, IEE, Savoy Place, London WC2R OBL, United Kingdom. Tel: 071 240 1871 ext. 222.

5-10 **12th IMEKO World Congress**
China International Conference Center, Beijing, China
Information: Mr. Shi Shangping, IMCI '91 Office, China International Conference Center for Science and Technology, P.O. Box 300, Beijing 100086, China. Tel: (86) (1) 8313335.

9-12 **21st European Microwave Conference**
The International Congress Centre, Stuttgart, Germany
Information: Microwave Exhibitions and Publishers Ltd., 90 Calverley Road, Tunbridge Wells, Kent TN1 2UN, United Kingdom. Tel: (44) 0 892 544027. Fax (44) 0 892 541023.

11-13 **MIDCON**
Rosemont/O'Hare Exposition Center, Rosemont, IL
Information: MIDCON/91, 8110 Airport Blvd., Los Angeles, CA 90045. Tel: (800) 877-2668. Fax: (213) 641-5117.

RF courses

RF Component Modeling
July 15-17, 1991, Los Angeles, CA
Adaptive Signal Processing
August 12-16, 1991, Los Angeles, CA
Analog MOS Integrated Circuits
September 16-20, 1991, Los Angeles, CA
Information: UCLA Short Course Program Office. Tel: (213) 825-3344. Fax: (213) 206-2815.

Radar Reflectivity Measurement: Techniques and Applications
July 15-18, 1991, Atlanta, GA
Modern Electronic Defense
August 21-23, 1991, Atlanta, GA
Infrared/Visible Signature Suppression
October 22-25, 1991, Atlanta, GA
Radar Cross Section Reduction
October 29-November 1, 1991, Atlanta, GA
Information: Education Extension, Georgia Institute of Technology. Tel: (404) 894-2547.

Synchronization in Spread-Spectrum Systems
July 15-19, 1991, Washington, DC
Global Positioning System: Principles and Practice
August 12-14, 1991, Washington, DC
Grounding, Bonding, Shielding and Transient Protection
August 13-16, 1991, Washington, DC
December 10-13, 1991, San Diego, CA
Digital Cellular Telephony for Mobile Applications
August 26-30, 1991, Washington, DC
Microwave Radio Systems
September 4-6, 1991, Washington, DC
Introduction to Radar ECM and ECCM Systems
September 4-6, 1991, Washington, DC
Information: The George Washington University, Continuing Engineering Education, Merril A. Ferber. Tel: (202) 994-8522 or (800) 424-9773.

Satellite Communication Systems
July 22-26, 1991, Guildford, United Kingdom
New Broadcast Standards and Systems
July 21-26, 1991, Southampton, United Kingdom
Electromagnetic Compatibility
September 15-20, 1991, Canterbury, United Kingdom
Microwave Measurements
September 22-27, 1991, Canterbury, United Kingdom
Information: The Institution of Electrical Engineers, Savoy Place, London WC2R 0BL, UK.

DSP Without Tears
July 22-24, 1991, San Jose, CA
July 29-31, 1991, Northbrook, IL
August 5-7, 1991, Arlington, VA
Information: Right Brain Technologies. Tel: (404) 420-3834. Fax: (404) 967-1672.

Seminar on the High Intensity Electromagnetic Radiated Fields (HIRF)
July 23-25, 1991, Mariposa, CA
October 23-24, 1991, Mariposa, CA
Seminar in EMI Software (EMCAD1)
August 21-22, 1991, Mariposa, CA
December 4-5, 1991, Mariposa, CA
Advanced HIRF Seminar for Commercial Flight Applications
September 24-26, 1991, Mariposa, CA
Information: CKC Laboratories, Registrar. Tel: (209) 966-5240. Fax: (209) 742-6133.

Fiber Optical Communication Technology and Systems
August 26-30, Switzerland
Combined Digital Coding and Modulation Techniques
October 14-18, 1991, Spain
Fast Algorithms for Adaptive Signal Processing
November 4-8, 1991, United Kingdom
Adaptive Signal Processing
November 4-8, 1991, United Kingdom
Information: CEI-Europe/Elsevier, Mrs. Tina Persson, Box 910, S-612 01 Finspong, Sweden. Tel: +46 (0) 122-17570. Fax: +46 (0) 122-14347.

Modern Power Conversion Design Techniques
July 15-19, 1991, Chicago, IL
October 21-25, 1991, San Francisco, CA
Information: e/j Bloom Associates, Joy Bloom. Tel: (415) 492-8443. Fax: (415) 492-1239.

Electromagnetic Propagation
August 20-22, 1991, Syracuse, NY
ELINT Analysis
September 10-12, 1991, Syracuse, NY
ELINT Interception
September 17-19, 1991, Syracuse, NY
ELINT/EW Applications of Digital Signal Processing
September 17-19, 1991, Syracuse, NY
Information: Research Associates of Syracuse. Tel: (315) 455-7157.

Basic Network Measurements Using the 8510B Network Analyzer
July 29-31, 1991, Los Angeles, CA
July 29-31, 1991, Boston, MA
August 5-7, 1991, San Francisco, CA
Microwave Fundamentals
July 15-18, 1991, Los Angeles, CA
Designing for EMC
July 11-12, 1991, Atlanta, GA
August 22-23, 1991, New York, NY
Information: Hewlett-Packard Company. Tel: (714) 999-6700.

Digital Signal Processing Workshop
July 16-18, 1991, Campbell, CA
September 11-13, 1991, Norwood, MA
Information: Analog Devices, DSP Applications Department, Maria Butler. Tel: (617) 461-3672.

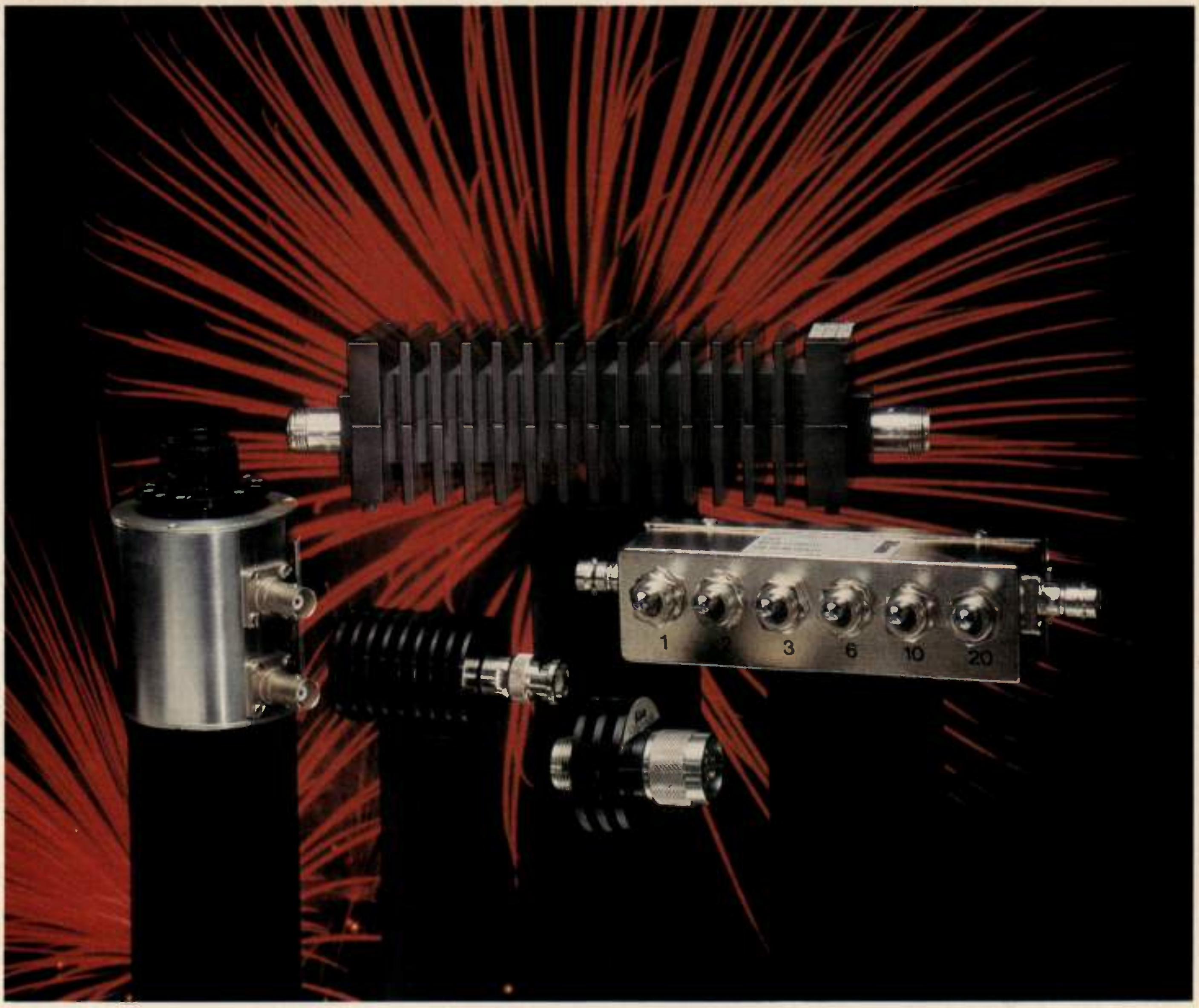
Introduction to Telecommunications
July 16-19, 1991 Los Angeles, CA
July 23-26, 1991, Boston, MA
Introduction to Datacomm and Networks
July 16-19, 1991, Los Angeles, CA
July 23-26, 1991, Boston, MA
Hands-On Datacomm Troubleshooting
July 23-26, 1991, Boston, MA
July 30-August 2, 1991, San Diego, CA
Digital Signal Processing: Techniques & Applications
July 23-26, 1991, Washington, DC
July 23-26, 1991, Toronto, Canada
Information: Learning Tree International. Tel: (800) 421-8166, (703) 893-3555, (203) 417-8888.

New Facility for Signal Processing Research — The National Institute of Standards and Technology has added a new research facility built around a "video supercomputer" to study signal processing techniques needed for future high-performance computer displays and video imaging systems. The new facility features a "Princeton Engine" video computer created by the David Sarnoff Research Center which merges video with a massively parallel supercomputer. A typical application is software simulation of integrated circuits that might be used to process video signals. The $1.5 million machine was funded by DARPA as part of a larger program to develop improved imaging systems for advanced tanks and aircraft, defense mapping, command and control communications, advanced materials research, and other military applications.

NOAA to Flight Test Experimental Doppler Radar — An experimental, French-built dual-beam Doppler radar antenna will be test flown this summer aboard a National Oceanic and Atmospheric Administration (NOAA) aircraft flying hurricane research missions. Under development by the Paris based Centre de Recherches en Physique de l'Environment (CRPE) for several years, the antenna will be installed on one of NOAA's two P-3 Orion aircraft as part of the on-board instrumentation package, allowing French and American scientists to evaluate its potential for meteorological research. The beam from the new antenna electronically sweeps fore and aft alongside the aircraft's track as it parallels severe weather systems, collecting pseudo dual Doppler measurements which can be processed to determine three-dimensional wind fields.

Telecommunications Trade Deficit Improves — Statistics recently released by the U.S. Commerce Department indicate that the United States trade deficit in telecommunications equipment fell markedly during 1990 dropping over $1.1 billion to $792 million from $1.9 billion in 1989. This was the lowest annual deficit since the 1980s and was spurred by continued strong export growth. Several factors contributed to the reduction including: a weaker U.S. dollar, the reduction in foreign trade barriers and an increasingly international outlook on the part of the U.S. telecommunications equipment manufacturers.

Motorola and PacTel to Conduct CDMA Trial — Motorola and PacTel recently announced that they have signed an agreement to conduct an extensive field test and market trial of Code Division Multiple Access (CDMA) digital cellular technology in PacTel Cellular's Southern California service area. Among the field testing activities anticipated for summer 1991 is the validation of the Common Air Interface (CAI) specification which both companies helped develop. If validated, the CAI will allow cellular network equipment and cellular phone vendors to develop CDMA products, including dual mode subscriber units, that will operate in the cellular systems.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Top Foreign Markets — The Electronic Industries Association (EIA) has announced its list of the top foreign markets for electronics exports along with the top ten trading partners for electronics imports. Canada ranked first, importing more than $12.5 billion worth of U.S. electronics products. Japan ranked second at $8.4 billion and the United Kingdom third, with $6.2 billion. The top ten foreign countries account for approximately $52 billion or 71 percent of the total $72.8 billion of U.S. electronics exports in 1990. Total imports of electronics reached $78.9 billion, resulting in a $6.1 billion deficit in electronics.

SHS Expands — Scientific Hardware Systems has moved to a larger facility. They are now located at 33446 Western Avenue, Union City, CA 94587. Tel: (415) 471-0398; Fax: (415) 471-1650.

ARDIS Marks First Anniversary — ARDIS, a 50/50 partnership of IBM and Motorola providing nationwide data radio networks, marked its first anniversary of operation recently. The formation of ARDIS was announced January 30, 1990 and the pre-existing IBM and Motorola networks were united and put into commercial operation on April 30, 1990.

Analog Devices' Products Now Available Through Distributors — Analog Devices' line of standard components is now available for sale through a network of North American distributors. Anthem Electronics, Bell Industries, Future Electronics, Hall-Mark Electronics and Pioneer Standard have begun accepting orders for Analog Devices' analog and mixed-signal components.

TriQuint/GigaBit to Add Third Company — A definitive agreement was recently signed that will add Gazelle Microcircuits to the merger of TriQuint Semiconductor and GigaBit Logic. The resulting company is expected to have revenues in excess of $40 million in 1991. The merger of the three companies is awaiting regulatory and shareholder approval and the transactions are expected to be completed by the end of May.

CAL Awarded Radar Contract — CAL Corporation has been awarded a $7.4 million contract from the Department of National Defense, Canada, to develop a prototype electrical power system for Canada's Space-based Radar (SBR) Satellite. SBR is a proposed military surveillance satellite system designed to detect and track aircraft. The contract, which is to extend to the end of 1993, will involve the study of the generation, distribution, and storage of energy used for SBR.

Arlon Microwave Relocates — The microwave absorber materials product line of Arlon, Microwave Materials Division has moved into the company's facility in Bear, Delaware. The move into Arlon's Bear facility will include engineering, manufacturing, research and development, quality control, and customer service functions.

Teklogix Forms Strategic Business Agreement — Teklogix and

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Everything you want in a GPS station clock, in one neat box:

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That's the **Model 8810** — a mature product, value-engineered and time-tested, just like the ones we've been providing to NASA and DoD for decades. And there's so much built into this unit, it's hard to describe. Just review the features listed below:

- Automatically determines geographical coordinates — no need to enter position anywhere on earth
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- Multiple time code and rate output options
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- Nonvolatile memory stores setup and data indefinitely
- Accurate to within 100 ns worldwide, 24 hours a day
- RS-232 remote control and time output (optional IEEE-488 output)
- RS-232 printer port
- Displays time, position, and REF-UTC/GPS
- Time display is keypad-selectable to UTC, GPS, or local time
- 115/230 VAC with optional 24 VDC backup
- Antenna with 50′ coax cable included
- Built-in test routines
- Fully modularized
- GPS receiver is drop-in replaceable
- Workmanship standards to MIL-STD-454
- Three-year limited warranty
- Plus, a host of desirable options

That's the **Model 8810,** from TRAK Systems. And at this price, there's nothing else like it on the market. So why pay more, and install boxes of equipment, when you can have it all in one neat unit?

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TRAK SYSTEMS
DIVISION OF **TRAK MICROWAVE CORP.**

INFO/CARD 19

IMREX Computer Systems have signed an agreement to co-market radio frequency data communications systems. The relationship calls for Teklogix to supply all RF hardware and IMREX, the necessary software. The two companies will combine their experience and strength in large site distribution applications. Teklogix will supply handheld and vehicle-mounted RF terminals, RF base stations and network controllers. IMREX will provide its Information Logistics System/400 software package. Teklogix recently received FCC certification for using spread spectrum technology in their hardware.

Analog Devices Signs SPICE Models Agreement — Analog Devices, Inc. has signed an agreement with leading vendors of computer-aided computer system suppliers to include SPICE models of Analog's components in conjunction with their CAD workstations and libraries. The five vendors, Cadence Design Systems, Inc., Mentor Graphics, Inc., Meta-Software, Inc. MicroSim Corp., and Valid Logic Systems, supply workstations and software used by designers. Under the agreement, models will be added to CAD workstation libraries, and distributed and supported by the respective CAD vendors.

Licensing Agreement for BiCMOS Process — Silicon Systems and Signetics have announced an agreement licensing Silicon Systems to use Signetics' proprietary QUBiC BiCMOS fabrication process in Silicon Systems' mixed signal integrated circuit products. Silicon Systems will begin production of devices fabricated with the QUBiC process later this year. Initial products will be primarily targeted toward disk drive applications, while subsequent offerings will be directed toward communications and automotive electronics.

Spectrum Technology Moves — Spectrum Technology recently moved to a larger facility in Santa Barbara, California. Their new address is 749 Ward Drive, Santa Barbara, CA 93111. Tel: (805) 964-7791: Fax: (805) 683-3481.

QUALCOMM Chosen for Trans-Continental Race — QUALCOMM has been chosen to provide two-way mobile satellite communications systems and services for the 1991 Interstate Batteries Great American Race, a 13 day, trans-continental road rally for antique cars. The OmniTRACS system will be used to forward time scores from remote checkpoints to the finish line in each city.

Radian Enters Cooperative R&D Agreement — Radian Corporation recently entered into a cooperative research and development agreement with NOAA. Under the Federal Technology Transfer Act, this agreement between Radian, Sonoma Technology and two NOAA laboratories will make available to the private sector technology involving wind and temperature profiling of the atmosphere. During the first year of the agreement, Radian will work with NOAA in the design of a production profiling instrument operating between 850 and 1200 MHz to collect wind and temperature profiles. As part of the effort Radian has opened an engineering development technology transfer office in Boulder, Colorado.

Racal-Dana Receives VXIbus Contract — Racal-Dana has announced that it has been awarded a contract from United Airlines for an avionics test system based on the VXIbus. The system is intended to permit in-house maintenance of selected avionics units, and is designed to allow for easy expansion. Terms of the contract were not released.

Burr-Brown and HMC Joint Venture — A new corporation has been formed as a joint venture by Burr-Brown Corporation and Hualoon Microelectronics Corporation. Monolith Technologies Corporation will manufacture analog I/O and mixed signal processing products and will target markets such as multimedia, digital telecommunications, and consumer audio markets. Secondary markets will include embedded control, test and measurement instrumentation and workstations and PCs.

Co-Primary Status for DAB — The General Assembly of the international Association of Broadcasting, recently endorsed setting aside portions of the L-Band radio spectrum for digital audio broadcasting and granting co-primary status to terrestrial and satellite DAB.

LeBlanc & Royle Enters Merger — LeBlanc & Royle Enterprises, a supplier of communication structures, equipment and related services has acquired BMS Communications Services. BMS specializes in telecommunications system design, engineering, installation and project management. Terms of the deal were not disclosed.

RF POWER FOR OEMS,
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ETO's 15 and 20 kW, microprocessor-controlled linear amplifiers power more of the world's high-field MRI scanners than all competitors *combined!* And since 1970 we've delivered over 10,000 "standard" kilowatt-and-up RF power amplifiers and generators.

ETO understands the needs of OEMs, including responsive application engineering, fast prototyping, system integration assistance, and regulatory approvals. We combine rapid manufacturing ramp-up with strict quality standards, timely delivery, and international field service. We provide everything from small modules to complex systems with the "partnering" support OEMs require.

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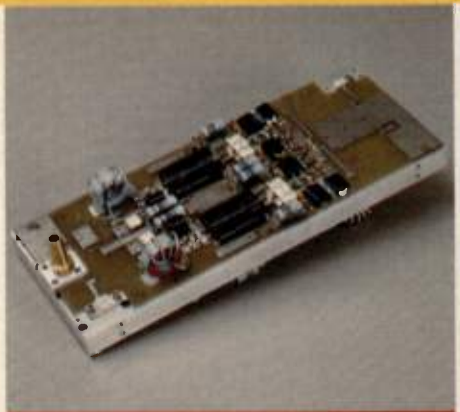
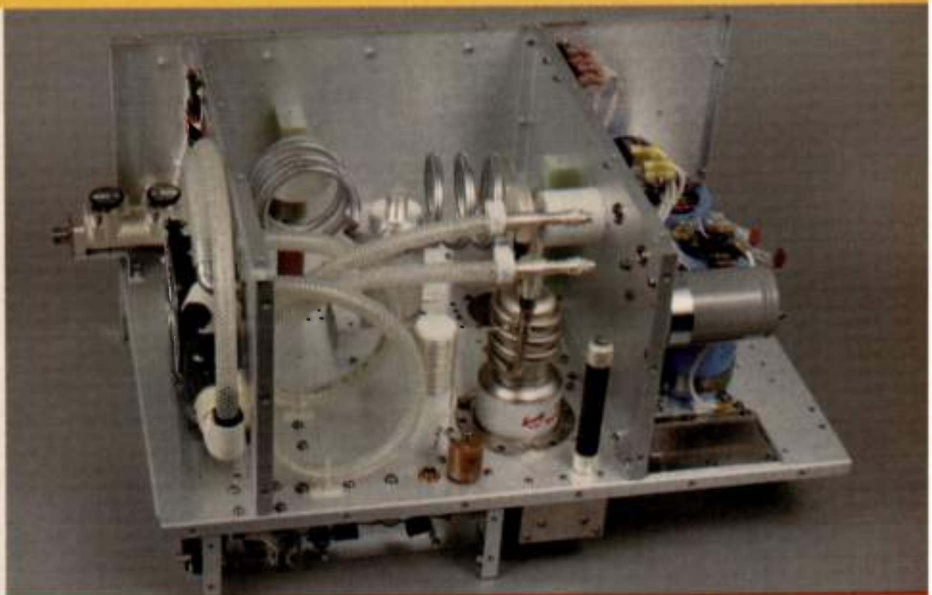
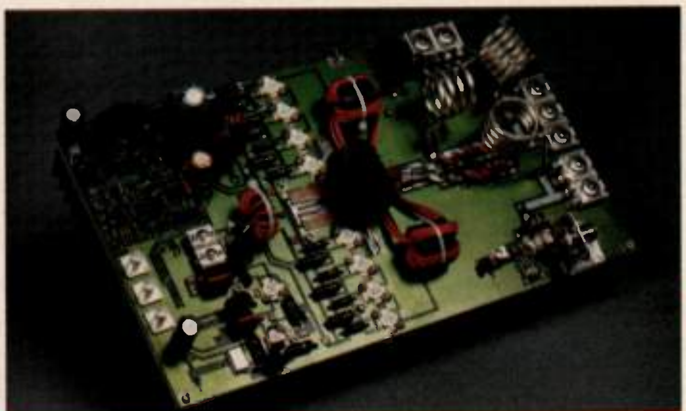


1 KW VHF POWER SUPPLY, ETO Model SGV-1D. *Water-cooled MOSFET design for plasma applications in the 50-150 MHz range. RF module only, or complete system including driver and power supply.*



5 KW RF POWER GENERATOR, ETO Model PG-5DW *for plasma and general industrial applications. RF deck of water-cooled version shown; available for any frequency to 90 MHz as a complete system including power supply and controller.*

20 KW RF LINEAR POWER AMPLIFIER, ETO Model PL-20DP. *Being delivered now to OEM's of high-field MRI systems. Available promptly for any frequency to 90 MHz. Microprocessor-based control system with integral LCD display permits local or remote management of the amplifier and its integral diagnostics.*



1 KW HIGH EFFICIENCY MOSFET HF POWER SUPPLY, ETO Model SG-1D *for plasma and other industrial applications. Available for 13.56, 27.12, or 40.68 MHz, or any frequency 2-41 MHz. RF module shown.*

Contact Don Fowler or Alysa Drew to learn how ETO can satisfy your RF power requirements.

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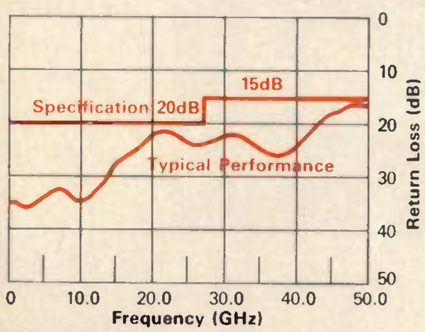
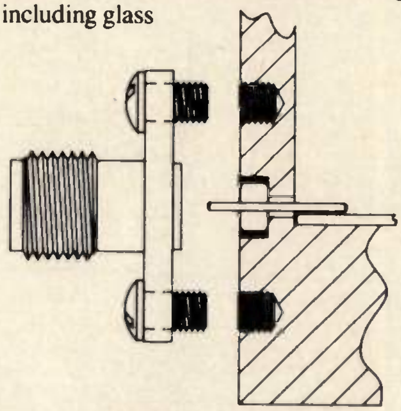
If you use spark plug connectors, we have a 2-piece design that is a one-for-one replacement. This uniquely engineered 2-piece spark plug allows you to replace a damaged interface without disturbing the hermetic package integrity.



Data obtained from launching part number 8557-5329-02 to .010 inch alumina microstrip transmission line.

Our Seals and Connectors Always Meet Your Requirements

Because we have in-house control of all the seal and connector manufacturing, including glass



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INFO/CARD 22

Contract Services in the RF Industry

By Liane G. Pomfret
Associate Editor

This report looks at three kinds of outside services: EMC test labs, calibration labs and design consultants. The rising popularity of consultants and outside laboratories offers many companies the possibility of reducing costs, while at the same time getting the services they need. It is not an industry without its problems, however. The rapid approach of EC92 has many in the EMC testing community worried. Additional standards and regulations are making it tougher for the calibration business. And as always, consultants are faced with the problems of running their own business.

Consultants don't appear to be suffering from the current economic situation, provided they are established, have their own equipment and offer excellent knowledge of their chosen field. Otherwise, it can be tough. Engineers who are new to the consulting field are often at a disadvantage — they lack equipment, experience and the ability to market themselves effectively. For those that can overcome these, business can be overwhelming. "I was told that if you can survive the first year, you can make it. I now work twelve hours a day and am just overwhelmed," says Al Helfrick of Helfrick and Associates. He is currently involved in developing consumer products for a company that wants to build in the United States, and he has had to turn down jobs from other companies in the past.

Other consultants offer their expertise for the training of a company's personnel. Neal Silence, an Engineering Consultant tries to sell his experience as a training tool - teaching others how to do their job quickly and efficiently. "Getting through to the division manager, that I can save them money, is tough" says Silence. Convincing people that in order to save money they must first spend money is never an easy task, especially when every dollar must be accounted for. When a consultant is hired, a company doesn't have to pay any benefits such as insurance or retirement funds, instead they are buying a "known cost for a known task," says Silence. Consultants are called on to do everything from research and development to design, testing, personnel training and even serving as an expert witness in a trial.

When a consultant is hired . . . they are buying a "known cost for a known task."

In much the same way, calibration laboratories are also seeing more business. The companies mentioned in this article only calibrate products they sell or manufacture, but are probably representative of the industry as a whole. There are essentially two types of calibration. Calibration to factory specifications and certified calibration which is traceable to NIST or MIL-specs. The latter is much more stringent and must be done more frequently in order to retain certification. "With the introduction of MIL-45662 requirements, it has forced equipment to be reviewed and calibrated on a regular basis," notes Leon Kuklinski, Product Service Manager at Bird Electronics.

Along with the increase in MIL-spec requirements, which has meant more business for some calibration labs, companies are finding that it is less expensive to have an older piece of equipment repaired and recalibrated than it is to buy a new one. Craig Leong, Lab Manager at Tucker Electronics notes that, "People are trying to get more mileage out of their equipment rather than spending money on new equipment." At the same time, much of the newer equipment is built so well that it does not need to be recalibrated as often. Despite these trends, the calibration laboratories continue to do well because of the very nature of their services.

EMC Laboratories

EMC testing laboratories are also doing relatively well, for the moment. New specifications and requirements have caused an increase in business for EMC labs, but they are about to run into some serious problems because of the unification of the European Common Market in 1992. In the meantime, new technologies such as spread spectrum, are requiring that closer attention be paid to EMI/RFI problems and EMC test labs are reaping the benefits.

Despite the increased testing and development for EMI, the changes in trade agreements for EC92, will virtually stop all American testing of products bound for the European market. According to a report in the July/August issue of *EMC Test & Design*, "Currently, U.S. EMC laboratories cannot attain Notified Body status which is the accreditation for the European community. Only member countries to the EC can attain this accreditation." Clearly, this poses problems not only for the independent testing labs but also for manufacturers of equipment destined for the European market. The same report also notes that "there is no unified U.S. voice addressing European concerns," and this should be a major concern for all EMC testing labs in the United States. While steps are being taken to negotiate a trade agreement between the EC and the U.S., there is much to be sorted out before a final solution is agreed upon.

The reasons for choosing an outside contractor vary. Instead of building an in house test or calibration lab which is a costly undertaking, send the equipment out to be tested or calibrated. Instead of hiring an engineer for one project at $40,000 a year plus benefits, hire a consultant for much less. Outside contractors have a lot to offer the RF industry and their success is assured despite the problems they now face. **RF**

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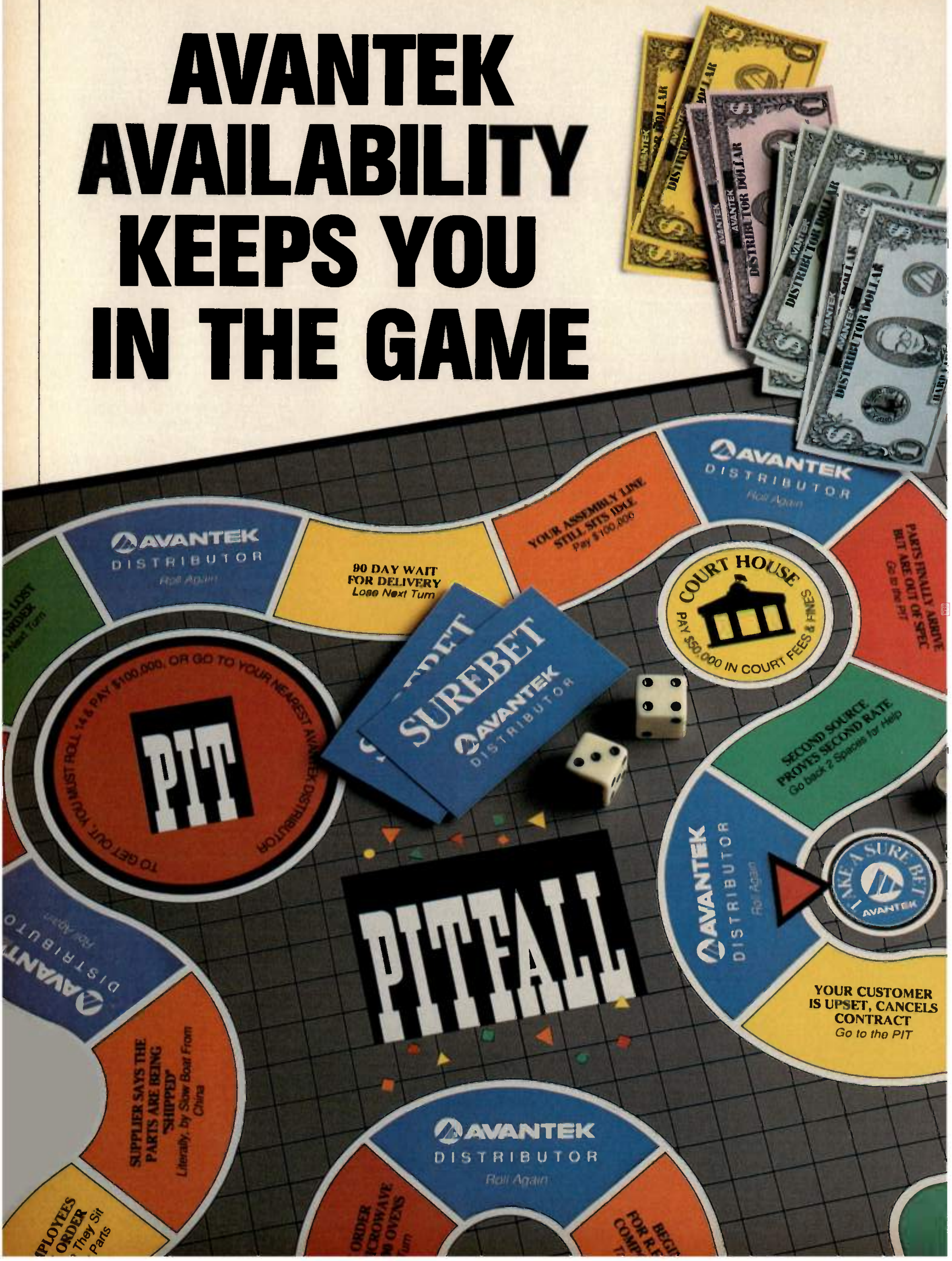
AVANTEK AVAILABILITY KEEPS YOU IN THE GAME



The Winners! Results of the 1991 RF Design and Software Contests

The results are in, and after the most difficult judging in the six-year history of our contest, we have our winners. But before we let you know who won, let's thank our judges, who spent far too many extra hours choosing just a few winners from 30 pounds of top-notch RF engineering. Judging the Design Contest were last year's winner, Kevin Randall of Interspec, Inc., RF Design's Consulting Editor Andy Przedpelski of ARF Products, and Editor Gary Breed. Dave Hertling at Georgia Tech joined Gary and Andy in judging the Software Contest, with help from fellow professor Bob Feeney.

This year, we had two contests, the sixth running of the Design Contest and a new competition for PC Software. In this first software contest, the number of entries nearly matched the design entries, and the quality was exceptional. The most difficult aspect of the new category was establishing criteria for judging. Such things as interest to a large number of engineers, ease of use, and the uniqueness of the problem all entered into consideration. Size and scope of a software entry were certainly considered, but so was the completeness and accuracy.

In the design contest, we had a good selection of circuits that fit into the "elegant simplicity" category. These will make good reading as we publish many of them over the coming year. There were also a number of good entries relating to design techniques, rather than specific circuits. These kept the judges interested all the way through the stack.

Another feature this year was an unusually large group of foreign entries in both contests. We had participants from five continents, including multiple entries from Australia and Poland, with others from Italy, England, Denmark, Japan, Finland, and Peru. Several entries were received from our Canadian readers, as well. We are pleased to see that there are active RF engineers all over the world.

The Software Winner

Taking the Grand Prize in the Software Contest was Mike Ellis, a Ph.D. student at Mississippi State University, on leave from the U.S. Army Corps of Engineers. Mike entered a filter design program package that he has been continually developing in conjunction with his formal and on-the-job studies. The

Mike Ellis' filter design program is our Software Contest winner.

program takes design data from well-known references, and combines them into a comprehensive program with a common file structure and menu-driven operation, making a complete design and analysis package. Mike's winning entry is described in the article "A Comprehensive Filter Design Program," which follows this report. The Grand Prize, a complete Macintosh computer system, loaded with software, was provided by ingSOFT Ltd. All the prizes are detailed in the accompanying sidebar.

The Design Winner

An active circulator design by Charles Wenzel, President of Wenzel Associates, was the Design Contest's winning entry. Using high-speed operational amplifiers, Charles was able to obtain the kind of isolation and constant impedance performance at low frequencies that ferrite circulators offer at microwaves. This circuit is the result of classic engineering problem-solving, trial and error, and finally — success. Initially developed to examine the output port reflection coefficient of an operating oscillator, the circulator has many applications in the measurement and monitoring of active and passive circuits. Charles, who won our design contest four years ago, receives a HP 8591A Spectrum Analyzer generously provided by Hewlett-Packard Company.

Winning the Design Contest is Charles Wenzel, with his active circulator project.

Runners-Up

Taking the second place spot in the Software Contest was Dan Swanson of Watkins-Johnson Company. Dan is Staff Scientist at W-J, specializing in computer analysis of microwave systems and subsystems. His entry, "A Microwave Transmission Line Calculator," covers the broad subject of transmission lines using a spreadsheet-like format. An excellent user interface impressed the judges with convenient operation and error-trapping. The program covers microstrip, stripline, coplanar waveguide, coaxial cables and twisted-wire lines, calculating electrical parameters from physical data and vice-versa. For his effort and accomplishment, Dan wins the student edition of S-Filsyn from DGS associates. This program will be described next month.

In the third position was Jack Porter, Senior Staff Engineer at Cubic Corporation. He wrote a filter analysis program

Dan Swanson captured second place in the Software Contest with his microwave transmission line program.

The world's most powerful digital filter on a single chip.

The new Harris HSP43220 DDF (Decimating Digital Filter) packs more power into a single-chip digital filter than ever before. With features

Decimation:	Up to 16,384
Tap Length:	Up to 512,000
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like programmable decimation to over 16,000, and up to 512,000 equivalent taps, it's a powerhouse of performance.

And despite its incredible power, our DECI-MATE™ software makes designing filters with the Harris DDF incredibly easy.

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*DECI-MATE is a trademark of Harris Corporation.

This is Eugene Mayle, whose active VHF filter took second place in our Design Contest.

for active and passive filters which allows the user to enter a circuit of up to 50 nodes and 200 components, with data tabulated at up to 300 frequencies. Like many engineer-authored programs, convenience and speed was the purpose for its creation. Time is an important engineering commodity! Jack's program will be published in the September issue of *RF Design*. The third prize is a package of signal processing components from Adams-Russell ANZAC Division.

Eugene Mayle took the second prize of a complete TESLA system simulation software package, donated by Tesoft. Gene is a Senior Design Engineer at R.L. Drake Company, and admits to becoming inspired to become an engineer by the high-tech gadgets portrayed in the "Mission Impossible" television program! Gene presented an active bandpass filter design for VHF, using JFET amplifiers in a positive-feedback arrangement to enhance selectivity at high frequencies. This technique will be presented in next month's issue.

Third Place was captured by John Roberts, an RF Systems Engineer at Northern Airborne Technology Ltd. in Kelowna, British Columbia. His prize package of ANZAC signal processing components was earned with a simultaneous AM/FM demodulation scheme, using an inexpensive FM IF/detector IC. This circuit can be seen in the September issue.

Our Special Drawing Winner

This year, a new prize was added, drawn at random from all of the non-winning entries. For this drawing, Ramsey Electronics provided an RSG-10 synthesized signal generator. The winner is Fulvio Perri, Research and Development Manager at ITELCO, a broadcast transmitter manufacturer in Orvieto, Italy. His design technique was one that had been well-regarded by the judges, although not in the top three finishers. In October, we will publish his method of designing and constructing vertically mounted power components.

Finally, thanks goes to Steve Lafferty at Tesoft, who provided unique T-shirts to all the engineers who entered. These will certainly become collectors items, and they added an element of fun and universal reward to the contest. We will encourage other sponsors to continue this tradition!

This year, we had two contests and doubled our entries. It is heartening to see that innovation and experimentation is still strong among RF engineers. The 1992 RF Design Awards Contest will be formally announced in the August issue, so it is already time to put on your thinking caps, refine that interesting idea, measure its performance, and document it thoroughly. Maybe next year everyone will see your face on our cover! ***RF***

Generous Prize Donors Make RF Design Awards a Success!

Grand Prize — Design: An HP 8591A Spectrum Analyzer was provided by Hewlett-Packard's Signal Analysis Division in Rohnert Park, California. The HP 8591A covers 9 kHz to 1.8 GHz with a stable synthesized LO. A −115 dBm noise floor and +30 dBm maximum input allows wide dynamic measurement range.

Grand Prize — Software: ingSOFT Ltd. was the donor of a complete Apple Macintosh computer system, including a model SE/30 with monochrome monitor, 4 MB RAM, 80 MB hard disk, and a dot matrix printer. Software awarded in this prize includes ingSOFT's RF Designer and RF Synthesist systems, both with 1-year support, plus additional design and support software —DesignWorks, MiniCad, Professional Layout, AutoRouter, Prograph, Pascal, C, Quick Basic, Full Impact, and Publish It!

Second Prize — Design: The TESLA RF System Block Diagram Simulator is provided by Tesoft, plus OrCAD/SDT/III schematic capture and the MODGEN model generator and Microsoft Fortran with which to add model system elements.

Second Prize — Software: DGS Associates provided the student edition of S/FILSYN, including virtually all of the features of the S/FILSYN design and synthesis program. Active, passive, microwave and digital formats are all included.

Third Prizes — Both Contests: A package of signal processing components, including mixers, couplers, limiters, etc., was provided by Adams-Russell, ANZAC Division. Third place winners in each category can stock up their design bench with these universal RF components.

Consolation Prize: Everyone who entered had a chance to win a major prize, an RSG-10 synthesized signal generator donated by Ramsey Electronics. This unit covers 1 kHz to 1 GHz with calibrated output of −130 dBm to +10 dBm level, programmable memory and AM/FM modulation.

Our thanks go to these companies, who have shown their support of the RF Design Awards Contest and their encouragement of RF engineering creativity by providing outstanding prizes to our winners!

Here are our third place winners. At the top is John Roberts, who entered a design for simultaneous AM and FM demodulation. Below him is Jack Porter, whose filter analysis program was a winner.

Harris puts all the most popular modulation techniques into one DSP chip.

The new Harris HSP45116 NCOM (Numerically Controlled Oscillator-Modulator) puts all the most popular digital modulation techniques on a single DSP chip. Including QAM, FM, AM, FSK, PSK, and complex down-conversion.

Sample rate: Up to 33 MHz
Frequency control: 32 bits
Phase control: 16 bits
Data input: 16-bit complex

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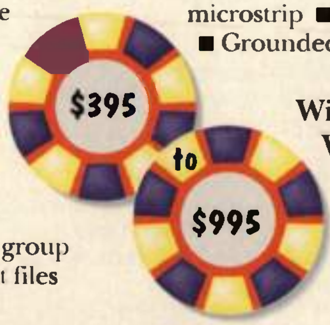

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A Comprehensive Filter Design Program

By Michael Ellis
Mississippi State University and
U.S. Army Corps of Engineers

Here is the winner of the first RF Design Awards PC Software Contest! This computer program, made up of numerous computation modules, synthesizes and analyzes the basic filter configurations (lowpass, highpass, bandpass, bandstop) using elliptic, Butterworth, Chebyshev rolloff models as well as image parameter designs. A number of related computation functions further enhance the utility of the program.

The programs that make up this filter design package were written as a result of studies throughout the author's academic career. The justification for writing them is to help understand and remember the principles taught in school, with regard to the design of electronic filters.

For convenience, the program runs from a main menu which calls the various program modules. File transfer between modules is performed automatically. Because of the complexity of the program, a comprehensive description of each section is not practical, and the reader is referred to the list of references.

Hardware Requirements

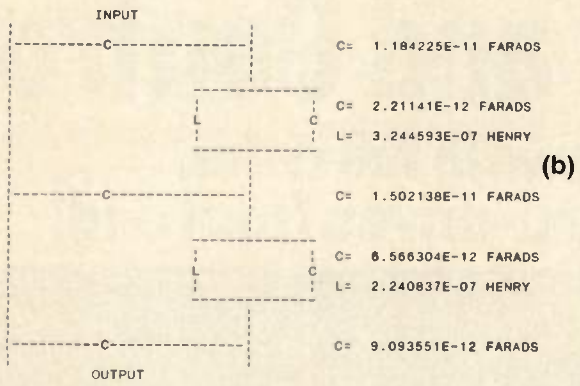
The program runs on an IBM PC/XT/AT or compatible unit with graphics capability. Actually, numerical data can be obtained using any available display

(a)

```
LOWPASS
ELLIPTIC
CUTOFF FREQUENCY IN HERTZ  100000000
TYPE FILTER ORDER  5
TYPE MAXIMUM ATTENUATION IN THE PASSBAND IN DB  .5
TYPE MINIMUM ATTENUATION IN THE STOPBAND IN DB  40
SOURCE RESISTANCE =  200  OHMS
LOAD RESISTANCE =  200  OHMS
PRINT STANDARD NETWORK (0) OR DUAL (1)  0

                              CRITICAL Q = 12.26788
```

(b)



(c)

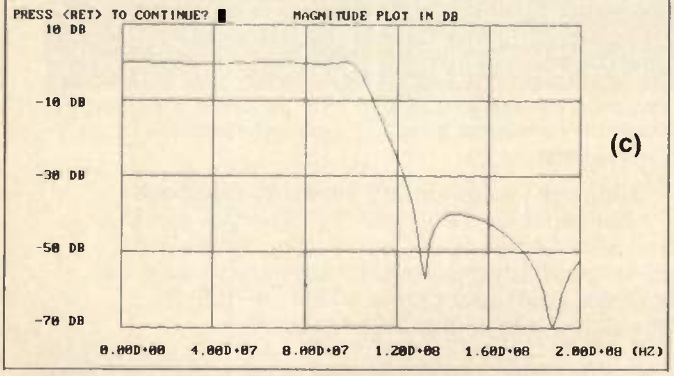


Figure 1. Input data (a), circuit design (b) and magnitude response plot (c) of a 5th order elliptic lowpass filter designed with this program package.

(a)

```
                    MAGNITUDE AND PHASE RESPONSE
TEST

IF DATA IS CONTAINED IN A FILE, PRINT FILENAME ELSE RETURN TEST
ANALOG(0) OR DIGITAL(1) BODEPLOT?  0
INPUT HIGHEST DEGREE OF NUMERATOR          0
INPUT HIGHEST DEGREE OF DENOMINATOR        3
INPUT NORMALIZED COEFFICIENTS OF NUMERATOR AS CALLED FOR
S** 0          1
INPUT NORMALIZED COEFFICIENTS OF DENOMINATOR AS CALLED FOR
S** 0          1
S** 1          2
S** 2          2
S** 3          1
BODEPLOT(0) OR LINEAR PLOT(1)?  1
HZ(0) OR RADIANS(1)?  0
INPUT LOW FREQUENCY END   500000
INPUT HIGH FREQUENCY END   2000000
INPUT FREQUENCY INCREMENT   100000
```

F	MAG	PHASE	GROUP DELAY (uS)
500000	.9922779	-60.25512	.3721777
600000	.9774579	-74.11614	.3982766
700000.1	.9459046	-88.91602	.4229611
800000	.8901139	-104.4321	.4362012
900000.1	.8080716	-120.0665	.4283995
1000000	.7071068	-135	.3978873
1100000	.6006725	-148.5346	.3524818
1200000	.5008783	-160.3307	.3029466
1300000	.4142711	-170.3894	.2568141
1400000	.3424029	-178.9013	.2172537
1500000	.2840883	173.8845	.1846438
1600000	.2371746	167.7306	.15817
1700000	.199452	162.436	.1367206
1800000	.1690014	157.839	.1192573
1900000	.1442686	153.812	.1049227
2000000	.1240347	150.2551	9.304442E-02

(b)

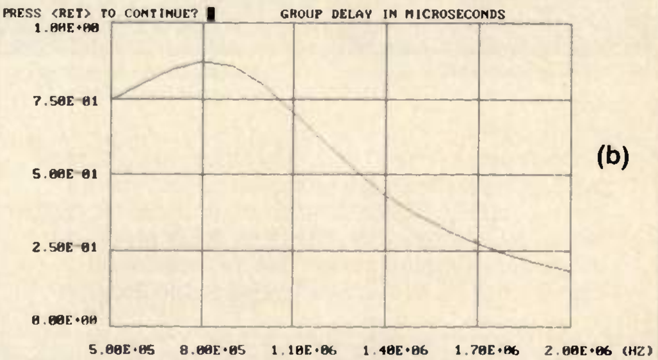


Figure 2. Phase and delay data (a) and a delay plot (b) of a 3rd order Butterworth lowpass filter.

and printer, but the graphical information requires a CGA/EGA/VGA or compatible monochrome graphics monitor. The program has an Epson-compatible driver which will print graphics by using the SHIFT-PRINTSCRN command.

For fastest and most convenient operation, the program should be loaded into its own subdirectory on a hard disk. It can be run from a floppy disk, but it will require a high density 5-1/4 in. disk or either a double density or high density 3-1/2 in. disk. All the modules will not fit on one 360k 5-1/4 inch disk. A math coprocessor is not required.

Program Features

The program is invoked by the command "RF" which brings up the main menu. From this menu, the user can call any of the computations. The program will perform the following calculations and plots, described here module-by-module:

Calculate Filter Order (RF1). This calculates the order necessary to implement a filter using passband and stopband parameters specified. For example, a bandpass filter would be specified by the upper and lower passband edges, upper and lower stopband frequencies and the required attenuation at those frequencies. This module can operate as a stand-alone program.

Passive Filter Design (RFDESIGN, CELLIP, SELLIP). The RFDESIGN module computes values for Butterworth and Chebyshev filters, and handles data input for CELLIP (odd order elliptic) and SELLIP (even order elliptic). Filter orders up to 40 for Butterworth and Chebyshev designs, or 20 for elliptic designs, can be handled. The lead element can be selected to be either shunt or series. Elliptic filters must have equal input and output terminations, while Butterworth and Chebyshev types can have unequal terminations. An example of a 5th order elliptic lowpass filter is shown in Figure 1.

The filter computations all begin with a lowpass prototype, transformed to the desired topology and scaled to the desired frequency. A schematic of the filter is displayed, and the data is saved in a transfer file for either numeric or plotted frequency, phase, and delay response calculations.

Pole-Zero Analysis (PZ) and Transfer Function (RF3). The user can obtain the filter transfer function and the location of poles and zeros.

Magnitude and Phase Plots (RF2). This program module will accept inputs from the keyboard, or from other modules of the package, such as pole-zero location, or from a stored filter function. Response (magnitude, phase, delay) versus frequency can be displayed in tabular form or plotted. An example of a third order Butterworth lowpass filter is shown in Figure 2.

General Circuit Analysis (RF5). This program module performs active and passive network analysis of circuits up to 25 nodes, taking data from a user-generated file, or from a file generated in the main program. Included is Monte

Mike Ellis — The First Software Contest Winner

Michael Ellis ia a full-time graduate student completing course work for a PhDEE at Mississippi State University in Starkville. He is on a one-year leave from the U.S. Army Corps of Engineers' Waterways Experiment Station (WES) in Vicksburg, Mississippi, his home town. An engineer at WES since 1987, Mike has been developing local area networks and telecommunications for the facility, which is the Corps of Engineers' major research center for the inland waterways system of channels, dams, etc. (A Cray X/MP supercomputer is across the hall from the lab where this photo is taken). His work has included fiber optic as well as wireline communications.

Mike recieved his BSEE and MSEE from Vanderbilt University in 1974 and 1976, respectively. He has worked in radar and microwaves at Georgia Tech Research Institute and Scientific Atlanta. He also worked on modem design at Hayes Microcomputer. His personal interests are analog design, filter analysis and design, digital signal processing, and computer program development. As a hobby, he builds his own test equipment (including an oscilloscope) and writes programs for plotting mathematical functions, antenna patterns, optimization routines and LAN simulation. Mike can be reached at 412 Elmwood, Vicksburg, MS 39180.

Carlo analysis, simulating variation of component values from user-specified tolerances and number of simulations. Each simulation is stored in a data file for examination.

Image Parameter Design (RF9). This 1940s-era filter design method can be used to design lowpass, highpass, bandpass and bandstop filters. The method is quick, and the filter stopband responses are generally sharper than Chebyshev filters. Because these filters are designed without knowledge of pole and zero locations, the general circuit analysis program (RF5) is needed to analyze and display their magnitude and phase.

Inductor Design (RF6). This module determines the number of turns of wire required to get the desired inductance in an air core inductor. This can run as a standalone program.

Partial Fraction Expansion and Inverse Laplace Transform (RF4). Impulse and

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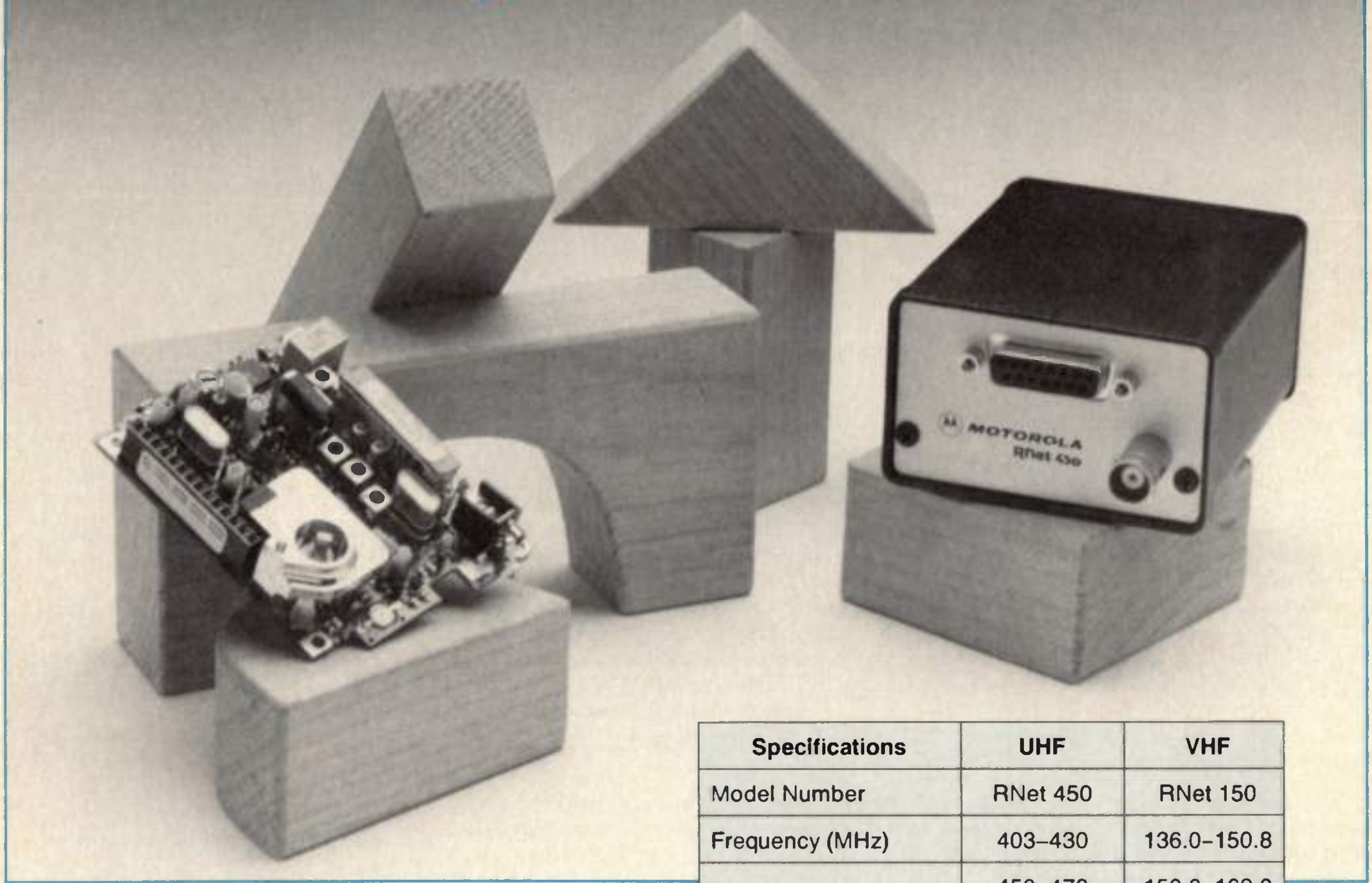

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Current Drain		
Standby:	16mA	20mA
Receive:	20mA	24mA
Transmit:	865mA (2W)	870mA (2W)
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step response can be determined using this program module, which takes its input from a user file or program-generated transfer file. The value of the time domain functions can be displayed in a table or plotted.

File Transfer (TFILE). This manages the data generated by the various program modules, maintaining proper format for exchange of data between the various computation and display modules.

Summary

This filter design program allows an RF engineer to quickly design and analyze various filter topologies, examine response, phase and delay characteristics, and analyze component sensitivity. Optional calculations allow time domain analysis and further mathematical analysis. Its straightforward menu should lead users through the program with little trouble.

This Grand Prize winning software is available from the RF Design Software Service, including a 30-page manual describing program operation. *See the advertisement on page 47* *for price and ordering information.* **RF**

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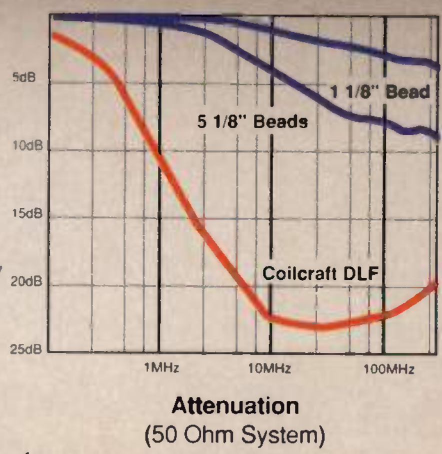

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Low Frequency Circulator/Isolator Uses No Ferrite or Magnet

By Charles Wenzel
Wenzel Associates, Inc.

This is the Grand Prize winner in the Design category of the 1991 RF Design Awards Contest. For his achievement, the author was awarded an HP 8591A portable spectrum analyzer from Hewlett Packard.

The ferrite circulator/isolator is an amazing and important tool for the microwave engineer. Unfortunately, for frequencies below several hundred megahertz, the size of the magnets and ferrite becomes unworkable and the cost skyrockets. With the advent of remarkably fast op-amps, it has become practical to construct a low power equivalent to the circulator that works all the way down to DC and exhibits superb reverse isolation and impedance characteristics to frequencies above 100 MHz.

Suitable for small signal applications, the active circulator is excellent for matching and tuning antennas, amplifiers, and oscillators. Figure 1 shows a schematic of the circuit. Figure 2 is a photo of the prototype of the device. The isolated 50 ohm resistance presented at each port makes experiments with non-linear or reactive devices such as detectors, mixers, frequency multipliers, and filters straightforward since both the signal source and the analyzer are isolated from the device under test. Engineers working with lower RF frequencies will find the active circulator to be a welcome addition to the test bench.

The purpose of the circulator is to absorb all energy entering a port and to pass that energy on to the next port. High reverse isolation ensures that the energy flows in one direction around the circulator and that the impedance of one port is not affected by the other ports. The microwave circulator uses the non-linear properties of ferrite immersed in a magnetic field whereas this circuit uses high speed operational amplifiers.

For the circulator to work properly, each port must exhibit the characteristics of a Thevenin equivalent consisting of a 50 ohm resistor and a voltage source with a voltage twice as large as the voltage arriving at the previous port. Note that this voltage source ignores signals leaving the previous port as well as any signals on any other ports. The factor of two makes up for the drop across the Thevenin resistance when a 50 ohm load is connected.

First, the 50 ohm resistance results from the two, 100 ohm resistors leading to virtual grounds — that is points that are held at a fixed voltage regardless of the current.

The Thevenin voltage source is a little less obvious since the two 100 ohm resistors are connected to two different voltages that average to the desired factor of two. Each op-amp amplifies its input signal by 3.236 which is applied to one of the resistors. A voltage divider drops this voltage down to 0.764 which is applied to the positive input of the next op-amp. Since the other resistor is connected to the feedback node of this op-amp, it sees the same 0.764 size signal. The average of 3.236 and 0.764 gives the desired factor of two. Figure 3 shows the forward gain versus frequency for different supply voltages. The differential gain is set so that signals leaving a port terminated with 50 ohms will generate no output at the following port. A load impedance other than 50 ohms generates a "reflection" which is passed on to the next port. The op-amps provide inherent reverse isolation as shown in Figure 5 and the power handling capability is shown in Figure 4.

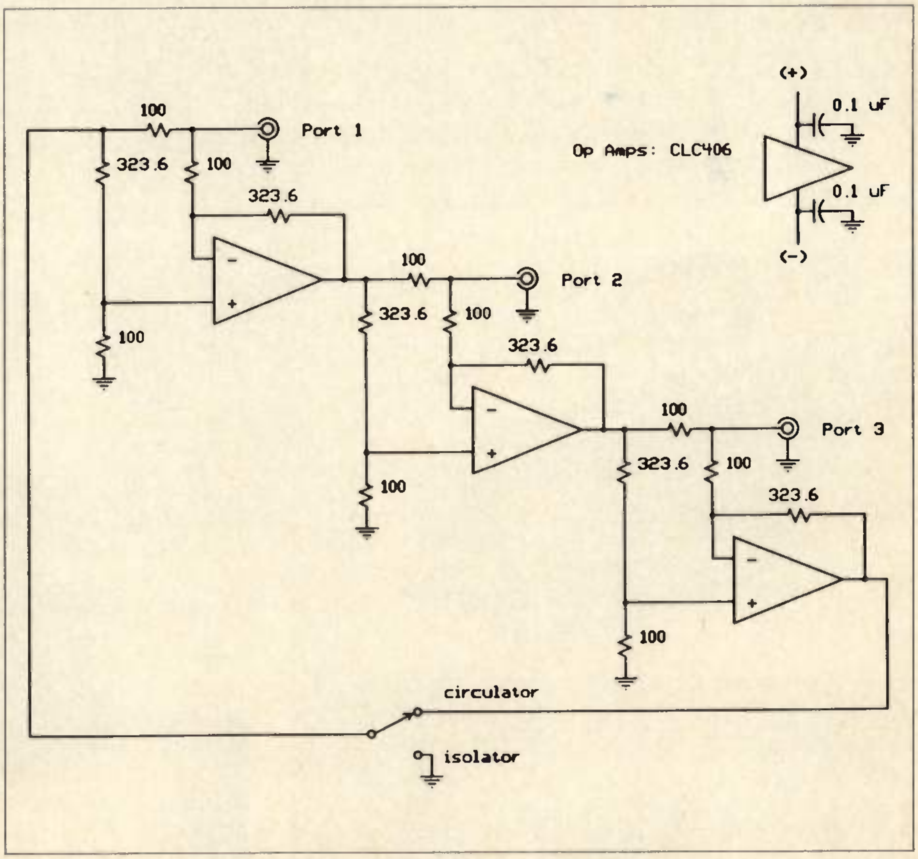


Figure 1. Schematic of low frequency circulator/isolator.

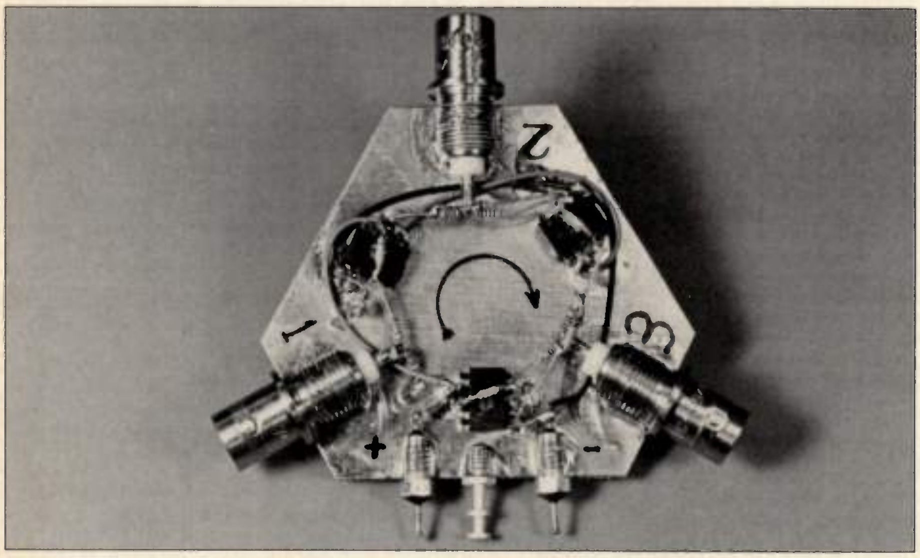


Figure 2. Constructed low frequency circulator/isolator.

The purist will note that a polarity reversal occurs from one port to the next due to the inverting op-amp configuration. More ports may be easily added to the circulator by repeating the obvious pattern.

Since the circulator works down to DC, its behavior can be observed with a multimeter. The port resistance can be measured with an ohm-meter and during the measurement the ohm-meter's test voltage appears at the next port (inverted). If -1 VDC is applied to port 1

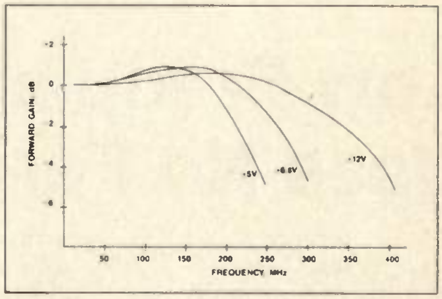


Figure 3. Forward gain versus frequency for different supply voltages.

then 1 VDC will appear across 50 ohms at port 2 and 0 VDC will appear at port 3 (as -1 VDC due to the op-amp inversion). Now if port 2 is shorted then the 1 VDC will "reflect in phase" and will destructively add to give 0 VDC at port 2 (an unusual way to describe why a short gives 0 VDC). This inverted volt circulates to port 3 where 1 VDC appears across the load!

Component Selection

The CLC406 op-amp selected for this

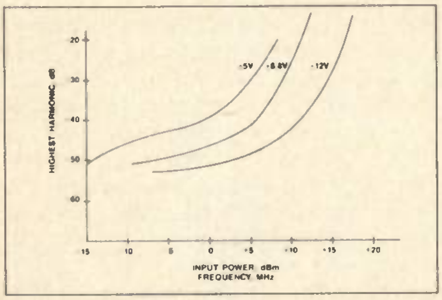


Figure 4. Distortion versus input power for different supply voltages.

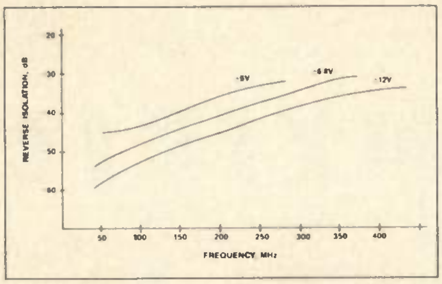


Figure 5. Reverse isolation versus frequency for different supply voltages.

design is not the fastest or highest power device that Comlinear Corporation manufactures, but instead represents the economy end of the spectrum with a price below $10. As Figures one through three show, this inexpensive amp delivers impressive performance at 5 VDC, even better performance near the absolute maximum rating at 6.8 VDC, and amazing performance well above its specified limit at 12 VDC! Operating above maximum ratings is not recommended. A better choice would be to select a faster, more powerful op-amp (or use sockets).

Stable, low inductance precision resistors are required for optimum results. The 323.6 ohm resistance can be achieved by paralleling a 330 ohm with a 16.8 kohm. The resistor values shown may be scaled to build a circulator with a different characteristic impedance. For example, a 75 ohm circulator would use resistors 1.5 times larger in all positions. It is interesting to note that a circulator could be built with a different characteristic impedance at each port.

Bypass capacitors must be connected to both power supply pins of each op-amp to the ground plane. The prototype uses 0.1 uF ceramic chip capacitors soldered directly from the IC to the ground plane.

Applications

The circulator is a natural choice for the matching and tuning of low level amplifiers. With the signal source connected to port 1, the amplifier's input or output to port 2, and a signal analyzer to port 3, the amplifier is turned for maximum return loss by adjusting for minimum signal at port 3. A high return loss is synonymous with a good VSWR since a well matched amplifier will "return," as a reflection, very little of the input signal. Figure 6 shows a typical application of the circulator/isolator.

Low level signal sources may also be adjusted for 50 ohm output impedance in a similar way. Simply adjust the frequency of the test signal until it is close to the carrier then tune the source for minimum reflection. Again, the re-

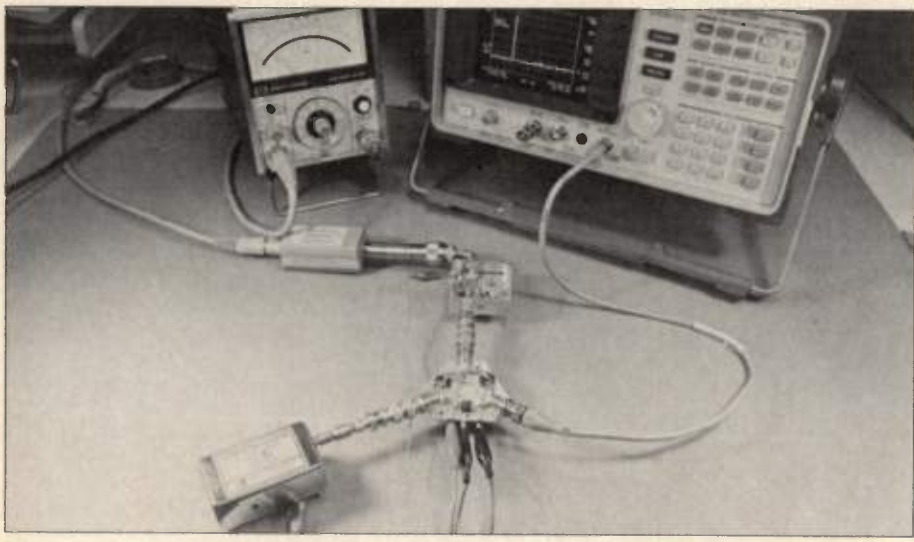


Figure 6. Typical application: adjusting the input impedance of a frequency multiplier.

flected signal appears at the next port. If the source's amplitude is too high for the circulator's op-amps to handle, just add an accurate attenuator. The circulator's accuracy is sufficiently high to "see" the return loss of a source through a small pad. Remember, the test signal passes through the pad twice and is attenuated each time so the return loss will seem better than it actually is by twice the attenuator value. In fact, a pad terminated with an open or short will exhibit a return loss exactly twice the pad's attenuation factor since the return loss of an open or short is zero.

Antennas may be tuned in a similar

manner without using large signals that might cause interference with others. A low power generator is connected to port 1, the antenna to port 2, and some form of power or signal level indicator to port 3. The signal level at port 3 is proportional to the transmission loss and should be minimized by tuning the antenna matching network.

A time domain reflectometer is easily realized by applying a fast square wave or pulse to port 1 and connecting the device or cable under test to port 2. Breaks in the cable or other high impedance anomalies will reflect pulses with the same polarity as the input whereas shorts or lower impedances will reflect inverted pulses. Remember the inversion from one port to the next. A clean test signal is necessary for good results.

Conclusion

The active circulator brings many of the features of its big brother, the microwave ferrite circulator, down to the lower RF frequencies. Although the active version obviously lacks the power handling capabilities of typical circulators, the small signal applications abound. ***RF***

About the Author

Charles Wenzel is President of Wenzel Associates, a manufacturer of speciality crystal oscillator products for high purity, high stability applications. Founded in 1978, his company has developed high performance oscillators for instrumentation, communications, and military systems. Wenzel Associates has 36 employees, and boasts the world's lowest noise crystal oscillator, as measured by the National Institute of Standards and Technology (NIST).

His winning design was the result of considerable experimentation and design using discrete transistors, all of which failed to work. Recently-developed high-speed operational amplifiers allowed Charles to realize the goals of high isolation, stability, and controlled input and output impedances. He reports that a number of typical low-frequency op amp circuits were tried at RF using these devices, with good success.

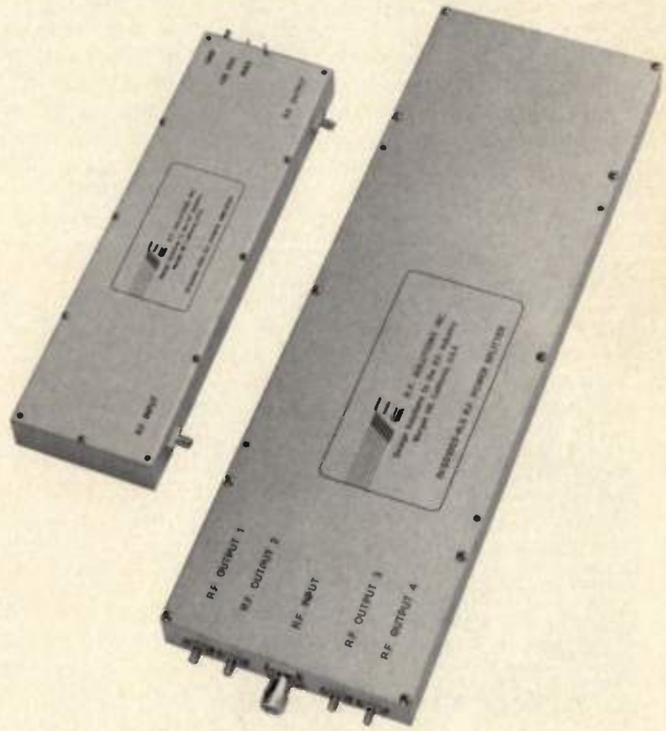
Charles, a native of Austin, has a BSEE from the University of Texas. His hobbies include experimenting with new circuits and relaxing while playing his guitar. He can be reached at Wenzel Associates, Inc., 14050 Summit Drive, Austin, TX 78728; telephone (512) 244-7741.

INFO/CARD 38

OFF THE SHELF

RF AMPLIFIERS

MODEL NUMBER	POWER Watts	GAIN dB	SUPPLY Volts	PRICE
FREQUENCY RANGE 5 – 50 MHz				
RFP0550-100	100	44	50	$2,100.00
RFP0550-1000	1000	16	50	$5,040.00
FREQUENCY RANGE 50 – 100 MHz				
RFP0800-100P50	50	30	50	$1,485.00
RFP0800-100P100	100	30	50	$1,660.00
RFP0800-100P200	200	30	50	$2,200.00
RFP800-100	600	16	50	$2,424.00
FREQUENCY RANGE 1 – 100 MHz				
RFP01100-300	300	46	50	$3,150.00
FREQUENCY RANGE 76 – 108 MHz				
RFP0810-600	600	16	50	$1,780.00
FREQUENCY RANGE 75 – 150 MHz				
RFP0800-150P50	50	30	50	$1,485.00
RFP0800-150P100	100	30	50	$1,660.00
RFP0800-150P200	200	30	50	$2,200.00
RFP800-150	500	14	50	$2,424.00
FREQUENCY RANGE 100 – 200 MHz				
RFP0800-200P50	50	30	50	$1,660.00
RFP0800-200P100	100	30	50	$2,900.00
RFP800-200	400	13	50	$3,636.00
FREQUENCY RANGE 225 – 400 MHz				
RFP0204-4	4	20	28	$ 484.00
RFP0204-10	10	30	28	$ 685.00
RFP0204-25	25	30	28	$1,140.00
RFP0204-50	50	40	28	$1,695.00
RFP0204-100	100	40	28	$2,200.00
FREQUENCY RANGE 400 – 500 MHz				
RFP0405-4	4	20	28	$ 435.00
RFP0405-10	10	30	28	$ 616.00
RFP0405-25	25	30	28	$1,026.00
RFP0405-50	50	40	28	$1,525.50
RFP0405-100	100	40	28	$1,980.00
FREQUENCY RANGE 1 – 500 MHz				
RFP00105-4	10	30	28	$1,450.00
RFP00105-25	25	30	28	$2,800.00
RFP00105-50	50	40	28	$3,752.00
RFP00105-100	100	40	28	$5,600.00



COUPLER/SPLITTER

MODEL NUMBER	INPUT/ OUTPUT PORTS	INSER-TION LOSS dB	POWER Watts	PRICE
FREQUENCY RANGE 5 – 50 MHz				
RFS100-5-50-4	4	0.3	100	$ 360.00
RFS1000-5-50-4	4	0.3	1000	$ 610.00
FREQUENCY RANGE 50 – 1000 MHz				
RFS100-FL-FU-2	2	0.15	100	$ 500.00
RFS100-FL-FU-3	3	0.15	100	$ 600.00
RFS100-FL-FU-4	4	0.3	100	$ 800.00
RFS100-FL-FU-6	6	0.3	100	$1,000.00
RFS1000-FL-FU-2	2	0.15	1000	$ 750.00
RFS1000-FL-FU-3	3	0.15	1000	$ 900.00
RFS1000-FL-FU-4	4	0.3	1000	$1,200.00
RFS1000-FL-FU-6	6	0.3	1000	$1,500.00

FL = Your Lower Frequency Limit
FU = 2 x FL

EXAMPLE: A four way Combiner with an output power rating of 1000 watts covering a frequency range of 100–200 MHz would have a part number of RFS1000-200-4.

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INFO/CARD 65

New High Speed/High Purity Synthesizers

Anritsu announces the MG2501A, MG2502A and MG2502B series of frequency synthesizers covering 1 to 300 or 600 MHz with 0.01 Hz resolution. This series is intended for demanding high performance applications, featuring phase noise performance of better than −120 dBc/Hz and spurious response of −70 dBc. The MG2501A and MG2502A models cover 1-300 and 1-600 MHz, respectively, and are intended for ATE applications with control via an IEEE-488 bus. Only an RF output connector and power switch are on the front panel.

The MG2502B includes complete front panel controls for manual setup and operation, providing such features as digital sweep of memory locations, start/stop, and dual sweep. The RF output range of all three instruments is +17 to −79.9 dBm with ± 1 dB level flatness. Frequency switching speeds are as fast as 5 us, depending on the control interface, which includes BCD and phase continuous BCD as well as the GPIB/IEEE-488. Up to 100 frequency memories may be swept in an UP, DOWN or UP-DOWN mode for agility testing and pseudorandom sequencing. A standard 10 MHz reference oscillator provides 5×10^{-8} stability after a 30-minute warmup, and an aging rate of 2×10^{-8}/day.

The MG2501 is priced at $10,800, the MG2502A is $12,960 and the MG2502B is $17,460.

Anritsu America, Inc.
INFO/CARD #250

Low Profile Ovenized Oscillator

OCXO Model 101AC is introduced by Reeves-Hoffman Division. The oscillator is offered in a 9 to 15 MHz frequency range for communications, instrumentation, GPS, SARSAT and other applications requiring substantial

precision. Stability over a −40C to +70C temperature range is $\pm 5 \times 10^{-8}$, while the specified aging rate is 1×10^{-9}/day at the time of shipment. Power requirements are +12 VDC, with turn-on power consumption of 7.5 watts and idle consumption of 0.75 watts, maximum at 25 degrees C. The unit is packaged in a low-profile 1.42 × 1.01 × 0.75 inch (l × w × h) case. Price of the Model 101AC OCXO is $160.00 (in 100 qty.).

Reeves-Hoffman
INFO/CARD #249

One-Instrument Spectrum/Network Analyzer

Hewlett-Packard's HP 3589A is a 10 Hz through 150 MHz spec-

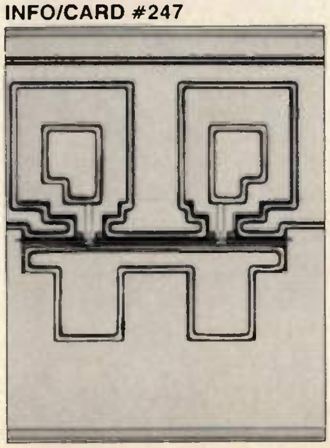
trum network analyzer, offering features of both instruments for the price of a spectrum analyzer alone. Also introduced are 50 and 75 ohm S-parameter test sets HP 35689A/B. The instrument includes new time-gated spectrum analysis functions for measurement of burst and other time-varying signals. Also included are measurement and display options which speed measurements. The HP 3589A provides network measurements of group delay, polar or Smith chart displays in either 50 or 75 ohm environments. The analyzer also offers log sweeps and has a 1 megohm input for high impedance measurements. HP Instrument BASIC is available for use, and a standard PC keyboard can be used for program creation and editing. The unit is priced at $21,750, and the 50 and 75 ohm test sets are $3650 and $4000, respectively.

Hewlett-Packard Co.
INFO/CARD #248

FETs Target Commercial Applications

The low cost NEC NE321 series now available from California Eastern Laboratories is offered in chip form (NE32100) and in an epoxy sealed metal/ceramic package (NE32184A, available on tape and reel). Applications from 0.5 to 13 GHz include DBS, TVRO, MMDS or generic LNAs and downconverters. Noise figure at 12 GHz is 1.0 dB, typical and 1.2 dB, maximum, with available gain of 10.5 dB, typical and 9.5 dB minimum. Fabricated with mushroom shaped gates, these FETs offer improved power handling capability and decreased gate resistance. Available from stock, the NE32184A is priced at $8.60 in 1000-piece quantities.

California Eastern Laboratories
INFO/CARD #247



GPS Primary Reference Source

Austron announces the availability of their Model 2202 automatic acquisition Global Positioning Sys-

tem (GPS) Satellite Time and Frequency Receiver, designated as a Primary Reference Source (PRS) for telecommunications applications. This version is specifically packaged to meet Bellcore standards. The Model 2202 provides a PRS that can interface to any Stratum 2 node in the network, using GPS signals calibrated by the U.S. Naval Observatory, which is traceable to the National Institutes of Standards and Technology (NIST). Accurate primary standards assure slip-free data transmission over the telephone network. A loran C option is available, providing an additional reference that is statistically combined with the GPS to provide an optimum reference.

Austron, Inc.
INFO/CARD #246

Hybrid Synthesizer

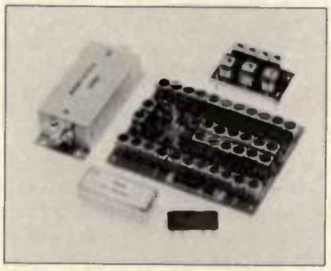
Gemtronic Engineering has introduced a hybrid VHF synthesizer in a 1 × 2 inch dual in-line package. The module is completely self-contained, requiring only an RF reference and a logic input to set operating parameters. Frequency range is ± 20 MHz over the 50-300 MHz band, depending on model. Step size is 20 to 200 kHz and power output is typically +3 dBm. Spurious output is −60 dBc or better, and phase noise is −70 dBc/Hz at 1 kHz offset, using a step size of 50 kHz. The price is $135 in small quantities. Custom modifications are available.
Gemtronic Engineering
INFO/CARD #245

SMT Inductor Kits

SMT inductor designer kits meeting MIL-C-83446 are available from Vanguard Electronics. 180 degree C rated wire, welded terminations, and lead frame design are features of these inductors. They are available as inductors or chokes for use in filters, oscillators, and amplifiers. Inductance values from 10 nH to 10 mH are provided in 10 percent tolerance values. Pricing is from $385.
Vanguard Electronics
INFO/CARD #244

Video Lowpass Filters

Arco Electronics announces the LP series of video filters for CCIR 601 NTSC or PAL circuits.



Standard and custom units fit many video processing applications. Typical of the line is 5.75 MHz lowpass filter 4.2.2 with 40 dB attenuation at 8 MHz. In 100s, the price is $65.00 each.
Arco Electronics
INFO/CARD #243

Power/Frequency Instrument

EIP Microwave introduces a new line of portable frequency counters optimized for field mainte-

nance and repair. The Model 25B measures carrier signal frequency and power level over 950 MHz to 20 GHz. Model 28B extends the upper frequency limit to 26.5 GHz. Both models have inputs for IF or baseband frequency measurements down to 10 Hz. Both include YIG preselectors for accuracy and protection. The Model 25B is priced at $4650; the Model 28B is $5650.
EIP Microwave, Inc.
INFO/CARD #242

Variable Gain MMIC

The Avantek IVA-05200 is a variable gain amplifier with DC-1.5 GHz bandwidth, differential or single-ended input and output, 30 dB gain controllable over a 30 dB range. Supply voltage is 5 VDC, with 0-5 VDC control voltage. The IC has an MTTF of 2 × 10^9 hours at a junction temperature of 55C. In 100s the price is $25.20 each.
Avantek, Inc.
INFO/CARD #241

1000 Watt Amplifier

A new 20-200 MHz amplifier providing 1000 watts Class AB linear power has been introduced by Power Systems Technology. RF input is 0 dBm for full power output. VSWR protection and graceful degradation of output in case of transistor failure are protection features provided. Primary power is 380 VAC 50/60 Hz, 3-phase, 5-wire. IEEE-488 bus for control and monitoring is an option.
Power Systems Technology
INFO/CARD #240

Directional Coupler

TRM, Inc. announces the Model DC210 directional coupler, operating over 10-2000 MHz with 20 dB coupling, flat to ± 0.4 dB. Insertion loss is 1 dB maximum, VSWR is 1.2:1 maximum, and directivity is 15 dB minimum.
TRM, Inc.
INFO/CARD #239

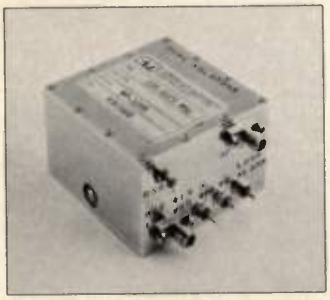
Narrowband SAW Filter

The FB70-2.2 from Phonon Corp. is a filter for 70 MHz

narrowband applications. 1 dB bandwidth is 2.2 MHz, with 40 dB rejection at 4.4 MHz bandwidth. Spurious responses, all non-harmonic, are suppressed more than 40 dB. Insertion loss is 24 dB maximum. Price of the FB70-2.2 is $85.50 each in quantities of 5.
Phonon Corporation
INFO/CARD #238

Coaxial Resonator Oscillator

Communications Techniques announces a series of phase locked coaxial resonator oscillators operating at frequencies of 700 MHz to 3 GHz. The series



PCRO features a high Q resonant circuit, low microphonics, low power consumption, and excellent phase noise. Overall dimensions of the standard units are 2.5 × 2.5 × 1.5 inches.
Communications Techniques, Inc.
INFO/CARD #237

High Current Superconductors

HITC Superconco announces commercial availability of high current carrying superconductors. The new MGA (Melt Growth Alignment) material has been tested to show critical current of 3500 Amps/cm^2 at 77 Kelvin and 100,000 Amps/cm^2 at 4.2 Kelvin in a one Tesla field. The material is available in spheres, rods, tubes, bars, discs or tiles.
HITC Superconco, Inc.
INFO/CARD #236

Lumped Element Filters

Piezo Technology now has a full complement of lumped element filters, including lowpass, highpass and bandpass configurations covering 2 kHz through 3 GHz. Products are available for both commercial and DoD markets.
Piezo Technology, Inc.
INFO/CARD #235

Encapsulating Epoxy

A new encapsulating epoxy with a dielectric constant of 2.5 is introduced by Pinnacle Technologies. PTEB400 also has nearly no linear shrinkage and a specific density of less than one.
Pinnacle Technologies, Inc.
INFO/CARD #234

Vector Modulator for DDS

Stanford Telecom STEL-1130 QAM chip can be used in conjunction with the STEL-1177 quadrature FM/PM Numerically Controlled Oscillator to generate signals with any modulation format at frequencies up to 25 MHz. The STEL-1130 offers 60 MHz throughput, 12 bits linearity for AM and PM, 16 bits for FM, offset binary or two's complement at NCO port, sum or difference of products, or individual outputs. Pricing is $170 (1-9); $60 (1000s).
Stanford Telecom
INFO/CARD #233

Amplified Noise Sources

Ultra-broadband noise sources from Veritech Microwave provide a wide range of Gaussian noise in any frequency band between

0.5 and 26.5 GHz. Thin film technology allows excellent power flatness over wide bandwidths. Customization is available, including digital or analog attenuators and signal combiners.
Veritech Microwave, Inc.
INFO/CARD #232

High Voltage Substrate

Cuflon HV has been developed for high voltage, low loss applications. The substrate is pure PTFE with a dielectric constant of 2.1, and a breakdown of 2500 volts (5 mils thick), an improvement over filled PTFE materials.
Polyflon Company
INFO/CARD #231

Timer/Counter

The Philips PM 6680 from Fluke is a high resolution pro-

grammable timer/counter, offering built-in statistics and mathematical functions. Basic frequency range is 225 MHz, extendable to 2.7 GHz. High speed measurements of 2000 readings per second, along with internal memory and math functions, allow analysis for frequency jitter, including standard deviation, min/max, drift, and other parameters. Advanced triggering is included for single-shot events. A complete set of timing capabilities are included, as well. Price of the PM 6680 is $2000.
John Fluke Mfg. Co.
INFO/CARD #230

Vacuum Capacitors

High power vacuum capacitors are available from Power Electronic Components for applications such as RF dielectric heating equipment, radio transmitters,

radar, and industrial power oscillators. The VECO^tm line is available in voltage ratings of 7.5 to 32 kV, and capacitance values of 6 to 1000 pF. Introductory pricing will be continued until September 1.
Power Electronic Components, Inc.
INFO/CARD #229

HP 8510 Calibration Kit

The new "C" version of the HP 8510 Vector Network Analyzer calibration kit is announced by Maury Microwave. The kits are available in all coaxial and waveguide series currently offered for the HP 8510A/B, including 7 mm, 3.5 mm, Type N, TNC, BNC, double-ridged waveguide, and sizes from WR430 to WR10. Other connector options can be provided.
Maury Microwave Corp.
INFO/CARD #228

Digital Tuner for VCO and Filters

The Model DCV008012 offers ± 10 volts tuning range from an 8-bit TTL digital word. The circuit operates in conjunction with a 12-bit D-A converter and a wideband, high slew rate operational amplifier. Resolution is better than 1 mV and settling is in 1 usec. Two EPROMs are provided to store VCO tuning characteristics. Price is $99 in 100s.
Princeton Phase Locks, Inc.
INFO/CARD #227

Tetrodes for FM Transmitters

Thomson Tubes Electroniques now has a family of power tetrodes and associated circuits for FM transmitters from 10 kW to

100 kW. All but the 100 kW tube (TH 546), which uses Hypervapotron® design, are forced air cooled. High linearity, high gain, and high stability are features of interest to transmitter designers.
Thomson Tubes Electroniques
INFO/CARD #226

Quartz Blanks

Bliley Electric Co. offers pure Z growth cultured quartz in a variety of lapped and cut formats fo electronic and transducer applications. Bliley quartz is available in standard Q, Premium Q and Swept grades. Angle orientation is established by X-ray inspection.
Bliley Electric Company
INFO/CARD #225

RFI- Reduction JFET

A new N-channel JFET in surface-mount packaging is designed to suppress RFI in sensitive detection equipment. By integrating two resistors and two MOS capacitors onto the chip, the BFR200 adds a lowpass filter, suppressing the 450-900 MHz frequency range. In production quantities, the BFR200 is priced at $0.40 each.
Philips Components
INFO/CARD #224

SMT EMI Filters

SMT feed-through EMI filters from Murata Erie incorporate true "T" circuit elements to achieve 40 dB attenuation at 100 MHz. Parallel capacitor values from 68

pF to 4700 pF are available. The devices are rated at 2 amps and 50 VDC.
Murata Erie North America
INFO/CARD #223

Power Dividers

The Vortex Model PDK-600 power divider covers 20 to 600 MHz with 35 dB minimum isolation and 1.2:1 maximum VSWR. Amplitude and phase balance are 0.2 dB and 2 degrees, respectively. Packaging is a 3.0 × 1.0 × 0.5 inch case (less connectors), with field-replaceable SMA jack or plug connectors. Price is $275 ($225 without connectors).
Vortex Microwave Corp.
INFO/CARD #222

Thin-Package Crystals

Raltron announces a new quartz crystal in an extremely thin package for high density applica-

tions. The Raltron HC-52/U (also known as the HC-45 slimline) measures 2.3 mm in thickness. 5 MHz to 360 MHz crystals are available in this package, with pricing ranging from 1.90 to 6.00 each in 10,000 quantities.
Raltron Electronics Corp.
INFO/CARD #221

Medium Power Attenuator

A 25-watt attenuator covering the DC-18 GHz range is announced by Lucas Aerospace. Model 46 includes N-connectors, and attenuation values from 3 to 40 dB. Maximum VSWR is 1.2:1 DC-8 GHz, and 1.35:1 max. at 18 GHz.
Lucas Aerospace
INFO/CARD #220

In-Cable Filters

Micro-Coax Components offers microwave filters integrated within semi-rigid coaxial cable for applications where space-savings is desirable. Filters are available in 0.085, 0.141 or 0.250 inch diameter cables, with cutoff frequencies from 250 MHz to 26.5 GHz with up to 25 sections. Numerous connector options and PC board mountings are offered.
Micro-Coax Components
INFO/CARD #219

Tuning Varactors

SOT-23 SMT packaged tuning varactors have been introduced by M/A-COM. The MA4ST400 series ion-implanted hyperabrupt junction devices are designed for octave-bandwidth tuning from HF through UHF. Single and dual common-cathode pairs are offered with 10 to 47 pF total capacitance and 6.0:1 to 9.5:1 capacitance ratio. Linear tuning performance is available using 3 to 8 volts control.
M/A-COM Semiconductor Div.
INFO/CARD #218

Boron Nitride Material

Boron Nitride ceramic substrate material with increasing mechanical strength with temperature is offered by Carborundum Co. Grade AX05 can be machined with standard "tool steel" equipment. High resistivity, dielectric strength and a low loss tangent and dielectric constant make the material suitable for many microwave applications.
The Carborundum Company
INFO/CARD #217

RFI/EMI Filter

AN AC line filter with suppression of RF energy in differential and common mode is offered by Okaya Electric. The RAV-BG Series protects against surges to 15 kV. 3 and 6 amp versions are available, with standard IEC connectors and either solder or faston connection terminals. Pricing is $16 to $18 in OEM quantities.
Okaya Electric America, Inc.
INFO/CARD #216

IF Signal Processor

Miteq announces a module combining a logarithmic amplifier, limiter and wideband discriminator in a 6 × 3 × 0.8 inch package. Designs are available for 10-160 MHz with bandwidths up to 40 MHz. Maximum log accuracy deviation is ± 1 db, discriminator linearity is ± 3 percent, and the unit will handle pulse rise and fall times o 20 nsec and 75 nsec, respectively.
Miteq
INFO/CARD #215

One Antenna Kit with everything, to go please.

A complete line of kits with upper limits to 18GHz that satisfy FCC, VDE, and MIL-STD 461 specifications, and more.

Antenna kits that meet your specifications of high quality and frequency response, and that are also responsive to your demands of portability and easy use. A.H. Systems offers nine different kits that fill the bill. Each comes in a single, lightweight case. Just one kit can contain all the antennas, probes and cables to perform E-Field 1KHz-18GHz, H-Field 20Hz-50KHz and conducted 20Hz-100MHz testing. Antenna factor calibrations are provided with each antenna.

So order one to go, with everything, or one of our other tantalizing specials.

MODEL #	FREQ. RESP.	DESCRIPTION
SAS-200/510	300 - 1800 MHz	Log Periodic
SAS-200/511	1000 - 12000 MHz	Log Periodic
SAS-200/512	200 - 1800 MHz	Log Periodic
SAS-200/518	1000 - 18000 MHz	Log Periodic
SAS-200/530	150 - 550 MHz	Broadband Dipole
SAS-200/540	20 - 300 MHz	Biconical
SAS-200/541	20 - 300 MHz	Bicon'l Collapsible

MODEL #	FREQ. RESP.	DESCRIPTION
SAS-200/542	20 - 300 MHz	Biconical, Folding
SAS-200/550	001 - 60 MHz	Active Monopole
SAS-200/560	per MIL-STD-461	Loop - Emission
SAS-200/561	per MIL-STD-461	Loop - Radiating
BCP-200/510	20 Hz - 1 MHz	LF Current Probe
BCP-200/511	100 KHz-100 MHz	HF-VHF Crnt. Probe

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A.H. SYSTEMS

INFO/CARD 44

1992 European EMC Requirements for Susceptibility

By Gary A. Breed
Editor

Much has been written about the European Economic Community's Directive 89/336/EEC, but continued attention to EC92 is required because of its far-reaching economic implications. For those readers who are primarily design engineers, not EMC specialists, this report will offer some insight into susceptibility regulations that will affect their design tasks in the near future.

Basically, the 1992 European Community directive requires minimum standards for emissions, and immunity (susceptibility) to both RF fields and electrostatic discharge (ESD). The anticipated standards represent tougher EMC requirements for manufacturers to meet, and in the case of immunity, completely new requirements for nearly all consumer electronics sold in Europe.

CENELEC Committee TC110 has the responsibility for establishing standards for immunity to both electromagnetic fields and electrostatic discharge. Early in the process, it was made very clear that immunity to RF fields was an important issue to the drafters of EMC policy. In the proposed standard, the regulated frequency range is 9 kHz to 400 GHz, with specifications drawn from existing IEC 801-3 and 801-6, including modifications currently proposed by the IEC.

Since immunity standards represent an entirely new set of mandated performance requirements, they are receiving much attention. Test laboratories, military equipment manufacturers, and only a few others have been working with immunity performance and measurement techniques readily adaptable to new EC requirements. Many commercial and consumer equipment manufacturers do not have experience in designing to meet immunity standards. This group will have the difficult task of rapidly acquiring immunity control engineering skills. Table 1 is a brief summary of the immunity requirements.

The proposed standard for immunity to radiated fields, EN 55 101-3, establishes test methods and limits. Again, the scope of the regulation is 9 kHz to 400 GHz, with standards currently applied only to 80-1000 MHz. Over this range, the field intensity that the EUT must be exposed to is 3 V/m, amplitude modulated (80 percent modulation depth) with a 1 kHz sine wave.

The performance limits of the EUT under these conditions are of two types. First, the function of the EUT must not be impaired; i.e. no malfunction or data loss in digital equipment, and no change in operation of analog-based equipment. The second standard applies to the level of the demodulated 1 kHz tone in analog equipment, which must be 40 dB below normal signal levels in the EUT. It is prudent to note that this −40 dB requirement might be acceptable for power supplies and telephone equipment, but it is not sufficient to avoid affecting the performance of most data acquisition, instrumentation and audio equipment.

The field generated must be a minimum of 3 V/m over the plane which includes the front, or nearest surface, of the EUT, using both vertical and horizontal polarizations. This differs from previous work by CISPR which requires a 3 dB field uniformity within the volume containing the EUT. Under the proposed standard, calibration of the field intensity levels is required at 10 MHz intervals between 80 and 200 MHz, every 25 MHz from 200 to 500 MHz, and at 50 MHz intervals between 500 and 1000 MHz. The test setup calls for testing inside a TEM cell, or in a shielded chamber with absorber lining.

These new standards will increase the cost and time of development of electronic equipment. However, industry and consumer groups are beginning to realize that the still-growing use of electronic devices in the home and office requires attention to immunity. Much of the electronics used for everyday communications, convenience and entertainment can be easily disrupted in RF fields that are modest compared to the 3 V/m proposed in EN 55 101-3. For this reason, realistic immunity performance standards would be welcome.

Another issue that will eventually be addressed is the frequency range proposed, particularly at the lower frequencies. Outside the 80 MHz lowest test frequency lie many European radio services, including medium-wave and short-wave broadcast, aviation and maritime communications and navigation, amateur radio, and various mobile communications. Most discussions have suggested that 30 MHz be considered a more realistic lower limit, the same as for radiated emissions.

ESD Immunity Requirements

Preliminary standard EN 55 101-2 covers ESD performance, based on IEC 801-2. The basic human body model is the

A) 50 Hz power frequency magnetic field.
B) RF electromagnetic field, AM modulated: 80-1000 MHz, 3 V/m unmodulated field intensity, 80 percent modulation depth. Reference IEC 801-3 Draft 3.
C) RF electromagnetic field, pulse modulated: 2.45 GHz, 10 V/m, 1 percent duty cycle. Not final.
D) Electrostatic discharge: 4 kV peak (Contact Discharge), 8 kV peak (Air Discharge). Reference IEC 801-2 Draft.
E) Electrostatic Discharge: 2 kV peak (Contact Discharge), 5 kV peak (Air Discharge). Reference IEC 801-2 Draft.
(Two ESD standards exist for differing performance levels.)

Table 1. Immunity to radiated interference — types of fields and basic performance requirements. Note that some standards are still under development.

150 pF/330 ohm circuit, with well-defined waveform parameters. The current peak after a specified 0.7-1.0 ns risetime is 11.25 amperes, with decay parameters of 6 amps at 30 ns and 3 amps at 60 ns. Immunity levels are set at 3 kV pulse for the Contact Discharge method and 8 kV for Air Discharge testing.

Contact Discharge testing is emphasized, except where contact is not possible, as is the case with fully insulated enclosures. For such non-conductive situations, 10 discharges at each point are required. Where conductive test locations are available, the proposed specification calls for 50 discharges at the three points with greatest sensitivity, and 50 discharges applied to a coupling plane placed atop the test stand, under the EUT.

Since IEC 801-2 is well-known, there may not be much new in the ESD portion of the 1992 comprehensive standard. However, some minor differences will undoubtedly surface. The number of discharges and the tolerance in the wave shape may vary from 801-2 standards, but these are extremely minor. With the emphasis on Contact Discharge testing, the determination of discharge locations on the EUT may be redefined form current ESD measurement standards.

The proposals outlined above are specifically directed at information technology equipment. EMC performance requirements for other types of equipment will generally follow these standards. Proposed standard EN 50 081 is a universal set of standards intended to apply as generally as possible to all types of electronics. To achieve this kind of generality, EN 50 081 defines the EUT in terms of AC and DC power ports, signal ports, plus radiation through the enclosure.

Concern Exists About Certification

Of greater concern than the actual standards are testing procedures and the process of obtaining approval for testing performed in U.S. laboratories. As the proposed rules are drafted, only European laboratories are assured of approval for EMC testing. Limited access to testing means limited access to the European electronics market. At best, U.S. test labs may be able to perform testing directly, or on a contract basis overseen by European laboratories. At worst, the implementation of these EMC regulations will result in de facto barriers against all electronic equipment manufactured (and tested for EMC compliance) outside Europe. ***RF***

Broadband RF Transformer Directional Couplers

By Mark McWhorter
Lorch Electronics

Directional couplers play an essential role in the design of radio communication systems. A directional coupler separates and samples signals based on the direction of signal propagation. The engineer uses these devices to unequally split the signal flowing in the mainline and to fully pass the signal flowing in the opposite direction. Well-known published articles describe coupler theory and applications.

Simple and inexpensive to fabricate, VHF- and UHF-band directional couplers are packaged as off-the-shelf items by numerous vendors. Directional couplers, however, can be built from material typically costing one-tenth the price of commercial packages. This article intends to provide theoretical and practical design information to aid the engineer in the expedient and inexpensive fabrication of broadband RF transformer directional couplers for system requirements.

Theoretical Equivalent Circuit Model Analysis

The broadband RF directional coupler shown in Figure 1 depicts two identical transformers wound on magnetically isolated cores represented by primary inductance L_1 and secondary inductance L_2. Port A is driven by voltage V_{in} with a source impedance of Z_o ohms. Ports B, C and D are terminated in Z_b, Z_c and Z_d, respectively (typically 50 ohms each), resulting in the equivalent circuit of Figure 2. The mainline energy path is Port A to Port B. Power from the mainline is coupled to Port D as a function of primary and secondary inductance. Port C is isolated from Port A. Because the coupler exhibits reciprocity, power on the mainline flowing from Port B to Port A will be coupled to Port C, isolating Port D.

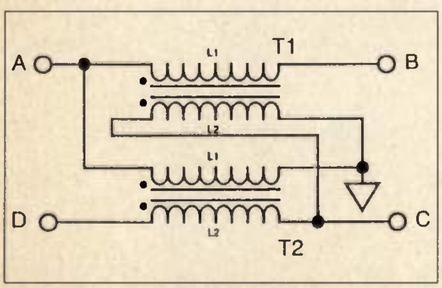

Figure 1. Broadband RF directional coupler.

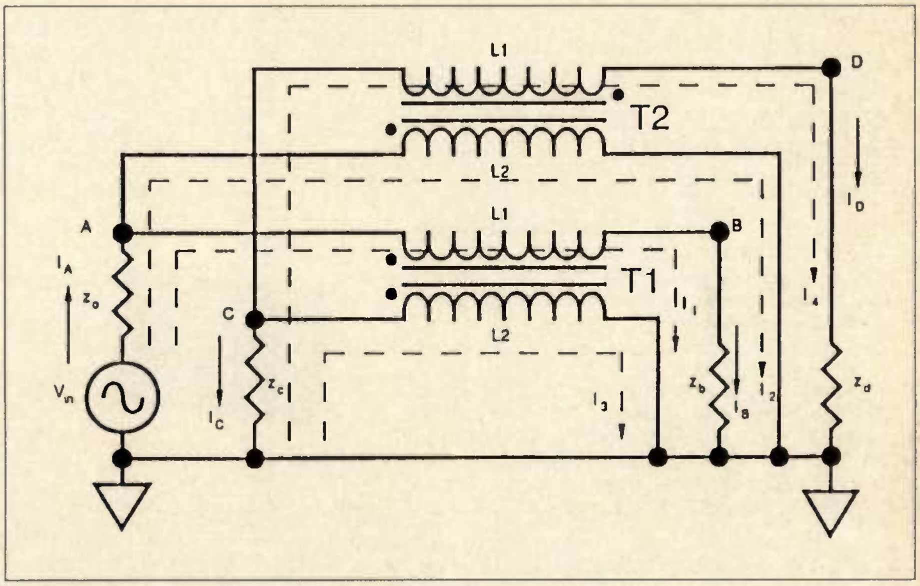

Figure 2. Directional coupler equivalent circuit.

Loop analysis of the equivalent circuit for this four-port device reveals the following set of equations derived from Kirchhoff's Voltage Law, resulting in the matrix equation in the form [Z][I] = [V].

$$\text{Loop 1:}\quad -V_{in} + I_1(Z_b + Z_o + j\omega L_1) + I_2 Z_o + I_3 j\omega M = 0 \qquad (1)$$

N	L_2/L_1	Z_a/Z_o	P_{ba}(dB)	P_{da}(dB)	Input VSWR
1	1	0.500	−3.01	−3.01	2.00:1
2	4	0.800	−0.97	−6.99	1.25:1
3	9	0.900	−0.46	−10.00	1.11:1
4	16	0.940	−0.26	−12.30	1.06:1
5	25	0.960	−0.17	−14.10	1.04:1
6	36	0.973	−0.12	−15.70	1.03:1
8	64	0.984	−0.07	−18.30	1.02:1
10	100	0.990	−0.04	−20.00	1.01:1
12	144	0.993	−0.03	−21.60	1.01:1
15	225	0.996	−0.02	−23.50	1.00:1

Table 1. Theoretical coupler performance.

Loop 2:
$$-V_{in} + I_1 Z_o + I_2(Z_o + j\omega L_2) - I_4 j\omega M = 0 \quad (2)$$

Loop 3:
$$I_1 j\omega M + I_3(Z_c + j\omega L_2) + I_4 Z_c = 0 \quad (3)$$

Loop 4:
$$-I_2 j\omega M + I_3 Z_c + I_4(Z_d + Z_c + j\omega L_1) = 0 \quad (4)$$

Inductive coupling between the primary and secondary is related by $M = k\sqrt{L_1 L_2}$, where k is defined as the coupling coefficient, possessing a value approaching unity for a well-designed transformer.

Loop currents are found by solving for the matrix [I], and the actual input, output, coupled and isolated port currents are derived from the following relationships:

$$I_a = I_1 + I_2 \quad \text{(Input Port Current)} \quad (5)$$

$$I_b = I_1 \quad \text{(Output Port Current)} \quad (6)$$

$$I_c = -(I_3 + I_4) \quad \text{(Coupled Port Current)} \quad (7)$$

$$I_d = I_4 \quad \text{(Coupled Port Current)} \quad (8)$$

If the coupler is designed to operate at frequencies such that ωL_2 is orders of magnitude greater than Z_o, k is set to equal 1, and $Z_b = Z_c = Z_d = Z_o$, then the solution for the port currents is reduced to:

$$I_a = \left(\frac{V_{in}}{Z_o}\right)\left(\frac{L_1 + L_2}{L_1 + 2L_2}\right) \quad (9)$$

$$I_b = \left(\frac{V_{in}}{Z_o}\right)\left(\frac{L_2}{L_1 + 2L_2}\right) \quad (10)$$

$$I_c = 0 \quad (11)$$

$$I_d = \left(\frac{V_{in}}{Z_o}\right)\left(\frac{M}{L_1 + 2L_2}\right) \quad (12)$$

Voltage at each port can now be expressed as follows:

$$V_a = \frac{V_{in} L_2}{L_1 + 2L_2} \quad (13)$$

$$V_b = \frac{V_{in} L_2}{L_1 + 2L_2} \quad (14)$$

$$V_c = 0 \quad (15)$$

$$V_d = \frac{V_{in} M}{L_1 + 2L_2} \quad (16)$$

Impedance looking into each port:

$$Z_a = \frac{V_a}{I_a} = Z_o\left(\frac{L_2}{L_1 + L_2}\right) \quad (17)$$

$$Z_b = \frac{V_b}{I_b} = Z_o \quad (18)$$

$$Z_d = \frac{V_d}{I_d} = Z_o \qquad (19)$$

Power at Port A:

$$P_a = V_a I_a$$

$$= \left(\frac{V_{in}^2}{Z_o}\right) L_2 \left(\frac{(L_1 + L_2)}{(L_1 + 2L_2)^2}\right) \qquad (20)$$

Power leaving the remaining ports:

$$P_b = \frac{V_b^2}{Z_o} = \left(\frac{V_{in}^2}{Z_o}\right)\left(\frac{L_2^2}{(L_1 + 2L_2)^2}\right) \qquad (21)$$

$$P_c = 0 \qquad (22)$$

$$P_d = \frac{V_d^2}{Z_o} = \left(\frac{V_{in}^2}{Z_o}\right)\left(\frac{L_1 L_2}{(L_1 + 2L_2)^2}\right) \qquad (23)$$

The ratio of the power out of Ports B, C and D to the power into Port A:

$$P_{ba} = \frac{L_2}{L_1 + L_2} \qquad (24)$$

$$P_{ca} = 0 \qquad (25)$$

$$P_{da} = \frac{L_1}{L_1 + L_2} \qquad (26)$$

Discussion of Theoretical Circuit Analysis

The preceding equations show that the input port to the coupler will be well-matched when $L_2 >> L_1$. If $L_2 = L_1$, the input impedance drops to one-half the source impedance, resulting in a voltage standing-wave ratio (VSWR) of 2.0:1. The equations also show that Port B and Port D will always be matched to Z_o. With Port A configured as the input, Port B becomes the mainline or thru-path output. Port C is isolated from Port A, and Port D becomes the coupled output.

Equation 26 shows that the system designer is not limited to popular catalog coupling values, but can tailor a device within the practical limits of L_1 and L_2. These equations assume perfect or unity coupling (k=1) between transformer primary and secondary. The inductance ratio between L_1 and L_2 is defined by the turns ratio N, where $N = \sqrt{L_2/L_1}$. Theoretical coupler performance is presented in Table 1. A Touchstone[R] model using the "XFERP" element was analyzed to further verify this analysis.

Results of Experimental Devices

An experimental 10 dB coupler was fabricated using a Siemens B62152-A0008-X030 double-aperture core. Each primary consisted of one turn of #33 Formvar-coated magnet wire. Each secondary consisted of three turns of #38 Formvar-coated magnet wire. A winding diagram and test results are shown in Figure 3 and Figures 4a-d, respectively. This coupler has been used in +31 dBm continuous wave (CW) and 1 percent duty cycle 50W pulsed-power applications with excellent performance in the 10-1000 MHz band.

Additionally, an experimental 20 dB coupler was fabricated using two Mi-

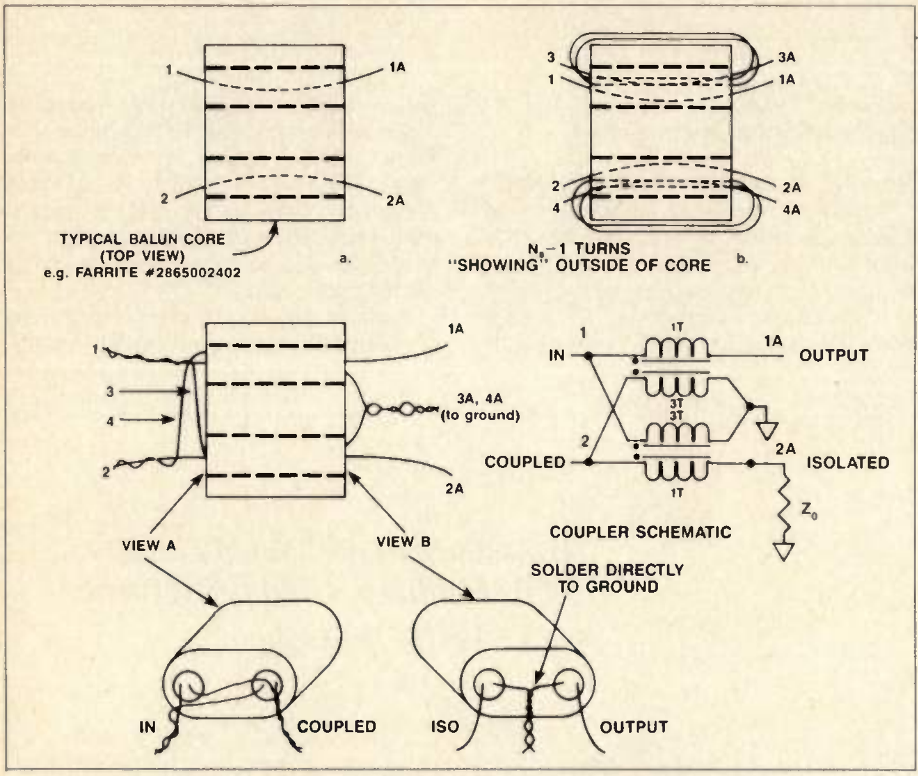

Figure 3. Typical winding for broadband 10 dB coupler at RF.

crometals T25-0 phenolic toroids to investigate high-frequency limitations of the device. Each primary consisted of one turn of #32 silver-coated, Teflon-insulated magnet wire. Each secondary consisted of 10 turns of #36 Formvar-coated magnet wire. This coupler has been used in +36 dBm CW and 1 percent duty cycle 180 W pulsed-power applications with excellent performance in the 500-2200 MHz band.

In general, a coupler can be fabricated using two shield beads, toroids or a single balun core. Low-frequency response is dictated by the ferrite material characteristics and core "form factor." High-end response is partially governed by total wire length, since the core effects are no longer dominant in this frequency range (4). Interwinding capacitance, leakage inductance, copper losses and transformer coupling below unity ($k < 1$) also degrade high-end performance. Properly built devices can achieve good performance exceeding two decades. Power-handling capabilities of 1000 W CW have been reported (3).

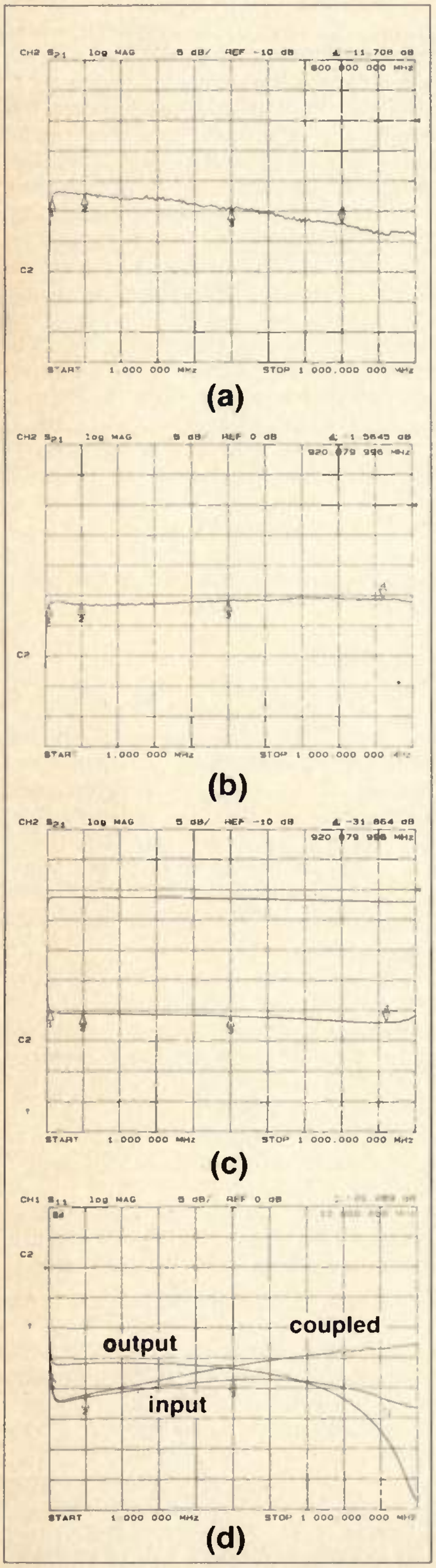

Figure 4. 10 dB coupler prototype, (a) coupling A to D, (b) insertion loss A to B, (c) directivity B to D, (d) return loss.

Data shows that the coupler should lie over the ground plane (especially at frequencies exceeding 500 MHz) to help terminate extraneous fields, which degrade loose coupling performance and isolation. Toroidal forms with a relative permeability of one have been shown to perform well for 20 dB couplers in systems exceeding 2000 MHz. Lower frequency devices perform well with initial permeabilities between 300 and 5000. Small shunt capacitance to ground (typically $3Z_o < Z_c < 6Z_o$) at Ports B and/or D can be used to improve match and directivity at the expense of bandwidth. At higher frequencies, lead length must be kept to a minimum to limit parasitic inductance. To achieve broadband performance, ground connection lengths must be minimized.

Increasing the number of turns in the primary is limited by the number of wires that can fit through a small core. Unbalancing the secondaries by adding an additional turn to only one secondary results in a coupling ratio different than those listed in Table 1, without severe directivity degradation. Changing the diameter of the primary wire relative to the secondary wiring changes the coupling by tenths of a dB. Using heavier gauge, Teflon-sleeved, silver-plated magnet wire for the single-turn primaries reduces mainline insertion loss and improves power-handling capability. The isolated port should connect to a good Z_o ohm load impedance, such as a small thick-film chip resistor. A small capacitor, such as an ATC100-series 0.5-2 pF, can be connected in parallel with the resistor to optimize directivity. By eliminating the load resistor, the directional coupler can be used as a four-port, dual-directional coupler.

Conclusion

Directional couplers for broadband VHF/UHF applications are analyzed using transformer theory and can be fabricated quickly and inexpensively. Well-designed directional couplers perform across two decades of bandwidth, and the engineer can fabricate his own device to exact requirements for a wide range of applications. ***RF***

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Acknowledgement

I wish to thank W.G. Beauregard, senior scientist, Olektron Corp., for his sage contribution to my further understanding of these RF devices.

About the Author

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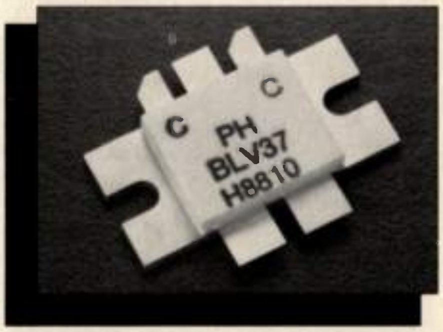
RF Transistors — Staying on Top of Technology

By Gary A. Breed
Editor

RF transistors, both power and small-signal types have seen constant improvements over the past several years. At times, the pace of development has been extremely fast as new ideas go to market. Makers of RF transistors have seen their business fueled by military radar and communications systems, mobile radio applications including cellular telephones, medical and industrial applications, and consumer entertainment and convenience products.

In the small-signal realm, we can divide the products into two categories: general purpose devices and high performance devices. Of course, a number of products include both. General purpose RF transistors are used extensively in consumer and commercial equipment, although replacement with integrated components continues to erode their market position. Applications range from simple oscillators for remote control devices (the "garage door opener" class of products) to radio and television receivers, cordless telephones, mobile radio equipment, instrumentation, and many other products. In consumer and low cost commercial equipment, transistors will continue to be used instead of ICs where they more readily achieve electrical performance like isolation and signal handling capability. Also, they continue to be used where re-design for IC technology is judged not to be cost-effective. Major suppliers of general purpose small signal RF transistors are Motorola, Siemens, Philips, SGS-Thomson, NEC, Matsushita, Samsung, Mitsubishi, Toshiba, and others.

High performance small-signal transistors, silicon and GaAs devices, have well-specified parameters which allow them to be selected by designers for optimum performance in RF systems. Noise figure, gain, stability, frequency, and of course, cost all are considerations. For example, new low cost GaAs FET transistors for microwave applications have recently been introduced by NEC (distributed in the U.S. by California Eastern Laboratories). Silicon devices have been rapidly developed by companies like Avantek to meet the technology challenge that GaAs FETs brought about a few years ago. Established leaders such as Mitsubishi and Hewlett-Packard are active, and new firms like Bipolarics are looking for a place in the market.



Transistor makers are working toward higher power and higher frequencies, like this 250-watt push-pull VHF device from Philips.

The newest developments in the market include Global Positioning System (GPS) receivers, consumer equipment such as satellite TVROs and CATV converters, plus commercial wireless local area networks (LANs) and high performance instrumentation. High performance RF transistors are needed for military applications; in communications, radar and countermeasures, where well-defined performance is required.

RF Power Transistors

In the power transistor arena, development of basic device technology and fabrication techniques have been the recent focus. Static induction transistors have come and gone from the headlines, while silicon FET devices have become solidly entrenched as the choice for HF and VHF devices. Motorola leads the market at the lower end of the radio spectrum, with competition from Philips, SGS-Thomson, and M/A-COM PHI. At VHF and UHF, competition is fierce, with these companies being challenged by newer firms like Semetex and PolyFet RF Devices, both with gold metallized silicon FETs. Some of the products of former transistor maker Acrian are being duplicated by new firms RF Products and GHz Technology. Other players in this frequency range include Mitsubishi and Toshiba.

The UHF to low microwave frequency range is easily the hottest slice of the RF market. The most promising emerging product technologies operate in this range. Cellular radio, Part 15 spread spectrum devices, GPS receivers, proposed new-generation cordless telephones (CTII) and personal communication system (PCS) applications all operate in this range. Scientific applications are more visible than ever, although they make up only a modest part of the market. High energy physics uses VHF and UHF power amplifiers to accelerate particle beams and excite lasers.

Military systems are still a significant market for RF transistors of all types. Upgrades of basic communications equipment are still underway, requiring both small signal and power devices, primarily in the VHF and UHF frequency range. Radar and countermeasures systems have not been completely cut off by recent budget limitations, particularly for the highest performance systems. Although the quantities of parts shipped for military programs is certainly down, the development of more capable devices and their applications continues.

Summary

Discrete transistors continue to be essential to the RF industry. The rise of highly integrated circuit functions has certainly cut down small signal applications, but overall growth has made up much of that reduction. Power transistors are stronger than ever, as they reach higher frequencies, higher power, and achieve greater reliability. Transistor development is as active as ever, with most manufacturers reporting considerable work on fabrication techniques to enhance yield and reliability. ***RF***

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EMSim[R] 3.0 is a product upgrade for the electromagnetic simulation of linear, multiport MMIC and MIC components. By graphically representing a circuit as regions of interconnected charges, EMSim 3.0 simulates circuit operation through a basic field theory approach which allows the designer to explore electromagnetic interaction over an entire planar circuit. Structures analyzed by EMSim can include a ground plane, two conductor layers and up to three separate dielectric layers. Lumped capacitance, resistance, and inductance elements can be embedded between internal circuit connections.

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LCC Incorporated recently introduced an expert system that allows cellular system engineers to automatically generate frequency plans. The Automatic Frequency Planning (AFP) tool is an additional module to the Advanced Network Engineering Tools (ANET) RF engineering software. In conjunction with ANET, AFP can generate an initial plan for a brand new system or reconfigure a frequency plan for an existing system.

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SPICE Models

A free disk containing SPICE models of Analog Devices' IC amplifiers is now available. The disk contains 176 models, with a hard copy list attached. The library includes both current- and voltage-noise models for some of the devices; also included are models of two instrumentation amplifiers. The models come on a single IBM-compatible high-density disk.

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A major upgrade, "Optimizing" Preprocessor, is now available at no charge to S/FILSYN users from DGS Associates, Inc. Users of the program can specify arbitrary passband loss and delay shapes for analog, digital and microwave filter circuits. The optimizer works well with passive LC, active RC and digital and microwave filters. The "Optimizing" Preprocessor program will be shipped free of charge to current S/FILSYN customers.

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CAE Software Driver

The HP 11755A RF simulator WorkSystem driver, provides a computer-aided-engineering software linkage between HP's vector arbitrary-waveform synthesizer and the Signal Processing WorkSystem from Comdisco Systems, Inc. The driver treats the VAWS hardware like another software functional block in the SPW library, making it easily accessible during the design process. The driver is $5,000 U.S. list and delivery is four weeks.

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RF literature

Catalog on Disk

Litton Electron Devices has produced its second IBM PC compatible computer disk catalog. The disk features coupled cavity traveling wave tubes and high power klystrons. Product information is accessible by application, product type or product number. Applications featured are ECM and radar. The disk will operate on EGA, VGA and monochrome graphics monitors and all data may be printed from the screen.
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A new 28 page catalog lists over 800 connectorized RF amplifiers covering 5 MHz to 2300 MHz. Prices, outline drawings, and accessory power supplies and accessory cables are also listed. Most units are available in two case sizes with a choice of SMA, N, TNC, or BNC connectors.
Applied Specialties Inc.
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VCO Specification Guide

M/A-COM Semiconductor Division offers a guide to specifying their new line of voltage controlled oscillators. The guide helps the engineers specify and select VCOs in a frequency range of 25 MHz to 10 GHz.
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Reusable PLL Design Chart

RF Prototype Systems is offering a free, reusable PLL Design Chart that would be of interest to synthesizer and PLL designers. The chart features step-by-step instructions, key decade slope lines to aid in plotting the open loop response of a second or third order PLL, phase noise floor data for commonly used phase detectors, procedure for predicting phase noise at the synthesizer output, and is erasable for continuous use.
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Semiconductor Selector Guide and Cross Reference

The *1991 Discrete Semiconductor Selector Guide and Cross Reference* lists Philips Components' full line of small signal leaded, power, RF/microwave, surface mount, and optoelectronic devices. The 206-page catalog contains an alphanumeric type index, comprehensive cross reference information, packaging specifications, and outline drawings. Postage-paid business reply cards are attached and can be used in requesting additional catalogs or more information.
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Short Form/Capabilities Catalog

A new 16 page short form catalog is available for Communication Techniques' signal sources including phase locked and free running DROs, VHF and microwave frequency synthesizers, oscillators, multipliers, subassemblies and special products. The publication lists the features and benefits of each product. Photographs and typical phase noise graphs are also provided.
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Electronic Equipment Product Guide

The *1991/92 Electronic Equipment Product Guide* is available from Leasametric. The guide contains illustrations and information on test equipment and workstations the company offers for rental or lease. A color coded table of contents, a manufacturer's index and detailed product specifications are included.
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GPS Product Brochure

Austron offers a Global Positioning System Products color brochure that briefly explains the system, its operational advantages as well as the benefits and applications available to users. Included are specifications for Austron's GPS time and frequency receivers.
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Component and Instrument Catalog

A new catalog from Lucas Weinschel describes their line of RF and Microwave components and instruments. Products offered in the catalog include fixed and variable attenuators, step attenuators, terminations and loads, precision adapters and connectors, solid state components, power splitters and dividers, synthesized signal sources, and attenuation measurement and power calibration equipment.
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Cable and Assemblies

Storm Products has released its new RF/Microwave Products Catalog. Some highlights of this catalog include: low loss flexible microwave cable assemblies, semi-rigid cable and assemblies, instrument cables, extra flexible cables, solder and delay lines.
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5535	32 ps	10 kHz	0.2 dB	50 V	10 mA
5540	8 ps	160 kHz	0.6 dB	50 V	100 mA
5550B	20 ps	100 kHz (<50 mA)	0.9 dB	50 V	500 mA
5555	20 ps	100 kHz	0.9 dB	50 V	500 mA
5575A	32 ps	10 kHz (<20 mA)	0.6 dB	50 V	500 mA
5580	32 ps	10 kHz	1.0 dB	50 V	1 Amp
5590	150 ps	10 kHz	0.1 dB	50 V	500 mA

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