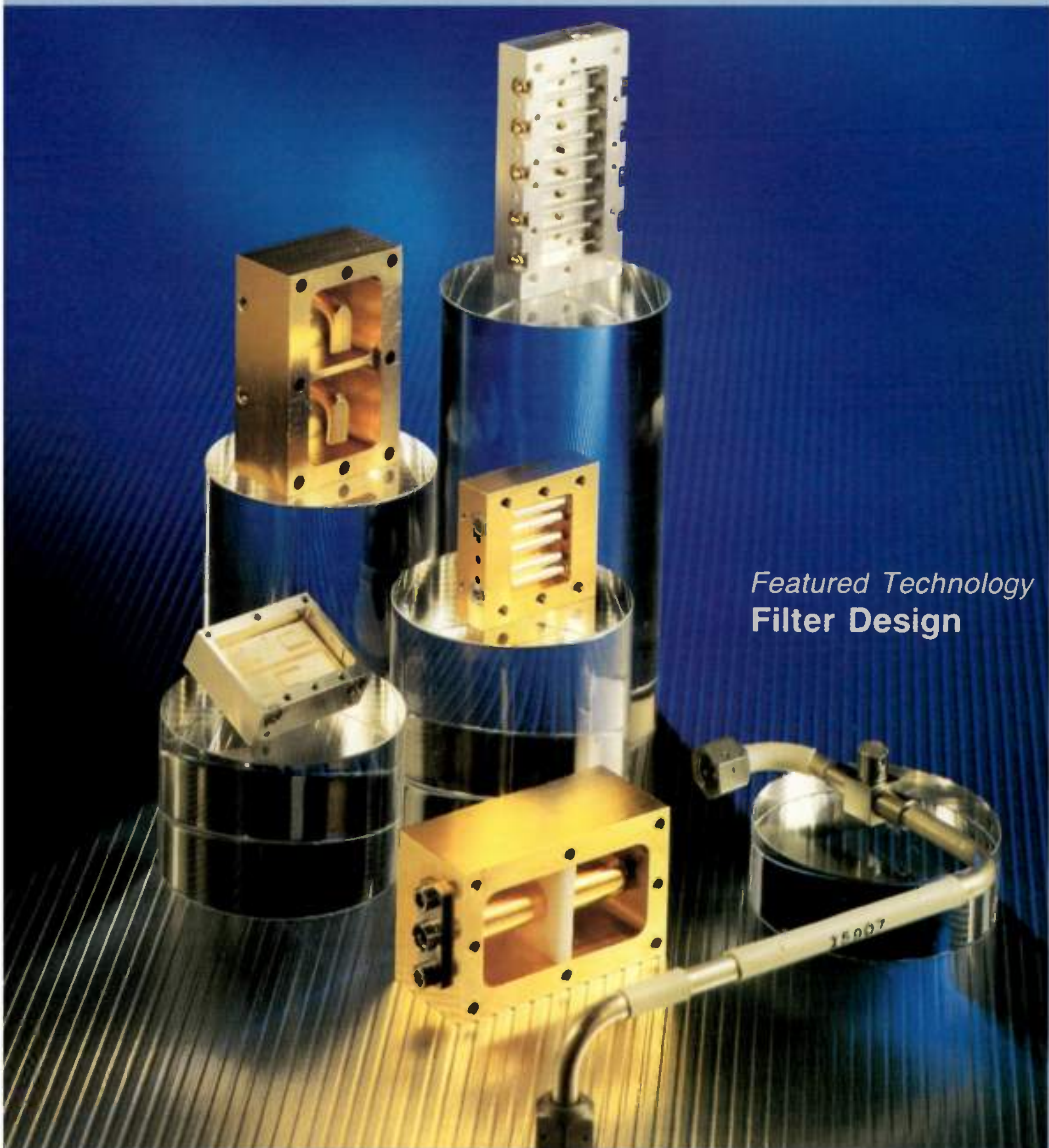
# RF design

engineering and principles

January 1991

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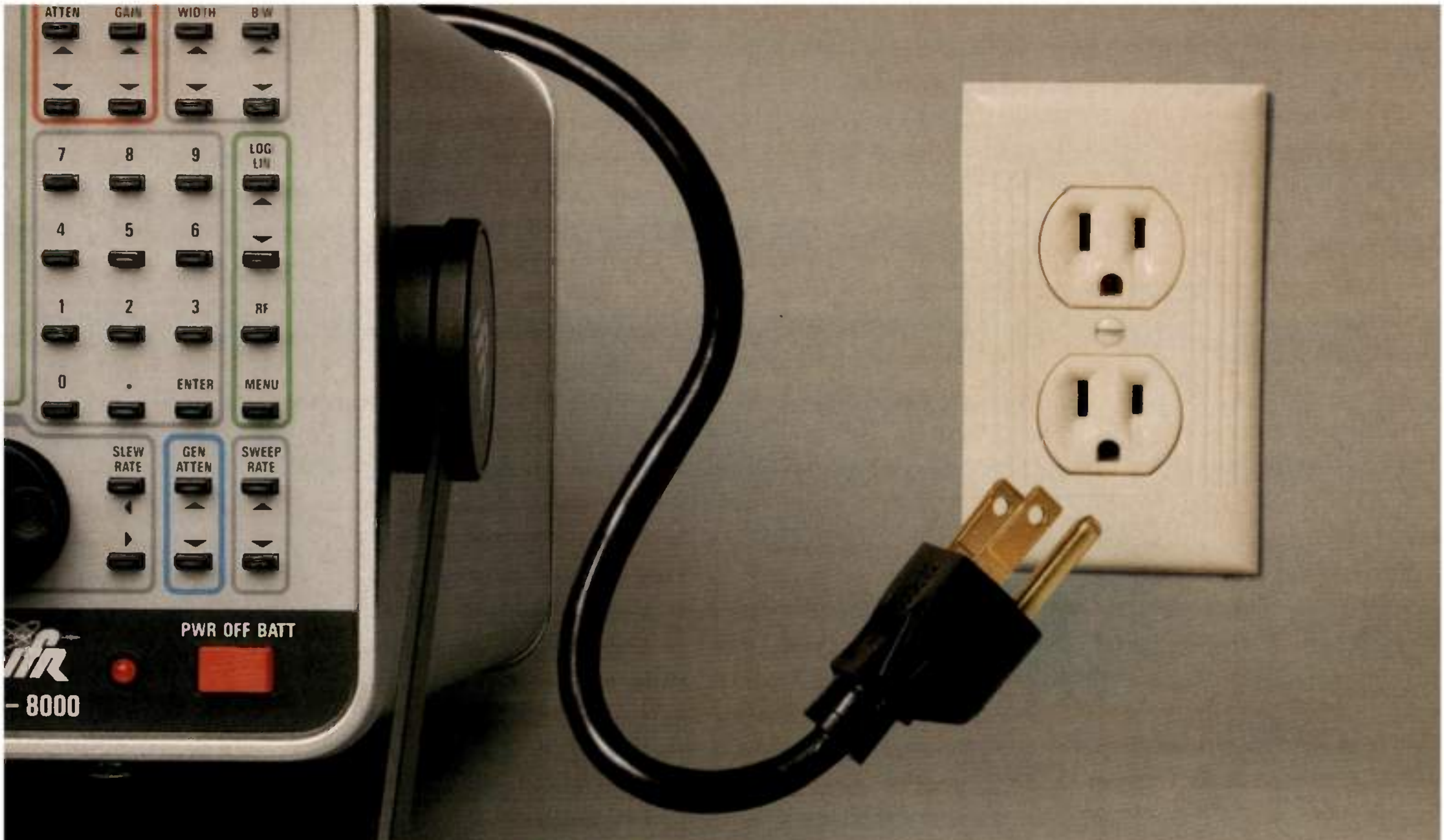


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|---|---|---|---|---|---|---|---|
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| DSO699 | SPST | 5-1500 | 0.9 | 60 | 23.0 | TO-8 | TTL |
| DSO990 | SPST | 10-2000 | 1.5 | 78 | 25.0 | 14 Pin DIP | TTL |
| DSO850 | SP2T | DC-2000 | 0.35 | 47 | 5.0 | TO-5 | 0/-7 |
| DSO813 | SP2T | DC-2000 | 0.65 | 47 | 200.0 | TO-5 | TTL |
| DSO812 | SP2T | 10-1000 | 0.5 | 54 | 50.0 | TO-8 | TTL |
| DSO860 | SP2T | 10-1500 | 0.5 | 47 | 40.0 | .380 sq | TTL |
| DSO602 | SP2T | 5-4000 | 1.5 | 55 | 22.0 | 14 Pin DIP | TTL |
| DSO842 | SP2T | 5-1500 | 0.9 | 75 | 50.0 | 14 Pin DIP | TTL |
| DSO864 | SP4T | 5-2000 | 1.3 | 55 | 28.0 | 16 Pin DIP | TTL |
| DSO874 | SP4T | DC-2000 | 2.0 | 60 | 75.0 | 16 Pin DIP | TTL |
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*Typical performance measured mid-band
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RF design

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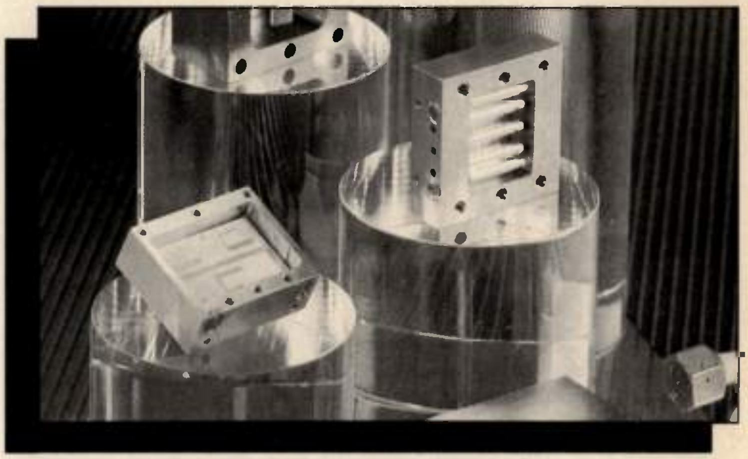
January 1991

## featured technology







*Cover photo is courtesy of Micro Mode Products, Inc.*

## emc corner



## design awards



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*RF editorial*

# RF Design in 1991

*By Gary A. Breed*
*Editor*

Since this is January, I suppose it is time to let you know what *RF Design* has planned for the year. We are always looking for a better way to get the right kind of information to you, so help us keep on the right track by letting us know what you think about the topics we choose, the authors we publish, and the overall usefulness of our magazine.

The only brand new item for 1991 is a monthly Product Report. Each issue will have a short summary of the business and technology status of a major RF product (or service) area. The first of these reports is on page 71, looking at EMC test labs. The next few reports will cover antennas, mixers, SAW and crystal oscillators, filters, capacitors and resistors. Hopefully, this background information on the products you design with will help you pick the best ones for your next project.

We will continue our Industry Insight column, but with the new Product Report covering specific markets, we can examine some broader industry segments like this month's look at mobile communications. SMT, HDTV, RF education, and consumer electronics are among the topics we'll cover this year. The regular surveys will continue, too. Your participation has been great, and we are getting a much better picture of what RF designers are interested in, and what projects are underway.

Another unchanged area is the EMC Corner. We will keep presenting notes on design, measurements and regulations in this important area. With lots of attention being given to designed-in EMC compliance, this column is more important than ever.

We always have difficulty choosing our monthly Featured Technology subjects — there is too much going on that needs attention! Filters, modulation, analog and digital signal processing, test and measurement, and high speed circuits are on tap for the first half of 1991. Of course, we will continue to provide articles on as many other subjects as possible, as space permits. Our new two-part contest is going strong,too. The July issue will be full of winning ideas in circuits and software, so make sure you don't miss it!

Well, a new year is also time for reflection on the state of the RF engineering profession. Some things haven't changed — managers complain that they can't hire enough experienced RF designers, and that colleges aren't teaching the new kids the right stuff. Other things are definitely changing —engineers are looking beyond their lab benches more often, sharing ideas through writing and speaking. The computer has finally become the normal method of making routine calculations as well as complex circuit and system modeling. Digital and analog technologies are combining in ways no one would have predicted ten years ago.

In my editorials, I tend to be enthusiastic and optimistic about RF technology, and sometimes wonder if such an outlook is valid. Well, in the last couple of months, I have received many comments that are in agreement with my optimism. Despite some significant trouble spots, the current consensus is that the next few years will see exciting times for the RF community. Let's hope we're right!

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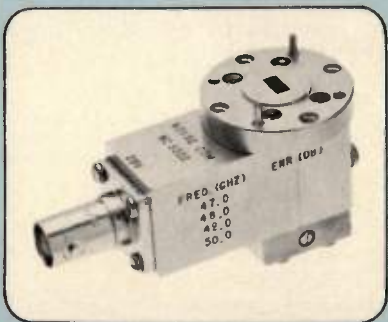


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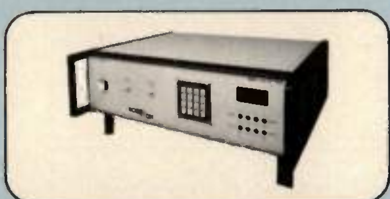

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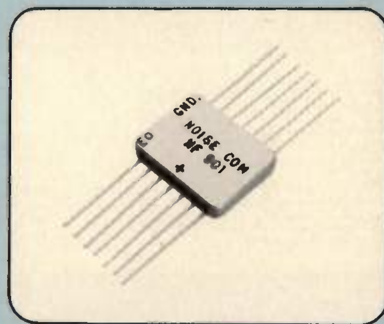


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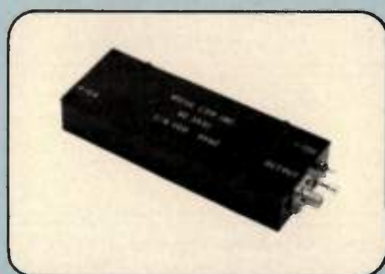

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**Disk RFD-0191: January 1991**
"A Plotter Subroutine for BASIC Programs" by Bert Erickson. Offers simple, quick plotting capabilities that can be included in BASIC programs. (BASIC) "RF System Noise Basics" by Frank Perkins and Al Ward. From RF Expo East 1990. BASIC programs compute noise temperature, cascaded NF, ENR, noise power, and more.
*** Reprint of RF Expo paper can be obtained for an additional $5.00 ***

**Disk RFD-1290: December 1990**
"Circuits for Wideband FM Demodulation," by Fotowat and Wong of Signetics. Program computes distortion of discriminator circuit. Includes HELP file and six examples. (FORTRAN source code listing and compiled, executable version)

**Disk RFD-1190: November 1990**
"Broadband Impedance Matching by Polynomial Synthesis" by David Lang. Generates a polynomial equalizer function directly from S-parameters, and synthesizes matching networks. (BASIC, source listing and compiled versions)

**Send for a complete listing of available programs, or circle Info/Card below.**

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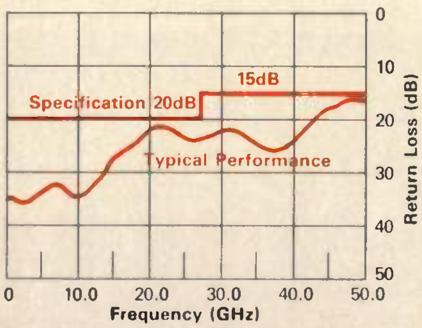


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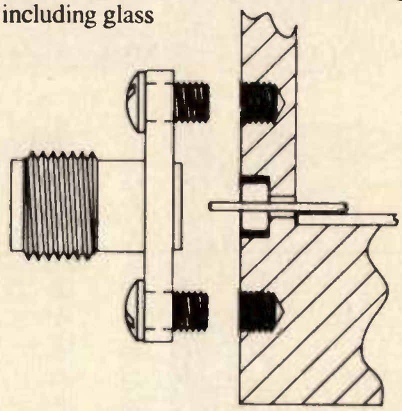

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# *RF* letters

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Editor:

My congratulations on your superb publication. It is a great pity that *RF Design* is not distributed via our nationwide W.H. Smith & Sons chain of magazine-bookshops (like *Scientific American* and other U.S. publications). British electronic periodicals are available from these outlets, but none can match *RF Design's* range of expertise.

Colin Bruce Sibley, PhD
Waddington, England

### Microstrip CAD Equations

Three equations in Tom Cefalo's article, "Microstrip CAD Program," October 1990, require correction. Equation 3b should have a W′ in it as follows:

$$f(W/H) = 6 + (2\pi - 6)\exp\left[-\left(\frac{30.666}{W'/H}\right)^{0.7528}\right] \qquad (3b)$$

In equation 7, 0.025 should be 0.027. Finally in equation 12 a division symbol is missing. The equation should read:

$$Z_o = \frac{Z_{oa}}{\sqrt{\varepsilon_{eff}}}$$

These equations are correct in the program which is available through the software service.

### ADC Settling Time Clarification

In Thomas Hack's article, "Measurement of Analog-to-Digital Converter Settling Time with Equivalent Time Sampling," November 1990, the bottom of the second paragraph on page 67, should read: "But if the analog-to-digital converter performs well at its maximum sample rate, we should expect that its settling time will be less than 1 clock period, which means we can't measure the settling time if we use real-time sampling techniques. The best we could do is infer that the settling time is less than 1 clock period and this isn't good enough when other parts in the system (such as MUXs) also contribute to total settling time." In addition, in the third column on the same page, the second sentence from the top should read: "Since this converter has a 100 ns minimum clock period, this is a suitable choice." In addition, Mr. Hack would like to acknowledge DSP Development Corporation, Cambridge, Mass., for use of their DADiSP Software in this article.

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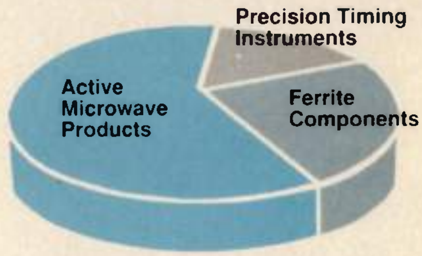


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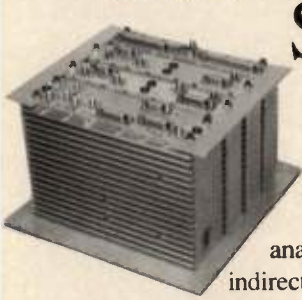

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# RF calendar

## January

**14-16** **4th Annual International Superconductor Applications Convention**
San Diego, CA
Information: SCAA, 27692 Deputy Circle, Laguna Hills, CA 92653. Tel: (800) 854-8263 or (714) 362-9701. Fax: (714) 362-9803.

**15-17** **ATE & Instrumentation West**
Disneyland Hotel, Anaheim, CA
Information: Tel: (800) 223-7126 or (617) 232-3976.

**22-24** **Hyper 91, Microwave Technology Exhibition and Congress**
Palais des Congres, Paris, France
Information: B.I.R.P., 25 rue d'Astorg, 75008 Paris, France. Tel: 33-(1)-4742-2021. Fax: 33-(1)-4742-7568.

**28-31** **Communications Networks '91**
Washington Convention Center, Washington, DC
Information: Michael Sullivan. Tel: (508) 820-8268.

## February

**5-7** **RF Technology Expo 91**
Santa Clara Convention Center, Santa Clara, CA
Information: Kristin Hohn, Cardiff Publishing Company, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel: (303) 220-0600, (800) 525-9154. Fax: (303) 773-9716.

**12-14** **4th International Smart Card Exhibition and Conference**
Novotel, Hammersmith, London
Information: Elisabeth Beckett, Marketing Manager, Agestream Ltd., Towermead Business Center, High Street, Old Fletton, Petersborough, PE2 9DY. Tel: (0733) 60535. Fax: (0733) 45522.

**24-28** **NEPCON West '91**
Anaheim Convention Center, Anaheim, CA
Information: Janet Schafer, Cahners Exposition Group, 1350 E. Touhy Ave., Des Plaines, IL 60017-5060. Tel: (708) 299-9311. Fax: (708) 635-1571.

## March

**18-21** **WESTEC '91**
Los Angeles Convention Center, Los Angeles, CA
Information: Event Public Relations Department of SME, One SME Dr., PO Box 930, Dearborn, MI 48121-0930. Tel: (313) 271-0777.

**26-28** **International Mobile Communications Expo**
Anaheim Convention Center, Anaheim, CA
Information: April Debaker, Cardiff Publishing Company, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel: (303) 220-0600, (800) 525-9154. Fax: (303) 773-9716.

## April

**7-10** **1991 US Conference on Gallium Arsenide Manufacturing Technology**
Reno, Nevada
Information: 1991 GaAs MANTECH Conference, Suite 300, 655 15th Street, N.W., Washington, DC 20005.

# RF courses

**Antennas: Principles, Design, and Measurements**
March 13-16, 1991, St. Cloud, FL
Information: Kelly Brown, SCEEE, 1101 Massachusetts Ave., St. Cloud, FL 34769. Tel: (407) 892-6146.

**Electrical Grounding of Communication Systems**
February 11-13, 1991, Madison, WI
**Cellular Radio**
March 25-28, 1991, Madison, WI
Information: University of Wisconsin - Madison, Department of Engineering Professional Development. Tel: (608) 262-2061. Fax: (608) 263-3160.

**RF/MW Circuit Design: Linear/Nonlinear Theory and Applications**
January 28-February 1, 1991, Los Angeles, CA
**Power Electronic Circuits: Theory and Practice**
February 11-15, 1991, Los Angeles, CA
Information: UCLA Short Course Program Office. Tel: (213) 825-3344. Fax: (213) 206-2815.

**Antenna Engineering**
February 5-8, 1991, Atlanta, GA
Information: Education Extension, Georgia Institute of Technology. Tel: (404) 894-2547.

**Troubleshooting Microprocessor-Based Equipment and Digital Devices**
January 15-18, 1991, Orlando, FL
**Basic Network Measurements Using the HP8510B Network Analyer**
January 14-16, 1991, Los Angeles, CA
**Microwave Fundamentals**
January 8-11, 1991, Los Angeles, CA
**HP11776A Waveform Generation Language User Course**
January 10-11, 1991, Los Angeles, CA
**Programming the HP 8510 Network Analyzer**
January 17-18, 1991, Los Angeles, CA
Information: Hewlett-Packard Company. Tel: (800) 472-5277.

**Communication and Radar Signals: Detection, Estimation & Geolocation Techniques**
January 9-11, 1991, Washington, DC
**Hazardous Radio-Frequency Electromagnetic Radiation: Evaluation, Control, Effects, and Standards**
January 16-18, 1991, Washington, DC
**Mobile Cellular Telecommunications Systems**
January 16-18, 1991, Washington, DC
**Fiber-Optics System Design**
February 4-6, 1991, Washington, DC
**Digital Telephony**
February 11-15, 1991, Washington, DC
**Introduction to Radar ECM and ECCM Systems**
February 20-22, 1991, Washington, DC
**Cellular Radio Telephone Systems**
February 25-27, 1991, San Diego, CA
**Principles of Digital Cellular Telephony**
February 25-March 1, 1991, Washington, DC
**Microwave High-Power Tubes and Transmitters**
February 25-March 1, 1991, Washington, DC
**Broadband Communication Systems**
March 4-8, 1991, Washington, DC
**Satellite Communications: System Planning, Design, and Operation at Ku and Ka Bands**
March 4-8, 1991, Washington, DC
**Antennas: Radiation and Scattering**
March 11-12, 1991, Washington, DC
**Microwave Radio Systems**
March 13-15, 1991, Washington, DC
**Introduction to Modern Radar Technology**
March 13-15, 1991, Washington, DC
Information: The George Washington University, Continuing Engineering Education, Merril A. Ferber. Tel: (202) 994-8522 or (800) 424-9773.

**Digital Signal Processing Workshop**
March 12-14, 1991, Campbell, CA
Information: Analog Devices, DSP Applications Department, Maria Butler. Tel: (617) 461-3672.

**Modern Microwave Techniques**
February 25-March 1, 1991, Garmisch-Partenkirchen, Germany
**Far-Field, Compact and Near-Field Antenna Measurement Techniques**
February 25-March 1, 1991, Garmisch-Partenkirchen, Germany
**Aspects of Modern Radar**
February 25-March 1, 1991, Garmisch-Partenkirchen, Germany
**MESFET and Hetrostructure Based MMICs**
February 25-March 1, 1991, Garmisch-Partenkirchen, Germany
**Modern Digital Modulation Techniques**
March 11-15, 1991, United Kingdom
**Digital Signal Processing: Filtering and Estimation**
March 18-21, 1991, United Kingdom
**Broadband Telecommunications**
March 18-22, 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.

**Introduction to EMI/TEMPEST Theory**
January 14, 1991, San Diego, CA
**EMI/TEMPEST Shielding**
Janaury 15-17, 1991, San Diego, CA
**EMP Hardening, Design, and Test for Facilities**
January 15-16, 1991, Washington, DC
**EMP Hardening, Design and Test for Electrical Equipment**
January 17-18, 1991, Washington, DC
**A Quick & Thorough Introduciton to NEC**
January 16-18, 1991, Washington, DC
**EMI, ESD and Radiation Hazards — Problems & Solutions**
January 17-18, 1991, Boston, MA
Information: Praxis International. Tel: (215) 524-0304. Fax: (215) 524-0438.

**Introduction to EMI/RFI/EMC**
February 20-22, 1991, Orlando, FL
Information: Besser Associates. Tel: (415) 949-3300.

**Linear Seminar for Designers**
January 29, 1991, Santa Clara, CA
February 6, 1991, San Diego, CA
February 7, 1991, Los Angeles, CA
Information: Linear Technology. Tel: (800) 637-5545.

**Modern Power Conversion Design Techniques**
February 25-March 1, 1991, San Diego, CA
Information: e/j Bloom Associates, Joy Bloom. Tel: (415) 492-8443. Fax: (415) 492-1239.

**Improved Contacts for High-Temperature Superconductors** —Researchers at the National Institute of Standards and Technology and Westinghouse Electric Corporation were recently awarded a patent for a technique for making ultra-low-resistivity contacts for various kinds of high-critical-temperature ceramic oxide superconductors. Contact resistivity using these methods is less than a billionth of that of conventional indium-solder contacts. In the past, scientists and engineers have run into problems with superconductors especially where the superconductor meets conventional electronic circuitry. A key factor in the problem, the researchers found, is the electrical degradation of the superconductor surface where it is exposed to air — especially moisture in the air. The newly patented methods include etching the superconductor surface to achieve a non-degraded state, or maintaining the non-degraded state by excluding air after fabrication of the superconductor until a noble metal contact pad is deposited on the surface by sputtering or evaporation.

The technology is available for licensing under U.S. patent number 4,963,523, "High-$T_c$ Superconducting Unit Having Low Contact Surface Resistivity and Method of Making." Interested parties should contact Bruce Mattson, Office of Technology Commercialization, A343 Physics Bldg., National Institute of Standards and Technology, Gaithersburg, MD 20899. Tel: (301) 975-3084.

**Mobile Radio and Personal Communications Conference Call for Papers** — Papers are now invited for the Sixth International Conference on Mobile Radio and Personal Communications. The Conference is being organized by the Institution of Electrical Engineers and will be held at the University of Warwick, Coventry, England December 9-12, 1991. Technical topics to be covered include: large/small cell techniques; indoor/outdoor propagation; speech coding; channel coding; modulation and multiple access; frequency sharing; channel characterization and equalization; system management; manufacture and test. Papers describing new work on any aspect of personal and land mobile, and also papers of a tutorial/overview nature which might be used to lead a theme session are invited. A synopsis of at least one A4-size page should be submitted by February 6, 1991. Submissions may be sent to: MRPC 91 Secretariat, IEE Conference Services, Savoy Place, London, WC2R 0BL, United Kingdom.

**International Frequency List Available on CD-ROM** — The International Telecommunication Union has published the International Frequency List (IFL) on CD-ROM (compact disc - read only memory). This publication contains information relating to radio frequency assignments recorded in the Master International Frequency Register (MIFR) and maintained by the International Frequency Registration Board. It provides users twice a year with a local copy of the IFL on a personal computer equipped with a CD-ROM reader. The compact disc is used with the CD-Answer information retrieval software delivered on the accompanying diskette and can be accessed by frequency, country code of station location, notifying administration, class of station, station name, geographical coordinates or geographical area and region code. Information concerning this service may be addressed to: I.T.U., General Secretariat, Sales Service, Place des Nations, CH-1211 Geneva 20, Switzerland.

**International Electronics Packaging Society Call for Papers** — A call for papers has been issued for the 1991 Electronic Packaging Conference to be held at the Sheraton Harbor Island Hotel in San Diego, California, September 15-19, 1991. Papers in the following areas are encouraged: Systems packaging, packaging for surface mount, printed wiring boards, multichip modules, modeling and simulation, packaging materials, device packaging, packaging reliability, interconnects for systems, packaging for fiber optics, plasma techniques, thermal management, design for manufacturability, and packaging for testing. A 300 word abstract should be submitted by February 15, 1991. Send eight (8) copies of the abstract to: 1991 Program Committee, IEPS, 114 N. Hale St., Wheaton, IL 60187. Tel: (708) 260-1044. Fax: (708) 260-0867.

**Format Convertor Passes Initial Tests for HDTV** — The Advanced Television Test Center (ATTC) has announced the successful demonstration of the process of format conversion which permits several different, incompatible forms of advanced television signals to be recorded in real time on a commercially available high definition digital videotape recorder. The new device was invented by ATTC Chief Scientist Charles Rhodes and developed by Tektronix, Inc. The format conversion process is key to the plans of the FCC Advisory Committee on Advanced Television Service for testing the several different advanced television transmission systems seeking to become the new U.S. television standard. The Format Convertor will permit "off-line" analysis of certain videotaped test results and creation of many of the official test materials.

Testing of the six proposed high definition television systems is slated to begin April 12. The six groups/consortiums are: The David Sarnoff Research Center, North American Philips Consumer Electronics Company, Massachusetts Institute of Technology, General Instrument Corporation, NHK Japan Broadcasting Corporation and Zenith Electronics Corporation. Each of the six groups must pay $175,000 to have their system tested, which represents less than ten percent of the actual cost of testing.

**EIA Components Group Reorganized** — A major reorganization of the Electronic Industries Association's Components Group was recently announced. The new structure creates a number of product specific divisions as well as several forums representing broader areas of interest common to manufacturers of electronic components. The new product divisions include: capacitors, resistors/networks, connectors and interconnect devices, switches as fuses, filters and delay lines, transformers and inductors, piezoelectric devices, relays, sensors, electronic display and tube, semiconductor devices as well as others to be determined by the membership. Forums have initially been organized into areas covering distribution, small business and sales and marketing. Others will be added as needed.

**Microgravity Processing Experiment in Space** — Canadian Astronautics Limited will undertake the HPGE Float Zone Furnace program for the eventual production of large diameter, ultra-pure germanium crystals in the micro-gravity environment of space. The NASA KC-135 aircraft is the most cost-effective means of operating experiments in microgravity for short durations. It enables the microgravity environment to appear for 20-25 seconds per parabola, with approximately 40 parabolas undertaken in a given day. The microgravity environment offers unique conditions for refining materials — conditions which are impossible on earth. The objectives of this experiment are to demonstrate functionality in microgravity of the entire Float Zone Furnace system, assess fluid behavior of liquid germanium, and investigate purification in microgravity.

**EIP Announces New Address** — EIP Microwave Inc., has announced their move to a new facility. Their new address is: 1589 Centre Pointe Drive, Milpitas, CA 95035. Tel: (408) 945-1477, Toll Free: (800) 232-3471. Fax: (408) 945-0977. EIP's corporate offices will remain in Newport Beach.

**Varian to Sell More Units** — Varian Associates recently signed a letter of intent to sell its Solid State Operations to Litton Industries. In addition, Varian also recently signed another agreement to sell several of its non-core operations to DKP Electronics, Inc. Those units are the Electro Optical Sensors division and three product lines — cryopumps, molecular beam epitaxy systems and a vacuum systems operation. A final contract for the sale of Varian's RF Subsystems is being negotiated with Signal Technology Corporation. Prices and terms were not disclosed and completion of the transactions is subject to a number of conditions, including the execution of definitive agreements.

**Mallory Capacitor Assets Purchased** — The assets of Mallory Capacitor Company have been purchased by Yosemite Investments Inc. Yosemite is an investment group who have formed the North American Capacitor Company. The Mallory logo will continue to be used in all facets of the business and no changes in operation are planned. The company's address, phone number and fax number will remain the same.

**Photonic Systems to Develop Acousto-Optic Spectrometer for NASA** — NASA has selected Photonic Systems to develop a special high-performance acousto-optic spectrometer for use in radio astronomy applications aboard spacecraft. The project objective is to create a wideband acousto-optic spectrometer capable of providing scientists with a greater understanding of the chemistry and dynamics of planetary and galactic objects. The system will accomplish this objective by permitting measurement of molecular rotational transitions in the millimeter and submillimeter wavelength region of the electromagnetic spectrum. The spectrometer will feature a 1 GHz bandwidth for each of four channels, 1 MHz resolution; and a capability for long integration times of more than 10 milliseconds without dynamic range loss.

**Avantek Receives $3 Million Contract** — Avantek, Inc. recently received a contract valued at nearly $3 million to conduct research into foundry fabrication of microwave integrated circuit chips under the MIMIC Phase 3 program. The sponsoring organization is the Directorate of R&D Contracting at Wright-Patterson Air Force Base. Avantek will design a chip set for advanced X-band radar transmit-receive modules, have the chip-set design and specifications approved by the Air Force, and produce an initial 50 three-inch wafers of the chips. After evaluation of the initial design and modification, Avantek will fabricate and test an additional 250 wafers.

**Hewlett-Packard to Supply Portable Spectrum Analyzers to U.S. and Royal Navies** — Hewlett-Packard Company announced that it has recently been awarded contracts to furnish portable spectrum analyzers to the U.S. Navy and the Royal Navy of the United Kingdom. The U.S. Navy Award, worth up to $8.1 million over the next three years, will provide HP 8560A-HO1 spectrum analyzers.The Royal Navy award also involves the purchase of a large number of analyzers over the next three years. This award will supply HP 8560A-002 spectrum analyzers with built-in tracking generators.

**RF Microsystems New Address** — RF Microsystems has relocated their development and manufacturing facility to a 12,500 square foot facility. Their new address is: 7191 Engineer Road, San Diego, CA 92111-1406. Tel: (619) 278-1300. Fax: (619) 278-3030.


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INFO/CARD 22

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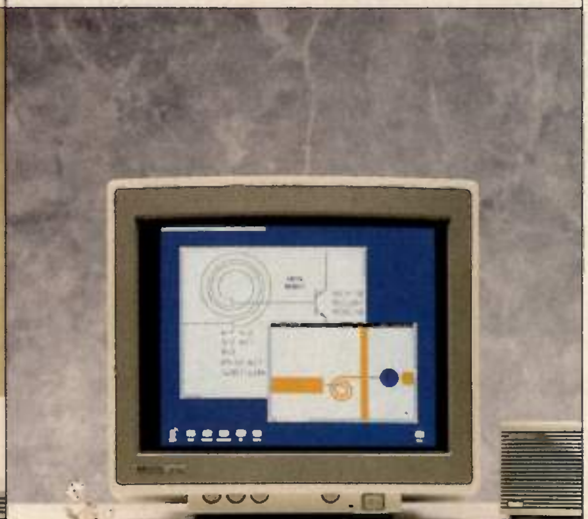

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INFO/CARD 23

# Mobile Radio: On a Fast Track

*By Liane Pomfret and Charles Howshar*
*Assistant Editors*

The general consensus in the industry is that mobile communications is emerging as an area of rapid growth with enormous potential. New terms and technologies are appearing on a weekly basis and the influx of information is so staggering that even those developing the technology are often bewildered. There are problems to be overcome if this market is to reach its full potential, but with increased awareness and technology, it is doubtful that they will remain problems for long. With the military market in a slump, mobile radio seems to be a "sure thing" and everyone is eager to get their share.

Within the mobile radio market, several areas are showing tremendous growth. Cellular radio is the area of most rapid growth right now. As for traditional land mobile communications some people have indicated that that area has flattened out. Dave Allen, Marketing Manager for Radio Communications Equipment at IFR Systems believes, "land mobile is going to stay flat and cellular and trunking are going to continue to grow." Rob Oeflein, Product Marketing Manager at Hewlett-Packard agrees, "The real action is taking place in the cellular area." Steve Skiest, RF Products Manager at Toko offers a possible answer for the recent surge, "Common sense would have it that as cellular becomes more available, more people that would have used two-way radios are now using cellular." While cellular is increasingly popular, it is also expensive for the average consumer. One solution is the PCN (personal communication network) which is somewhere between cellular and cordless phones in operation and cost, making it much more accessible to everyone. PCNs would only be available in limited areas, such as shopping malls, football stadiums, downtown, etc. However, PCNs are still three to five years away and will need to be granted spectrum space if they are to reach maturity. Experimental licenses for PCNs have been issued to several companies but final approval and licensing are still years away because of problems with spectrum allocation. Congress' recent defeat of the Emerging Telecommunications Technology Act has put plans such as this on hold for at least a year. But manufacturers are turning towards digital technology to help solve their problems.

*Prototype PCN Handset*
*Courtesy: Mercury Communications*

In the past few years, digital technology has become prevalent in many areas. Now it appears that it has reached the land mobile market as well. Jay Smith, Product Line Manager for Mobile Communications Products at Wavetek observes a possible problem with first generation hybrid technology. Cellular phones capable of handling both analog and digital technology will be larger than current analog models. Portable phone buyers may not want to cart around a bulky analog/digital cellular phone when they can carry a compact, lightweight analog phone. But John Walsh, Product Marketing Manager at SGS-Thomson Microelectronics, notes, "As the existing cell sites get filled in the United States, the demands on the system will speed up the change from analog to digital systems, enabling more people to use the systems." Cities such as Chicago, New York and Los Angeles have already reached capacity. The new digital technologies promise three to twenty times greater capacity and theoretically will be able to handle those markets. The two leading technology options for U.S. digital transmission are the EIA supported TDMA (time division multiple access) and the recently proposed CDMA (code division multiple access). Rob Oeflein comments that "There is no one standard that has been officially adopted."

The lack of a standard has hindered the development of cellular technology in the United States. The FCC has adopted a hands-off attitude which has left the Electronic Industries Association and manufacturers struggling to sort out which standard to adopt. As Dave Allen points out, "There's not a regulatory body in the U.S. like there is in Europe." Because Europe has a strong regulatory agency, they are several years ahead in their development of land mobile systems. For example, the United Kingdom has already issued at least three permanent licenses for personal communications networks, but they won't be available in the U.S. for a few years yet. The new cellular system coming on line in Europe is GSM, Group Speciale Mobile and will cover all of Europe with one common system. Commercial service is scheduled to begin in June of this year.

Companies are protecting their competitive positions by keeping quiet about technical developments they may have underway. However, research and development is growing in the academic world. For example, in the spring of 1990, Virginia Tech added a new group to their Bradley Department of Electrical Engineering. The Mobile and Portable Radio Research Group will focus on propagation prediction, system design and bit error simulation for cellular, microcellular, and indoor wireless communications. They are sponsored by Motorola Inc., Northeastern University, Purdue University, Tektronix, and others.

There is no doubt that large changes are going to occur over the next few years in the mobile radio market. The switch to digital technology along with increased popularity among consumers points towards a bright future. However, there are both technical and regulatory problems that must be ironed out if the market is going to move forward. **RF**

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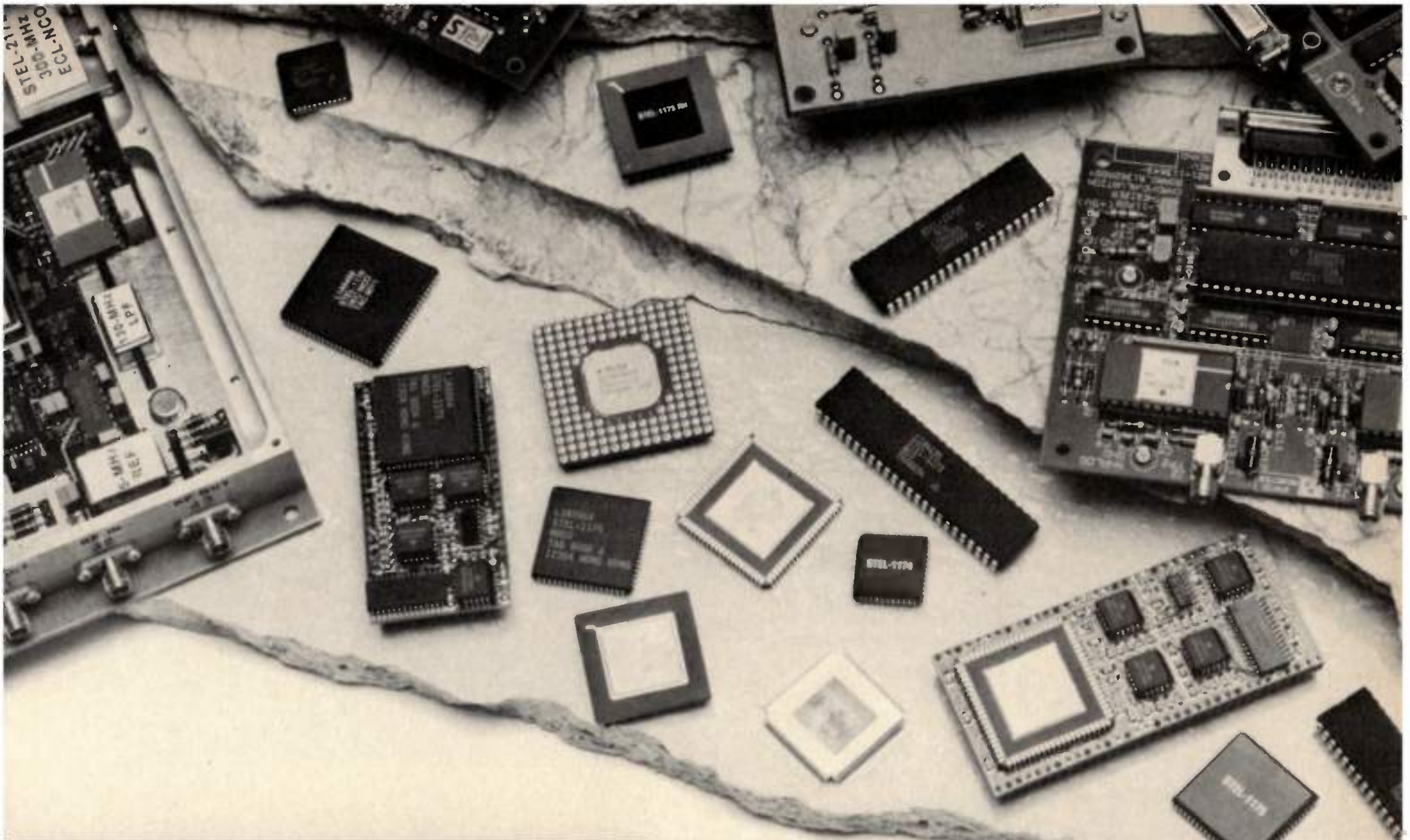

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| **STEL-1273** | based on 1173, 0-20 MHz |
| **STEL-1275** | based on 1175, 0-25 MHz |
| **STEL-1375A** | miniature assembly based on 1175 |
| **STEL-1376** | miniature assembly based on 1176 |
| **STEL-1377** | miniature assembly based on 1177 |
| **STEL-1277** | based on 1177, 0-25 MHz |
| **STEL-2272** | based on 2172, 0-130 MHz |
| **STEL-2273** | based on 2173, 0-400 MHz |

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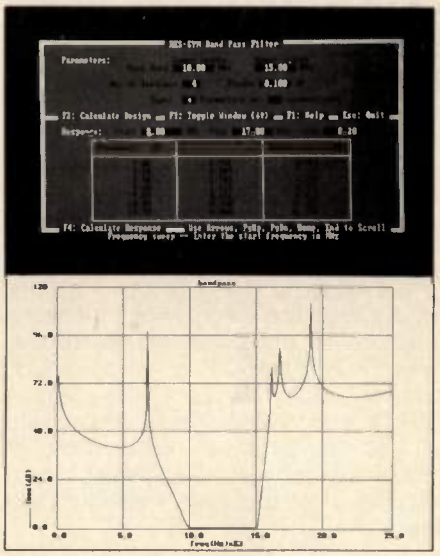

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# A Distributed Resonant Circuit with Improved Filtering Properties

By Stanislaw Rosloniec
Warsaw Technical University

*The resonant circuit composed of a lumped element capacitor and a uniform TEM transmission line short-circuited at its end, Figure 1a, is widely used at RF and microwave frequencies (1,2,3). In broadband systems, however, it should be applied rationally, especially when elimination of parasitic signals of harmonic components is required. It is evident that the circuits similar to that shown in Figure 1a are unsuitable for this purpose. Therefore, it will be shown how the filtering properties of a resonant circuit of this type can be improved by replacement of the uniform line segment with a corresponding nonuniform stub, see Figure 1b.*

In the first part of this article, the analytical relationships between the input and characteristic section impedances of the proposed stub are discussed. Next the previously analyzed stub, called a stepped impedance element, is converted to forms which can be easily realized in the microstrip line technique. Finally, the results of the experimental investigation of the resonant circuit including such a converted distributed element are given.

## Stepped Impedance Element

As mentioned earlier, Figure 1b shows an electrical scheme of the proposed stepped impedance element. According to references 3 and 4, its input impedance $Z_L(f)$ can be expressed in terms of the signal frequency f, one-section delay time $t_0$, and characteristic impedances $Z'_{Si}$ of the sections where i = 1,2,...,5. The suitable choice of these parameters enables one to design the resonant circuit ensuring a parallel resonance at the fundamental frequency $f_0$ and extremely low values (theoretically equal to zero) of the impedance $Z_{in}(f) = Z_L(f)/[1 + j2\pi f \times C \times Z_L(f)]$ at harmonic frequencies, i.e. $f_2 = 2f_0$, $f_3 = 3f_0$, $f_4 = 4f_0$, and $f_5 = 5f_0$. In order to design the resonant circuit with such a frequency response, Figure 2, we have to find the appropriate values of the parameters mentioned above. For this purpose the input impedance function $Z_L(f)$ will be expressed as a quotient of two polynomials, namely

$$Z_L(f) = \frac{N[S(f)]}{M[S(f)]} \quad (1)$$

where $N(S) = S^5 + a_3S^3 + a_1S$, $M(S) = b_4S^4 + b_2S^2 + b_0$, $S = j\tan(2\pi ft_0)$, $j = \sqrt{-1}$, and $a_1$, $a_3$, $b_0$, $b_2$, and $b_4$ are real coefficients.

From equation 1 we see that at any frequency f, the input impedance $Z_L(f)$ achieves a minimum value of zero if the polynomial N[S(f)] takes a value of zero at this frequency. In the design algorithm presented here it has been assumed that the one-section delay time $t_0 = 1/(14f_0)$ (4,5). Under this assumption the conditions

$$Z_L(i \times f_0) = 0 \quad \text{for } i = 2, 3, 4, 5 \text{ and } 7 \quad (2)$$

are satisfied if $a_1$ = 30.1836 and $a_3$ = 20.7681.

Physically this means that at these values of $t_0$, $a_1$, and $a_3$ the signal components of frequencies $2f_0$, $3f_0$, $4f_0$, $5f_0$, and $7f_0$ are fully filtered, i.e. reflected backwards toward the source.

Let us now consider the situation in which the stepped impedance element under discussion is used instead of the line segment of characteristic impedance $Z_{eq}$ and electrical length $\theta_{eq}(f_0) = \theta_{eq0}$ (Figure 1a). It has been confirmed numerically that such a replacement can be done successfully over the frequency range from 0 to $2f_0$ if the following conditions are satisfied.

$$Z_L(f_k) = jZ_{eq}\tan\left(\theta_{eq0}\frac{f_k}{f_0}\right) \quad (3)$$

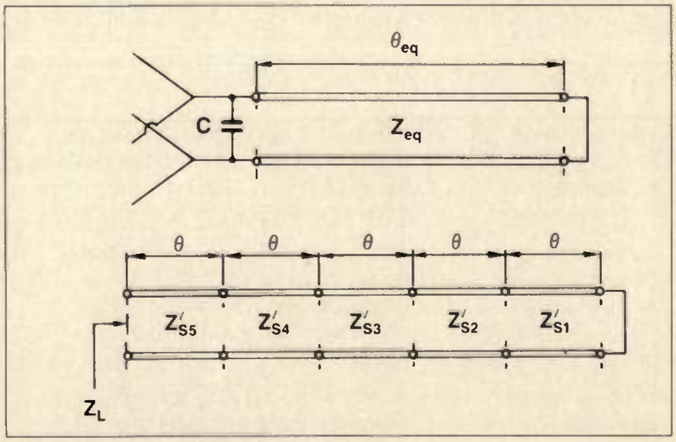


**Figure 1. A distributed resonant circuit: (a) electrical scheme of a conventional configuration, (b) five-section stepped impedance element.**

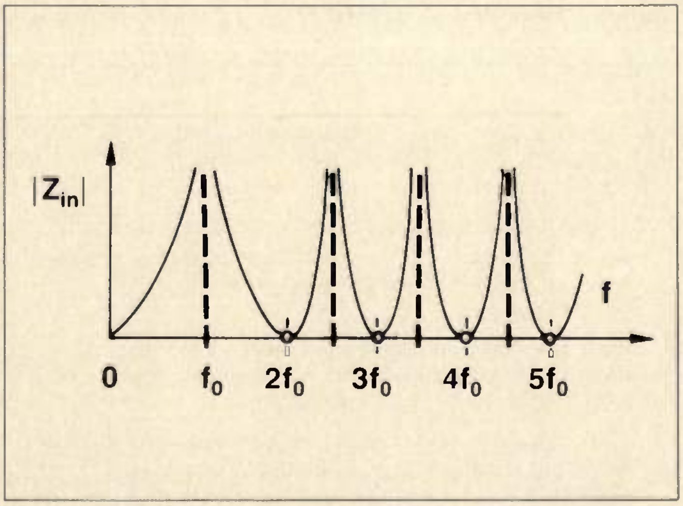


**Figure 2. Input impedance response vs. frequency.**

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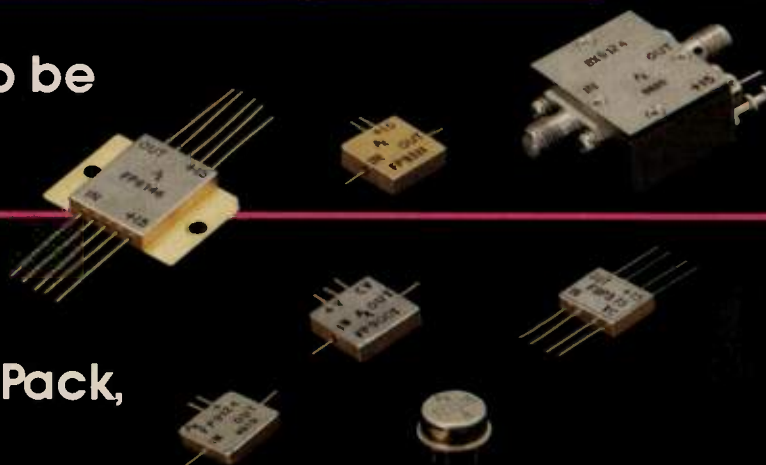

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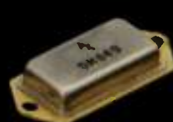

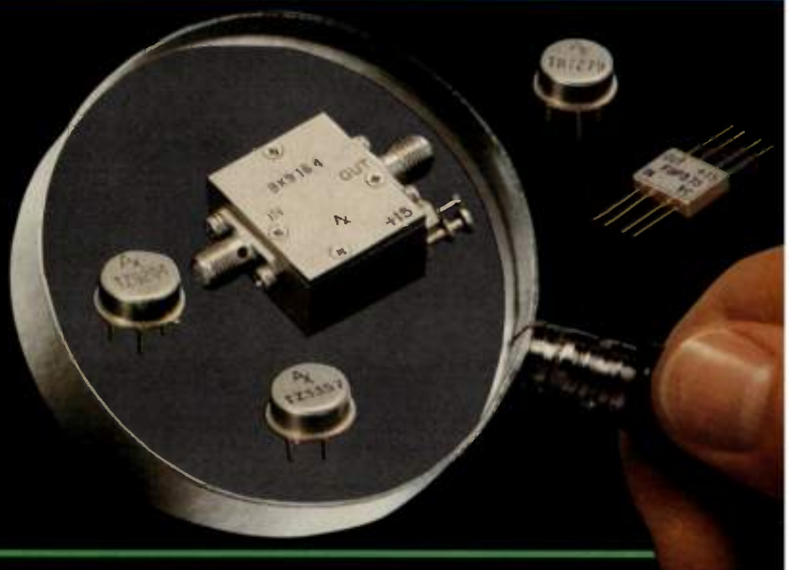

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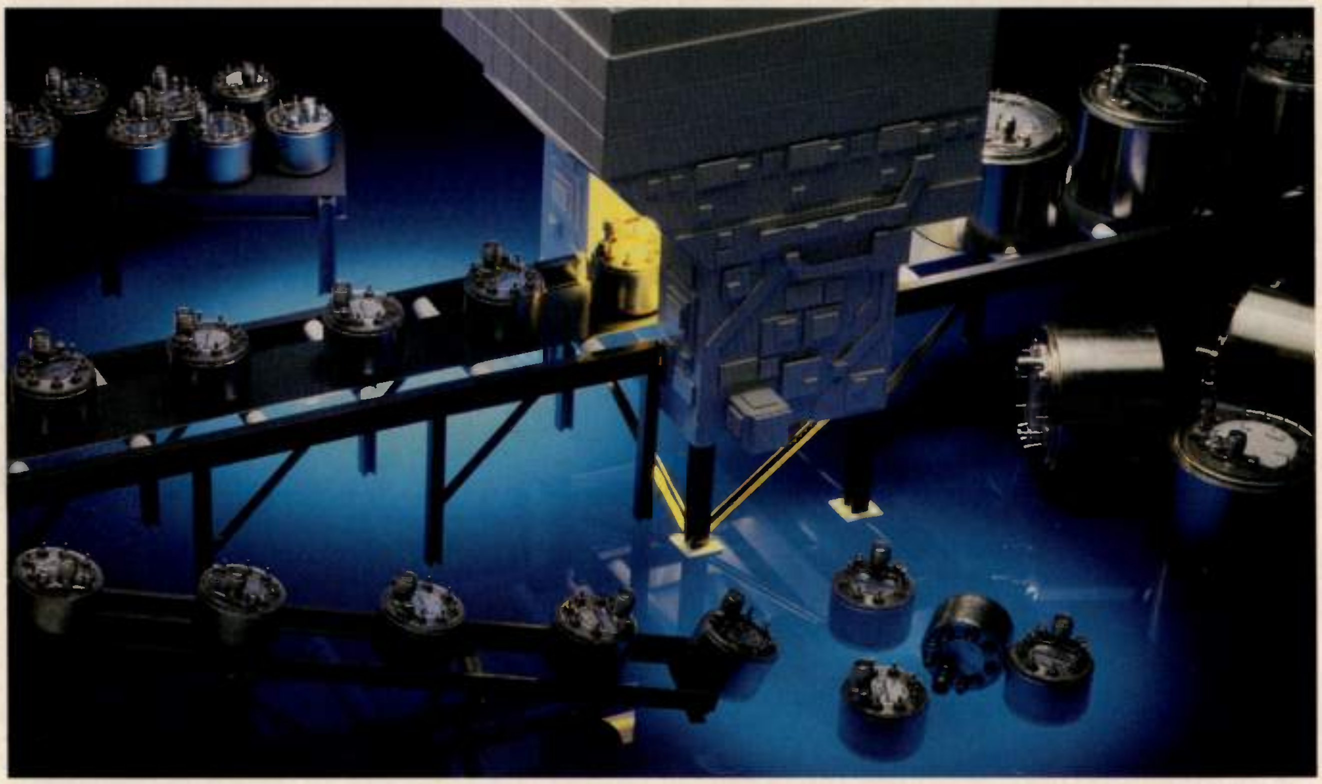

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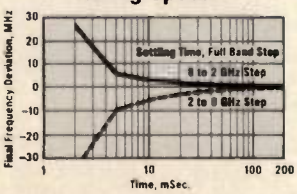


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at frequencies $f_k$ equal to $f_1 = 0.75f_0$, $f_2 = 0.99f_0$, and $f_3 = 1.25f_0$. After rearrangement of equation 3 we get a set of equations which are linear with respect to the coefficients $b_0$, $b_2$, and $b_4$ of the polynomial M(S). By solving these equations we obtain the values of the above-mentioned coefficients and next the characteristic impedances of the line sections shown in Figure 1b are calculated. For this purpose the following explicit formulas can be used:

$$Z'_{S5} = \frac{1 + a_1 + a_3}{b_0 + b_2 + b_4} \tag{4a}$$

$$Z'_{S4} = \frac{a_1 - 1 + Z'_{S5}(b_4 - b_0)}{2b_0 + b_2 + \dfrac{1 - a_1}{Z'_{S5}}} \tag{4b}$$

$$Z'_{S3} = \frac{a_1 - b_0(Z'_{S4} + Z'_{S5}) + \dfrac{Z'_{S4}}{Z'_{S5}}}{b_0 + b_4\left(\dfrac{Z'_{S5}}{Z'_{S4}}\right) - \dfrac{1}{Z'_{S4}} - \dfrac{1}{Z'_{S5}}} \tag{4c}$$

$$Z'_{S2} = \frac{a_1 - b_0(Z'_{S3} + Z'_{S4} + Z'_{S5})}{b_0 + \dfrac{Z'_{S4}}{Z'_{S3}Z'_{S5}}} \tag{4d}$$

$$Z'_{S1} = \frac{Z'_{S2}Z'_{S4}}{b_0Z'_{S3}Z'_{S5}} \tag{4e}$$

To complete the design, the electrical length of these sections must be calculated from the assumed condition $t_0 = 1/(14f_0)$. It is easy to prove that this length at the fundamental frequency $f_0$ is equal to $\pi/7$ radians.

Unfortunately, it has been found numerically that in the most practical cases, the realization of this stepped impedance element in the printed circuit technique is impossible, or rather difficult. This is because the ratio of the maximum and minimum values of the section impedances is too large and the minimum values of the characteristic impedance of the sections are close to several ohms. Therefore, this element serves only as a prototype circuit in the presented design algorithm. Its parameters can be used to calculate the corresponding stub-line configuration circuit which can be realized without difficulty. An example of such a converted circuit is shown in Figure 3. This circuit becomes equivalent to the stepped impedance element shown in Figure 1b if:

$$Z''_{S2} = \frac{1}{b'_2 + b'_0 - \dfrac{1}{Z'_{S5}}} \tag{5a}$$

$$Z''_{S1} = Z''_{S2}\,\frac{b'_2}{b'_0 - \dfrac{1}{Z'_{S5}}} \tag{5b}$$

where:

$$b'_0 = \frac{1}{(Z'_{S1} + Z'_{S2})} \tag{5c}$$

$$b'_2 = \frac{Z'_{S1}}{Z'_{S2}(Z'_{S1} + Z'_{S2})} \tag{5d}$$

Two useful microstrip line versions of this converted circuit are shown in

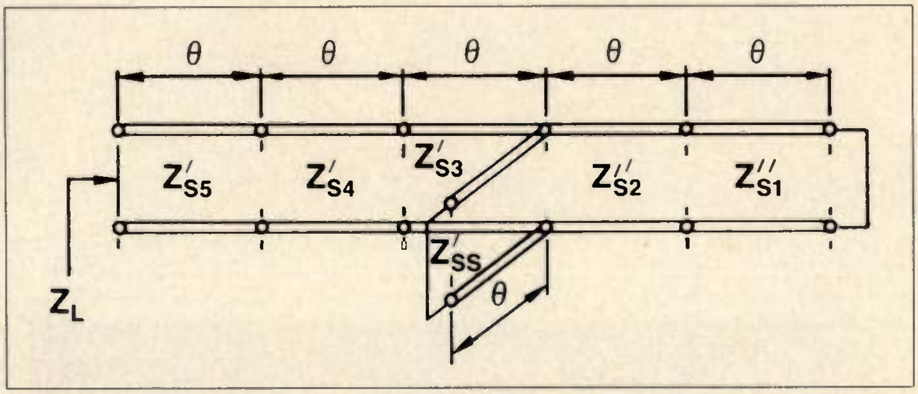


**Figure 3. The converted version of the stepped impedance element shown in Figure 1b.**

Figure 4. As seen from equation 5, by the suitable choice of the impedance $Z'_{SS}$ (Figure 3) we can change the values of impedances $Z_{S1}$ and $Z_{S2}$ of the circuits shown in Figure 4. These impedances, as well as $Z_{S3}$, $Z_{S4}$, $Z_{S5}$, and $Z_{SS}$, should satisfy the condition of the physical realizability given by

$$Z_{0min} \leqslant Z_{Si} \leqslant Z_{0max} \quad \text{for } i = 1, 2, ..., 5 \tag{6}$$

where $Z_{0min}$ and $Z_{0max}$ denote the minimum and maximum values of the permissible impedances respectively.

It has been found numerically that for both circuits presented in Figure 4 the constructional parameter ir = $[\max(Z_{Si},Z_{SS})]$ $/[\min(Z_{Sj},Z_{SS})]$, where i,j = 1,2,...,5, reaches its minimum value when the shunt stub is connected with the second and third sections (Figure 3) and $Z''_{S1} = Z'_{SS}$. Thus the characteristic impedances $Z_{S1}$ and $Z_{SS}$ are also equal.

The optimum value of the impedance $Z'_{SS}$, understood in such a way, can be easily obtained from equation 5 by solving the corresponding standard quadratic equation (see the computer program listing at the end of the article).

### Experimental Results

The experimental model of the resonant circuit under investigation has been designed for the following data: $f_0$ = 0.5 GHz, C = 1 pF, $Z_{eq}$ = 50.415 ohm, and $\theta_{eq0}$ = 0.45π radians. The input impedance $Z_L(f)$ of the stepped impedance element calculated from equations 1, 2, and 3, see Figure 1b, is

$$Z_L(f) = \frac{S^5 + 20.7681S^3 + 30.1836S}{.211099S^4 + .705378S^2 + .190699} \tag{7}$$

where S = jtan[πf/(7$f_0$)]. Consequently, the section impedances of the converted circuit such as shown in Figure 4a are: $Z_{S1} = Z_{SS}$ = 37.228 ohm, $Z_{S2}$ = 50.966 ohm, $Z_{S3}$ = 66.847 ohm, $Z_{S4}$ = 64.843 ohm, and $Z_{S5}$ = 46.922 ohm. The electrical lengths of these sections at the fundamental frequency $f_0$ are equal to π/7 radians.

Figure 5a shows an outline of this resonant circuit constructed in the microstrip line technique by using an epoxy-glass substrate with permittivity, $\varepsilon_r$, of 4.32 and thickness, h, of 2 mm. Its experimentally obtained insertion loss function L(f) is shown in Figure 5b.

### Conclusions

The validity of the presented design formulas has been confirmed both by numerical analysis and experiment. Here it should be pointed out that the resonant frequencies at which the insertion loss function L(f), Figure 5b, achieves its local maxima are dependent only upon the properties of the distributed stepped impedance element. In other words, these frequencies are independent of the shunting capacitance C and introduced load impedance (Figure 5a).

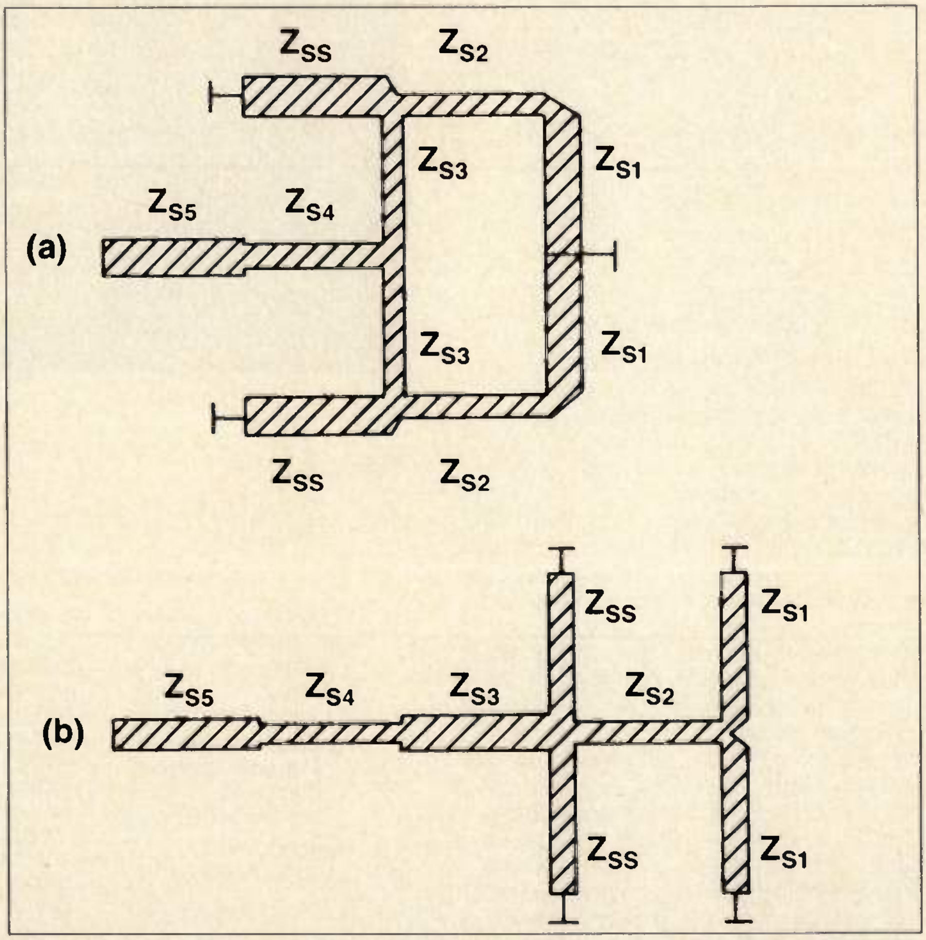


**Figure 4. Two microstrip line structures of the circuit shown in Figure 3: (a) $Z_{S1} = 2Z''_{S1}$, $Z_{S2} = 2Z''_{S2}$, $Z_{S3} = 2Z'_{S3}$, $Z_{S4} = Z'_{S4}$, $Z_{S5} = Z'_{S5}$, and $Z_{SS} = 2Z'_{SS}$. (b) $Z_{S1} = 2Z''_{S1}$, $Z_{S2} = Z''_{S2}$, $Z_{S3} = Z'_{S3}$, $Z_{S4} = Z'_{S4}$, $Z_{S5} = Z'_{S5}$, and $Z_{SS} = 2Z'_{SS}$.**

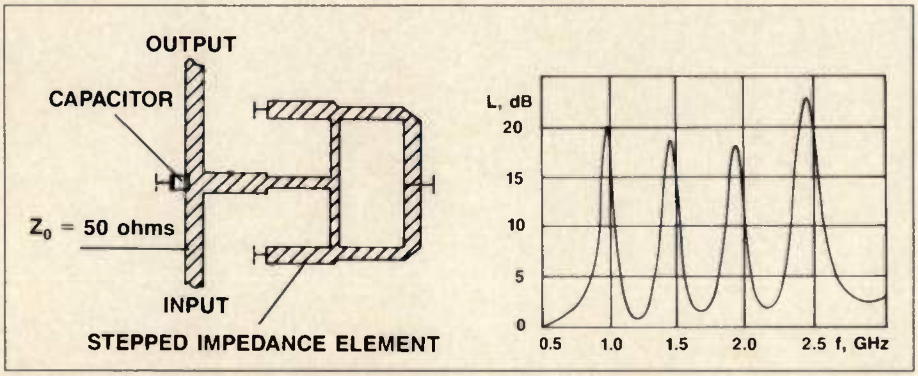


**Figure 5. The investigated resonant circuit: (a) microstrip line layout, (b) measured insertion loss function.**

Figure 5b shows that the measured resonant frequencies are slightly shifted with respect to the corresponding theoretical values. In my opinion, this shifting results from the fact that the microstrip line discontinuities have not been taken into account in the design process.

In practice the circuit under consideration can be utilized as a simple harmonic filter as well as a component element of more complicated filtering structures. By way of example the bandpass filter incorporating such stepped elements (instead of the shunt quarter-wave length stubs) has been investigated. The obtained frequency response indicates that this filter is also nontransparent for third and fifth harmonic components.

From the standpoint of practice it is important that the proposed circuit is easy to construct in the microstrip line technique and its geometric dimensions are relatively small, i.e. are comparable with the quarter part of the wavelength evaluated at the fundamental frequency. *RF*

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## Author Information


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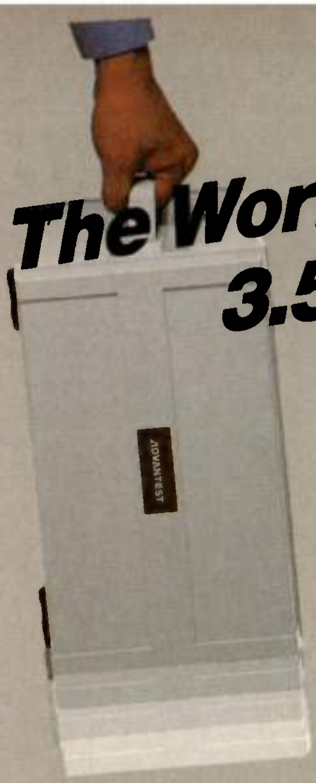
```
 0
10 REM IRC
20 CLS
30 PRINT"This program is an integral part of the paper"
40 PRINT"* A distributed resonant circuit with improved filtering"
50 PRINT"properties * by Stanislaw Rosloniec, Warsaw 1990."
60 PRINT
70 PRINT"Data:"
80 PRINT
90 INPUT"fo[Hz]=",FR
100 IF FR <= 0 THEN PRINT"Error: fo <= 0": GOTO 90
110 INPUT"C[F]=",CO
120 IF CO < 0 THEN PRINT"Error: C < 0": GOTO 110
130 INPUT"Zeq[ohm]=",ZEQ
140 IF ZEQ <= 0 THEN PRINT"Error: Zeq <= 0": GOTO 130
150 PRINT
160 PRINT"Please wait !"
170 PRINT
180 LET PI=3.1415927#
190 DIM A(3,4)
200 DIM Z(5)
210 LET DL=1/(14*FR)
220 LET A1=30.1836
230 LET A3=20.7681
240 LET R=.75
250 GOSUB 730
260 LET A(1,1)=S*S*S*S
270 LET A(1,2)=-S*S
280 LET A(1,3)=1
290 LET A(1,4)=PCN
300 LET R=.99
310 GOSUB 730
320 LET A(2,1)=S*S*S*S
330 LET A(2,2)=-S*S
340 LET A(2,3)=1
350 LET A(2,4)=PCN
360 LET R=1.25
370 GOSUB 730
380 LET A(3,1)=S*S*S*S
390 LET A(3,2)=-S*S
400 LET A(3,3)=1
410 LET A(3,4)=PCN
420 GOSUB 840
430 LET B0=A(3,4)
440 LET B2=A(2,4)
450 LET B4=A(1,4)
460 REM Impedances
470 LET Z(5)=(1+A1+A3)/(B0+B2+B4)
480 LET Z(4)=(A1-1+Z(5)*(B4-B0))/(2*B0+B2+(1-A1)/Z(5))
490 LET Z(3)=(A1-B0*(Z(4)+Z(5))+Z(4)/Z(5))/(B0+B4*Z(5)/Z(4)-1/Z(4)-1/Z(5))
500 LET ZO2=(A1-B0*(Z(3)+Z(4)+Z(5)))/(B0+Z(4)/(Z(3)*Z(5)))
510 LET ZO1=ZO2*Z(4)/(Z(3)*Z(5)*B0)
520 LET BOO=1/(ZO1+ZO2)
530 LET BO2=BOO*ZO1/ZO2
540 REM Calculation of ZSS
550 LET BB= -2*(BOO+BO2)
560 LET CC=BOO*(BOO+BO2)
570 LET DD=BB*BB-4*CC
580 LET YSS=(-BB-SQR(DD))/2
590 LET Z(2)=1/(BOO+BO2-YSS)
600 LET Z(1)=1/YSS
610 FOR I=1 TO 5
620 IF Z(I) <= 0 THEN PRINT"Unsuitable input data , please reduce the value of c
apacitance C": GOTO 1100
630 NEXT I
640 PRINT"Results, see Figure 3"
650 PRINT
660 PRINT"to[s]=";DL
670 PRINT
680 FOR I=1 TO 5
690 PRINT"ZS(";I;")[ohm]=";Z(I)
700 NEXT I
710 PRINT"    ZSS[ohm]=";1/YSS
720 GOTO 1100
730 REM Subroutine 730
740 LET OS=2*PI*FR*R*DL
750 LET CS=COS(OS)
760 LET SN=SIN(OS)
770 IF ABS(CS) < .000001 AND SN > .999999 THEN LET S=1000000!: GOTO 800
780 IF ABS(CS) < .000001 AND SN < -.999999 THEN LET S=-1000000!: GOTO 800
790 LET S=TAN(OS)
800 IF CO=0 THEN LET OE=PI/2  :GOTO 820
810 LET OE=ATN(1/(2*PI*FR*CO*ZEQ))
820 LET PCN=(A1*S-A3*S*S*S+S*S*S*S*S)/(ZEQ*TAN(OE*R))
830 RETURN
840 REM Subroutine GAUSS
850 FOR K=1 TO 3
860 LET C=0
870 FOR M=K TO 3
880 LET D=A(M,K)
890 IF ABS(C)>=ABS(D) THEN GOTO 920
900 LET C=D
910 LET L=M
920 NEXT M
930 IF C<>0 THEN GOTO 970
940 PRINT
950 PRINT"Singular matrix"
960 GOTO 1100
970 LET A(L,K)=A(K,K)
980 LET A(K,K)=C-1
990 FOR J=K+1 TO 4
1000 LET D=A(L,J)
1010 LET A(L,J)=A(K,J)
1020 LET A(K,J)=D
1030 LET D=D/C
1040 FOR I=1 TO 3
1050 LET A(I,J)=A(I,J)-D*A(I,K)
1060 NEXT I
1070 NEXT J
1080 NEXT K
1090 RETURN
1100 REM Control subroutine
1110 PRINT
1120 INPUT"Enter END or CONT :",N$
1130 IF N$="CONT" THEN RUN 10
1140 IF N$="END" THEN END
1150 GOTO 1110
```

**Figure 6. Program used to solve quadratic equation for distributed resonant circuit with improved filtering.**

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# Electronically Tunable Active Filters

By Yue Xu
Department of Electrical Engineering
The Ohio State University

*Active filters have been used for many years, but often at frequencies up to only a few tens of kHz due to limitation of the unity gain bandwidth of op amps. Recently, much improved op amps became available for higher frequencies. The objective of this paper is to describe electronically tunable active filters. We shall show that, for example, the center frequency, $f_o$, of a bandpass filter can be conveniently tuned over a wide range (up to MHz) by a voltage without explicitly changing its bandwidth and gain. Thus, the filter can be controlled by a microprocessor and used in a variety of applications.*

The basic circuit of an active BP filter is shown in Figure 1. The circuit is very simple, without strict demands on elements and is suitable for applications with Q < 100.

For the above circuit, according to the principles of op amps and the node equations, we can easily find:

$$V'(s) = \frac{V_o(s)}{R_3}\left(\frac{-1}{sC_2}\right) \quad (1)$$

$$\frac{V_i(s) - V'(s)}{R_1} = \quad (2)$$

$$\frac{V'(s) - V_o(s)}{\frac{1}{sC_1}} + \frac{-V_o(s)}{R_3} + \frac{V'(s)}{R_2}$$

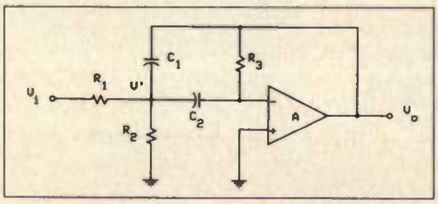


**Figure 1. A second order band-pass filter.**

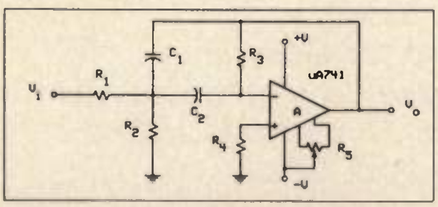


**Figure 2. Complete circuit for a second order bandpass filter.**

Eliminating V′(s) in equation 2 and using equation 1, we get

$$\frac{V_o(s)}{V_i(s)} = \quad (3)$$

$$\frac{-\frac{1}{R_1}}{\frac{1}{sC_2}\left(sC_1 + \frac{1}{R_2} + \frac{1}{R_1}\right)\frac{1}{R_3} + \frac{1}{R_3} + sC_1}$$

so that:

$$H(j\omega) = \left.\frac{V_o(s)}{V_i(s)}\right|_{s=j\omega} = \quad (4)$$

$$\frac{-\frac{R_3}{R_1}\left(\frac{C_2}{C_1+C_2}\right)}{1 + j\omega\left(\frac{C_1C_2}{C_1+C_2}R_3\right) + \left(\frac{1}{R_1} + \frac{1}{R_2}\right)\frac{1}{j\omega(C_1+C_2)}}$$

We can express $H(j\omega)$ as:

$$H(j\omega) = \frac{-H(f_o)}{1 + jQ\left(\frac{\omega}{\omega_o} - \frac{\omega_o}{\omega}\right)} \quad (5)$$

in which:

$$H(f_o) = \frac{R_3}{R_1} \times \frac{C_2}{C_1 + C_2} \quad (6)$$

$$Q = \frac{\sqrt{C_1C_2R_3\left(\frac{1}{R_1} + \frac{1}{R_2}\right)}}{C_1 + C_2} \quad (7)$$

$$\omega_o = \sqrt{\frac{R_1 + R_2}{R_1R_2R_3C_1C_2}} \quad (8)$$

We may choose $C_1 = C_2 = C$, thus:

$$H(f_o) = \frac{R_3}{2R_1} \quad (9)$$

$$Q = \frac{1}{2}\sqrt{R_3\left(\frac{1}{R_1} + \frac{1}{R_2}\right)} \quad (10)$$

$$\omega_o = \frac{1}{C}\sqrt{\frac{1}{R_3}\left(\frac{1}{R_1} + \frac{1}{R_2}\right)} \quad (11)$$

We can solve for $R_1$, $R_2$, and $R_3$ from equations 9, 10, and 11 (for a value of C given in Table 1):

$$R_1 = \frac{Q}{2\pi f_o C\ H(f_o)} \quad (12)$$

$$R_2 = \frac{Q}{2\pi f_o C[2Q^2 - H(f_o)]} \quad (13)$$

$$R_3 = \frac{2Q}{2\pi f_o C} \quad (14)$$

| f(Hz) | C |
|---|---|
| 1-10 | 10-20 $\mu$F |
| $10$-$10^2$ | 0.1-10 $\mu$F |
| $10^2$-$10^3$ | 0.01-0.1 $\mu$F |
| $10^3$-$10^4$ | $10^3$-$10^4$ pF |
| $10^4$-$10^5$ | $10^2$-$10^3$ pF |
| $10^5$-$10^6$ | $10$-$10^2$ pF |

**Table 1. Ranges of C for different frequency ranges for Figure 2.**

Now we can determine all the elements of the BP filter from the given parameters Q, $H(f_o)$, $f_o$. An example is shown in Figure 2 with $H(f_o) = 10$, $f_o = 1$ kHz, Q = 5 and C = 0.01 $\mu$F (from Table 1). From equations 12, 13 and 14 we get:

$R_1$ = 7.95 kohm
$R_3$ = 160 kohm
$R_5$ = 5.6 kohm
$R_2$ = 1.99 kohm
$R_4 = R_3$

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| | W110F | 5MHz—110Mhz | 55 | ±.5 | 1.1 Typ 1.2 Max | +15 | 2:1 | +15 | 80 | C/SMA |
| | W110H | 5MHz—110MHz | 30 | ±.5 | 1.2 Typ 1.4 Max | + 5 | 2:1 | +15 | 30 | C/SMA |
| | W500K | 1KHz—500MHz | 30 | ±1 | 1.7 Typ 2.2 Max | + 3 | 2:1 | +15 | 25 | C-75/BNC |
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| | W500EF | 5MHz—500MHz | 60 | ±.5 | 1.3 Typ 1.4 Max | +20 | 2:1 | +15 | 190 | A/SMA |
| | W500H | 5MHz—500MHz | 33 | ±.5 | 1.2 Typ 1.4 Max | + 5 | 2:1 | +15 | 25 | C/SMA |
| | W1G2M | 10KHz—1000MHz | 30 | ±1 | 2.0 Typ 3.0 Max | + 5 | 2:1 | +15 | 35 | C-75/SMA |
| | W1G2H | 5MHz—1000MHz | 30 | ±.5 | 1.3 Typ 1.5 Max | + 5 | 2:1 | +15 | 40 | C/SMA |
| | W2GH | 500MHz—2000MHz | 22 | ±1 | 4.0 Typ 4.5 Max | + 5 | 2:1 | +15 | 30 | C/SMA |
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| | P150ML | 400KHz—150MHz | 24 | ±1 | 11 Typ | +29.5 | 2:1 | ±24 | 600 | H/BNC |
| | P500A | 2MHz—500MHz | 37 | ±.5 | 4.5 Typ | +30 | 2:1 | +24 | 500 | H/SMA |
| | P500L | 5MHz—500MHz | 17 | ±.7 | 10 Typ | +30 | 2:1 | +24 | 420 | H/BNC |
| | P500ML | 2MHz—500MHz | 16 | ±1 | 11 Typ | +28 | 2:1 | +24 | 600 | H/BNC |
| | P1GB | 50MHz—1000MHz | 30 | ±1 | 5.5 Typ | +30 | 2:1 | +20 | 800 | A-S/SMA |
| | P1000M | 5MHz—1000MHz | 20 | ±.5 | 6 Typ | +21 | 2:1 | +20 | 200 | H/SMA |
| | P2GF-2 | 10MHz—2000MHz | 32 | ±1 | 7.5 Typ | +30 | 2:1 | +15 | 1000 | FW1/SMA |
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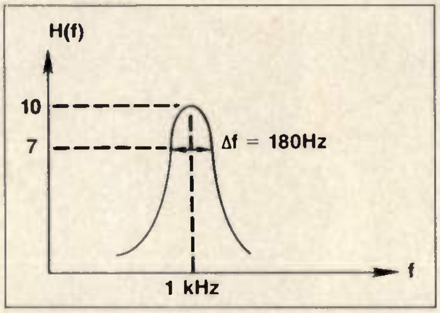



**Figure 3. Characteristic graph of H(f) versus f for the circuit shown in Figure 2.**

The characteristic of H(f) versus f is shown in Figure 3.

The circuit should be carefully adjusted to satisfy the required relations. According to equations 9, 10 and 11, both $H(f_o)$ and Q are independent of C. Only $\omega_o$ is inversely proportional to C. $H(f_o)$ is independent of $R_2$ also. Thus, the procedures of adjustment are:

1. Adjust $R_3$ to obtain $H(f_o)$.
2. Adjust $R_2$ to change Q (i.e. Δf).
3. Adjust $C_1$ and $C_2$ simultaneously to obtain $\omega_o$.

Note that possible parasitic oscillation in the circuit should be properly eliminated, eg., by circuit compensation.

Incidentally, if the required bandwidth is very wide, it is better to choose a lowpass and a highpass combination filter than a bandpass filter. The characteristics of the bandpass filter can easily be changed to a lowpass or a highpass filter by simply changing the resistors to condensers and vice versa. Table 2 gives the detail information.

In Table 2, H(0), H(∞), and $H(f_o)$ are the values of the transfer function at f = 0, ∞ and $f_o$ respectively. For the lowpass or highpass filter, "d" is the damping coefficient, related to the shape of the H(f)-f curve. When $d < 0.707$, the H(f)-f curve shows a peak. At $d = 0.707$, the curve becomes flat. "$\omega_n$" is the 3 dB cutoff frequency. For bandpass filters, the shape of the curve is determined by Q.

## Electronically Tunable Second Order BP Filter

In order to make a BP filter with its $f_o$ shifted by an applied voltage, put $Q = f_o/\Delta f$ into equations 12, 13 and 14 then,

$$R_1 = \frac{1}{2\pi\Delta f\, H(f_o)C} \tag{15}$$

$$R_2 = \frac{1}{2\pi C\left[\frac{2f_o^2}{\Delta f} - \Delta f\, H(f_o)\right]} \tag{16}$$

$$R_3 = \frac{1}{\pi\Delta f C} \tag{17}$$

where Δf is the −3 dB bandwidth. Clearly, $f_o$ can only be varied by $R_2$, after $R_1$, $R_3$ and C are chosen. So electronically changing $R_2$, by a JFET, for example, results in a voltage controlled $f_o$.

To expand the frequency coverage of the filter, i.e., to expand the range of variable resistance between D and S of the FET, it is better to select a FET with a large $I_{dss}$. For example, $I_{dss}$ should be 5-8 mA or larger. Meanwhile, pinch-off voltage $|V_p|$ also should be large enough. Sometimes for higher frequency coverage, a resistor (> 500 ohms) can be connected between D and S of the FET. A practical example is shown in Figure 4.

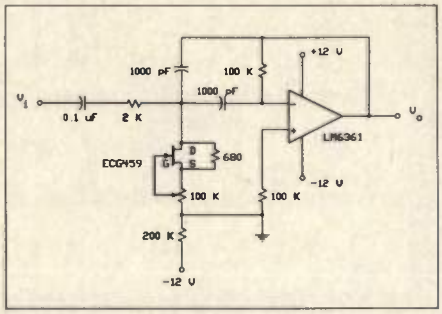



**Figure 4. An electronically tunable second order bandpass filter.**

The elements are calculated by the equations mentioned earlier. When $R_5$, a 100 kohm pot, is adjusted, the gate voltage is changed. This tuning voltage can also be an external gate voltage of any waveform.

In terms of the circuit in Figure 4, $R_1$ can be chosen between 1 kohm an 10 kohm. To get large gains (to reduce $R_1$), one should keep $V_i$ low to avoid saturation and distortion of $V_o$. The purpose of adding $R_2$ in Figure 4 is to raise $f_o$ to higher frequencies, essentially maintain the same Δf. For example, when $R_2$ is absent in Figure 4, the tuning range is 25 to 35 kHz; with $R_2$ added to the circuit, the tuning range becomes 33 to 42 kHz. The highest center frequency ($f_o$) is limited by the unity gain bandwidth of the op amp. Here, LM6361 has a unity gain bandwidth as high as 32 MHz, so it works well in a few tens of kHz range.

The simple circuit described above is very versatile due to its flexibility and reliability. The gain, bandwidth (Q), and $f_o$ can easily be changed. *RF*

## Acknowledgement

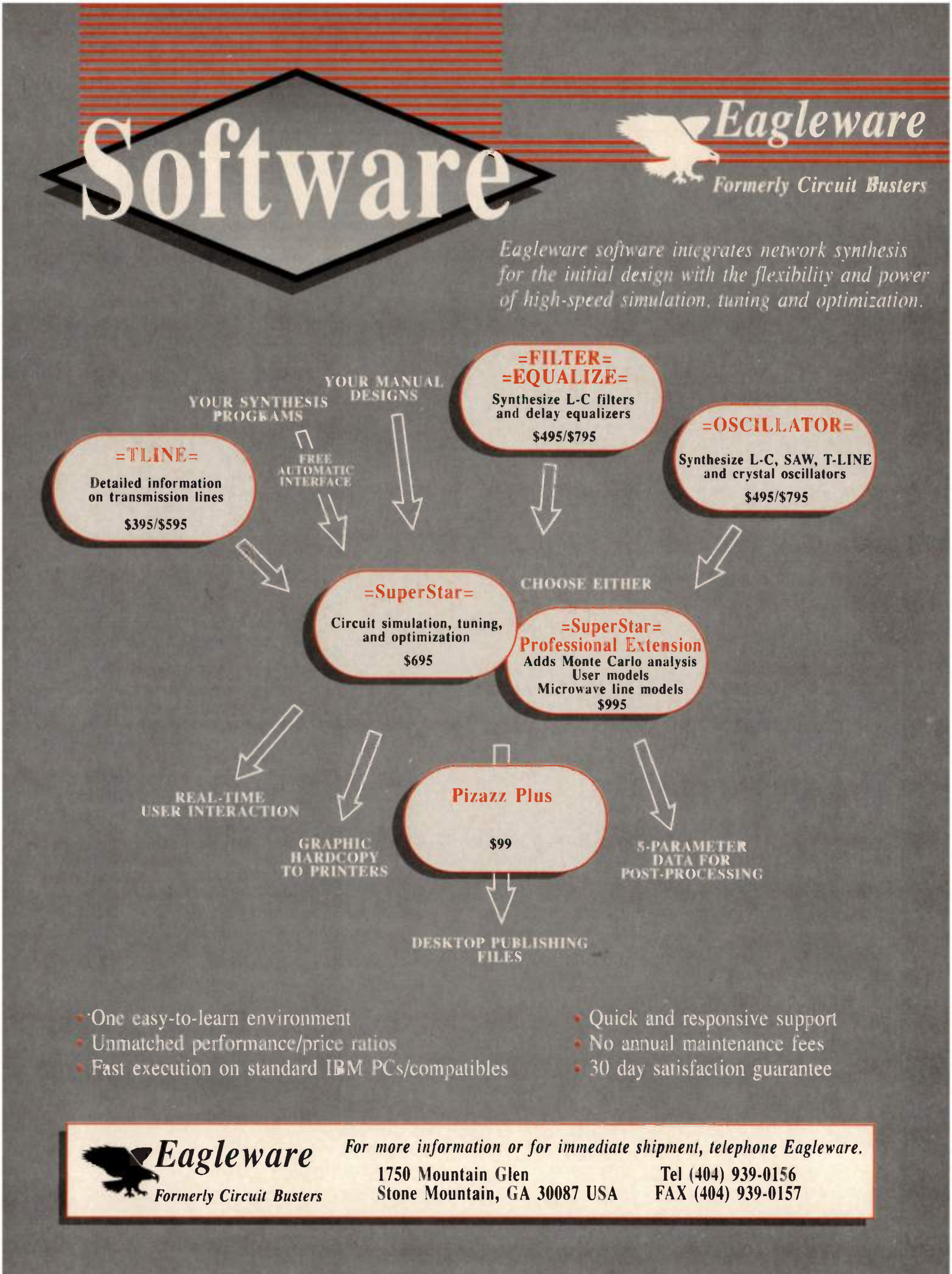
I would like to take this opportunity to acknowledge the research support of Dr. Donald P. Cohen.

| LOWPASS | HIGHPASS | BANDPASS |
|---|---|---|
| $R_1$ | $1/sC_1$ | $R_1$ |
| $1/sC_1$ | $R_1$ | $R_2$ |
| $R_2$ | $1/sC_2$ | $1/sC_2$ |
| $R_3$ | $1/sC_3$ | $1/sC_1$ |
| $1/sC_2$ | $R_2$ | $R_3$ |
| $H(0) = -\frac{R_3}{R_1}$ | $H(\infty) = -\frac{C_1}{C_3}$ | $H(f_o) = \frac{R_3}{R_1}\frac{C_2}{C_1 + C_2}$ |
| $\omega_n = \frac{1}{\sqrt{R_2R_3C_1C_2}}$ | $\omega_n = \frac{1}{\sqrt{C_2C_3R_1R_2}}$ | $\omega_o = \sqrt{\frac{R_1 + R_2}{R_1R_2R_3C_1C_2}}$ |
| $d = \frac{1}{2}\sqrt{\frac{C_2}{C_1}}\left(\sqrt{\frac{R_2}{R_3}} + \sqrt{\frac{R_3}{R_2}} + \frac{\sqrt{R_2R_3}}{R_1}\right)$ | $d = \frac{1}{2}\sqrt{\frac{R_1}{R_2}}\left(\frac{1}{\sqrt{C_2C_3}} + \sqrt{\frac{C_2}{C_3}} + \sqrt{\frac{C_3}{C_2}}\right)$ | $Q = \frac{\sqrt{C_1C_2R_3(1/R_1 + 1/R_2)}}{C_1 + C_2}$ |

**Table 2. Values of variables for lowpass, highpass and bandpass filters for Figure 2.**

### About the Author

Yue Xu received his BSEE from North China University in the People's Republic of China, and is currently doing research at The Ohio State University. He has published articles in Chinese journals on RF and microwaves. He may be reached at Department of Electrical Engineering, 205 Dreese Laboratory, 2015 Neil Avenue, Columbus, OH 43210-1272. Tel: (614) 292-7251.



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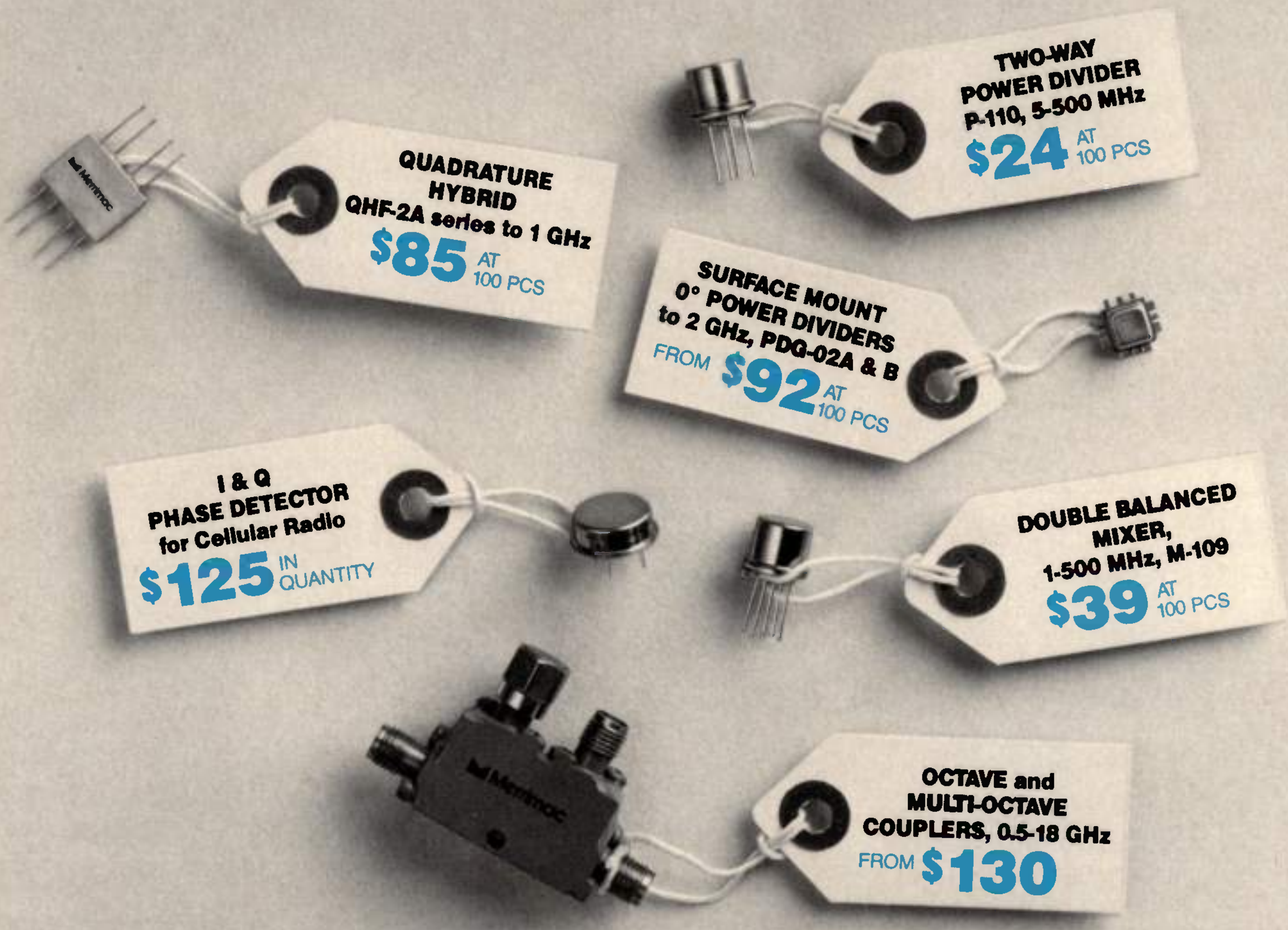


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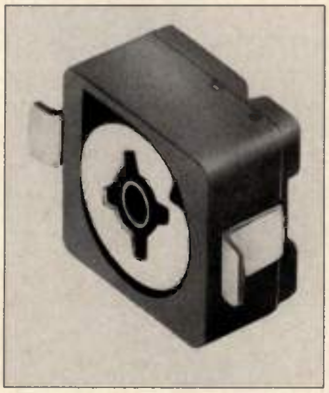

Celsius. Seven capacitance ranges (from 1.7 - 3.0 pF to 13.0 - 50 pF) are available. Each corresponds to the ranges for the J-leaded and top tuning gull-wing models already offered by Sprague-Goodman. The capacitors are 4 × 4.5 × 2.7 mm in size, and prices for Surftrim[R] gull wing trimmer capacitors with reverse leads start at $0.51 for quantities of 1,000.
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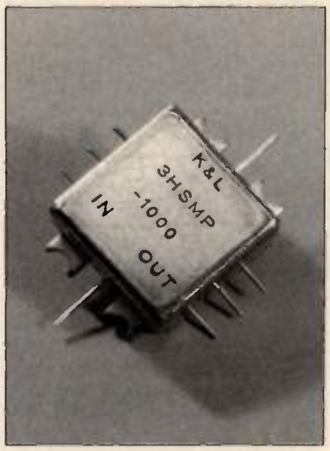


package and has 1.5:1 VSWR and less than 1 dB insertion loss over the 400 to 2000 MHz frequency range. The filter features a cut-off frequency of 200 MHz with a shape factor of 3.0:1 from 3 to 40 dB. Phase matching within ±3 degrees from 400 to 2000 MHz is available. Both units are laser welded for hermetic seals, and both filters are 0.50 inches × 0.50 inches × 0.24 inches (1.27 × 1.27 × 0.60 centimeters) in size.
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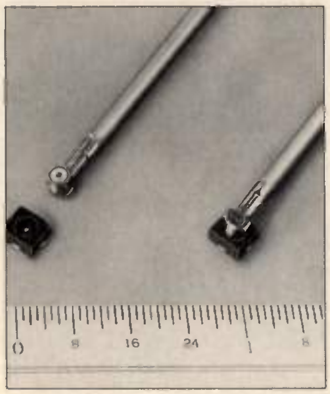
**INFO/CARD #209**

## MRI Pulse Amplifier

ENI has introduced an advanced solid state RF amplifier for Magnetic Resonance Imaging systems. The model MR-5001 provides 5 kW of pulse power over the 10-86 MHz frequency range for systems with 0.5 to 2.0 Tesla magnetic field strength. The MR-5001 has gain linearity of ±2 dB for a 40 dBc dynamic range and ±0.5 dB long term gain stability. Digital Signal Processing provides user-variable RF pulse width and duty cycles up to 5 ms pulse width and 5 percent duty cycle at full peak power. Each module is a fully front-serviceable, field-replaceable unit which can be easily removed and replaced in minutes. With an MTBF of over 10,000 hours, the MR-5001 offers exceptional operational reliability and its modular design reduces downtime to a minimum.
**ENI**
**INFO/CARD #208**

## Surface Mount Mini Coaxial Connector

A new 50 ohm subminiature coaxial jack for surface mount applications is now available from



Murata Erie North America. It features a VSWR of better than 1.2:1 through 2 GHz and is designed for application with microstrip lines and coplanar wave guides. The CCR Series is also suitable for reflow soldering.
**Murata Erie North America**
**INFO/CARD #207**

## Signal Monitoring Modular Receivers

Apcom has introduced a compact receiver designed for signal monitoring in the 20 to 520 MHz band. Each receiver is tuned through the 500 MHz operating band in 1 kHz increments with the IEEE-488 bus. Front panel controls on each receiver are used to select AM or narrow band FM detection. The standard IF bandwidth is 15 kHz and bandwidths up to 300 kHz are available.
**Apcom, Inc.**
**INFO/CARD #206**

## Wideband Buffer Amplifiers

The 600 MHz AD9620 and 750 MHz AD9630 unity-gain wideband buffer amplifiers from Analog Devices respectively slew at 2,200 and 1,200 V/μs and guarantee 1.6 and 1.5 ns maximum rise and fall time for a 1 V step over the operating temperature range. Prices are $19 for the AD9620 in 100s and $6.25 for the AD9630 in 100s.
**Analog Devices**
**INFO/CARD #205**

## 65 Watt RF Power Amplifier

The DBP065D01B 65 Watt RF power amplifier from Decibel Products covers the 869-896 MHz frequency range. It is compatible with cellular operations using Bell System plug-in amplifiers and meets high power RSA requirements. Input power can be 0.7 to 1.6 Watts and output power is stable at ±1 dB.
**Decibel Products**
**INFO/CARD #204**

## Switch Distribution Systems

Watkins-Johnson has introduced a series of matrix switch distribution systems available in the following bands: DC-20 kHz, DC-20 MHz, 1-30 MHz, 20-500 MHz, 20-1000 MHz, and narrow IF bands over 80 - 200 MHz. The designs are based on reed relay, FET, or PIN switch technology and are offered in the following input/output configurations: 6×6, 8×8, 10×10, 16×16, 24×28, and 30×40.
**Watkins-Johnson Company**
**INFO/CARD #203**

## GaAs FET Amplifiers

The 7900 Series of wideband GaAs FET amplifiers now available from Narda provide 18 to 40 dB of gain with output power levels of +12 to +20 dBm, depending on the model. Two gain/power models are available from stock in five bands: 2 to 6 GHz, 4 to 8 GHz, 2 to 8 GHz, 6 to 18 GHz, and 8 to 18 GHz.
**Loral Microwave-Narda**
**INFO/CARD #202**

## Low Loss Circulators and Isolators

M/A-COM's Radar Products division has released low loss circulators and isolators for cellular telephone applications. The circulators provide 0.2 dB of loss over the −30 to +85 degree Celsius temperature range and are offered in a frequency range of 935 to 960 MHz. These circulators are suitable for use in solid state amplifiers and combiner networks.
**M/A-COM Radar Products Division**
**INFO/CARD #201**

## I/Q Splitter

With a 20 MHz system clock, the PDSP16350 I/Q Splitter can produce waveforms up to 10 MHz with 0.001 Hz resolution. It features 16 bit phase and amplitude accuracy, with spur levels down to −90 dB and amplitude and phase modulation modes. A direct digital synthesizer produces simultaneous sine and cosine values.
**Plessey Semiconductors**
**INFO/CARD #200**

## Surface Mount Filter Packages

Integrated Microwave has introduced IMpac™ surface mount filter packages featuring high performance Mil-Spec lumped element miniature filter technology. Lowpass, highpass, and bandpass designs in a variety of transfer functions, including Chebyshev, Bessel, and Gaussian are available. For these designs, impedance is 50 ohms, isolation is 70 dB, and the frequency range is DC to 5000 MHz.
**Integrated Microwave**
**INFO/CARD #199**

## Modulation Domain Analyzer

The HP 5373A is a tool for the design of pulsed RF systems. It studies agile carrier, staggered

pulse repetition interval, chirp, phase jitter, and similar modulations on pulsed or non-repetitive signals. The analyzer is priced at approximately $30,000 and delivery is four weeks ARO.
**Hewlett-Packard Company**
**INFO/CARD #198**

## Phase Locked Oscillators

A series of phase locked oscillators that cover the 100 MHz to 24.0 GHz frequency range have been introduced by Phoenix Microwave Labs. Phase noise is typically −100 dBc, 10 kHz from the carrier on a 6.0 GHz unit, while harmonics are −20 dBc and spurious −80 dBc. The internal reference unit is 1.25" × 2.25" × 2.25" is size, and an external reference unit is 0.625" × 2.25" × 2.25".
**Phoenix Microwave Labs, Inc.**
**INFO/CARD #197**

## 600 MHz Operational Amplifier

Sipex Corporation has released the SP2539, a high slew rate, wide bandwidth monolithic operational amplifier. It features 600 V/µsec slew rate and 600 MHz gain bandwidth product. It is stable for closed loop gains of 10 or greater and has a 9.5 MHz power bandwidth.
**Sipex Corporation**
**INFO/CARD #196**

## 450 MHz BETRS Repeater System

Peninsula Engineering Group has developed a non-frequency translating repeater for point-to-multipoint 450 MHz BETRS. The SRF-450 is compatible with any manufacturer's BETRS system and has 77 dB of gain across a 670 kHz bandwidth. It has an MTBF of more than 85,000 hours and consumes 60 Watts of power.
**Peninsula Engineering Group, Inc.**
**INFO/CARD #195**

## ECL Compatible Oscillators

The K1149 Series ECL-compatible crystal clock oscillators from Champion Technologies now has a frequency range from 40 to 160 MHz. The oscillator can be soldered in standard wave-line operations without damage and takes up 0.820" × 0.520" on a circuit board. Its seated height is 0.245" for 40 to 125 MHz and 0.335" for 125 to 160 MHz.
**Champion Technologies, Inc.**
**INFO/CARD #194**

## VHF High Power Switchless Combiner

The VHF High Power Hot Switch and Switchless Combiner can combine and/or switch two transmitter inputs to one or both of the combiner outputs. The switching operation is done under full power without interruption of programming. It covers the 174 to 216 MHz frequency range and has a power rating of 100 kW.
**Micro Communications, Inc.**
**INFO/CARD #193**

## 3 Watt Flange-Mounted Attenuator

Florida RF Labs has released a 3 Watt, flange-mounted, conduction-cooled attenuator that offers 1.35:1 maximum VSWR to 4.0 GHz. It is offered in attenuation values up to 20 dB. These units are available in 1 dB increments from 1 to 10 dB also.
**Florida RF Labs, Inc.**
**INFO/CARD #192**

## Digital Receiver Development System

ERA Technology has designed an IBM PC compatible development system for high performance digital filtering and signal generation for GEC Plessey Semiconductors' PDSP16350 (modulator) and PDSP16256 (filter) DSP chips. The board is available with either a 12 bit resolution, 1 MHz ADC, or an 8 bit 20 MHz DAC. 16 bit digital input and output ports are also provided.
**GEC Plessey Semiconductor**
**INFO/CARD #191**

## 1 kW UHF-TV Transmitting Tube

The NL347 provides 1 kW of output power when common amplification of vision and sound is

required. Higher power levels are possible if video and sound are transmitted separately. A tube and cavity combination is available to OEMs, and technical assistance and drawings are available.
**Richardson Electronics, Ltd.**
**INFO/CARD #190**

## RF Amplifier

Amplifonix Model TM6440 RF Amplifier features 12 dB gain, VSWR of 2.0:1, and +7.5 dB minimum. It has a frequency range of 10 to 400 MHz and a noise figure of 5.0 dB maximum. It is available in

4 pin TO-8, flatpack, surface mount, and connectorized housings.
**Amplifonix**
**INFO/CARD #189**

## DC Coupled Double Balanced Mixer

Model 4827 from Loral Microwave-Narda handles RF and LO frequencies from 2 to 26.5 GHz with IF coverage from DC to 500 MHz. The mixer uses batch-matched Schottky barrier diodes and planar construction to assure symmetry. This unit can also be used as a third harmonic mixer.
**Loral Microwave-Narda**
**INFO/CARD #188**

## 75 Ohm CATV Semi-Rigid Cables

Rosenberger/Micro-Coax has released two 75 ohm semi-rigid coaxial cables that are UT-85-75 with an outer diameter of 0.085" and UT-141-75 with an outer diameter of 0.141". Both are available with copper outer jacket and a variety of plating options.
**Rosenberger/Micro-Coax**
**INFO/CARD #187**

## PIN-Schottky limiter

A PIN-Schottky limiter designed for receiver protection and power leveling applications has been developed by FEI Microwave. The A9L301B features 1 Watt CW capability, 0.5 to 18 GHz bandwidth, VSWR of less than 2.2:1, and insertion loss of less than 2.3 dB.
**FEI Microwave, Inc.**
**INFO/CARD #186**

## Selective CATV Test Filter

Model 7056 from Microwave Filter Company isolates a 10 MHz spectrum for testing of composites and triple beat. The 3 dB passband is 437-447 MHz, and 10 MHz passbands are also available. The 60 dB stopbands are 0-434 MHz and 450-500 MHz. Impedance is 75 ohms and connectors are type F.
**Microwave Filter Company, Inc.**
**INFO/CARD #185**

## 5 MHz Analog I/O System

The ZPD1004, Burr-Brown's PC-based 12 bit, 5 MHz analog I/O system uses the ADC604 to achieve −80 dBc. It has a ±1.25 V input range, 68.6 dB SNR, and a ±0.1 percent of FSR gain error. The one channel model is priced at $3,594, and the two channel unit is $5,693.
**Burr-Brown Corporation**
**INFO/CARD #184**

## Coaxial Connector Series

The PMMA™ series of coaxial connectors from Automatic Connector is suited for applications where exact pre-mating alignment is impossible. The series is a miniature version of the PMA™ plug and includes straight and right angle plugs and jacks to be used with most of the popular semi-rigid and flexible cables.
**Automatic Connector, Inc.**
**INFO/CARD #183**

## SPDT Switch

Model 62P008 SPDT switch features 5 ns switching and 40 dB isolation from 2 to 11 GHz in a package size of 1.25" × 0.9" × 0.5". The switch is ECL compatible and is available with SMA connectors. It can toggle at 50 MHz, has insertion loss less than 2 dB, and VSWR of less than 2:1. The 62P008 is priced at $950.
**ECM Devices, Inc.**
**INFO/CARD #182**

## Spectrum Analyzers and ROM Card

The HP 8594A and 8595A portable spectrum analyzers cover the 9 kHz to 2.9 GHz and 9 kHz to 6.5 GHz frequency ranges respectively. Resolution bandwidths range from 1 kHz to 3 MHz and second and third order harmonic distortion is below 70 dBc. Used in the HP 8594A and 8595A spectrum analyzers, the HP 85715A GSM measurement personality card contains measurement routines and a user interface to make transmitter tests of Pan-European digital cellular-radio networks. The HP 8594A is priced at $14,995, the HP 8595A is priced at $19,760, and the HP 85715A is priced at $2,000.
**Hewlett-Packard Company**
**INFO/CARD #181**

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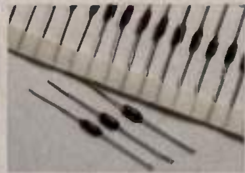

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INFO/CARD 39

# RFI Measurements Using a Harmonic Comb Generator

By Ken Wyatt and Dean Chaney
Hewlett-Packard Co.
Colorado Springs Division

*Most manufacturers of electronic equipment must comply with a variety of regulations in order to market their products worldwide. One of these regulations, of course, is radiated emissions (RFI). The regulatory agencies require that these emission levels be measured outdoors at an open area test site (OATS) to ensure there are few reflective objects to distort the measured signals. In many cases, however, manufacturers prefer to make these measurements in a semi-anechoic chamber in order to speed up the tests. This is especially valuable for engineering evaluations where a number of tests may be performed rapidly. For those manufacturers who do not own an open site facility, it is an advantage to be able to predict whether a product will pass the regulatory limit prior to scheduling open site time. Thus, there exists the need to compare a chamber with an open site in order to determine the correlation. It may also be desireable to compare an open site to another open site.*

**Figure 1a. Portable comb generator with monopole antenna attached.**

The following article describes a simple radiated emissions "standard" which may be constructed that will provide a solution to the above problem. This "standard" radiates a series of harmonics which may be measured as an ordinary product under test. Additionally, it may be used to measure the repeatability of the measurement system and to determine the shielding effectiveness of enclosures. Construction information and a detailed parts list are included (Table 1).

At our facility, the generator is measured weekly so as to reduce delays caused by unrealized system problems such as broken connectors. We also accumulate this weekly data and use it to calculate a running average of system measurement repeatability performance. All of these tests will be discussed later in more detail (Table 1).

## Circuit Description

The basic design was originally "lifted" from a circuit in an old piece of test equipment and adapted for use as a comb generator by Phil Luque of HP's Boise Division. The basic design was repackaged to make it portable for use at our facility (see Figures 1a and 1b). A miniature version was also constructed that runs from a standard 9V battery (Figure 2). This miniature unit may be used to measure the shielding effectiveness of smaller modules or handheld products.

**Figure 1b. View of the comb generator being measured inside a semi-anechoic chamber.**

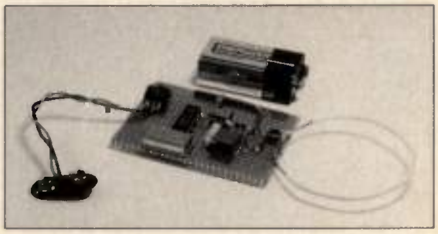


**Figure 2. Miniature version of the comb generator.**

The generator has useful harmonics every 5 MHz from 30 to over 1000 MHz. Figure 3 shows the direct generator output (as measured at its output connector) plotted to show the harmonic amplitude levels. The amplitude stability is within 1.2 dB over a temperature range of 0 to 55 degrees C and frequency accuracy better than 100 Hz. The frequency response of the generator is not critical so long as sufficient energy is present at all frequencies of interest.

The unit is powered from a rechargeable sealed lead-acid battery to eliminate power cords and their resulting re-radiation problems. The battery was sized to provide up to 6 hours of use.

The schematic consists of two portions; a voltage regulator (Figure 4a) and the harmonic generator (Figure 4b). There are two options for the regulator. The regular-sized portable uses a low-dropout circuit, while the miniature 9V battery-operated version uses a simple 3-terminal 5V regulator. However, an alkaline battery is used in this situation and the operating life is only about three hours.

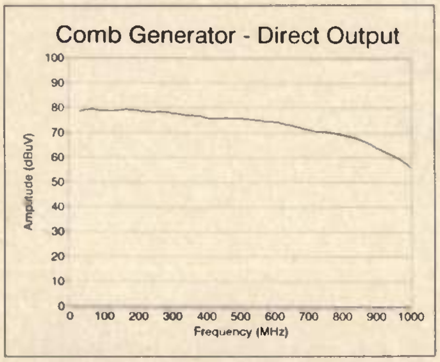



**Figure 3. Amplitude plot of the direct output from the output connector. There are useful harmonics every 5 MHz out to 1500 MHz.**

Operating time depends more on the amp-hour capacity of the battery than on the voltage, so the regular-sized generator was operated from 6 volts rather than 12 volts. Because the integrated circuits require 5 volts, we could not afford to lose too much voltage across the regulator. This required the voltage regulator to be a special low-dropout design. Since finishing the design, a number of manufacturers now offer low-dropout integrated voltage regulators which may be used instead.

The harmonic comb generator is composed of a 10 MHz crystal oscillator (Y1) which is divided by two by the D flip-flop U2. The resulting 5 MHz signal is then amplified by the line driver U3. U3 connects to the step recovery diode (SRD) CR2 via a biasing network. The SRD creates a very fast edge which produces harmonic energy out to around 1500 MHz. The section of semirigid coax (Z1) is used as an energy storage device (current source) during the reverse-biased state of CR2. The SRD drives the output through an 8 dB attenuator circuit, which provides a 50 ohm impedance at the output.

Q1 through Q4 and VR1 form a low dropout voltage regulator. Diode CR1 acts as a DC block and DS1 is a charge indicator. The miniature comb generator uses the single regulator U1. Several different antenna designs have been used with the generator. The monopole antenna (Figure 5, center) was designed to resonate at about the mid-band (500 MHz) and was constructed using a brass rod 1/8 inches in diameter and 5 inches long. Later on, a horizontal dipole was constructed using semi-rigid coax and some stiff wire (paper clips). This antenna is supported about 4.5 inches above the generator using various coaxial adapters. These two antennas are currently used for the repeatability and correlation study.

A horizontal loop antenna was also constructed for use during shielding effectiveness tests (described later on). The two-inch diameter loop was also made using a large paper clip and a binding post-to-BNC adapter.

The enclosure used, a "Bud" box, caused some interesting directional effects as the reception frequency was increased into the UHF region. Polar plots at a single frequency normally yielded several narrow lobes roughly paralleling the long dimension of the generator enclosure. A 12" diameter aluminum ground plane disk was installed at the base of the monopole antenna and this helped but did not completely solve the problem at all frequencies. A larger diameter disk would probably be the solution if a perfectly circular radiation pattern was desired. We decided that the utility of the generator would be reduced with such a potentially large disk attached and so decided to eliminate it entirely and rotate the generator to find the maximum signal just as we would for a real product.

## Construction

The unit was constructed using a double-sided prototyping style circuit board with all components wired point-to-point (See Figures 6 and 7). Lead length was minimized around the RF portions of the circuitry, especially around CR2 and CR3. One side of the board was used as a ground plane. The length of Z1 may be shortened to achieve a flatter output response characteristic at the expense of output amplitude. Bias control R8 can be adjusted for the best output amplitude stability.

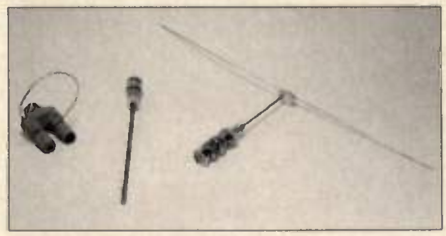


**Figure 5. An assortment of antennas used with the portable comb generator.**

A simple 12V wall charger was used to replenish the internal 6V battery. Resistor R2 was sized to provide a charging current of approximately 100 mA. This current was less than the 20 hour "trickle-charge" rate for the 2.6 amp-hour battery, thus it may be charged over long periods of time without fear of overcharging. Q1 is a general-purpose, P-channel JFET selected for an $I_{dss}$ of 3 mA and is used as a current source. This value is not extremely critical, but is simply the nominal operating current for zener

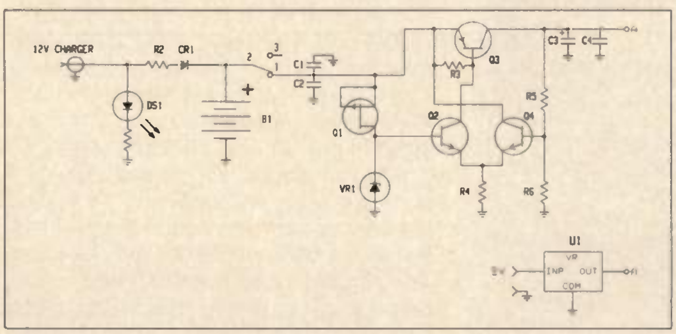



**Figure 4a. Schematic diagram of the power supply and battery charging circuit. U1 is an optional voltage regulator used for the 9V battery operated miniature comb generator.**

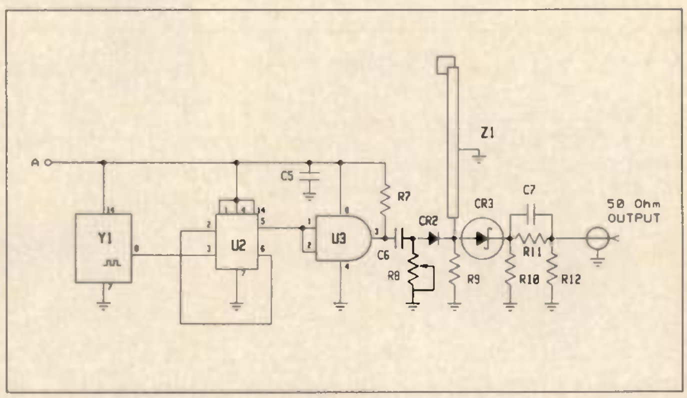



**Figure 4b. Schematic diagram of the comb generator circuit.**

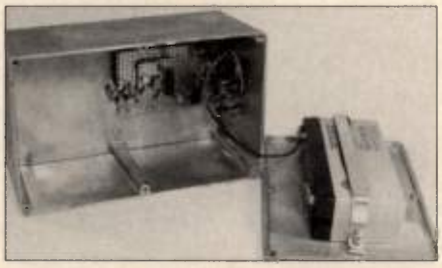


**Figure 6. Interior view of the comb generator showing the battery and mounting arrangement.**

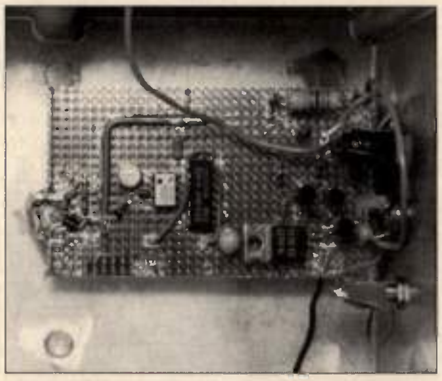


**Figure 7. Close-up view showing the circuit board construction details. Note that transmission line Z1 has a 90 degree bend for better fit on the board. The RF circuitry is built on the left half, while the power supply and charging circuitry is on the right half.**

diode VR1. If this FET is difficult to locate, a 1.2K resistor or one of the newer low-dropout voltage regulators now available may be substituted.

Connecting the finished generator to a spectrum analyzer should yield harmonics every 5 MHz at an amplitude level similar to that shown in Figure 3. Adjust the bias control R8 and length of Z1 (if desired) for a stable and flat amplitude response. Following this, finish packaging the board and optionally check the amplitude and frequency stability versus temperature. An HP 11941A Close-Field Probe was used to verify that there was no signal leakage from the seams of the enclosure.

### System Measurement and Performance Verification

By making repeated measurements of the generator and recording these versus time, it is possible to determine system faults, such as bad antennas, broken coax fittings or failed test equipment. This may reduce delays caused by unrealized system problems. For example, one of our neighboring divisions borrowed the generator to perform some chamber-to-open site correlation studies. When the generator was measured in their chamber, it became quite apparent that there was an unusual loss from 30 to 150 MHz. It turned out that their biconical antenna was defective and measuring 10 to 20 dB low in that range.

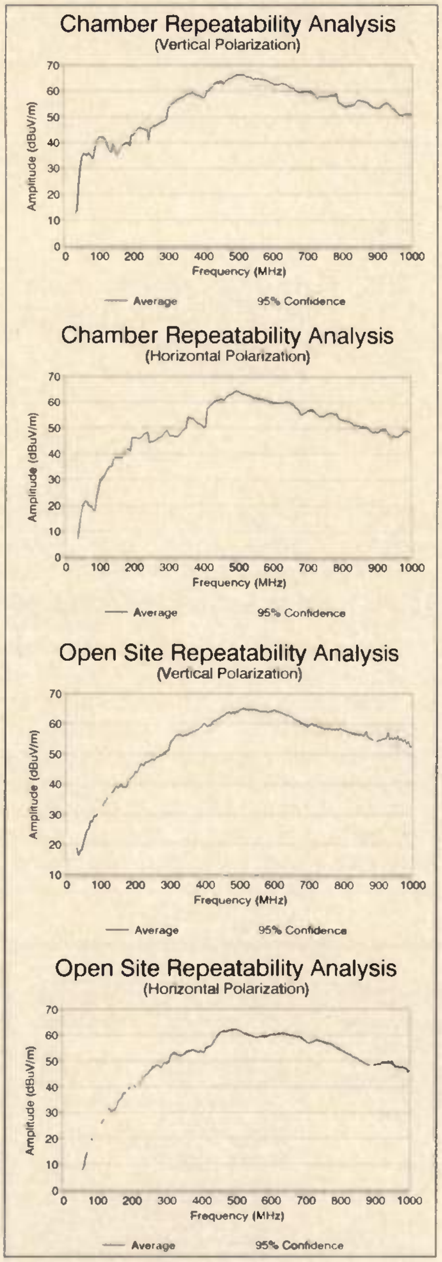



**Figure 8. Repeatability data measured in the chamber and at the open area test site for both vertical and horizontal polarizations.**

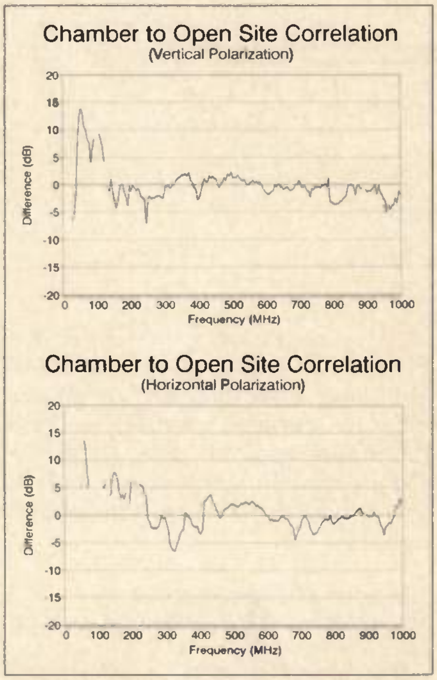



**Figure 9. Correlation data between the chamber and open area test site for vertical and horizontal polarization.**

In addition, by accumulating this weekly data, the system repeatability and correlation performance may be determined. We have recently completed the construction of a 3 meter semi-anechoic chamber for use in engineering evaluation of our products under development. Naturally, the two most important questions in the engineer's mind are "How repeatable are the measurements I'm taking?" and "How do the measurements compare with those taken at the open area test site?". By regularly measuring a standard source, and plotting the mean amplitude along with plus or minus twice the standard deviation (95 percent confidence level), we end up with plots as shown in Figures 8a through 8d. The central plot is the mean (or running average, in our case) of a sample of data, while the upper and lower plots indicate the range where we would expect 95 percent of the measurement data to fall. The chamber data shows that throughout the range 30 to 1000 MHz, the vertically polarized repeatability is ± 2 dB, with a few areas ± 3 dB. Interestingly enough, roughly the same performance was obtained at the open area test site. The horizontal polarized repeatability for the chamber was ± 1 dB with some areas of ± 3 dB.

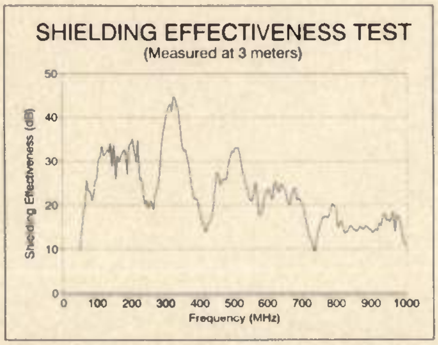



**Figure 10. This is a typical plot of shielding effectiveness of an enclosure versus frequency. This technique may be used to evaluate prototype enclosures before the actual product is fully operational.**

The open site repeatability was ± 0.5 dB over most of the range with a couple places of ± 1 dB.

The generator was measured using 50 MHz-wide frequency bands. The antenna height was adjusted to optimize the amplitudes within this band. An HP 8568B spectrum analyzer was placed into the "MAX HOLD" mode while the comb generator was rotated on a turntable. Both vertical and horizontal polarizations were measured. Occasionally, discontinuities may be observed in the chamber data because, for simplicity, we assumed a constant antenna factor for each 50 MHz band.

One other bit of information we may obtain from this data is the correlation between the chamber and the open site. Now I realize that there is still some debate regarding the practicality (or sense) in making such a comparison, but I will present the information just the same.

**Capacitors**

| | |
|---|---|
| C1 | 470 pF |
| C2 | 2.2 μF/35V |
| C3 | 10 μF/35V |
| C4,5 | 0.1 μF |
| C6 | 0.01 μF |
| C7 | 6.8 pF |

**Resistors**

| | |
|---|---|
| R1 | 390 |
| R2 | 56/2W |
| R3 | 1K |
| R4,6 | 178 |
| R5 | 261 |
| R7 | 23.7/0.5W |
| R8 | 50 ohm trimpot |
| R9,11 | 51.1 |
| R10,12 | 110 |

**Diodes**

| | |
|---|---|
| CR1 | 1N4001 rectifier |
| CR2 | HP 5082-0180 step recovery |
| CR3 | HP 5082-2810 hot carrier |
| DS1 | LED panel light |
| VR1 | 2.4V/400mW zener |

**Transistors**

| | |
|---|---|
| Q1 | P channel JFET (select for $I_{dss}$=3mA) |
| Q2,4 | 2N3904 |
| Q3 | TIP42A |

**Integrated Circuits**

| | |
|---|---|
| U1 | 3-terminal 5V regulator (used only for "mini" comb generator) |
| U2 | 74LS74 |
| U3 | 75451 |

**Miscellaneous**

| | |
|---|---|
| B1 | 6V/2.6AH battery (Yuasa NP2.6-6 sealed lead acid 5.25″L × 2.375″H × 1.25″W |
| S1 | SPDT power switch |
| Y1 | 10 MHz crystal oscillator |
| Z1 | 2.0″ long 0.085″ diameter semi-rigid coax (shorted at one end) |

BNC antenna connector

Charger jack 1/8″ miniature phone jack

Charger - 12V/300 mA (International Components Corp. Model ICC-3-750-1015)

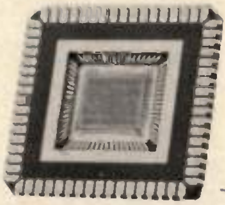
Enclosure - Bud CU-247 Econobox 7.375″ × 4.6875″W × 2.25″H

**Table 1. Parts list for the comb generator.**

Ideally, measurements made in an anechoic chamber and those made at an open area test site should agree closely. However, when you throw in variables, such as, the low frequency degradation of absorber, different measurement distances and cable layout variations of an actual product, these ideal assumptions begin to fail. Figures 9a and 9b show the vertical and horizontal correlation data between our chamber and open site at frequencies from 30 to 1000 MHz. Below 100 MHz, the correlation drops off rapidly as would be expected for a chamber size of 16 w × 28 l × 14 h (in feet). There also appears to be a resonance just above 200 MHz and, as somewhat of a surprise, a couple of broad deviations above 700 MHz. We are currently investigating the cause of these last three deviations. On the average, though, the correlation is within ± 2 dB for the comb generator. The measurements made at the open site were taken at 10 meters and I used a constant factor of 10 dB for conversion to the 3 meter measurement distance. The coax cable loss versus frequency has been accounted for both sites. All this data is stored within a spreadsheet for ease in manipulation.

## Shielding Effectiveness of Enclosures

In addition to assuring measurement system performance, we have found it

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possible to determine the total composite shielding effectiveness of new product enclosures. The advantage in making early tests on prototype enclosures is in identifying weaknesses early in the development while it is still inexpensive to make modifications. We can also compare new enclosures to existing ones to understand the relative effectiveness of a new design.

To determine the shielding effectiveness of an enclosure, the comb generator is installed inside the empty prototype and the system is measured as it would be for an ordinary product. Next, the generator is placed on the turntable by itself and its output remeasured. The difference (dB) is the system shielding effectiveness. Since this measurement is made at all azimuths, the data should indicate the worst case and include such weaknesses as seams, holes, and other penetrations. Figure 10 shows a sample plot of the shielding effectiveness of an Elamet-coated plastic enclosure (1). Note how the shielding effectiveness appears to drop off rapidly below about 80 MHz. Due to the small-sized loop antenna, emissions at low frequencies are very nearly in the noise level, especially when the antenna is further shielded inside an enclosure. This is simply lack of dynamic range in the measurement. The actual shielding effectiveness would remain in the range 20 to 30 dB.

Use of the miniature version of the generator allows the measurement of some of the smaller enclosures or plug-in modules. Note that the test may be performed using either an E-field (monopole) or H-field (loop) antenna. The loop antenna is usually used because it more closely approximates the actual condition of currents running through traces on a circuit board.

## Summary

We have attempted to demonstrate the utility of a simple harmonic comb generator for use in several EMC applications. Hopefully the use of such a device will aid in achieving consistent, error free RFI measurements. In addition, it may prove useful in making an early determination of enclosure shielding effectiveness.


## Acknowledgements

I would like to thank Phil Luque for the original concept, Roy Wheeler for encouraging this effort, Bob Witte for acting as a proofreader, and to Bob Dockey and Bob Hinton for their development of the measurement software. *RF*


## References


1. Elamet is a vapor-deposited aluminum coating about 2.5 um thick. Elamet is a trade name of DeGusa GmBh.



### About the Authors

Ken Wyatt is the Product Regulations Manager and Dean Chaney is an EMC Engineer for Hewlett-Packard Company, Colorado Springs Division. They may be reached at PO Box 2197, Colorado Springs, CO 80901. Ken's telephone number is (719) 590-2852. and Dean's is (719) 590-2899.

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# A Linear Driftless VCO

*By Luis Cupido*
*C&TC Corporation*

*There are RF applications that still require analog controlled oscillators. For applications where feedback is not used in the oscillator control circuitry, linearity and low drift are highly desireable performance features. This article describes a method of achieving a voltage-variable frequency without many of the problems associated with conventional VCOs.*

Most VCO designs with tight specifications imply the use of stable mechanics and temperature controlled or compensated design. The design presented here is more a system than an oscillator, but used as a module, it acts like a VCO. Thus it has one voltage input and a signal output which has its frequency proportional to the input voltage. No drift is observed compared with a free running VCO.

An additional feature is that it needs no special devices or mechanics and wide temperature range is well supported with very little degradation of performance.

## Circuit Description

Figure 1 is a diagram of the circuit described here. Basically, the circuit is a PLL system with an ordinary VCO. Additional digital circuitry produces a continuously variable reference (Figure 2).

A continuously variable reference is generated from 2 quartz crystal controlled oscillators with outputs that are multiplexed to generate a signal such that the mean frequency value is somewhere between the frequency of the 2 crystal oscillators.

By selecting the multiplexing ratio of those two references, a third signal at the mean frequency between reference 1 and reference 2 is obtained. The multiplexing circuitry is driven by a variable duty-cycle signal at the output of a comparator. The two comparator inputs are a reference signal with triangular waveform and the input voltage. This circuit generates an output pulse with the width a function of the input voltage.

The VCO is controlled by a loop filter that takes the mean of the error signal at the output of the frequency detector. By design we must assure that the loop filter is slow enough to extract the mean and produce a DC signal with no noise in it.

The frequency detector must be one that produces a signal proportional to the frequency difference, while keeping within the active region of operation at any input frequencies. Therefore, the VCO is locked on the mean of the reference signal times the prescaling factor.

Figure 3 is a complete block diagram of the circuit.

## Design Example

Let's take an example of application to make some design calculations: The substitution of a PLL with 50 kHz steps in the 900 to 990 MHz band with this concept, for a continuous manual tuning. Most of the decisions were made in order to get a circuit as compact as possible.

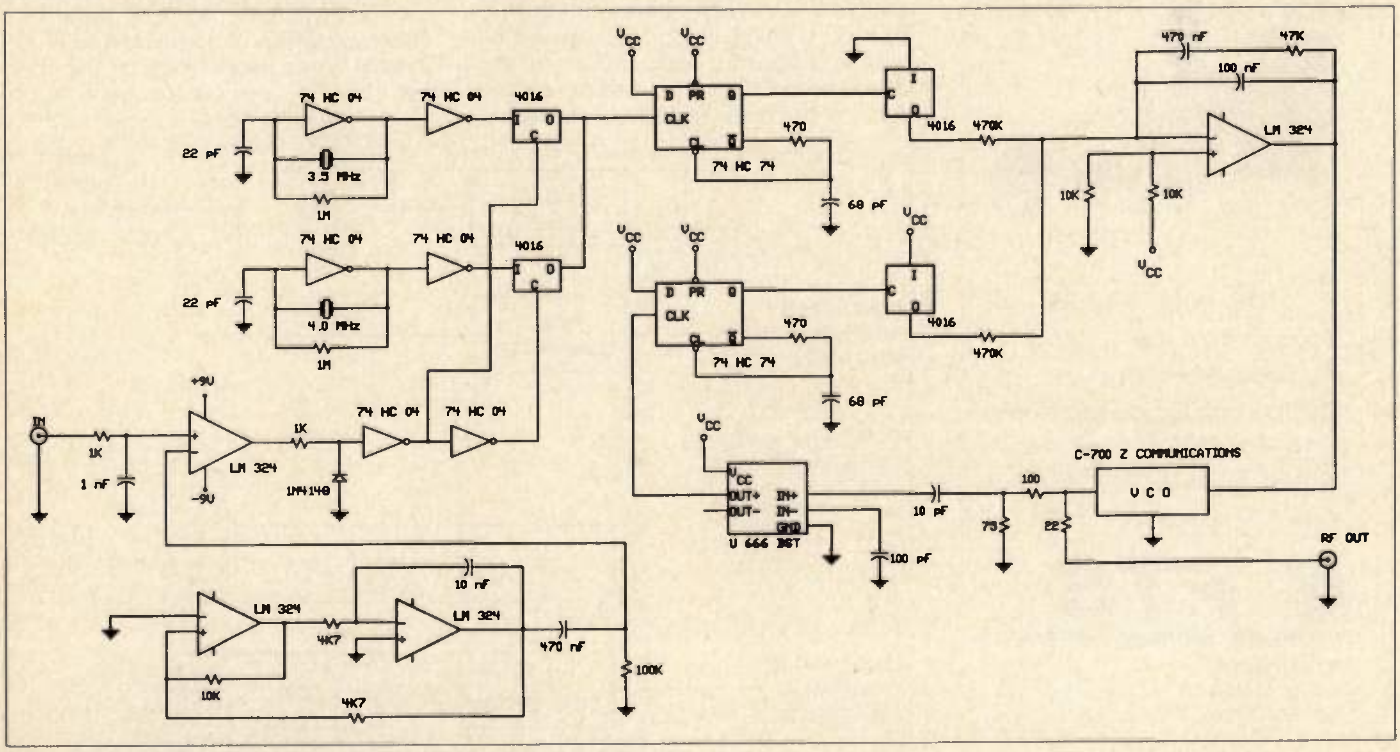


**Figure 1. Design example of a linear driftless VCO.**

The VCO is a commercial one with no special specifications. It only has to cover the desired band and provide enough drive power for both the existent circuit and the prescaler. An ECL prescaler with 1/256 factor is used to translate the frequency information to values that could be processed by conventional digital devices. So 900/256 = 3.515 MHz and 990/256 = 3.867 MHz are values that enable us to chose the upper and lower references. These were rounded to the nearest standard values 3.500 MHz and 4.000 MHz. The actual minimum and maximum values now are 896 MHz and 1024 MHz.

A triangular waveform generator is implemented with 2 op amps in a common configuration. To avoid offset voltage introduced on the comparator, the op amp's output is AC coupled. The level comparator is a FET input op amp and only the offset drift with temperature must be observed. The multiplexer is a conventional one implemented with CMOS analog switches.

The frequency detector is a critical part of this circuit, and for this purpose a specific design is used. The frequency detector will produce as many $V_{DD}$ pulses as the cycles of input 1, and as many $V_{SS}$ pulses as the cycles of input 2. These pulses are used to charge a capacitor in an integrator that acts as a loop filter.

The loop filter produces a DC signal, so it must be well filtered at the frequency of the pulses. Also, the multiplexing frequency will appear at the output of the frequency detector as the result of the changing reference. Therefore, the lowest frequency to be filtered will be the multiplexing one, with the worst case at the middle of the tuning range where there is a 50 percent duty-cycle at the multiplexer.

For this design a 10 kHz multiplexing signal was used. The needs for attenuation of 10 kHz are calculated from the maximum VCO deviation with noise, that is, the maximum degradation of oscillator phase-noise.

The VCO needs from 2 to 6 volts to go from 900 to 990 MHz. If we admit a deviation with noise of 50 Hz on the VCO, then noise is at 125 dB below the tuning voltage range. For that, a 2nd order filter with a bandwidth of 8 Hz will assure enough attenuation of the multiplexing signal. By practical optimization, an integrator with 200 ms time constant followed by a 100 ms RC network was used to reduce the 10 kHz side bands down to −70 dB. A complete circuit diagram of this implementation is shown in Figure 1.

## Design Considerations

For different frequencies the design changes are straightforward. For speeding up the tuning time of this system several improvements might be done:

- Increase the multiplexing rate that allows faster loop filters;
- Increase the loop filter order, keeping the loop's stability, allowing wider loop filter bandwidth, i.e., a faster loop filter.
- With some degradation on the spectral purity of signal a full band tuning time of 20 ms is easily obtained.

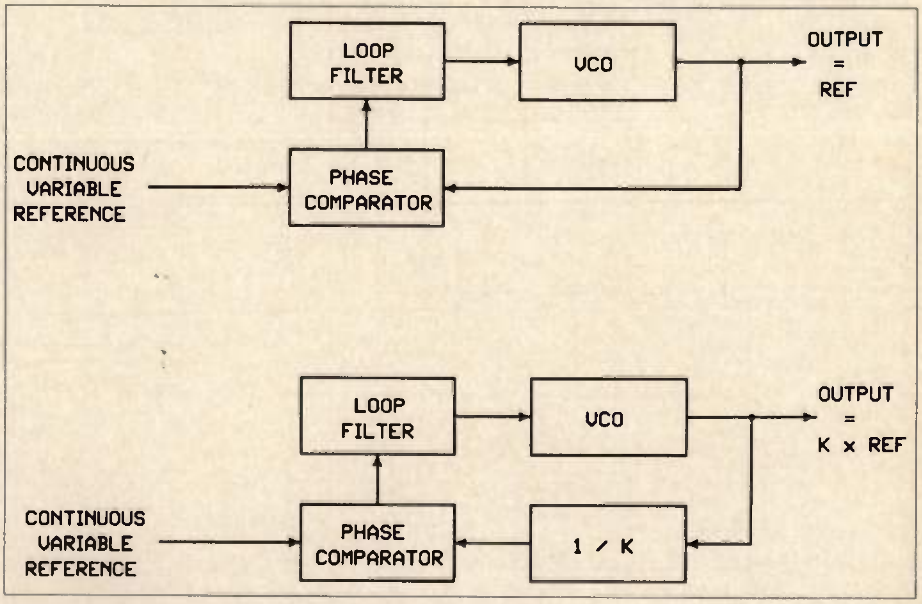


**Figure 2. PLL system with an ordinary VCO.**

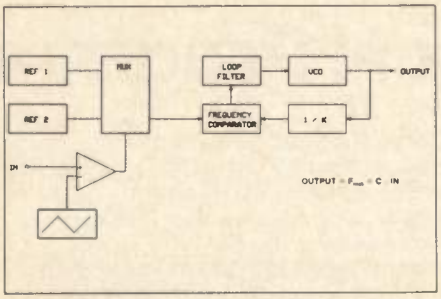


**Figure 3. Complete block diagram of a linear driftless VCO.**

### Frequency Drift

The maximum theoretical frequency drift of the system is the worst case of all drifts added in the same direction. These include the references' drift, plus the comparator DC offset, plus the amplitude change of the triangular signal. Drift on the triangle wave generator's DC point doesn't affect the performance because its output is AC coupled.

For the example explained above, the drift (for a temperature variation from 10C to 30C) would be around:

Out of the loop drifts:

- XTAL references ± 5 Hz is easily obtained
- Comparator input offset of <100 $\mu$V is found in conventional comparators
- Frequency detector out drift (less than the drift on $V_{DD}$) <50 mV
- Triangular wave amplitude variation <100 $\mu$V — for well regulated supply (5 percent voltage drift)

Inside the loop drifts:

- Integrator input offset of <50 $\mu$V is found in conventional op amps VCO drift of 1 MHz is the data sheet specification of the used model.
- The effect of components causing drifts inside the loop is divided by loop gain at DC. By the use of an integrator after the frequency detector, the effect of integrator offset of VCO offset is reduced to zero (or almost). (Loop gain at DC = infinite.)

So the drift observed on the VCO of the above example will be:

- Caused by the XTAL drift, 10 Hz × 256 = 2.560 kHz
- Caused by comparator uncertainty or drift 100 $\mu$V; the input tuning is –5, +5 V to approx. 100 MHz, sensitivity = 10 MHz/volt so $10 \times 10^6 \times 100 \times 10^{-6} = 1$ kHz.
- Caused by $V_{DD}$ drift = 50 mV on the frequency comparator with pulses with less than 30 percent duty, and only $V_{DD}$ pulses are affected. The number of $V_{SS}$ pulses is equal to the number of $V_{DD}$ pulses. But also $V_{DD}/2$, reference for the integrator will drift along. So 30 percent × 1/2 – 1/2 × 30 percent = 0 percent, then theoretically no drift with this cause will be observed.
- Asymmetry on width of $V_{DD}$ pulses in relation with $V_{SS}$ pulses will cause drift of the VCO. Precise resistors and capacitors will reduce this already small drift.
- Amplitude variation on triangular wave <100 $\mu$V at –5 to 5 V for 100 MHz, 10 MHz/volt, $10 \times 10^6 \times 100 \times 10^{-6} = 1$ kHz.

### Measured performance

On an implementation with the above referenced specifications the following characteristics were measured:

- Frequency drift (from 10C to 30C) = 5.2 kHz.
- Tuning speed = 5.5 ms/MHz.
- Noise sidebands at 10 kHz = –70 dBc.

The author welcomes any comments on this design, would appreciate hearing of the results of any tests with this concept. *RF*

**About the Author**

Luis Cupido is the Development Manager and Engineering Director at C&TC, Electronic Engineering SA. He received his degree in Electronics and Telecommunications from the University of Aveiro, Portugal in 1988. He may be reached at C&TC, Av. Dr. Lourenco Peixnho, Edificio Delta, 18 -2D, 3800 Aveiro, Portugal.

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# The RF Expo West Technical Program

*The papers to be presented in Santa Clara represent a broad cross-section of RF engineering subjects, from tutorials on basic components to descriptions of major RF systems.*

## Tuesday, February 5 — 8:30 to 11:30 a.m.

### SESSION A-1: RF DIODES

**The PIN Diode - A Tutorial**
***Raymond W. Waugh and Jack H. Lepoff, Hewlett-Packard Company***
Under ideal conditions, the PIN diode acts as a current controlled variable RF resistor. However, there exist certain limitations related to frequency and power. This paper covers the low and high frequency limitations of PIN diodes, power limitations, attenuator performance, and control parameters.

**The Schottky Diode Mixer - A Tutorial**
***Jack H. Lepoff, Hewlett-Packard Company***
A major application of the Schottky diode is in frequency mixers. This tutorial paper covers basic mixer performance parameters, and describes how the characteristics of Schottky diodes affect mixer performance.

**PIN Diode Theory and its Design Tradeoffs**
***Peter Sahjani, M-pulse Microwave***
A wide variety of PIN diodes are available, from a number of manufacturers. This paper discusses the four most important tradeoffs that must be considered when evaluating PIN diode specifications for a particular application.

### SESSION A-2: POWER AMPLIFIER PERFORMANCE

**High Power RF Calibration**
***Daniel Hoshiko, Bird Electronic Corp.***
Accurate high power calibration is difficult to accomplish, requiring careful attention to the entire system. Comparisons between the use of attenuators and microwatt meters and high power RF calorimeters are discussed, with a focus on the intricacies of high power RF calorimetry.

**Synthesis of Test Signals for Linearity Measurement of High Power Amplifiers**
***Gilles Brassard, SPAR Aerospace Limited***
This paper describes a flexible approach to the synthesis of complex test signals for the measurement of linearity of power amplifiers. Two-tone test theory is presented, and a practical approach for the synthesis of such signals is proposed, based on a computerized synthesis of signals reproduced with an arbitrary waveform generator.

**Very Low Phase Noise in a Pulsed 10 kW L-Band Triode Power Amplifier**
***Richard Ferranti, MIT Lincoln Laboratory***
In doppler radar, phase noise can mask weak target returns appearing near a large signal, such as ground clutter. This paper includes a description of phase noise and spurious tests performed on a triode power amplifier designed for the L-band Clutter Experiment.

### SESSION A-3: FREQUENCY SYNTHESIS

**Synthesizer Switching Time and Physical Mechanics**
***Earl McCune, Jr., Digital RF Solutions***
Modern communications requirements have grown to where synthesizer switching time is often the limiting factor of performance in the system. This paper reviews the basic physics of motion, as they are related to the motion of frequency: switching time.

**Interference Problems in UHF Frequency Synthesizer**
***Mikko Pesola, Nokia Mobile Phones***
A clean signal with low sidebands and low residual modulation are important goals in synthesizer design. These can be affected by interference. This paper discusses interference mechanisms and coupling paths, with special attention paid to sidebands in a synthesizer which uses a separate prescaler.

**Direct-Digital Waveform Generation Using Advanced Multi-Mode Digital Modulation**
***Bar-Giora Goldberg, Sciteq Electronics***
This paper defines methods by which a direct-digital synthesizer (DDS) can provide precise all-digital manipulation of every characteristic and modality of the output signal. An architecture is presented that integrates these capabilities.

### SESSION A-4: ANALYTICAL TECHNIQUES

**Symbolic Circuit Analysis**
***Jerry Bares, Bares Inc.***
A symbolic circuit analysis program, SCAN, for linear circuits in the DC to GHz range is described. SCAN can calculate all common circuit functions, two-port parameters and equivalent noise sources for circuits described by SPICE-like files.

**Modeling and Simulation of Multicoupled Microstrip Lines in High Speed Integrated Circuits**
***Wei-Xu Huang and Qui Zhang, Compact Software***
The continued introduction of high speed, high density solid state devices and the rapid growth in RF design technique have together created a need for accurate interconnection simulation. This paper reports on a CAD tool to simulate the nonlinear lossy multi-coupled microstrip lines, using a field based, computation-efficient model.

## Tuesday, February 5 — 1:30 to 4:30 p.m.

### SESSION B-1: RF SYSTEM PERFORMANCE

**The Testing of a Communications Satellite Repeater**
***Neal C. Silence, Microwave Engineering Consultant***
The testing of a typical communications satellite repeater is described. The system description, typical performance standards, test sequence, measurement setup and test software configuration are presented. Current trends, particularly cost reduction are also covered.

**Interoperability Testing of FED-STD-1045 HF Radios**
***Paul C. Smith, David R. Wortendyke, Christopher Redding, U.S. Department of Commerce, NTIA***
The testing program described in this paper was established to evaluate system performance and assess the degree of interoperability among adaptive HF radio systems used by Federal agencies.

**Generalized Modulation Mathematics Applied to RF/Microwave System Simulation**
***John Baprawski, EEsof, Inc.***
To simulate a system with a complex modulated carrier, the frequency-domain and time-domain characteristics should be observable at various points of interest within the system, as well as at the output. Describing signals in the I-Q domain offers a mathematical convenience for analytically simulating a modulated carrier.

### SESSION B-2: RF APPLICATIONS

**Embedded Microcontroller Techniques Applied to an RF Subsystem**
***Edwin Tucker, FEI Microwave***

An embedded microcontroller system for use in a UHF to Ku-band upconverter is described. Highlighted is the use of Field Programmable Gate Arrays (FPGA) to provide flexibility in input/output and miscellaneous logic functions. Control functions, interface methods, and reconfigurability are discussed.

**2.45 GHz Microwave Dissolution System**
***Ian Dilworth, University of Essex***
This paper describes, in tutorial fashion, the development of a 2.45 GHz microwave heater which is to be used in a hostile environment.

**JPL's NUSCAT Scatterometer: A Tool to Measure Winds at Sea**
***Jon T. Adams, Jet Propulsion Laboratory***
NUSCAT is an airborne 14 GHz research radar which seeks to more accurately define the relationship between ocean surface reflectivity and surface wind speed. This paper describes the development of the system.

## SESSION B-3: POWER AMPLIFIER DESIGN

**Solid State Power Amplifier Technology for V-Band (60 GHz)**
***Joseph A. Mancini, Rome Air Development Center***
Three-terminal (transistor) solid state technology is reaching a level of development where alternatives to traveling wave tubes and IMPATT diode based amplifiers exist for power amplification at V-band. Current development at RADC in the planning and sponsoring of a 5 watt, 60 GHz solid state amplifier for MILSATCOM space crosslinks is described.

**A Rapid Deployment Prototype Solid State Kilowatt Linear Amplifier for 2 to 50 MHz Using MRF-154s**
***Joel Paladino, JPal Consulting***
Design and construction considerations are presented for a 1000-watt output power amplifier using two Motorola MRF-154 600-watt power transistors. Problem areas arising from high power in a small space are the primary focus of this practical presentation.

**Class-E Power Amplifier Output Power, Collector Efficiency, and Output Impedance vs. Parasitic Resistances, Transistor Switching Times, and Network Loaded Q**
***Nathan Sokal, Laszlo Drimusz, Istvan Novak, Design Automation, Inc.***
Design equations are presented to calculate the output power, efficiency and output impedance of nominally tuned Class-E amplifiers, including the effects of parasitic-loss resistances, transistor switching times, and network loaded Q.

## SESSION B-4: MICROWAVE APPLICATIONS

**X-Band 16-Way Radial Power Divider/Combiner for High Power SSPA Application**
***V. Subrahmanya, V.K. Lakshmeesha, V. Sambasiva Rao, S. Pal, ISRO Satellite Centre***
Developmental efforts to replace TWTAs with solid state power amplifiers require high power combiners. This paper describes design, construction and performance of an 8.3 GHz 16-way divider/combiner using a radial structure.

**Design of Microwave Switching Systems for Automated Test**
***Bob Rennard, Hewlett-Packard Company***
Efficient testing of RF and microwave systems usually means automation, and the routing of signals to and from test equipment and devices under test. The test set design process is discussed, including matrix architectures, components, and critical performance parameters.

**Effects of the Magnetic Polarization on Microwave Components in Microstrip Configuration on Ferrite Substrate**
***George Sajin, Research Institute for Electronic Components***
This paper describes some effects caused by the magnetic polarization of the ferrite substrate on microwave components in microstrip, including antennas, directional couplers and filters.

# Wednesday, February 6 — 8:30 to 11:30 a.m.

## SESSION C-1: GaAs MMIC RF APPLICATIONS

The session covers the use of GaAs MMICs in RF systems operating below 3 GHz. Several short papers address the following topics:

**GaAs MMICs for Commercial and Consumer Electronics**
***Pang Ho, Pacific Monolithics***

**High Frequency GaAs MMIC Power Amplifier for Cellular Telephone Applications**
***Tom Holden, Pacific Monolithics***

**Low Frequency GaAs MMIC Multiplier**
***Rob Benton, Pacific Monolithics***

**GaAs MMIC Insertion in Subsystems Below 3 GHz**
***Greg Horvath, Fazal Ali and Rob Benton, Pacific Monolithics***

**RF Circuit Applications of GaAs Heterojunction Bipolar Power Transistor (HBT)**
***Mike Kim, TRW, and Fazal Ali, Pacific Monolithics***

## SESSION C-2: ENGINEERING PRODUCTIVITY

**Electronics Alternatives to Photocopied Notebooks**
***Lon V. Cecil, RF Monolithics***
An overview is presented of current programs and techniques for documenting the ideas, tests, configurations, and results of engineering projects. Low cost methods of automating data acquisition and recording are also presented, as well as integration of data into word processing and publishing programs.

**Improving Productivity with Design Tools**
***Bob Rennard, Hewlett-Packard Company***

Technologies are maturing, nearly everyone can work in silicon, and more firms can make effective use of GaAs. Foundries bring these capabilities to everyone. With competitive forces increasing due to decreased military spending and growing consumer demands, maximum efficiency in product development and manufacturing is more important that ever.

**The Use of Silicone Electrically Conductive Film Adhesives**
***Harold Sexson, Silicone Rubber Specialties Div., Arlon, Inc.***
This paper covers mechanical, electrical and thermal properties of silicone-based conductive adhesives, as well as practical considerations for their application.

## SESSION C-3: TEST SYSTEMS

**Using VXIBus Based Products for RF Test Systems**
***Malcolm Levy, Racal-Dana Instruments***
New ATE standards such as the VXIbus are ideal for RF test systems, as they allow measurement devices, switches, and interfaces to be contained in one compact unit.

**Radiated Emissions Test Performance of the GHz TEM Cell**
***John D.M. Osburn, The Electro-Mechanics Company (EMCO)***
The GHZ TEM Cell offers potential for lower-cost testing of both radiated emissions and EMI susceptibility. This paper presents a quantified comparison with Open Area Test Site (OATS) measurements.

**Measuring Power With a Vector Network Analyzer**
***Joel Dunsmore, Hewlett-Packard Company***
In characterizing many RF components, accurate measurements of output power, as well as match and gain, are required. Vector network analyzers provide high-speed gain and match information, and with the technique described in this paper, the power accuracy of a precision power meter can be transferred to the VNA receiver.

## SESSION C-4: RECEIVER DESIGN

**Receiver Techniques for Spread Spectrum Systems**
***F.J. Pergal, Communications Systems Engineering***
Commercial use of spread spectrum opens up many new product possibilities. The paper covers system considerations for the design of spread spectrum systems.

**LNA Design Techniques for GPS Applications**
***Al Ward, Avantek***
This paper discusses the various technologies available for use in GPS receiver low noise amplifier applications. Both MMIC and discrete transistor approaches are considered. General design techniques, simulations and test results for silicon and GaAs FET amplifiers, and an examination of design tradeoffs are included.

**Advances in Logarithmic Amplifiers**
***Peter E. Chadwick, Plessey Semiconductors Ltd.***
A review of applications for logarithmic amplifiers is presented, along with data on current developments in logarithmic amplifier products.

# Wednesday, February 6 — 1:30 to 4:30 p.m.

## SESSION D-1: TRANSMISSION COMPONENTS

**Flexible Construction Delay Lines**
***Mark Brooks, Thin Film Technology Corp.***
This paper describes the design and fabrication of delay lines on a flexible dielectric substrate of FEP (Fluorinated Ethylene Propylene), with the intent of creating a fast rise-time with up to 10 ns delay.

**Flexible Construction Delay Lines: Performance and Reliability**
***Mark Brooks, Thin Film Technology Corp.***
Delay line components are needed for critical timing adjustment in many digital and analog applications. Fast rise time, low EMI/RFI, and temperature-stable performance are needed. This paper reports on a patent-pending design using flexible-construction, focusing on electrical performance and reliability.

**A Modular Design Approach for Hybrid Digital Programmable Attenuators**
***Joseph Mazzochette, EMC Technology, Inc.***
This paper will describe the design and implementation of modular digital programmable attenuator (DPA), with data demonstrating its performance. Tutorial information on the installation and operation of the DPA and several signal processing applications are also included.

## SESSION D-2: POWER TRANSISTORS

**Determination of M.T.F. for Microwave Transistors**
***J.M. Lemenager & M. Etienne, Philips Components***
The results of a long-term study on the failure mechanisms in RF power transistors are presented, covering the various types of failure modes, and their causes.

**RF Power Device Impedances: Practical Considerations**
***Alan Wood, Bob Davidson, Motorola, Inc.***
The definition of large signal series equivalent input and output impedances for RF power transistors is explained, along with techniques for measuring these parameters. How these parameters change under varying load and bias conditions is examined, and the impact of these variations is demonstrated in a broadband test fixture.

**Design and Performance of a Broad-band, High-voltage, UHF Power Static Induction Transistor Amplifier**
***M. Abdollahian, R. Regan, R. Gage, E. Bulat, GTE Laboratories***
This paper describes the design and performance of a 100-watt static induction transistor amplifier that operates over the 470-860 MHz band (TV bands IV and V) with 6 dB gain and nearly 50 percent drain efficiency.

## SESSION D-3: OSCILLATORS

**A Quantitative Comparison of VHF/UHF Signal Sources Using Overtone**



INFO/CARD 51

### AT and SC Cut Quartz Crystal Oscillators

*Ian Dilworth, University of Essex*

There are many applications requiring stable signal sources in the 100 MHz - 1.5 GHz region. The aim of this paper is to critically compare and contrast oscillators and their multiplier chains using AT-cut overtone crystals, and recently available SC-cut crystals.

### Simulation and Modeling Techniques Applied to an Optimum 18.5 GHz DRO Design

*Murat Eron and Jason Gerber, Compact Software, Inc.*

A design procedure is described for a Ku-band DRO, starting with a commercial packaged device, parameter extraction, modeling and optimization of the circuit design. Results are compared with the operation of the oscillator as it is built.

### Specifying Local Oscillator Phase Noise Performance -How Good is Good Enough?

*Rob Gilmore and Richard Kornfeld, QUALCOMM*

Definitive criteria are presented for specifying local oscillator phase noise performance for use in communications systems. In the absence of such criteria, many oscillators tend to be under- or over-specified. Emphasis is on digital modulation, but analog systems are also considered.

## SESSION D-4: DIGITAL MODULATION

### Performance of a π/4-DQPSK Signal in a Direct Conversion Receiver

*K. Anvari, M. Kaube, D. Woo, NovAtel Communications Ltd.*

This paper describes a time and frequency domain simulation package which augments analytical modeling and hardware simulation activities, providing a flexible and useful tool for isolating sources of channel impairments, evaluating tradeoffs, and making overall performance predictions.

### MSK Generation by Using ILO Techniques and its Limitations

*S. Myrillas, Northern Telecom*

Direct baseband to microwave Minimum Shift Keying (MSK) generation offers considerable simplicity. The feasibility of such a system has been investigated through development of a 4 Mbits/sec experimental system where injection locking techniques were applied to the VCO to improve frequency stability.

### QPSK Modulator in Thick Film at X-Band

*V. Sambasiva Rao, D.V. Ramana, A. Bhaskaranarayana, S. Pal, ISRO Satellite Centre*

A QPSK modulator transmitting two 50 MBPS data streams on an X-band carrier is reported. Used for a remote sensing satellite, the modulator is implemented with two biphase modulators on an alumina substrate with a microstripline configuration.

## Amateur Radio Reception Planned for Santa Clara

Wednesday evening, from 6:00 to 7:30 p.m., a social reception for amateur radio operators will be held. The first ham radio gathering last year in Anaheim, and another this past November at RF Expo East in Orlando proved extremely successful and much fun.

If you are a ham radio operator, or if you just like the kind of comaraderie that takes place among hams, plan to attend. Bring a QSL card to post on the bulletin board.

Food and drink, plus some very nice door prizes are provided by the event sponsors, which include over a dozen RF Expo West exhibiting companies.

# Thursday, February 7 — 8:30 to 11:30 a.m.

## SESSION E-1: COMPONENT APPLICATIONS

### A Low Distortion PIN Diode Switch Using Surface Mount Devices

*Raymond W. Waugh, Hewlett-Packard*

One of the practical applications of surface-mounted PIN diodes is in low cost RF switches. A low distortion SPDT switch is described, using a new type of PIN diode designed specifically for low distortion applications.

### Computer Aided Design of Step Recovery Diode Comb Generators

*Martin P. Wilson, Ferranti International*

This paper describes the performance of Step Recovery Diodes used as frequency comb generators. A model is produced and a computer simulation derives the circuit behavior. The resulting phase noise performance is analyzed and it is shown how the performance of such comb generators can be chaotic.

### Breadboarding Circuits for Manufacturability in the 600 MHz to 2 GHz Range

*John Horvath, Minaret Radio*

Practical circuits are presented which accomplish low cost UHF receivers, oscillators, and other circuits using low cost integrated circuits and MMICs.

## SESSION E-2: MOBILE RADIO SYSTEMS

### Surface Acoustic Wave Filters With Low Insertion Loss for Use in Mobile Communication

*Christian Kappacher, Halvor Skeie, Don Allen, Crystal Technology*

This paper covers recent developments in low loss SAW filters, with an example of a 74 MHz filter with 350 kHz bandwidth and 7 dB insertion loss.

### Digital Cellular Modulation and its Measurement

*Dave Whipple, Hewlett-Packard*

There are a number of driving forces in Europe and North America that are causing a shift to digital modulation for cellular radio telephone systems. This paper discusses the pertinent forms of digital modulation and the methods required for modulation, demodulation, and measurement of deviations from ideal modulation in operational systems.

### Low Loss Highly Selective Active RF Tracking Filters for Mobile Communications Systems

*Masood Ghadaksaz, GTE laboratories*

This paper describes an approach in which the dissipation losses of the varactor diode and other components can be compensated for using an active element. Several experimental active varactor tuned filters for mobile communications bands are presented.

## SESSION E-3: FILTER DESIGN

### Capabilities and Applications of SAW Coupled-Resonator Filters

*Allan Coon, RF Monolithics, Inc.*

Two issues currently inhibit the effective use of this technology: 1) Lack of awareness by the design community of current capabilities, and 2) Systems originally designed for conventional filtering technologies may not achieve optimum cost and performance because SAW CR filters were not considered in the initial system design.

### Linear Phase High Pass Digital Filter Using the Matched Delay Subtractive Approach

*Somnath Mukherjee, Applied Microwave Corp.*

This paper shows that a matched delay subtractive (MDS) approach can be adapted elegantly to digital filters as well as analog filters, and discusses design considerations for linear phase filters.

### A Different Technique for Tuning Microwave Filters

*Robert M. Livingston, Rockwell International*

A simple technique is described for tuning bandpass filters with narrow pass bands, ten percent or less. The technique involves precisely setting the frequencies of very narrow notches in the filter return loss characteristic while it is being tuned. **RF**

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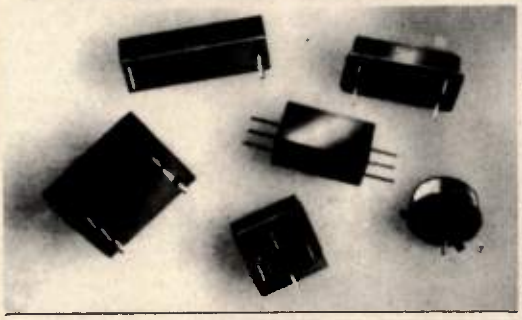

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# A Plotter Subroutine for BASIC Programs

*By Bert K. Erickson*
*General Electric*

*When a computer program has a parameter that must be modified several times to search for an acceptable result, the print statements will provide long lists of comparative data. However, in the process of searching for the final result, the user must look at line after line of large numbers which is not always appreciated. For these intermediate runs, a graphical display would be convenient even though it has limited accuracy.*

The program described here was used to observe Fast Fourier Transform spectral data which can vary considerably as the input parameters are modified. However, the same program can be used to display continuous functions. The program is quite short and can be added to any main program as a subroutine. The only requirements are that the main program and the subroutine use the same array and input statement to designate the number of data points. If the amplitude can be arranged to have a value between ± 999 then the vertical axis will be scaled between the minimum and maximum values and the horizontal axis will designate subscript numbers for the columns.

The subroutine has default values for a small screen that has an 80 by 25 text format. After numbers are printed on the scales, 75 columns are left for data points and the amplitude is divided into 22 rows. Although it would be impressive to use a graphics card and draw lines between coordinate points, the problem of printing numbers for the scale can become complicated. In this subroutine a character in an 8 by 8 matrix was used to represent a point to keep the program very simple. The program listed has a check solution for the raised cosine waveform shown in Figure 1. Use N=74 to display 75 points and use Shift PrtSc for a printed copy. Press Return if you wish to exit the program. To expand the section near the origin, change the D$ print default from "****" to "*.**" and use N=5 to get the plot shown in Figure 2. To use the program as a subroutine, delete the first line. If you have a monitor with a large screen, change the column and row defaults to display more data points.

*This program is available on disk from the RF Design Software Service. See page 8 for ordering information.* **RF**

**About the Author**

Bert Erickson is a senior engineer with the Government Electronic Systems Department of General Electric. He received his BSEE from the University of Wisconsin and his MSEE from Union College. He can be reached at the General Electric Co., CSP 5-H4, Syracuse, NY 13221. Tel: (315) 456-7741.

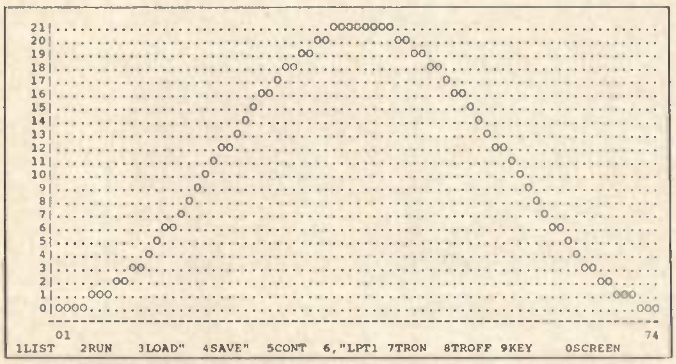


**Figure 1. Plotted points for a raised cosine waveform.**

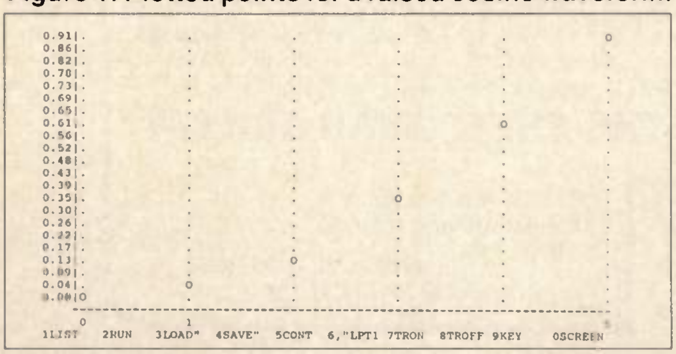


**Figure 2. Expansion of section near the origin.**

```
10 DIM A(80):GOSUB 400:GOSUB 30:END
20 'PGM PLOTS SEQUENTIAL DATA
30 D$="####":MX=-1000000!:MN=1000000!:CLS
40 PRINT"SCREEN COLUMN DEFAULT  M = 80":M=80
50 PRINT"SCREEN ROW DEFAULT     R = 22":R=22
60 PRINT"PRINT USING DEFAULT   D$ = ";D$
70 INPUT"NUMBER OF DATA POINTS, N = ",N
80 K=INT((M-6)/N-1):T$=SPACE$(K)
90 FOR J=0 TO N
100 IF A(J)=>MX THEN MX=A(J)
110 IF A(J)=<MN THEN MN=A(J)
120 NEXT J
130 L=(MX-MN)/(R-1):Q=MX:CLS
140 FOR I=0 TO R-1
150 Q=MX-L*I:PRINT USING D$;Q;:PRINT"|";
160 FOR J=0 TO N
170 IF ((K+1)*J+5)>M THEN 250
180 IF A(J)=>(Q-L/2) AND A(J)=<(Q+L/2) THEN 220
190 IF J=0 THEN PRINT".";
200 IF J>0 THEN PRINT T$;".";
210 GOTO 240
220 IF J=0 THEN PRINT"O";
230 IF J>0 THEN PRINT T$;"O";
240 NEXT J
250 PRINT:NEXT I
260 PRINT"     ";:FOR J=0 TO (K+1)*N+1:PRINT"-";
270 NEXT J
280 PRINT:P=(K+1)*N+5:IF P>M-2 THEN P=M-2
290 M$=STR$(N):IF K>0 THEN 310
300 PRINT"     01";TAB(P);M$;:GOTO 340
310 Q$=SPACE$(K-1):IF N=1 THEN 330
320 PRINT"     0";Q$;1;TAB(P);M$;:GOTO 340
330 PRINT"     0";TAB(P+1);M$;
340 INPUT"",Z$:RETURN
400 CLS:PRINT"WAIT":X=2*3.14159/75
410 FOR J=0 TO 75:A(J)=10.5*(1-COS(J*X))
420 NEXT J:RETURN
```

**Figure 3. Subroutine program.**

# EMC Test Laboratories: Gearing Up for a Busy Future

By Charles Howshar and Liane Pomfret, Assistant Editors

As electronic designs shrink and the number of products requiring compliance certification increases, better solutions to electromagnetic interference are needed. As a result, the use of EMC test laboratories is growing. Adding to the complexity created by these new designs is the impending release of the European Community 1992 standards (EC92).

"Five years ago, hardly any companies knew much about EMC. Since then, we have seen more and more designing for EMC being incorporated in the initial stages of a design," comments Finbarr O'Connor, EMC Manager for R & B Enterprises. "This makes our job of testing much easier," he adds. Even so, the number of designs requiring higher frequencies and lower power is growing, and these designs have a greater susceptibility to EMI. As a result, the problems that manufacturers have to solve are becoming more complex and the need for EMC test labs is even greater. "There has been an increase in the number of commercial products being tested," O'Connor states.

*Many EMC labs have recently expanded their facilities, such as this at ACME Testing.*

## EC92 Specifications

"People are starting to look at susceptibility more since EC92 is coming," observes Tom Cokenias, Vice President of Engineering for Electro-Service Corporation. The European Community 1992 standards effort has brought quite a bit of attention to the EMC testing market. Most people feel that EC92 will bring more business to EMC test labs, but there still may be difficulties. A major concern is that American EMC test labs do not have a governing body set up to get EC92 approval for their testing methods. "EC92 can be a total disaster for independent labs because there is no way for U.S. labs to become notified labs (term for accredited labs in Europe)," states Walter Poggi, President of Retlif, Inc. There have not been many specifications released about EC92, and those that have been printed are vague or difficult to obtain. This may cause difficulties for companies who want to test for the European market. "There are rumors that Europe won't take our test results because we aren't accredited with their system," comments Cedric Brownfield, EMC Specialist for Norand EMC Test Lab. American and European specifications are not written using the same references. Consequently, differences will cause headaches for American test labs trying to do EMC testing for the European market. A logical solution for this problem would be the development of a national EMC test lab accreditation agency specifically for EC92 procedures. The National Voluntary Laboratory Accreditation Program (NVLAP) has many international standards, and is the body most qualified to set up the accreditation. As Mike Howard, President of Liberty Labs, notes, "A lot of mechanisms in NVLAP have been in place for 3 to 4 years and companies are going to NVLAP for accreditation."

The trend towards lab accreditation in the United States is increasing. Although accreditation is not required at present, it will be a critical factor in the future. Many test labs feel that accreditation gives the manufacturers confidence in the lab. "Five to eight years from now accreditation will be a requirement; it is very important," comments Norand's Brownfield. Steve Dininsky, Project Engineer for Detroit Testing Labs, adds, "NVLAP certification is becoming a de facto standard. There are more companies coming under the requirements for EMC testing." Dennis Hennigan, EMI Tempest Engineering Specialist for Chomerics agrees but feels that things are moving slowly, "The Navy is pushing for accreditation of labs, but only about a dozen are certified at present."

While test labs are falling in line under EMC test standards, the FCC and other governing bodies are rewriting specifications for many tests in order to keep up with the advances in EMC technology and test equipment, and results are becoming apparent. "Since the FCC rewrite of Part 15 we have seen quite a few products with spread spectrum applications," comments Electro-Service's Cokenias.

With the changes occurring in the EMC testing arena, EMC test labs are gearing up for a busy future, and the prospect of Europe's 1992 standards is causing many companies to rethink their market plans. With the increased usage of electronic equipment in our society, the required compatibility testing has become a growth industry. Further, the trend toward condensing electronics does not offer the luxury of space for insulating EMI susceptible electronics from those circuits that emit electromagnetic radiation. So design and testing for EMC at the earliest stages of development are critical to proper operation of electronic devices. RF

## Components and Instruments

Loral Microwave-Narda has released catalog #26, which details their full line of products including 25 new items. Products described include amplifiers, power dividers and hybrids, adapters, attenuators, power meters, and other components and instruments for the radio frequency industry.
**Loral Microwave-Narda**
**INFO/CARD #230**

## Software Catalog

Eagleware has released a catalog detailing their line of RF applicable products. The most recent addition to the product line is Super-Star Professional Extension, a circuit simulation, tuning, and optimizing tool that includes Monte Carlo analysis, user models, and microwave line models.
**Eagleware**
**INFO/CARD #229**

## Coil Design Manual

Goguen Industries has introduced their coil designer's manual which includes drawings, calculations, and ordering forms for customer-specified coils, chokes, toroids that Goguen Industries manufactures.
**Goguen Industries, Inc.**
**INFO/CARD #228**

## Measuring Equipment

Rohde & Schwarz has released a catalog detailing their lines of test and measurement equipment. Measuring Equipment 90/91 includes descriptions of signal generators, analyzers, EMI testers, network analyzers, power meters, and many other products.
**Rohde & Schwarz**
**INFO/CARD #227**

## Attenuator Calibration Application Note

"Fast, Accurate Calibration of General Purpose Microwave Attenuators" has been produced by Wavetek Microwave. The note explains how to achieve calibration lab accuracy with the 8003-ACS series Attenuator Calibration Systems. Good measurement practices and various nomographs are also included to help determine the worst case measurement uncertainty.
**Wavetek Microwave, Inc.**
**INFO/CARD #226**

## Inductors Catalog

A catalog containing inductors with values ranging from 0.01 μH through 500,000 μH has been released by J. W. Miller Division of Bell Industries. The catalog covers an extensive range of high current filter chokes and coils, and epoxy conformal coated inductors.
**J. W. Miller Division of Bell Industries**
**INFO/CARD #225**

## Proceedings of Piezoelectric Devices Conference

Volume Two of the Proceedings of the EIA's 12th Piezoelectric Devices Conference is now available. It contains the 13 papers presented at the conference that were not included in Volume One. The two-volume proceedings may be ordered for $60.
**Electronic Industries Association**
**INFO/CARD #224**

## Filter Products

Lark Engineering has announced its filter products catalog which features RF and microwave filters covering the 1 MHz to 18 GHz frequency range. Charts and graphs are presented showing the frequency ranges for standard and special filters of each type. Design aids and graphs are also included.
**Lark Engineering Company**
**INFO/CARD #223**

## Ceramic Resonators

Murata Erie North America has released a catalog providing specifications on their line of ceramic resonators for frequency control applications. Ceramic resonators in the frequency range from 190 kHz to 32 MHz are detailed, including models for surface mount application.
**Murata Erie North America**
**INFO/CARD #222**

## LPTV Filters

A catalog describing RF filters for low power TV and FM stations has been released by Microwave Filter Company. Included are channel combiners, transmitter and sideband notch filters, and an overview of the industry. An over the air premium channel security system is also featured.
**Microwave Filter Company, Inc.**
**INFO/CARD #221**

## Flexible Cable Care Guide

W. L. Gore announce the availability of a guide to flexible cable and connector use and maintenance. The guide also contains a VSWR/return loss conversion table and frequency band. The card includes information on most common problems experienced in cable usage and their solutions.
**W. L. Gore & Associates, Inc.**
**INFO/CARD #220**

## Short Course Catalog

RF and microwave courses are available through in-house presentation from Besser Associates' short course catalog. Topics include linear and nonlinear CAE, component modeling, component, subsystem and system design, and measurement and time management.
**Besser Associates**
**INFO/CARD #219**



INFO/CARD 60

## Block Diagram Simulator

TESOFT has released TESS Version 1.1 block diagram simulator. It includes 24 newly added filters, high resolution plotter drivers for HP LaserJet, HP pen plotters and HI pen plotters. 64 kilobytes of memory space have been added. TESS is $695 and options include symbol libraries for OrCAD and PCAD schematic capture and MODGEN model generator which lets users add new model blocks.
**TESOFT**
**INFO/CARD #218**

## EMI/EMC Solutions Software

HP Express and RS Express have been announced by Liberty Express. The HP Express package is for automating EMC measurements utilizing the HP 8566/HP 8568 Series of spectrum analyzers, and RS Express is for EMI/EMC measurements utilizing either the Rohde & Schwarz ESH3 or ESVP receivers. Both programs provide for full automation of EMI measurements. Each package is being sold as a site license for $2,000, or they may be purchased jointly for $3,500.
**Liberty Express**
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## S- and Noise-Parameter Data Library

Avantek is offering a complete library of S- and noise-parameter data on diskettes formatted for IBM-compatible personal computers. The Avantek DesignPak™ files are supplied in ASCII format and can be used by many simulations programs including Touchstone®, Super Compact®, and SuperStar Professional Extension®. Included on the free diskette set is information about Avantek's silicon bipolar transistors. GaAs FETs, and GaAs MMICs.
**Avantek, Inc.**
**INFO/CARD #216**

## Mixed-Mode Circuit Modeling Software

OOTMs (Object-Oriented Transcendental Modeling) uses OrSPICE and OrCAD/SDT III to expand the modeling option available with PSpice. It can be used to mathematically define any block function and link the definition to a single icon. The minimum software package includes OrCAD/STD III, PSpice/Probe with Behavior Modeling Option, OrSpice with Basic and Intermediate OOTMS and is priced at $2,785.
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