RF design

engineering principles and practices

October 1990

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RF Transistors

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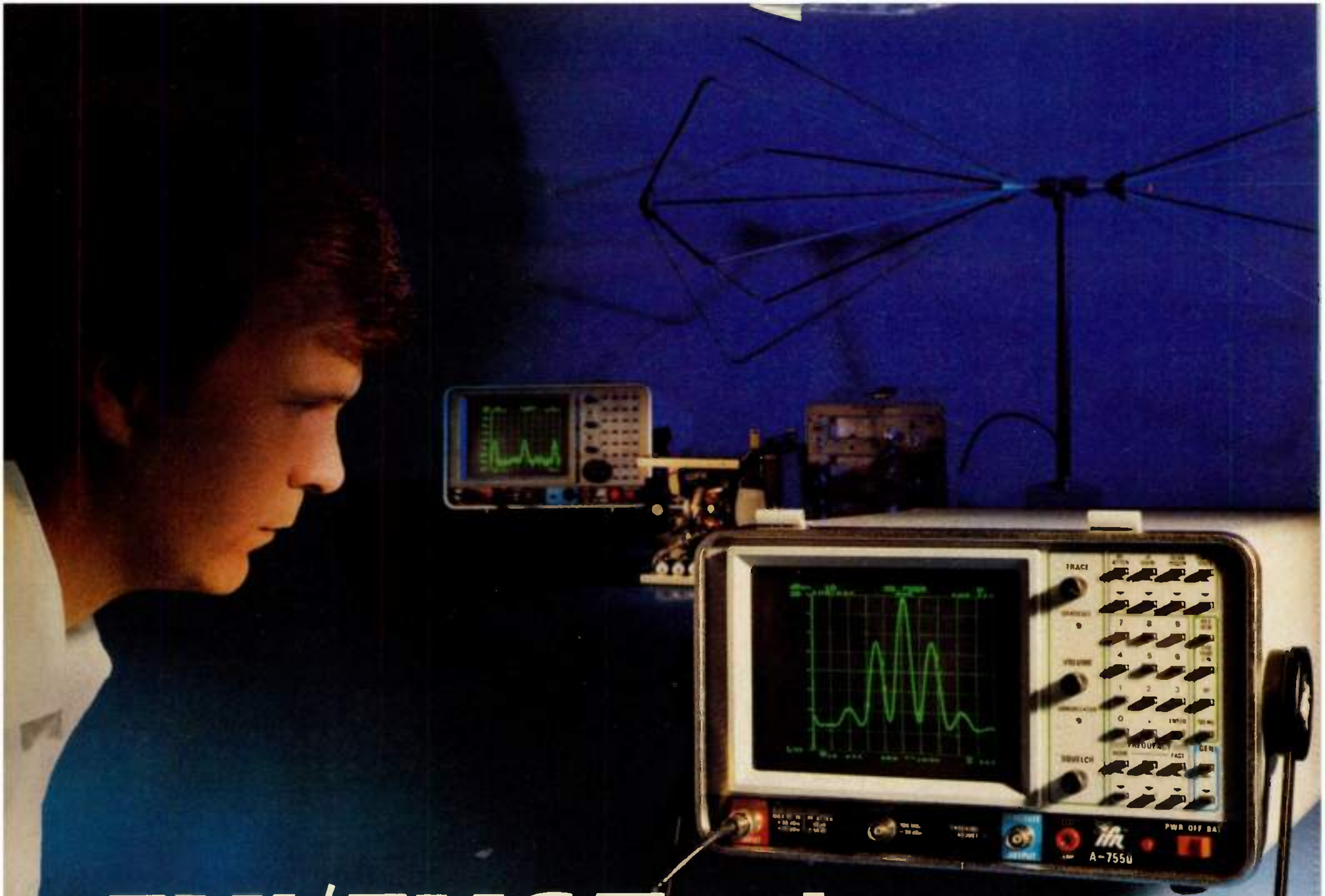

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Equally at home in the laboratory, on the manufacturing floor, or in the field, IFR's A-7550 and A-8000 Spectrum Analyzers with optional built-in Quasi-Peak Detectors provide complete EMI/EMC testing capability from 10 KHz to 1000 Mhz. In addition, the extended range of the A-8000 allows the study of interfering signals up to 2600 Mhz in frequency.

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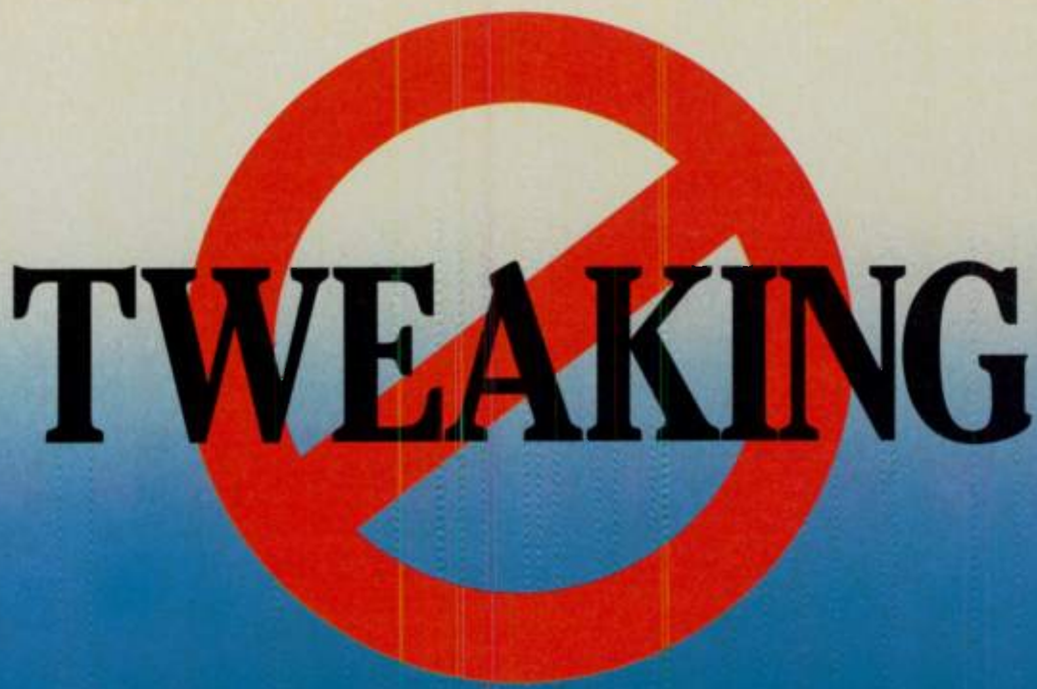
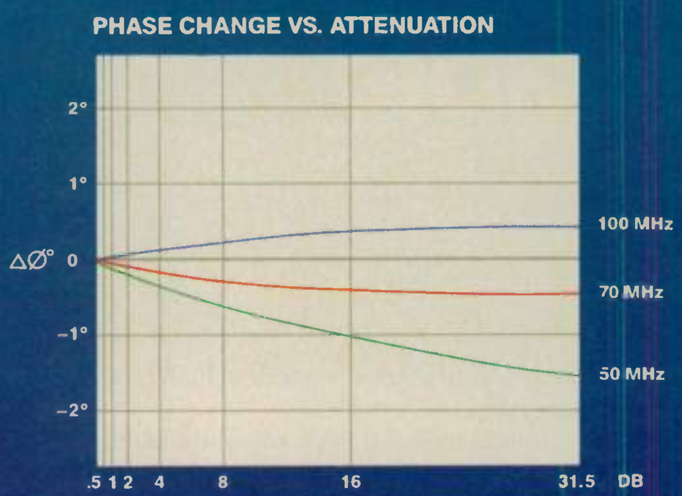
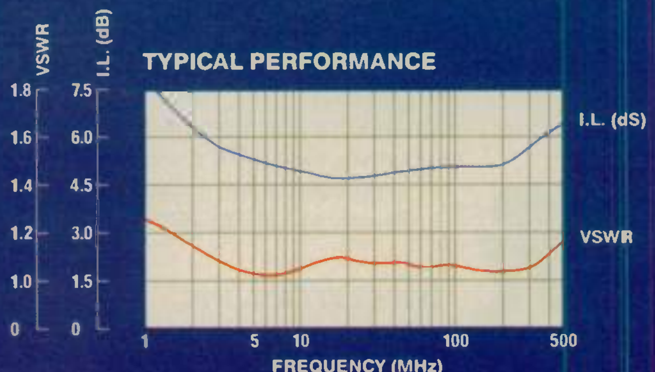


DAICO
Constant Insertion Phase Attenuators Eliminate Tweaking.





OPERATING CHARACTERISTICS

PARAMETER	MIN	TYP	MAX	UNITS	CONDITION
SWITCHING TRANSIENTS		54.0	100.0	mV	PEAK VALUE
TRANSITION TIME		5.0		nSEC	90%/10% or 10%/90% RF
SWITCHING SPEED		20.0	35.0	nSEC	50% TTL to 90%/10% RF
MONOTONICITY GUARANTEED					
INSERTION LOSS		4.9	6.0	DB	
$\triangle$ PHASE		0.4	±1.0	DEG	70 MHz
ATTENUATION RANGE	0		31.5	DB	
STEPS					0.5, 1, 2, 4, 8, 16dB
VSWR		1.08	1.35/1		

For systems that demand constant insertion phase, ordinary digital attenuators won't cut it—but the DAICO DA0616 will.

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RF design

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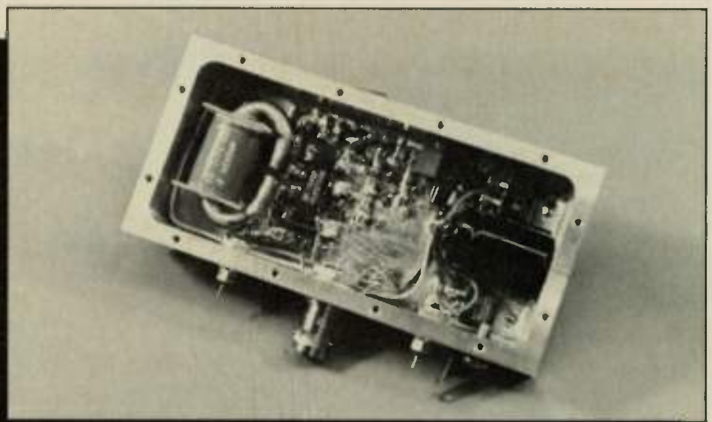
October 1990



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R F DESIGN (ISSN 0163-321X USPS 453-490) is published monthly plus one extra issue in September. October 1990. Vol. 13 No. 11 Copyright 1990 by Cardiff Publishing Company, a subsidiary of Argus Press Holdings, Inc., 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111 (303) 220-0600. Contents may not be reproduced in any form without written permission. Second-Class Postage paid at Englewood, CO and at additional mailing offices. Subscription office: 1 East First Street, Duluth, MN 55802. Domestic subscriptions are sent free to qualified individuals responsible for the design and development of communications equipment. Other subscriptions are: $36 per year in the United States, $45 per year in Canada and Mexico, $49 (surface mail) per year for foreign countries. Additional cost for first class mailing. Payment must be made in U.S. funds and accompany request. If available, single copies and back issues are $4.00 each (in the U.S.). This publication is available on microfilm/fiche from University Microfilms International, 300 Zeeb Road, Ann Arbor, MI 48106 USA (313) 761-4700.

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RF editorial

The World View

By Gary A. Breed
Editor

A recent quote from an industry leader goes something like this: "Either you're an international company, or you're not going to be in business very long." Perhaps it's overstated, but it fits my own observation that RF companies who are doing well are getting much of their business overseas — mainly in Europe and the Far East.

Those of you who have any doubt that world markets dominate trade should take note of the situation in the Middle East. Much of Iraq's motivation in the seizure of Kuwait was to help raise the price of oil, paid mostly by customers in the U.S., Japan and Europe. Iraq needs to pay off its war debts, accrued from purchases of military equipment from France and the USSR. Iraq also owes the U.S. a couple billion dollars for agricultural products. Empire-building is an expensive undertaking.

The crisis is complicated by the many foreign citizens who are being held hostage. This leverage would not be possible if the oil business was not a strongly multinational industry, with personnel from many different countries working in the Middle East. Presidents and Prime Ministers are discovering the difficulties that can arise when their countries' citizens travel and work in other parts of the world.

Now, look at the forces gathered in Saudi Arabia in response to the Iraqi actions. The forces are principally U.S. soldiers, airmen and sailors, but with help from Egypt, France, Great Britain, Italy, and other countries. Japan is sending money, and even poor Bangladesh has made a significant effort to support these forces. These efforts are not being made because Saddam Hussein has committed an act of war against Kuwait, but because that act will affect the huge financial interest many countries have in the world's oil resources.

What lessons can RF companies learn from this example? Mainly, we should understand that the concept of a "world economy" is correct. Selling products only within one country puts a ceiling on sales potential, and puts a company at the mercy of one set of political and economic policies. To be fair, this approach has the advantage of simplicity, and works well for a number of businesses. However, foreign companies may choose to compete in the same market, probably with different production costs, profit expectations and sales tactics.

One key to successful international sales is making use of your own particular advantages. For example, Japan and Taiwan have successfully utilized a strong traditional work ethic — they get a lot of output from their workers. Some European countries have gained an advantage from their heritage of skilled craftspeople. The poorest nations have unskilled but plentiful labor and can economically produce low-tech goods.

Here in the U.S. we have our own strong traditions — innovation and creativity — attributes that make the U.S. the world leader in many businesses. Innovation and creativity are also apt descriptions of RF technology; strengths that have been used to create efficient communications systems, high performance instruments, outstanding software design tools, advanced components and circuit developments. Successful RF companies are showing us that these products are marketable to customers all over the world.

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- Wide variety of packages

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- Minimum crest factor 5:1
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- High power—up to 13 dBm
- Minimum crest factor 5:1
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- Storage temperature -65 to +125° C
- Operating temperature -55 to +85° C
- Temperature coefficient 0.025 dB/° C

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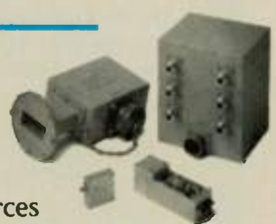

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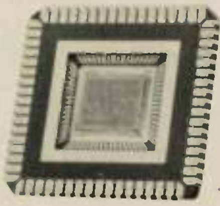

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INFO/CARD 7

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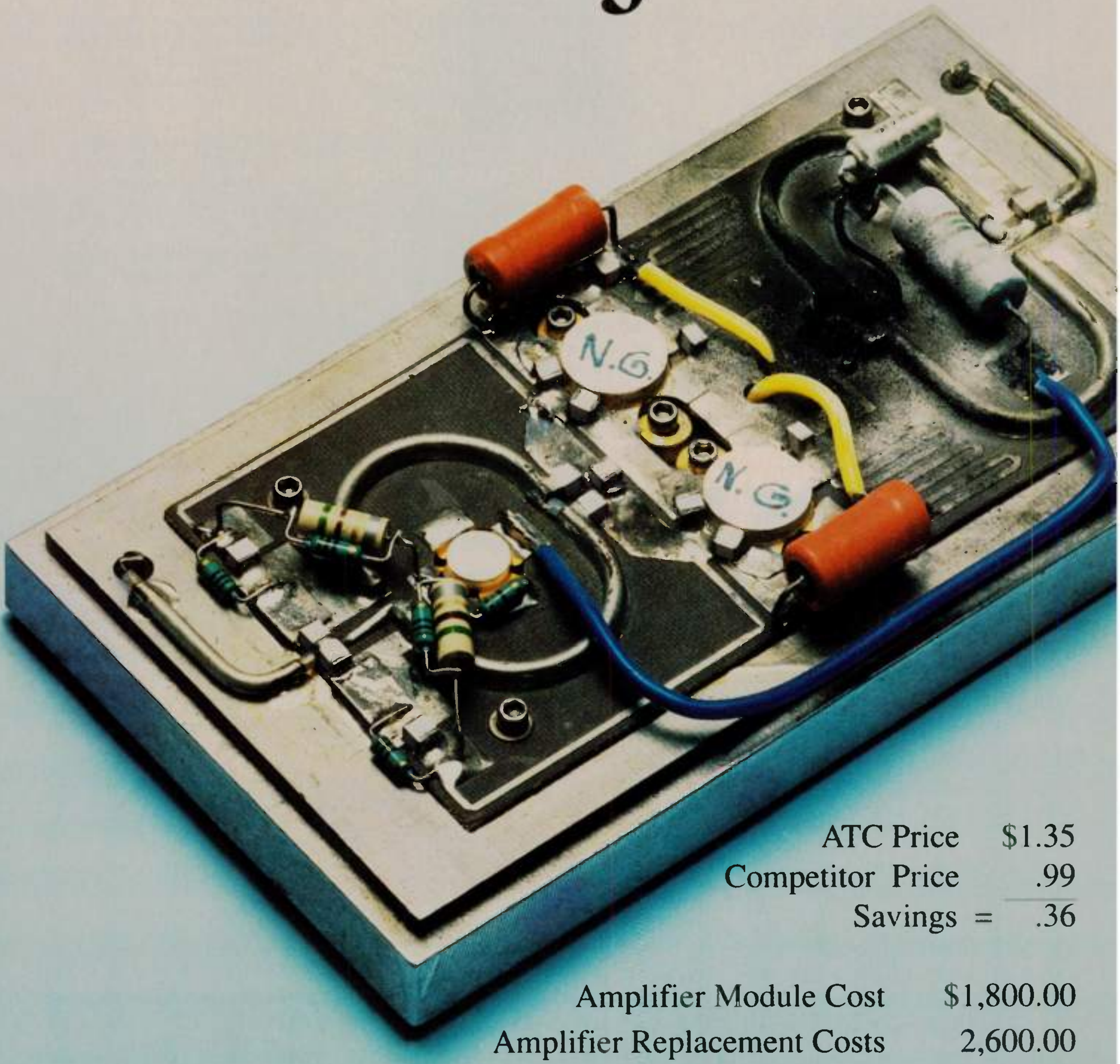

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INFO/CARD 8

RF calendar

October

15-18 **Electrical Manufacturing and Coil Winding '90**
O'Hare Expo Center, Chicago, IL
Information: Electrical Manufacturing & Coil Winding '90, 2400 East Devon Avenue, Suite 205, Des Plaines, Illinois, 60018.

17-20 **EMC Expo 90**
San Mateo County Expo Center, San Mateo, CA
Information: EMC Technology, P.O. Box D, State Route 625, Gainesville, VA 22065. Tel: (703) 347-0030.

22-26 **Systec 90**
Munich Trade Fair Center, Munich, Germany
Information: Kallman Associates, 5 Maple Court, Ridgewood, NJ 07450-4431. Tel: (201) 652-7070. Fax: (201) 652-3898.

30-Nov 1 **Electronic Imaging Conference East**
Hynes Convention Center, Boston, MA
Information: MG Expositions Group, 1050 Commonwealth Ave., Boston, MA 02215. Tel: (800) 223-7126 or (617) 232-3976.

November

5-8 **North American ISDN Users' Forum**
NIST, Gaithersburg, MD
Information: Dawn Hoffman, B364 Materials Building, NIST, Gaithersburg, MD 20899. Tel: (301) 975-2937.

6-8 **22nd International SAMPE Technical Conference**
Boston Park Plaza Hotel, Boston, MA
Information: SAMPE, P.O. Box 2459, Covina, CA 91722. Tel: (818) 331-0616.

6-10 **Electronica**
Munich Trade Fair Center, Munich, West Germany
Information: Kallman Associates, 5 Maple Court, Ridgewood, NJ 07450-4431. Tel: (201) 652-7070.

12-15 **AUTOFACT '90**
Cobo Conference and Exhibition Center, Detroit, MI
Information: Carol Valykeo. Tel: (313) 271-0777.

13-15 **RF Expo East 90**
Marriott Orlando World Center, Orlando, FL
Information: Kristin Hohn, Cardiff Publishing Company, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel: (303) 220-0600; (800) 525-9154.

13-15 **WESCON '90**
Anaheim Convention Center, Anaheim, CA
Information: WESCON/90, 8110 Airport Blvd., Los Angeles, CA 90045. Tel: (213) 215-3976. Fax: (213) 641-5117.

27-28 **Technology 2000**
DC Hilton Hotel, Washington, DC
Information: Bill Schnirring or Joe Pramberger, NASA Tech Briefs' Editor at NASA Tech Briefs, 41 East 42nd St., Suite 921, NY, NY 10017. Tel: (212) 490-3999.

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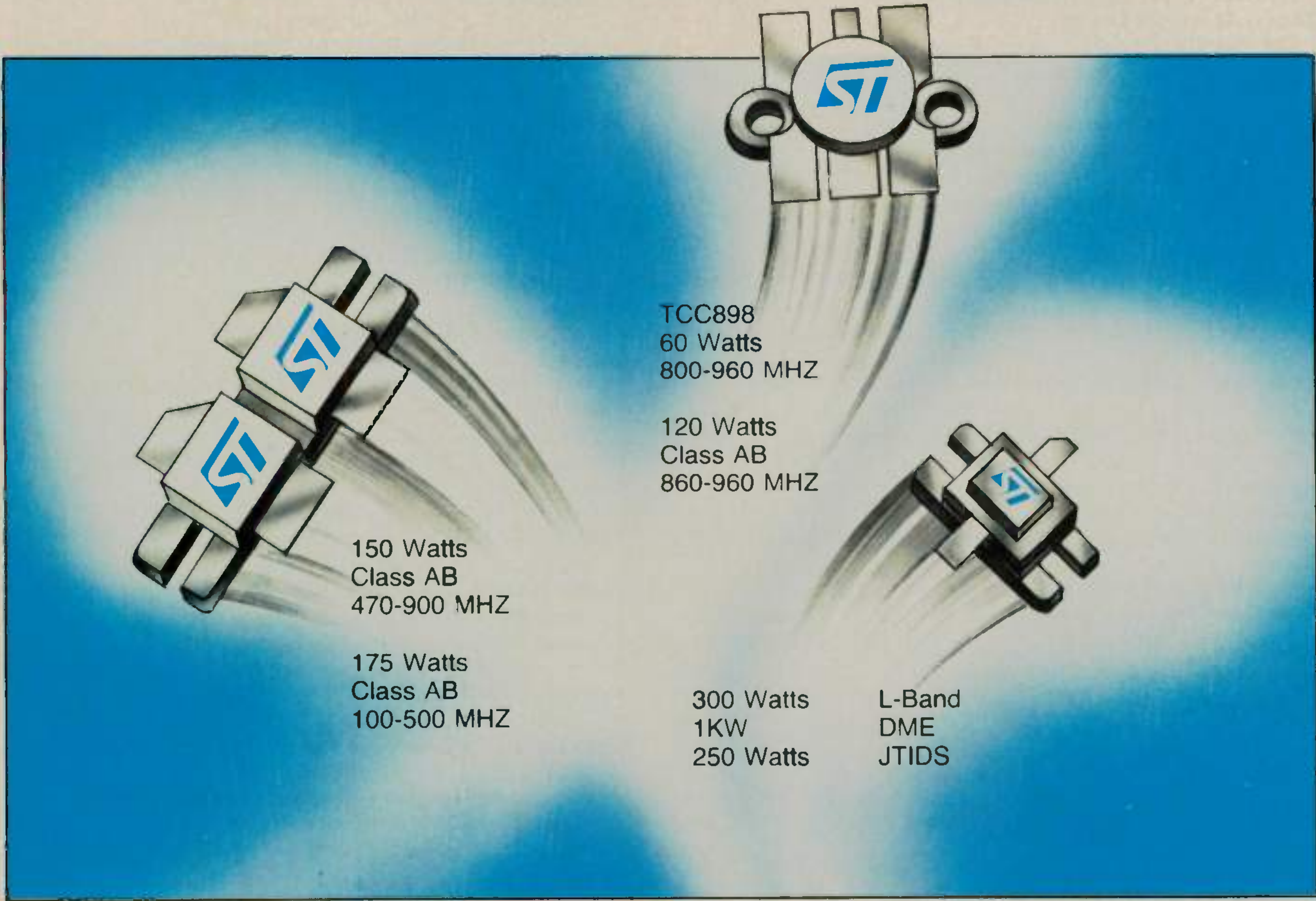

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806	960MHz	Class C, Land Mobile	Up to 60 Watts
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0.7	2.5GHz	Microwave, Oscillators	Up to 2 Watt
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INFO/CARD 10

RF courses

Analyzing Communications Systems Performance
October 15-17, 1990, Washington, DC
Modern Receiver Design
October 15-19, 1990, London, England
Electronic Warfare Systems
October 15-19, 1990, Washington, DC
Electromagnetic Interference and Control
November 5-9, 1990, Washington, DC
Frequency-Hopping Signals and Systems
November 5-7, 1990, Washington, DC
Cyclostationary Signal Processing
November 7-9, 1990, Washington, DC
Grounding, Bonding, Shielding and Transient Protection
November 12-15, 1990, Orlando, FL
Satellite Communications Engineering Principles
November 19-21, 1990, Washington, DC
Ionospheric Radio Propagation for System Planners
November 27-30, 1990, Washington, DC
Spread Spectrum Communications Systems
December 3-7, 1990 Washington, DC
Electronic Countermeasures
December 3-7, 1990, San Diego, CA
New HF Communications Technology: Advanced Techniques
December 3-7, 1990, San Diego, CA
Information: George Washington University, Merril Ferber. Tel: (800) 424-9773; (202) 994-6106. Fax: (202) 872-0645.

Basic Telephony
October 22-24, 1990, Madison, WI
Digital Switching
October 25-26, 1990, Madison, WI
Information: University of Wisconsin-Madison, College of Engineering. Tel: (800) 222-3623; (414) 227-3200. Fax: (414) 227-3119.

Infrared/Visible Signature Suppression
October 23-26, 1990, Atlanta, GA
Polarimetric Radar Technology
October 30-November 2, 1990, Atlanta, GA
Principles of Modern Radar
November 5-9, 1990, Atlanta, GA
Far-Field, Anechoic Chamber, Compact and Near-Field Antenna Measurements
November 27-30, 1990, Atlanta, GA
Phased-Array Antennas: Theory, Design and Technology
November 27-29, 1990, Atlanta, GA
Information: Education Extension, Georgia Institute of Technology. Tel: (404) 894-2547.

Management of Electromagnetic Energy Hazards
October 24-26, 1990, New Brunswick, NJ
Information: Office of Continuing Professional Education, Cook College, Rutgers University. Tel: (201) 932-9271.

Anomalous Microwave & RF Propagation
October 18-19, 1990, College Park, MD
Digital Satellite Communications
November 3-5, 1990, College Park, MD
Modern Frequency-Time & Spatial-Time Signal Processing
December 3-6, 1990, College Park, MD
Information: Applied Technology Institute, Jim Jenkins. (301) 997-6814.

Troubleshooting Microprocessor-Based Equipment and Digital Devices
October 23-26, 1990, Chicago, IL
October 30-November 2, 1990, Nashville, TN
November 26-29, 1990, Houston, TX
December 3-6, 1990, Phoenix, AZ
Information: Micro Systems Institute, Janet McHenry. Tel: (913) 898-4695.

DSP Without Tears™ for Engineers
October 24-26, 1990, Atlanta, GA
Information: Right Brain Technologies. Tel: (404) 420-3834. Fax: (404) 252-4122.

Introduction to EMI/TEMPEST Theory
October 15, 1990, San Diego, CA
How to Meet EMI/TEMPEST Shielding Requirements for Rooms and Facilities
October 16-18, 1990, San Diego, CA
Physical Security for Sensitive Compartmented Information Facilities
October 19, 1990, San Diego, CA
EMP Hardening Design and Test for Facilities
October 23-24, 1990, Washington, DC
EMP Hardening Design and Test for Electrical Equipment
October 25-26, 1990, Washington, DC
November 14-16, 1990, Washington, DC
Information: Praxis International, Inc.. Tel: (215) 524-0304. Fax: (215) 524-0438.

EMC for Digital Designers
October 23, 1990, Bloomington, Minnesota
ESD Immunity for Electronic Equipment
October 24, 1990, Bloomington, Minnesota
Information: Amador Corporation, Diane Swenson, Tel: (612) 465-3911.

Microwave Circuit Design: Linear and Nonlinear
October 24-26, 1990, Dallas, TX
October 29-31, 1990, Boston, MA
Information: Vendelin Engineering. Tel: (408) 867-2291.

Transient Voltage Suppression Design Seminar
October 30, 1990, Fairfield, NJ
November 1, 1990, Rochester, NY
November 6, 1990, Atlanta, GA
November 8, 1990, Baltimore, MD
Information: GSI Educational Services. Tel: (800) 776-8358.

Academy (Schematic)
October 22-23, 1990, Westlake Village, CA
Academy (Layout)
October 24-25, 1990, Westlake Village, CA
Information: EEsof, Ginger Craft. Tel: (818) 991-7530.

Basic Network Measurements Using the HP8510B Network Analyzer
October 22-24, 1990, Los Angeles, CA
October 23-25, 1990, Atlanta, GA
November 13-15, 1990, Dallas, TX
Microwave Fundamentals
October 29-November 1, 1990, Los Angeles, CA
Information: Hewlett-Packard Company. Tel: (800) 472-5277.

RF Expo West Call for Papers — Engineers are invited to present a paper for the technical program at RF Expo West 91, to be held February 5-7, 1991 at the Santa Clara Convention Center, Santa Clara, California. Topics of current interest include: EMC Topics, Part 15 Design, Modulation/Demodulation, Frequency Synthesis, Filter Design, Oscillators, Receiver Design, Power Amplifiers, and Antennas. In addition, topics on virtually any RF subject are welcome. Of special interest are tutorials on traditional or advanced RF topics. Send an outline or abstract of the proposed paper by October 22, 1990 to the RF Expo West Program Chairman c/o RF Design, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111.

Qualcomm's CDMA Technology Adopted by AT&T, NYNEX and Ameritech Mobile — AT&T, NYNEX and Ameritech Mobile have signed agreements to evaluate, develop and implement Qualcomm's Code Division Multiple Access (CDMA) technology for wireless personal communications equipment. Utilization of CDMA would allow for up to twenty times the present capacity using the same frequency bands currently allotted to cellular users. CDMA works by assigning a signal a unique, binary code and transmitting it via spread spectrum using a digital multiple-access technique. This allows a large number of signals to use the same part of the spectrum simultaneously. In addition to increased user capacity, CDMA is less expensive and offers rapid availability. According to Allen Salmasi, Vice President of Planning at Qualcomm "CDMA is a cost-effective technology that requires fewer, less expensive cells and no costly re-use patterning, offers inexpensive mobile and portable radios, and provides for much lower system cost per subscriber because of large capacity." With the signing of these agreements, AT&T NYNEX and Ameritech Mobile join Pactel in supporting CDMA Digital Cellular technology. The companies expect to have CDMA-based systems available by early 1991.

NATO and Harris RF Sign Contract — Harris RF Communications recently signed a contract to supply an advanced HF radio communications network, known as Cross Fox, to the Norwegian Defence Communications and Data Services Administration, on behalf of NATO. The Cross Fox system is a distributed, computer controlled HF communication network used by the allied NATO Navies for ship-to-shore and shore-to-ship communications. The depot repair facility will provide special test fixtures and software development facilities that will allow NATO to provide on-going maintenance for the Cross Fox system.

Bell Atlantic to Begin Technical Trial of CT2-CAI — Bell Atlantic Mobile Systems announced that it will conduct this nation's first technical trial of second generation cordless telephone technology, telepoint CT2-CAI (common air interface). CT2 has been described as a combination of cellular and pay phone services, in that a user could not receive calls and calls could not be automatically "handed off" from

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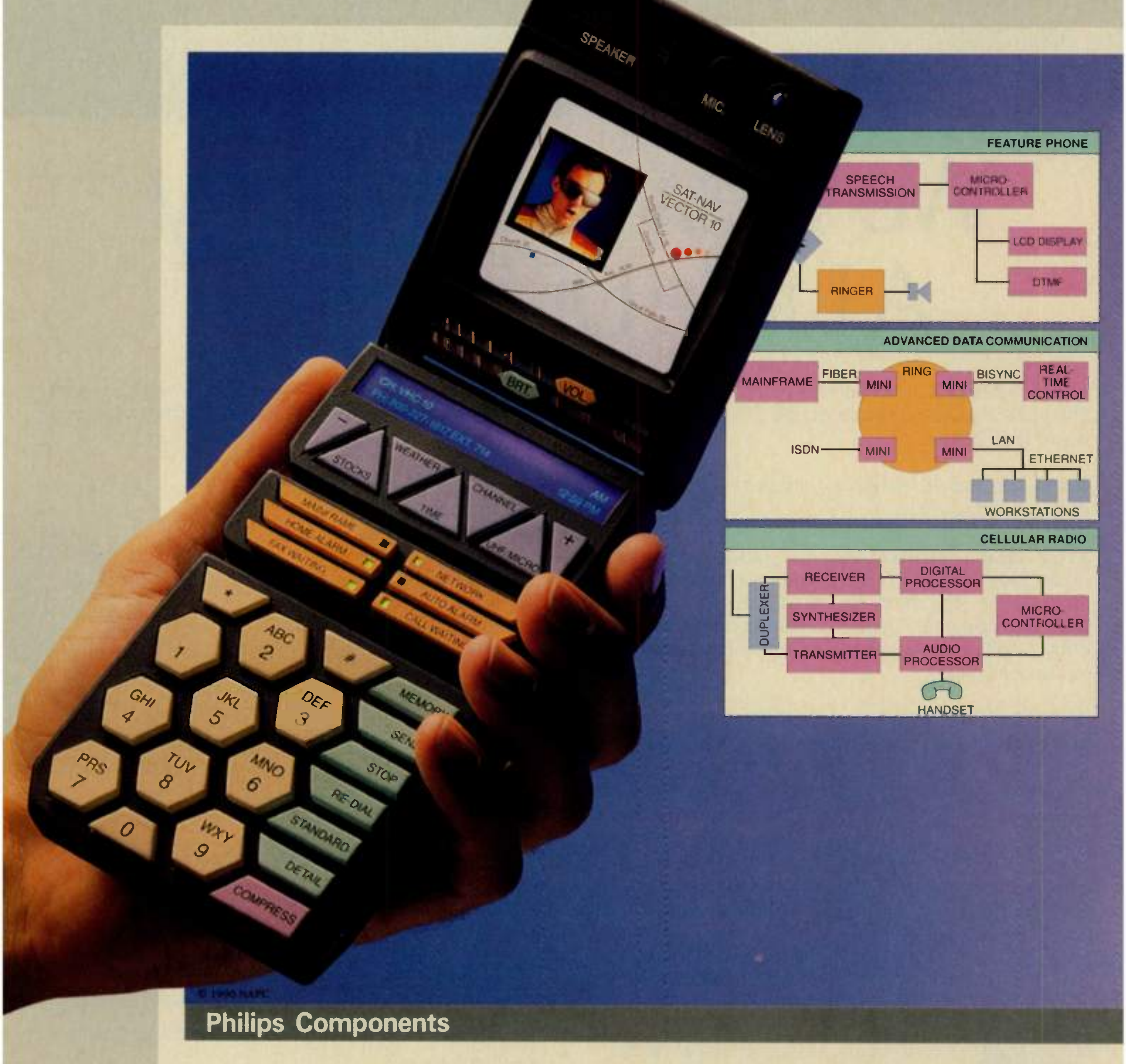

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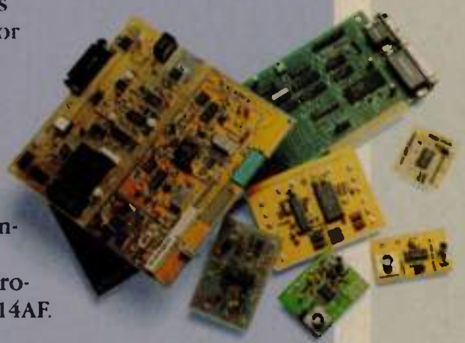

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one base station to another. The trial will be conducted at the 891.5-894 MHz range and will take place over a three month period in the Philadelphia, PA area. A small number of base stations and handsets will be used and monitored to determine the feasibility of mingling telepoint CT2 and cellular units in the same spectrum. If technically successful, Bell Atlantic Mobile will begin evaluating the need for a market trial to test consumer demand.

Clock and Oscillator Publication Available — A new publication from NIST will be of interest to managers of calibration laboratories in private industry, universities, the military and government agencies. *Characterization of Clocks and Oscillators* (NIST TN 1337) is a collection of published papers designed as a reference for those involved in characterizing and specifying high performance clocks and oscillators. It is an interim replacement for NBS Monograph 140, *Time and Frequency: Theory and Fundamentals*. The current volume includes tutorials, standards and definitions, and specific measurement and analysis techniques (with correction and notes indicating current recommended IEEE notation). TN 1337 is available from the Superintendent of Documents, US Government Printing Office, Washington, DC 20402. Order by stock number 003-003-03019-8 for $17 prepaid.

AIM Forms Radio Frequency Data Communications Committee — The Automatic Identification Manufacturers have established a committee consisting of companies that manufacture and sell radio frequency data communications (RFDC) equipment. The committee will focus on promoting RFDC as a technology that complements other Auto. ID technologies. Its areas of concern are regulatory issues and technical information for users of RFDC. The committee will deal with issues such as allocation of the electromagnetic spectrum, the frequencies on which RFDC systems can operate, the amount of power that system antennas can generate, and the maximum allowable height of base station antennas.

GaAs MANTECH Call for Papers — The 1991 U.S. GaAs MANTECH Conference to be held April 7-10, 1991 in Reno, Nevada has issued a second call for papers. Papers are invited on GaAs related topics including: manufacturing science and technology, design for manufacturability, materials production and qualification, processing technology, process control and yield enhancement, quality, reliability and radiation hardness assurance, testing, manufacturing cost issues, computer integrated manufacturing, product development, production and applications, and government and university efforts in manufacturing science and technology. The deadline for receiving abstracts is November 1, 1990. An original and thirty copies of an extended abstract should be sent to: 1991 GaAs MANTECH Conference, Suite 300, 655 15th Street, N.W., Washington, DC 20005.

KW Microwave Acquired from Signal Technology — KW Microwave has been bought from Signal Technology Corporation by an investment group led by Mr. Shukdev Tantod. The company will continue to operate under the KW Microwave name and in the present facility located at 5855 B Oberlin Drive, San Diego, California. The new ownership of KW Microwave Corporation now qualifies the company as a Minority Owned Small Business.

Call for Papers — The 3rd International Symposium on Recent Advances in Microwave Technology has issued a call for papers for their May 22-25, 1991 Conference. The symposium will cover topics in microwave technology and applications including: components and circuits, antennas and radar, MICs and MMICs, remote sensing, biological effects and other applications, communications systems, CAD techniques, propagation and measurements, electro-optics, microwave and millimeter wave optical technology, microwave superconductivity and microwave education. One original and 3 copies of the 4-page manuscript prepared according to the instructions (sent on request) are required by January 15, 1991. For more information contact: Banmali Rawat, Chairman, Technical Program Committee, Electrical Engineering and Computer Science Department, University of Nevada, Reno, NV 89557-0030. Tel: (702) 784-6927. Fax: (702) 784-1300.

QK Genwave Formed — Quarzkeramik GmbH has created a joint venture with Genwave Corporation to be known as QK Genwave Corporation.

QK Genwave will manufacture high performance oven-controlled oscillators as well as provide sales and technical support. For more information contact: QK Genwave Corporation, PO Box 547, Amesbury, MA 01913. Tel/Fax: (508) 388-6787.

Anthony RF Products Established — Susan and William Anthony recently announced the opening of a new manufacturing facility in Plant City, Florida. The facility will manufacture RF and microwave filters in the frequency range of 10 MHz to 18 GHz, utilizing a variety of design approaches. Product types include micro-miniature lumped component filters, cavity, combline, and interdigital filters, tunable bandpass and band reject filters, and tubular filters. Fixed frequency filters are offered in highpass, lowpass, bandpass, and band reject circuits. Inquiries may be directed to: Anthony RF Products, Inc., 4288 US Highway 92W - Unit 4, Plant City, FL 33567. Tel: (813) 752-8455. Fax: (813) 752-3808.

EIP Microwave Acquires Two Cushman Electronics Products — EIP Microwave Inc. has purchased from Cushman Electronics, Inc. the assets and manufacturing rights for the Cushman CE-24A and CE-80B products. The CE-24A is a frequency selective level and noise meter used in field testing of analog transmission systems. Applications include measurements of tones, noise, crosstalk and frequency response in cable, open wire, and radio multiplex systems. The Cushman CE-80B is an automatic PCM fault locating test set used in testing PCM carrier span lines.

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Tests include a noise threshold test, the standard MEASURE 1, 2, 3 fault locating patterns, and the Pulse Period, or obscure trouble, stress test.

Analog Devices Buys Precision Monolithics Inc. — Analog Devices recently announced the acquisition of Precision Monolithics Inc.. With the acquisition, the newly expanded company becomes a $540 million organization. Terms of the sale were not released.

Varian Signs Continental Letter of Intent — Varian Associates has reached a tentative agreement to sell its Continental Electronics unit to Tech-Sym Corporation. Varian is selling Continental along with other non-core businesses as part of a major company restructuring. While the purchase price was not disclosed the transaction is subject to a number of conditions which must be approved by the Boards of Directors of the two companies before final approval is given.

Electrical Engineering/Electronics Bulletin Available — The *Technical Progress Bulletin* covers NIST's Center for Electronics and Electrical Engineering and its programs, which provide national reference standards, measurement methods, supporting theory and data and traceability to national standards. Included are abstracts of papers and published works arranged by topic. To receive the most recent issue or to be placed on the mailing list, write to or call (stating your professional affiliation or technical interest): Technical Progress Bulletin, Center for Electronics and Electrical Engineering, B358 Metrology Bldg., NIST, Gaithersburg, MD 20899. Tel: (301) 975-2220.

AIL Systems Awarded US Navy Contract — AIL Systems Inc. has been awarded a $28.1 million contract from the US Navy to provide spare subassemblies and components for the ALQ-99 tactical jamming system installed in the Grumman/Navy EA-6B Prowler aircraft. The ALQ-99 system was designed and developed by AIL Systems in the early 1960s for the Grumman EA-6B and has undergone several major modernization upgrades since that time. The system allows Naval Prowler crews to respond to a wide range of hostile radar threats.

Eaton to Supply EMS System to Korean Laboratory — The Electronic Instrumentation Division of Eaton Corporation has received an order for a complete Electromagnetic Susceptibility System from the Anyang Radio Research Laboratory where its counterpart Electromagnetic Interference (EMI) system is already in place. The system will be used in the immunity testing of telecommunications equipment for PABX and digital telephone switching systems. The EMS system operates over the frequency range of 20 Hz to 1 GHz. In addition it also has an ultra-broadband field monitoring system for the 10 kHz to 1 GHz range. It provides for both conducted and radiated susceptibility testing.

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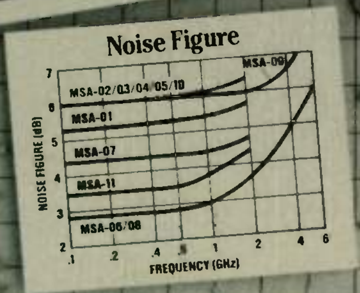

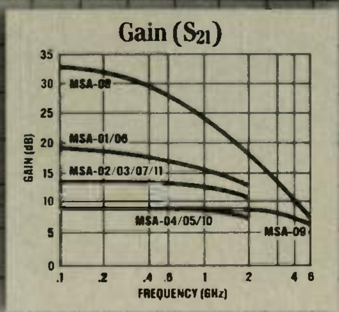

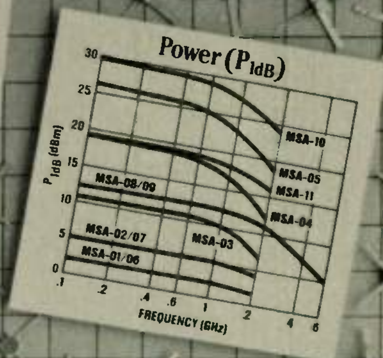

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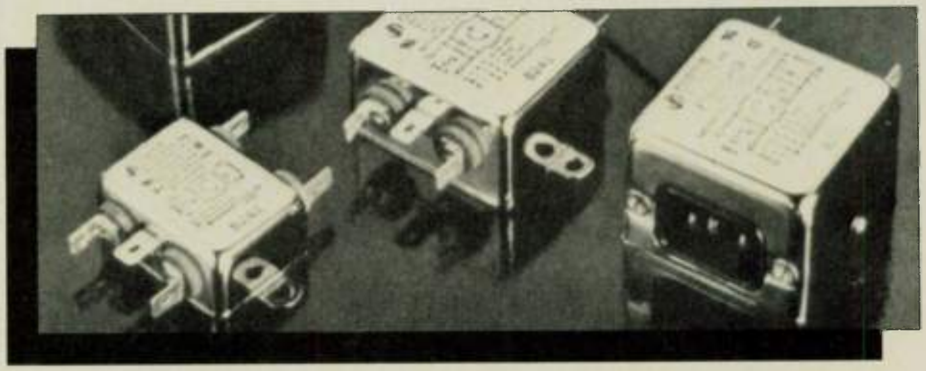
INFO/CARD 26

EMI Control — Essential For Design

By Charles Howshar and Liane Pomfret, Assistant Editors



The suppression of electromagnetic interference (EMI) is a critical element in the design of products operating at radio frequencies. Companies are now paying more attention to the problems caused by EMI and looking for ways to combat its effects while still in the design stage. With advances in electronic design and component size reductions, electromagnetic interference problems are increasing. Often engineers do not take into account electromagnetic interference and must redesign a circuit with provisions for EMI control. Lester Dant, Vice President of Ad-vance Magnetics, Incorporated, comments, "We see a lot of retrofitting. There are always new products that require shielding which may not have been considered in the original concept." Another area where EMI is causing problems is in the office environment. With more and more computers and other electrical equipment being installed in offices, EMI concerns in this environment are becoming more and more critical. Dale van Scoyk, Vice President of North American Sales for Corcom, Incorporated remarks, "Office environments have more RFI [radio frequency interference] in a condensed area, so office automation problems occur."

In the past few years, concern with EMI has substantially increased. Interest has grown in such diverse markets as computer system protection in classified areas (Tempest), lightning control (EMP), satellites, aerospace, and military markets. Terry Plummer, President of The Zippertubing Company, states, "It's really across the board. There's quite a bit of interest from companies with military, black box, aircraft, and computer applications." He adds, "Back in 1983 when the FCC put regulations into effect, there was a lag in manufacturing EMI control products. From that time our sales have increased steadily." Although there have been many cuts in defense spending, the EMI control market is basically running full speed ahead. There have been some minor cuts, but they haven't affected the market much. "The biggest growth that we're experiencing is in the commercial end more than the military. There's a softening of military demand, but an upsurge in PCs and automotive demands," adds Murata Erie's Product Marketing Manager, Robin Wilson.

Regulations

New regulations for EMC will be going into effect in Europe and the United States within the next few years and companies are adjusting their market plans accordingly. On January 1, 1992, the European Common Market EMC Directive making EMC immunity testing mandatory in Europe will go into effect and many European companies will be unable to comply without making changes to their designs. This regulation will also affect United States manufacturers who wish to market their products in Europe. Companies with outlets in both Europe and the United States will have an advantage over those based solely in the U.S.A. in that they will be able to design separate products for the markets on either side of the Atlantic. "You have to have facilities in Europe in order to stay competitive in the European market, especially the military market," comments Robin Wilson. "There has been a lot of talk about the continent-wide regulations that are going into effect in Europe in 1992 but there have been insufficient preparations for the changes. It will be a more consolidated approach to EMI regulations, but it will be difficult for some companies to adapt to," remarks Joe Fischer, Vice President in Charge of Engineering for Fischer Custom Communications, Incorporated.

New Applications

With the increased demand for EMI control, many new applications are being developed. "For the commercial market, the trend is towards surface mount technology," comments Robin Wilson. "We've been trying to incorporate thermal plastics in EMP (electromagnetic pulse) control for airplanes," states Burt Bergsrud, Vice President of Marketing for Glenair Corporation. "There is demand for signal level filtering where there are cable connections, and we're developing a line of power entry modular connectors for this application," remarks Corcom's van Scoyk.

Although military spending cuts have affected the electronics industry, the electromagnetic interference control market has barely been touched. "The commercial market is growing very fast, and so far, we haven't been affected by military cutbacks at all," remarks Charles Belser, Marketing Representative for Glenair. And, as electronic processes continue to speed up and circuits continue to shrink in size, the need for EMC will continue to grow. Chomerics' Joe Butler says, "We are spending a lot of time and money on new regulations and new applications, because we feel that the commercial market has great potential." With the advances that have come in the medical field, specifically nuclear magnetic resonance imaging, EMC companies will have another very promising market to sell to. As Lester Dant remarks, "A lot of ultrasensitive medical devices, like MRI equipment, have to be shielded, and that gives us a greater number of industrial consumers." The market for EMI control products is expanding and outlook for the future is strong. Given the trend toward new technologies, conservation of size, and changing regulations, EMC will continue to grow for some time to come. RF

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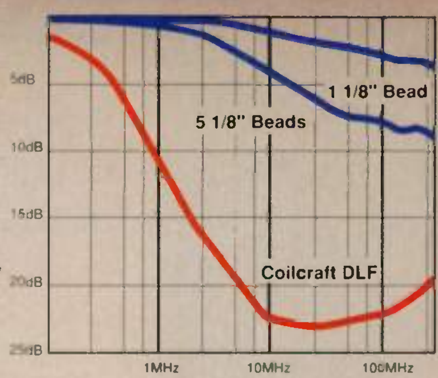

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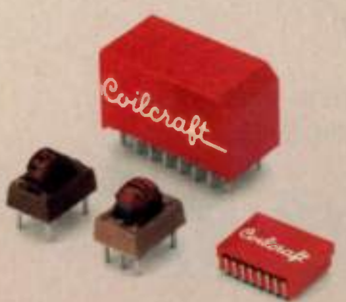

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INFO/CARD 22

A Portable Low Cost RF Voltmeter

By Dale Lindseth
Therma-wave, Inc.

This article describes the design of a portable battery powered RF voltmeter that covers the frequency range from 10 kHz to 10 MHz. This was designed for field service personnel as an alignment and troubleshooting aid for instrumentation installed in semiconductor fabs. Requirements were that the device be portable, low cost, battery powered, and that it could fit into the standard tool kit used by field service personnel. Such an instrument could not be located on the current marketplace.

The instrument is capable of making AC voltage measurements from 10 kHz to 10 MHz with a high degree of accuracy. Actual size is 4 × 6 × 2 inches (reference Figure 1). Useful battery life is three hours, with a charger input jack available for charging the internal Ni-Cad battery. Output is in the form of a DC voltage, intended to be applied to a portable DVM for voltage readout. Charger requirement is 12 volts at 120 mA.

The instrument is calibrated to read the RMS value of a sine wave. The unique feature of the instrument is that it is truly portable, and covers the frequency range starting where typical DVMs leave off (10 kHz) and extending up to 10 MHz. The wide frequency range was designed to cover certain measurement frequencies (1, 3 and 10 MHz), as well as intermediate frequencies, such as the 100 kHz IF. In addition, low-level AC voltage measurements (to .2 mV RMS) can be made with a high degree of accuracy. A wide band (10 MHz) amplifier output is available for amplification and inspection of low-level AC signals to 10 MHz. Such low-level signals cannot be measured accurately with an oscilloscope alone due to poor resolution and noise.

Description of Operation

A block diagram of the voltmeter is shown in Figure 2. Refer to the block diagram in the discussion to follow.

Input Section

The input section consists of an input buffer with an input impedance of 1 M ohm shunted by 15 pF, and a selectable 50 ohm termination. The 50 ohm termination is convenient when making measurements in a 50 ohm system. It is especially useful when measuring higher frequency signals (above 1 MHz or so) since it eliminates undesirable effects of cable capacitance, as well as the 15 pF input capacitance of the meter.

Maximum safe input levels are as follows:

Input termination = 1M ohm ⩽ 100 Volts peak
Input termination = 50 ohms ⩽ 10 Volts AC
⩽ 50 Volts AC+DC

Range Selector

Following the input buffer, is a 4 decade step attenuator which reduces the input level to within a 10:1 range at its output. Output signal is .15 to 1.5 mV RMS nominal. Range selection is as follows:

Range	Attenuation	Multiply By
.2-2 mV RMS	0 dB	1×
2-20 mV RMS	20 dB	10×
20-200 mV RMS	40 dB	100×
200-2000 mV RMS	60 dB	1000×

Calibrated output range is .2-2 VDC. Thus when making a measurement, the range selector switch is first rotated to a position that produces a DC output within the calibrated range. DC output voltage is then multiplied by the factor listed above, to obtain the actual input voltage in millivolts. The voltmeter is calibrated to read the RMS value of a sine wave.

1 MHz Filter

The 4 decade step attenuator is followed by an amplifier (A_v = 26 dB nominal), then a 1 MHz selectable bandpass filter. Nominal bandwidth of the filter is 200 kHz. The 1 MHz filter is very useful because the Therma-probe ion implant monitoring system runs at 1 MHz in most applications. The 1 MHz filter reduces noise level when measuring low-level signals. It is also useful when it is desirable to measure only the 1 MHz component (usually the fundamental) of the signal in question. When the signal to be measured is at other than 1 MHz, the filter is switched to the 'out'' position. Resulting response is then flat to 10 MHz. Insertion loss through both paths is −7.5 dB nominal.

For applicability as a general piece of test equipment, the 1 MHz bandpass filter should be converted to a low pass filter instead.

AMP Out

The selectable filter is followed by another stage of amplification (A_v = 26 dB nominal). Amplifier output is applied to the precision high speed rectifier for AC to DC conversion. It is also applied to the AMP output terminal through a 200 ohm series isolation resistor. The AMP output connector provides a wideband output useful for amplification and inspection of low-level signals to 10 MHz. Nominal AC output level (RMS) = DC output level divided by 10, unterminated. Although the AMP output is considered to be uncalibrated, the open circuit output voltage should be accurate to within 5 percent. When terminated in 50 ohms, the AC output level (RMS) = DC output level divided by 50, due to the divider action of the series isolation resistor.

Referred to the input, gain from input to AC output is:

1. .2-2 mV range, gain
= 100 unterminated

Figure 1. A low cost, portable RF voltmeter.

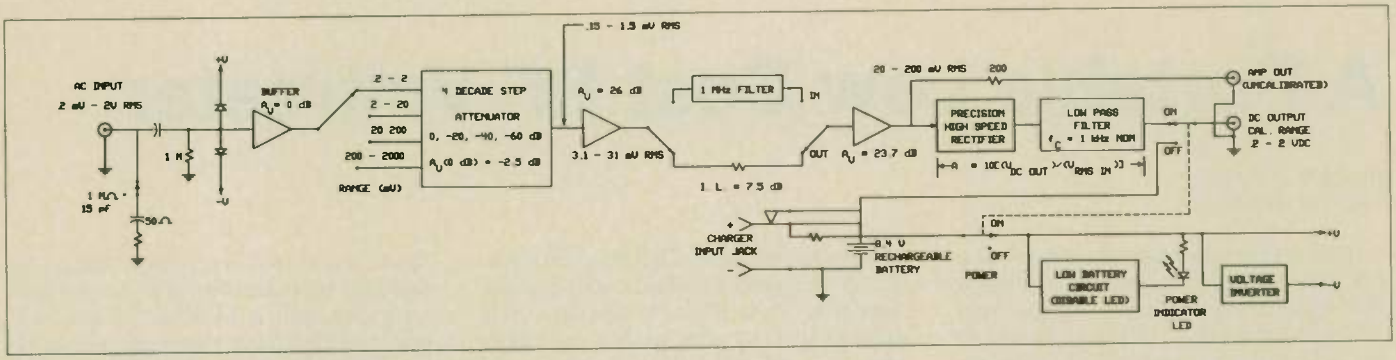


Figure 2. Block diagram - RF voltmeter.

= 20 terminated in 50 ohms

2. 2-20 mV range, gain
   = 10 unterminated
   = 2 terminated in 50 ohms

AC to DC Conversion

The AC to DC conversion circuitry consists of a precision high speed rectifier followed by a low pass filter. Full wave rectification is achieved by splitting the positive and negative halves of the input waveform, then feeding the two halves individually into the two halves of a differential amplifier with low pass filter. The output is thus a DC voltage which is applied to the DC output connector. Transfer function from DC output to AMP output is:

$$\frac{\text{DC output (volts DC)}}{\text{AMP output (Volts RMS)}} = 10.0$$

where AMP output = open circuit output voltage.

Power Supply/Charger

Voltmeter power is supplied from an internal rechargeable battery pack. Battery voltage is 8.4 VDC nominal. Capacity is 600 mA-hours on a fully charged battery. To extend battery life when the unit is switched on, it is best not to leave the range switch in the 200-2000 mV position since the voltmeter consumes about 45 mA additional current in this position. The negative supply voltage is derived from the battery through the use of an on-board inverter.

The battery can be recharged through the charger input jack on the face of the meter. An external plug-in charger is used for this purpose. Charger output is 12 VDC at .12 amps. Battery charge time is 4 hours nominal. The unit is intended to be operated from battery power. If the battery becomes excessively discharged, the unit may be operated from the charger input voltage, however measurements will typically be 1 percent high due to the increased

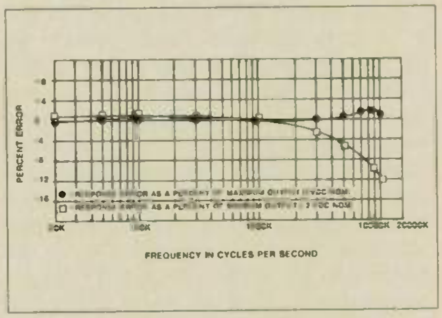


Figure 3. Overall frequency response.

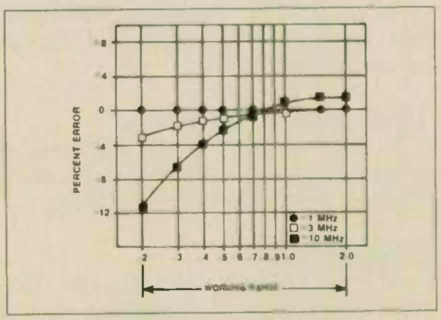


Figure 4. Response linearity.

supply voltage. In a severely discharged state the voltmeter may not function properly, however this condition will be flagged by the low battery indicator.

Low Battery Indicator - When power is turned on, the power indicator lights under normal conditions. If the battery voltage drops below approximately 7.2 volts, the power indicator light turns off flagging a low battery condition.

State of Charge Indicator - When power is turned off, the battery voltage is automatically switched to the DC output connector. State of charge can thus be monitored with the external DVM.

Overall Accuracy and Linearity

Accuracy specification for the portable RF voltmeter is ± 2 percent of full scale output (2 VDC) to 3 MHz and ± 5 percent of full scale output to 10 MHz. There are two primary sources of error. These are:

1. Frequency response.
2. Nonlinearities inherent to the high speed precision rectifier.

Frequency response errors are due to amplifier roll-off at high frequency, as well as stray capacitance throughout the circuit. The effect of stray capacitance in general is minimized by keeping resistor values small. A plot of the overall frequency response of the meter is shown in Figure 3, which shows the frequency response error in percent as a function of frequency. The figure shows two curves. The upper curve shows the frequency response error as a percent of maximum output (2 VDC nominal). The lower curve shows frequency response error as a percent of minimum output (.2 VDC nominal). As can be seen the overall flatness is very good. Roll-off of the lower curve is caused by nonlinearities in the precision rectifier circuit, which will be discussed later.

Errors associated with the precision rectifier are more clearly represented by Figure 4, which shows the percent measurement error as a function of output signal level. There is very little degradation in accuracy over the full calibrated output range (.2-2 VDC) to 3 MHz. Beyond 3 MHz, nonlinear effects begin to creep in at the lower end of the range. Worst case error which occurs at 10 MHz and at the low end of the range is −11 percent typically, or about −1 dB. The resulting errors were considered acceptable. Possible methods for improving this will be discussed later, however reference to this figure will provide a good estimate of the correction factor as a function of output signal level and frequency for critical measurement applications.

The voltmeter is calibrated at the nominal battery voltage which is 8.4 VDC. As the battery discharges, the battery voltage will drop to 7.2 VDC after which the power indicator will shut off indicating a low battery condition. At the low battery level, measurements will be −0.7 percent low typically. Normally the unit is not operated off the external charger, however, when it is, operating voltage is approximately 12 VDC. Under these conditions measurements are about +1.3 percent high.

4 Decade Step Attenuator

A schematic of the 4 decade step attenuator is shown in Figure 5. Accuracy is maintained to within ± 1 percent per step by using .1 percent precision resistors to set the attenuation. Accuracy is tested at 1 MHz. A total error of ± 2 percent is allowed over the full 60 dB range.

For obvious space reasons, it was desirable to use a single rotary switch mounted to the PCB in order to do range selection. The effect of stray capacitance across the switch terminals is a problem at the higher frequencies, causing signal feed-through to the output. In order to reduce this to a negligible level, impedance levels were kept as low as possible, and the final 20 dB range step was activated through an on-board relay energized by a second pole on the rotary switch. The PCB was laid out very carefully to keep stray capacitance to a minimum. The relay chosen was a teledyne, with low switch capacitance (.5 pF) in a metal can which is grounded to further reduce capacitive coupling to the signal lines from the input side of the attenuator.

Precision High Speed AC to DC Converter

The AC to DC conversion circuitry is shown in Figure 6. It consists of a high speed precision rectifier followed by a low pass filter. Full wave rectification is achieved by splitting off the positive and negative halves of the input wave-form and feeding them separately into the respective halves of a differential low pass filter/amplifier. During the negative half of the input wave-form, the amplifier slews in a positive direction until the output exceeds the turn on voltage of the

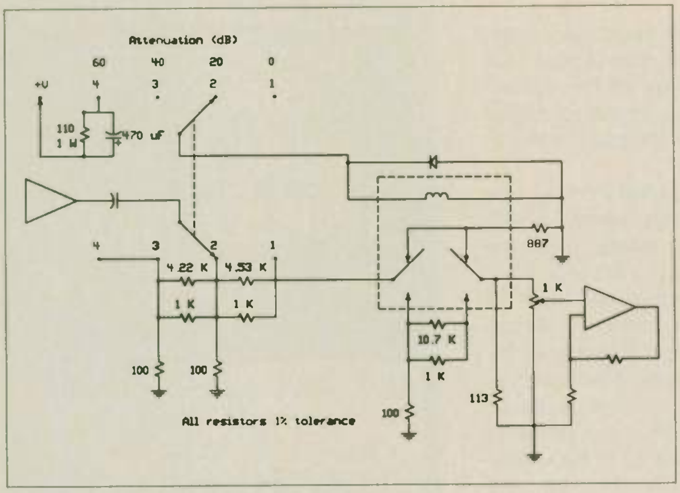


Figure 5. 4 decade step attenuator.

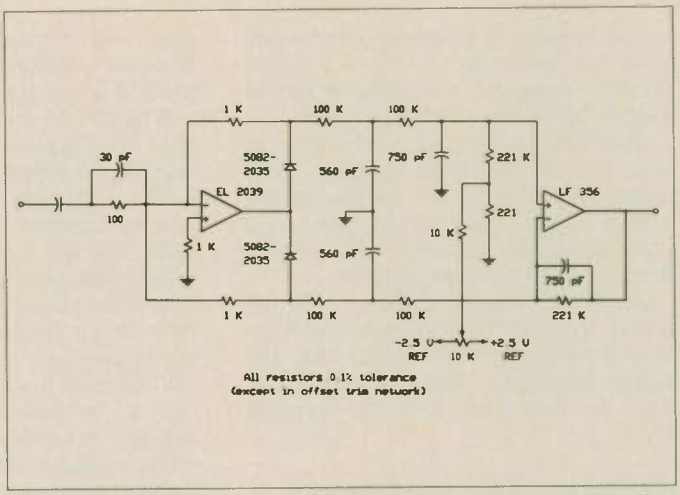


Figure 6. Precision high speed AC to DC converter.

upper diode (approximately .5 V). The feedback is then closed through the series diode - 1K resistor combination. Closed loop gain is 10 with output taken at the diode/resistor junction. The output drives the non-inverting half of the differential low pass filter. Gain of the differential low pass filter is adjusted to result in an overall transfer function, V_{out} (DC)/V_{in} (RMS) = 10.0. Low capacitance schottky diodes are used to reduce the turn-on voltage and preserve the high frequency response. Feedback impedances were also kept low to reduce the effect of stray capacitance. The amplifier is not allowed to saturate, since the feedback is closed for both halves of the input cycle.

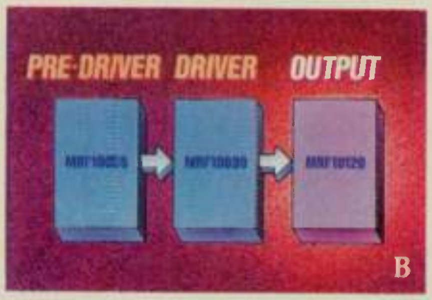
The critical element is the amplifier, since the application requires a high slew rate, and high open loop gain to 10 MHz (and beyond). As will be seen, it is also important that the open loop gain is as flat as possible to 10 MHz. For the rated output range of .2-2 VDC, the corresponding peak rectifier output is .28-2.8 Volts. To preserve the frequency

RF Design News

High gain power modules for mobile cellular radios.

From the industry leader in power modules comes a new high gain improvement. The industry standard, the MHW806A, now comes in a 0-dBm version as the MHW807 Series. Instead of the previous power requirement of 30 mW, the new series requires only 1 mW to obtain 6W of output power, thanks to two new gain stages.

The MHW807 Series is perfect for all cellular radio applications. They offer controllable, stable performance over more than the 35 dB range in Po that's needed. Two different frequency models are available: 820 to 850 MHz and 870 to 905 MHz.



Long pulse microwave power transistor.

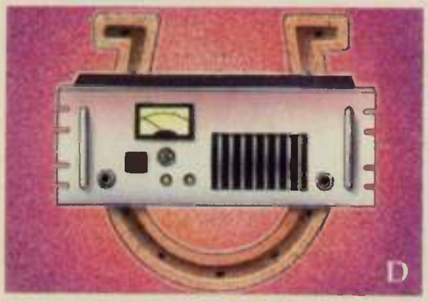
Motorola continues to expand its long pulse microwave power transistor portfolio with the introduction of its new 120 watt L-Band transistor, the MRF10120. This output device completes the lineup consisting of the pre-driver MRF10005 and the MRF10030 driver.

The MRF10120 operates on a power supply of 36 volts and delivers 120 watts of peak power for typically less than 15 watts of peak RF input power. It's designed for common base amplifier applications such as JTIDS (military) and Mode S (commercial) transmitters. The frequency of operation extends from 960 to 1215 MHz.

Satellite microwave power transistors.

Three new microwave power transistors are available for large-signal output and driver amplifier stages for satellite up/down links. The MRA1600-2, MRA1600-13 and MRA1600-30 are designed for Class C, common base amplifiers that operate in the 1600-1660 MHz frequency range. They provide 2.2, 12.7 and 30 watts of minimum power respectively.

These devices offer the highest in reliability and performance. They feature gold metalization, diffused ballast resistors and internal compensation for impedance matching control. All this is offered in a low-cost microwave package for cost efficiency.



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response to 10 MHz, the minimum required amplifier slew rate is $2\pi \times 10M \times 2.8 = 176$ volts per microsecond. The amplifier is capable of slewing at 600 volts per microsecond typical, therefore slew rate limiting is not a problem. There is a small delay while the amplifier slews from 0 to .5 volts (in order to turn on the diode), however at 600 volts per microsecond, this is also minimal. The critical parameter turns out to be amplifier open loop gain. The available open loop gain at 1 MHz is 54 dB nominal. Closed loop gain is 20 dB. This leaves 34 dB of available loop gain (closed loop gain of 20 dB is required for stability). Error due to the finite loop gain is thus about 2 percent. In addition, there is an equivalent offset (referred to the input) of about 1 mV required to overcome the turn-on voltage of the diodes. This translates to about 3.6 percent error at the low end of the output range, and 0.36 percent error at the high end of the range.

Estimated total error is thus 5.6 percent at the low end of the range, reducing to 2.4 percent at the high end of the range. Actual measured error is shown in Figure 7, which is close to expected. Working range was chosen to be .2-2 volts at the DC output. This is the most linear portion of the curve, keeping a safe level below the point of amplifier output compression.

In order to correct for the linearity error due to finite loop gain and diode turn-on voltage, a fixed offset voltage is fed into the output through the differential low pass filter. Thus, the correction term is proportionately larger at the low end of the range, than at the high end, as desired. Calibration and linearity correction is performed at 1 MHz as follows:

1. With the AC input at zero, the offset voltage at the DC output jack is adjusted to the approximate value needed for correction.
2. A 1 MHz signal is connected to the AC input jack, its input level adjusted for the proper value to result in the ideal 2 VDC at the DC output jack. The voltmeter gain pot is then adjusted for the proper 2 VDC at the output jack.
3. The input is attenuated by exactly 20 dB. The offset voltage is readjusted for the proper (.2 VDC) output.
4. The input level is increased by 20 dB, and the process is repeated starting with step 2, until the 1 MHz gain is calibrated at both the low and the high end of the range. The resulting measurement error over the full output range is also shown in Figure 7. This is very close to the ideal.

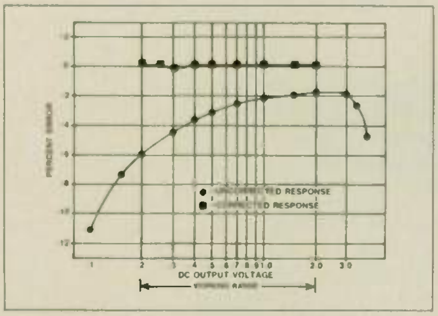

Figure 7. Measurement error over the output range.

The linearity correction is done at 1 MHz. At lower frequencies, the linearity correction remains valid, however, as input frequency increases beyond 3 MHz, linearity errors begin to creep in again at the lower end of the calibrated output range.

This is due to the fact that the open amplifier gain is falling off. Open loop −3 dB bandwidth of the amplifier is about 6 MHz. As the loop gain begins to roll off, the errors increase. A 30 pF compensation capacitor is used at the rectifier input to compensate for roll-off at high frequency and at the high end of the output range. Corresponding error at the low end of the range at 10 MHz is typically −11 percent (refer to Figure 4).

An attempt at second order linearity correction was made to correct for these errors, with reasonable success. This was done by making the high frequency compensation nonlinear. The change was not implemented however, because of limited space on the PCB. Of course, the preferred method of improving accuracy would be to use a better op-amp.

Suggestions for Improvement

There was no concerted effort made to reduce the cost of the voltmeter since it was not an issue for this low volume application. Some cost reduction could be done in both packaging and electronics design. The input buffer is a hybrid. A similar device can probably be purchased in monolithic form today. The teledyne relay is also costly. Some searching may turn up a similar device at lower cost.

Installation of a low drop-out DC regulator in series with the supply would eliminate the small error due to lack of supply regulation.

Some sort of second order linearity correction could be implemented in order to improve accuracy at the low end of the calibrated range between 5 and 10 MHz.

A portable low cost RF voltmeter design was presented that covers the frequency range from 10 kHz to 10 MHz. The meter is portable, yet capable of high accuracy, low level AC measurements in a frequency range that cannot be touched by normal low-cost meters. It was designed as a special purpose piece of test equipment to be used by field service personnel at Therma-wave, Inc. for performing alignment and troubleshooting of ion implant monitoring equipment used in semiconductor fabs. Conversion of the internal 1 MHz bandpass filter to a low pass filter instead would make the meter more useful as a general purpose tool that could be used in a wide variety of applications. *RF*

About the Author

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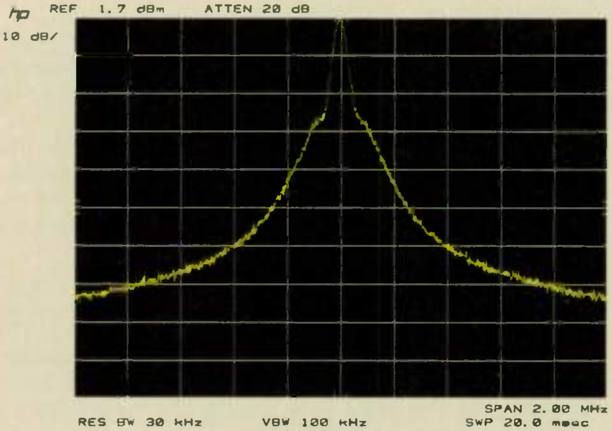
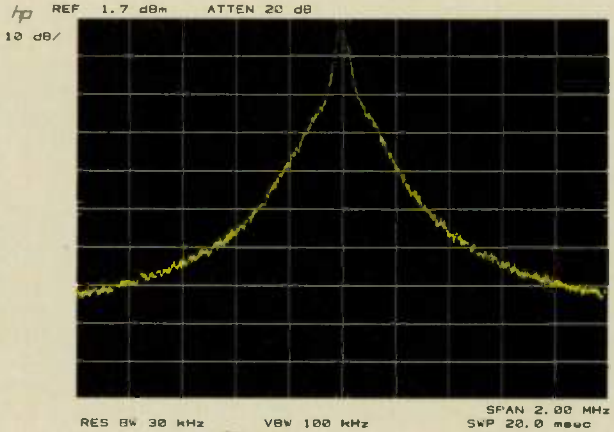
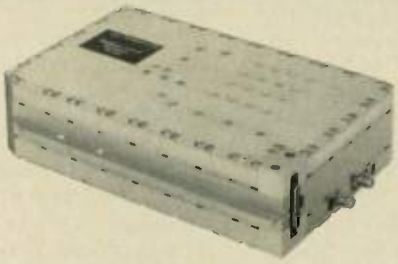
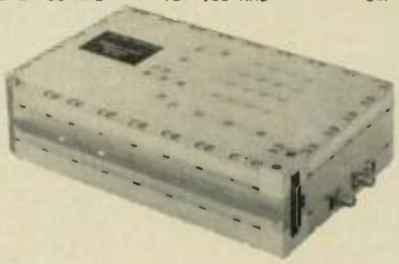
One synthesizer is operating at 27 G's of random vibration.

Can you tell which?









Both synthesizers are exactly the same. Both were designed and built by TRAK — a 30-year DoD supplier — for use in a tactical airborne environment. But only one is actually being subjected to 27 G's of random vibration, worst-case axis.

A keen, experienced eye may correctly deduce that the chart on the right represents the one under vibration. And we think you will quickly see the application possibilities in a synthesizer that appears — like this one — virtually immune to vibration.

Electrical specifications:

Frequency:	I/J band
Bandwidth:	Octave
Step size:	5 MHz
Switching speed:	150 μseconds, typical
Spurious:	−60 dBc
Power dissipation:	35 watts
Size:	8 x 5 x 2 inches (80 in^3) maximum

- Excellent performance in high-vibration environments
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INFO/CARD 30

Microstrip CAD Program

By Thomas V. Cefalo, Jr.
MITRE Corporation

Engineering time is a major contributor to the development cost of RF products. In order to reduce design time, engineers are making greater use of software design tools. This article presents an easy-to-use program to synthesize microstrip lines and other related parameters, based on closed-form equations which take into account the presence of a cover over a microstrip line.

To begin, it's important to review the fundamental principles of microstrip theory (1). Microstrip is just another form of transmission line which is used to carry electromagnetic waves between two points. As seen from Figure 1, the geometry of a microstrip transmission line consists of a thin conducting strip and a solid conducting ground plane separated by a dielectric substrate. Many different types of conducting and dielectric materials have been investigated but the most common are copper conductors and teflon or fiberglass substrates.

Shown in Figure 2 are the electric (solid lines) and magnetic (dash lines) fields of some familiar transmission lines. The mode of propagation is said to be in a transverse electromagnetic mode (TEM) for the coaxial and stripline transmission lines. In the TEM mode, both the fields are in a plane 90 degrees to each other and to the direction of propagation. Unlike the first two transmission lines, the field topology for microstrip shown in Figure 2c, is asymmetric. The fields pass through both the substrate and the air. Since the fields are passing through two different mediums, the relative dielectric constant ε_r, no longer remains a constant but becomes a function of the W/H ratio. This results in a new parameter called the effective dielectric constant ε_{eff}, which takes into account the distribution of the fields between the air and the substrate. The effective dielectric constant will always be lower than the relative dielectric constant.

The consequence of the electromagnetic field distribution is that the mode of propagation along the microstrip is no longer purely TEM but one that resembles it called quasi-TEM. Because of the quasi-TEM mode, microstrip theory is not an exact science, therefore microstrip equations are also not exact but instead are very accurate approximations. If one assumes that the fundamental mode of propagation is quasi-TEM, then the phase velocity of the microstrip is given in equation 1, where c is the velocity of light (3×10^8 m/s).

$$V_p = \frac{c}{\sqrt{\varepsilon_{eff}}} \tag{1}$$

The wavelength within the microstrip line is given in equation 2.

$$\lambda_g = \frac{\lambda_o}{\sqrt{\varepsilon_{eff}}} \qquad \lambda_o = \frac{c}{f} \tag{2}$$

The characteristic impedance of a microstrip line is given in equation 3 where C is the capacitance per unit length.

$$Z_o = \frac{1}{V_p C} \tag{3}$$

An important factor often overlooked in designing a microstrip circuit is a cover over the microstrip. In most applications, a microstrip circuit is placed in an enclosure. Again, since the fields are not completely within the substrate, a cover would have to be positioned at a height that would not cause interference to the fields. When this is not possible, the cover prematurely terminates the fields which in turn increases the density of field lines in the air. As a result, the line capacitance increases, which effectively lowers the characteristic impedance and the effective dielectric constant.

Microstrip Impedance Equations

The closed-formed equations for microstrip were taken from the articles written by March (2) and Bahl (3). The most accurate equations are those by March which are used in the microstrip program. The dimensions for covered microstrip are shown in Figure 3. It should be noted that the equations do not take into account the presence of side walls. The distance between the side wall and the microstrip line must be a minimum of five times the strip width W, otherwise the impedance and dielectric constant will be affected. Also, the "X" dimension of the enclosure should be chosen such that the waveguide modes are below cutoff.

The following equations are used in the program to generate the microstrip transmission line impedance. The equations are corrected for the effects of a finite conductor strip thickness (4). $Z_{oa\infty}$ is the characteristic impedance of open microstrip (no cover).

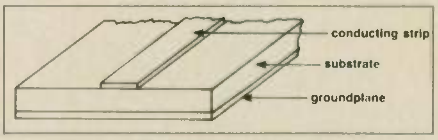

Figure 1. Geometry of microstrip.

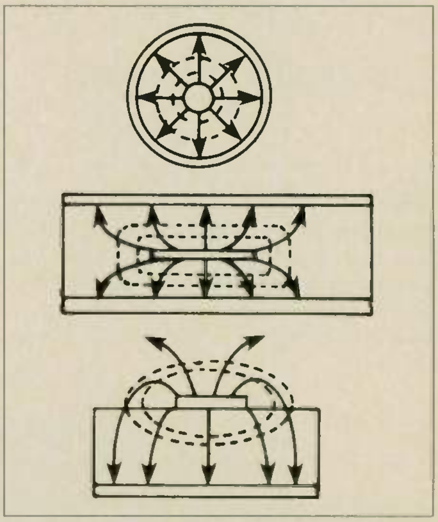

Figure 2. Field configurations. (a) coaxial, (b) stripline, (c) microstrip.

$$Z_{oa\infty} = 60 \ln\left[\frac{f(W/H)}{W'/H} + \sqrt{1 + \left(\frac{2H}{W'}\right)^2}\right] \tag{3a}$$

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

$$W' = W + \Delta W \tag{3c}$$

$$\Delta W = \frac{t}{\pi}\left(1 + \ln 4 - 0.5 \ln\left[\left(\frac{t}{H}\right)^2 + \left(\frac{t}{\pi W}\right)^2\right]\right) \tag{4}$$

The characteristic impedance Z_{oa}, is given in equation 5, as the distance between the cover and substrate is decreased. Z_{oa} is a correction factor due to the presence of the cover. It should be noted that the correction factor is valid only for an air dielectric, $\varepsilon_r = 1$.

$$Z_{oa} = Z_{oa\infty} - \Delta Z_{oa} \qquad \text{where } \Delta Z_{oa} = PQ \tag{5}$$

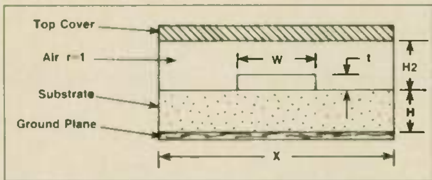

Figure 3. Microstrip dimensions.

$$P = 270\left(1 - \mathrm{Tanh}\left[1.192 + 0.706\sqrt{1 + \frac{H_2}{H}} - \frac{1.389}{1 + H_2/H}\right]\right) \quad (6)$$

$$Q = 1.0109 - \mathrm{Tanh}^{-1}\left(\left[.012\,\frac{W}{H} + 0.177\left(\frac{W}{H}\right)^2 - 0.025\left(\frac{W}{H}\right)^3\right] \Big/ (1 + H_2/H)^2\right) \quad (7)$$

$$\varepsilon_{eff} = \left(\frac{\varepsilon_r + 1}{2}\right) + q\left(\frac{\varepsilon_r - 1}{2}\right) \quad (8)$$

The filling factor is q, q_∞ is the filling factor for an infinite cover height, q_t is the correction factor for the conductor thickness and q_c is the correction factor for a non-finite cover height.

$$q = (q_\infty - q_t)q_c \quad (9a)$$

$$q_\infty = \left(1 + \frac{10H}{W}\right)^j \qquad j = a\left(\frac{W}{H}\right) b(\varepsilon_r) \quad (9b)$$

$$a\left(\frac{W}{H}\right) = 1 + \frac{1}{49}\ln\left[\frac{\left(\frac{W}{H}\right)^2 \left(\frac{W}{H}\right)^2 + \left(\frac{1}{52}\right)^2}{\left(\frac{W}{H}\right)^4 + 0.432}\right] + \frac{1}{18.7}\ln\left[1 + \left(\frac{W}{18.1H}\right)^3\right] \quad (9c)$$

$$b(\varepsilon_r) = -0.564\left(\frac{\varepsilon_r - 0.9}{\varepsilon_r + 3.0}\right)^{0.053} \quad (9d)$$

$$q_T = \frac{2\ln 2}{\pi} \cdot \frac{t/H}{(W/H)^{1/2}} \quad (10)$$

It should be noted that q_c is accurate if H_2/H is greater than or equal to one.

$$q_c = \mathrm{Tanh}\left(1.043 + 0.121\,H_2/H - \frac{1.164}{H_2/H}\right) \quad (11)$$

Finally, the characteristic impedance of the microstrip line is shown in equation 12.

$$Z_o = Z_{oa}\sqrt{\varepsilon_{eff}} \quad (12)$$

It's reported (2) that the equations fo Z_o and ε_{eff} are accurate to less than ±0.5 percent for a W/H of 0.01 to 50, ε_r of to 60 and 1 to infinity for H_2/H. Th accuracy for the filling factor equation is ±0.2 percent for a W/H of 0.01 to 10 and an ε_r of 1 to 128.

Microstrip Program Description

The microstrip program is menu driven and written in IBM's Advance BASIC. There are nine microstrip func tions that can be selected from the menu window. The software is programme with nine types of substrate materials Table 1 lists the programmed substrat materials and their corresponding di electric constants. If a board material i not listed in the menu window, simpl enter "0" for other when prompted fo a substrate and enter a new materia name and dielectric constant.

Although the software was designe to operate on a color computer, it ca be easily modified to run on a mono chrome system. To use the progran with a monochrome computer, remov the color statements from the progran lines. The following paragraphs de scribe each of the microstrip function in the program.

Substrate Material	Dielectric Constant
Alumina	9.9
Beryllia	6.8
Epoxy-Glass G10	4.8
Duroid 5780	2.2
Duroid 6006	6.0
Duroid 6010	10.2
Teflon Fiberglass	2.55
Quartz, fused	3.8

Table 1. Programmed substrat data.

Effective Dielectric Constant

This function is somewhat of a option to the user since the effectiv dielectric constant is calculated an displayed in the other functions. It advantage is if a user is only intereste in the effective dielectric constant it ca be quickly obtained because this is th only parameter the program is calculat ing.

Width of a Microstrip Line

This function calculates the width o a microstrip line for a given characteris tic impedance. If a cover is not being used, just locate it well above the microstrip (3-4 inches), when prompted for the height in the program. This effectively places the cover well out of the electromagnetic field area. The strip width has a range from 1 to 1500 mils. If a given impedance causes the calculated width to exceed this range, then the user is prompted to change the impedance accordingly.

The method in which the line width is calculated is rather simple but effective. The program enters a loop and begins calculating an impedance with an initial width of 100 mils. An error function compares the calculated and desired impedance values. If the error is positive, the loop continues increasing the line width in 100 mil steps until a negative error is produced. When a negative error occurs, the last 100 mil step is subtracted from the width. The loop is started again using the previous line width for the initial value but the width step size is now 10 mils. This process continues down to a width step size of 0.01 mils, (0.001 mil steps if the line width is less than 10 mils). The final value of the microstrip line width is determined when the impedance error converges to a range of ±0.01 percent.

Characteristic Impedance

This function calculates the impedance of a microstrip line for a given line width. The impedance is calculated directly from the equations that have been previously described.

Microstrip Inductor and Capacitor

A length of microstrip transmission line can be used to simulate a lumped-constant component (5,6,7). A microstrip inductor and a capacitor are shown in Figures 4a and 4b. Note that the width of the inductor is less than that of the transmission line and the opposite is true for the capacitor. To maintain this geometry, $Z_o' > Z_o$ for an inductor and $Z_o' < Z_o$ for a capacitor where the transmission lines system impedance is Z_o and the impedance to stimulate a lumped-constant component is Z_o'. This condition is checked in the program and the user is prompted when those conditions are violated. The width of Z_o' is calculated from function 2 (Width of a Microstrip Line).

The physical length of a microstrip inductor and capacitor is given in equation 13, where L is the inductance in Henrys and C is the capacitance in Farads.

$$l = \frac{LV_p}{Z_o'} \qquad l = Z_o' C V_p \tag{13}$$

The equivalent electrical length θ, is given in equation 14.

$$\theta = \frac{l\, 360^\circ \sqrt{\varepsilon_{eff}}}{\lambda_o} \tag{14}$$

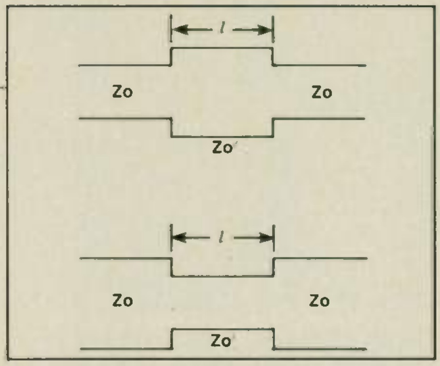

Figure 4. Microstrip inductor (a) and capacitor (b).

INFO/CARD 33

Loss Factors

There are many different types of transmission lines, but they are all affected by a common ailment, dissipation loss (8,9). For microstrip, the greatest losses are due to the conductor, including the skin effect and the dielectric substrate. These losses are given in the following equation.

$$\alpha_c(\text{dB/in}) = 23.39\ \sqrt{f\varrho} \qquad (15)$$

The conductor resistivity ϱ, is in ohms/cm. This is a simplified expression for the conductor loss because it assumes there is no surface roughness and the top conductor and ground plane are the same material.

At DC the current density is evenly distributed through the cross-sectional area of the conductor. This uniform distribution is altered as the frequency is increased and the current flow becomes constrained near the surface of the conductor. This is referred to as the skin effect (8) and the penetration of current flow in a conductor is the skin depth. The skin depth is defined as the thickness at which the current density decreases to 1/e or 37 percent relative to the value on the surface. In other words, it is the thickness in the conductor where 63 percent of the current flows. As the frequency increases, the skin depth decreases. The relative permeability μ_r, for non-ferromagnetic substrates is one.

$$\delta = 1.981 \times 10^3 \sqrt{\varrho/f\mu_r}\ \ \text{(inches)} \qquad (16)$$

Since the current penetration is very small (usually thousandths of an inch), one can take advantage of this and plate the surface of a conductor with a highly conductive metal to reduce the conductor losses. This is especially important at higher frequencies.

The second source of loss in microstrip is the dielectric loss in the substrate given in equation 17.

$$\alpha_d = 2.56f\left(\frac{\varepsilon_{eff}(f) - 1}{\sqrt{\varepsilon_{eff}(f)}}\right) \times (1.2)^{f/34}\text{Tan}\delta_0\ \text{(dB/inch)} \qquad (17)$$

Tan δ_0 is the loss tangent of the dielectric material. In general, dielectric losses are usually very small and conductor losses will exceed the dielectric losses.

Dispersion

Up to this point, the quasi-TEM mode of propagation has been used for microstrip analysis. This mode produces accurate results up through the lower range of the microwave spectrum. At higher microwave frequencies, propagation enters into what is called the "hybrid mode" and the quasi-TEM mode is no longer accurate as the fundamental mode of propagation. It is the hybrid mode that causes a transmission to become dispersive (2,9,10). Dispersion causes the characteristic impedance and effective dielectric constant to change. As the frequency increases, the phase velocity decreases and both the impedance and effective dielectric constant increase. The effects of dispersion are less for high impedance microstrip lines on thinner substrate.

Getsinger's (11) expression for the dispersion is given in equation 18.

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INFO/CARD 37

New Network Analyzer For Precision Baseband and RF Measurements

By Alan Fryer
Hewlett-Packard Company

The well-known Hewlett-Packard line of vector network analyzers has been expanded with the introduction of the model HP 8751A, offering precision measurements from 5 Hz to 500 MHz. Hardware, software, and signal processing features allow measurements to be made with high speed and high precision, with built-in analysis capability.

Major performance capabilities of the HP 8751A Vector Network Analyzer include:

- A fast swept-synthesized source with 0.001 Hz resolution, permitting accurate crystal-filter and SAW device testing. Sweep time, including measurement time, is as little as 0.4 ms per point.
- Two independent channels with −130 dBm sensitivity and selectable IF bandwidths from 2 Hz to 8 kHz.
- A tuned receiver with 110 dB of dynamic range free of unwanted spurious responses. Up to 130 dB can be achieved by controlling output power level.
- A dynamic accuracy of 0.05 dB magnitude and 0.3 degrees phase.
- Full two-port calibration with twelve term error correction and interpolation.

Test time is reduced significantly using the segmented sweep mode, an efficient alternate to logarithmic and linear sweeps. For example, the user can speed up filter measurements by instructing the analyzer to measure only a few key frequencies in the stopband, while maintaining a high resolution sweep through the passband. Up to four parameters (two per channel) can be displayed simultaneously. Together with the fast measurement capability, real-time tuning of low frequency, high resolution circuits can be accomplished. Display of a reference trace from memory further enhances tuning capability.

A high level of instrument control, data analysis, and program development is available with HP Instrument BASIC. Internal computing power allows program execution on board the instrument, with data provided via the standard 3 1/2 inch flexible disk, by menu-driven setup routines, or via the HP-IB/IEEE-488 bus. The addition of a keyboard makes the HP 8751A both a computer and a test instrument, able to directly control other instruments. A printer may be driven directly, with data buffered to avoid measurement delays. R-G-B outputs are available for an external color monitor.

Analysis of test results is made simpler with standard and optional features. Up to eight markers per trace (a total of sixteen) can identify key test points. HP Instrument BASIC adds power for mathematical analysis to manipulate and convert raw data into meaningful results. Conjugate Matching, a standard feature of the instrument, selects, computes and displays matching networks for optimum power transfer.

Conjugate Matching

Designers of RF and baseband circuits are constantly trying to intercon-

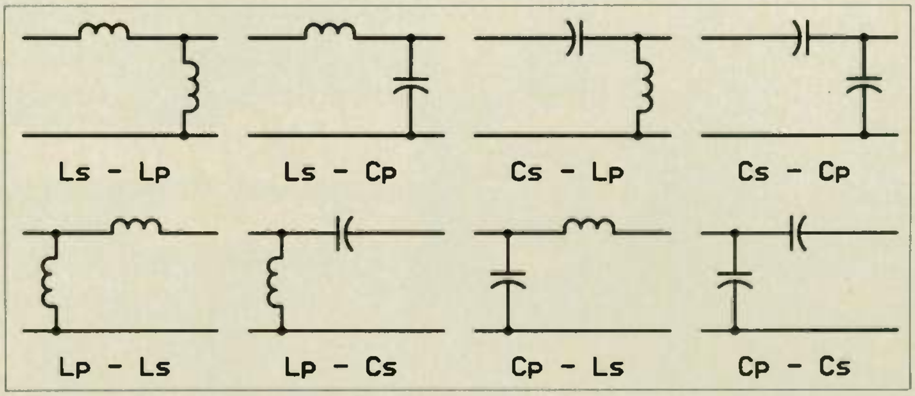

Figure 1. L-C configurations available with the Conjugate Matching feature.

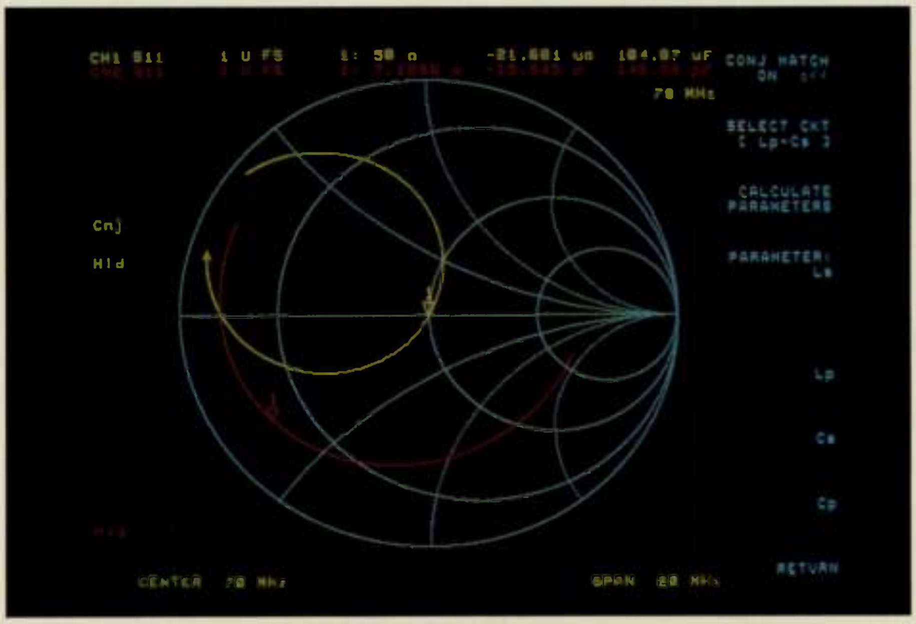

Figure 2. Screen display showing Conjugate Matching in operation.

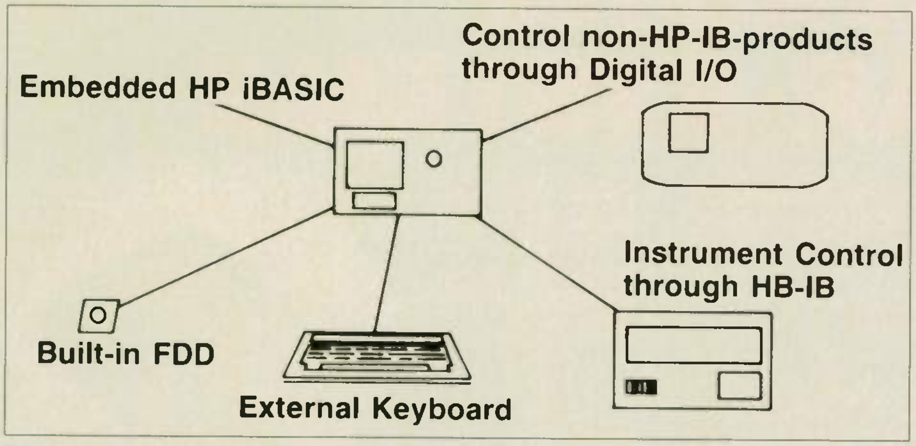

Figure 3. System configuration using HP Instrument BASIC.

nect devices with different impedance characteristics. Mismatch conditions can occur resulting in reflections and power loss, and possibly instability. Designing conjugate matching networks is not a trivial exercise. Smith charts have been used to design matching networks, and more recently, sophisticated software tools have become available.

The Conjugate Matching feature of the HP 8751A implements a single-frequency match analysis tool based on two-element L-C models (Figure 1). This feature has two functions: to approximate element parameters by automatically selecting the best models at a particular frequency; and to simulate the match achieved by any of the eight network models.

When the Conjugate Matching feature is activated, the analyzer presents the designer with a series of choices of which L-C model to use. Based on the system impedance and the position of the marker on the displayed results, values that best satisfy the test parameters of the model's elements will be computed and displayed (Figure 2).

Instrument Control and Data Analysis

HP Instrument BASIC, an optional accessory for the HP 8751A, is a direct subset of HP BASIC, containing all of the instrument input/output commands and many of the match functions. The addition of a HP-HIL keyboard converts the analyzer into the equivalent of a HP 9816 computer, supporting program development for instrument control and data analysis (Figure 3).

Both keyboard instruction statements and function keystroke memory can be used to create application programs. A sequence of setup keystrokes on the front panel of the unit can be recorded, then compiled into a program file. Larger workstations can be used to develop operating software which is then downloaded into the HP 8751A for operation.

In addition to the obvious applications of controlling the instrument's test parameters and measurement sequence, the internal computing power can be used for limit testing, event-initiated branching, relational testing, and logic functions. Storage of test results, recall of previous testing, and capture of calibration data are additional advantages of the HP8751A's computer-controlled environment.

The HP 8751A is priced at $22,500 . A high stability frequency reference (Option 001) is available for $850. HP Instrument BASIC, together with 1 MB RAM and keyboard (Option 002) is $1000. The companion HP87511A/B 50/75 ohm S-parameter test sets are priced at $5000. Also available are the HP 87512A/B 50/75 ohm transmission/reflection test kits, as well as power dividers, calibration kits, cable kits, and active probes, including a 5 Hz to 100 MHz probe with 1 megohm input impedance. *For more information, contact Hewlett-Packard at (800) 752-0900, or circle Info Card #200.* ***RF***

About the Author
Alan Fryer is Product Marketing Engineer for Hewlett-Packard Company, YIO U.S. Marketing Center, Santa Clara, Calif.

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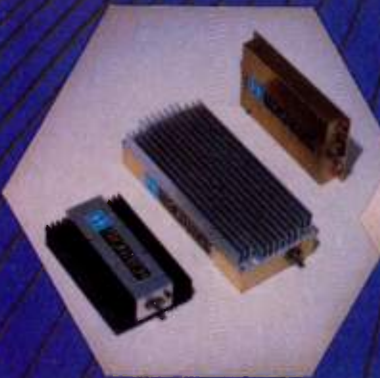
High power linear	400 — 1000 MHz	Amplifiers up to 80 Watts Linear for transmit applications
High power linear	1.7 — 2.3 GHz	GaAs Power Amplifiers for Cellular Radio Microwave Links



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RS-232 Radio Data Link Transceiver

Neulink has released the DCL 1200 Radio/Modem Transceiver which uses VHF, UHF, and 960 MHz FM radio channels to transfer data between computers or terminals. The DCL 1200 provides an interface for any RS-232-C (V.24) data application, and it can be used in remote locations as well as high density areas. Data transmission is at 1200 bits per second, in full or half duplex configurations. The DCL 1200 is a complete radio/modem package, which includes RF receiver and transmitter, modem and RS-232-C interface in a metal enclosure. Full duplex models include an internal duplexer as standard. All that is required to operate the DCL 1200 is to apply 12 VDC, an antenna, and attachment to an RS-232-C data source. Optional AC power supply and auxiliary battery backup are available. The DCL 1200 also has 0 to 2 Watts of adjustable RF power levels. It is IBM PC compatible and available with optional communications software. The DCL 1200 is UL, CSA, and VDE approved.

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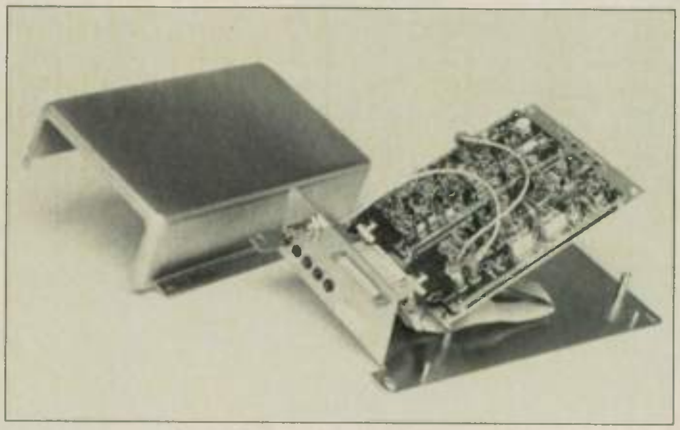


15 Watt Broadband Amplifier

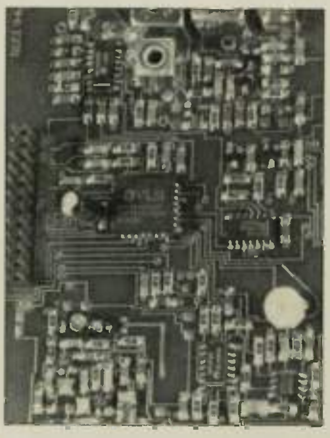
Amplifier Research has introduced a new solid-state, low-cost RF amplifier, Model 15A250. The phase response of the 15A250

makes it suitable for reproducing pulsed and non-sinusoidal waveforms throughout its frequency range of 10 kHz to 250 MHz. Applications for the amplifier include ultrasound, plasma physics, NMR, and RF susceptibility testing. Tolerance to load mismatch is total. It operates without damage, foldback, or oscillation under any conditions of source and load impedance, including shorted or open output terminals, at full rated output power. A front panel gain control lets the operator adjust the amplifier gain through at least 18 dB to a maximum gain of 42 dB. A 1.09 milliwat RF signal is the maximum input needed for full rated output power. Female BNC RF connectors are available on either front or back space. The price is $2700 and delivery is 60 days ARO.

Amplifier Research
INFO/CARD #212

Low Cost Spread Spectrum IC

The OCI-100 spread spectrum integrated circuit provides spreading and despreading functions for direct sequence spread spectrum complying with Part 15 of the FCC rules and includes most of the frequency synthesizer circuitry for operation in the 915 MHz band. The OCI-100 is compatible with low cost FSK receiver ICs and supports low-cost single modulus prescalers. Using the OCI-100, a complete 915 MHz spread spectrum radio can be built using off-the-shelf ICs or modules for the rest of the system. It operates at up to 125 kilobytes per second and sequence acquisition is very fast. Current drain is about 5 mA at 5 volts. It is supplied in a 28 pin PLCC package, is available im-



mediately and is priced at $15 in 1000 quantities.

O'Neill Communications, Inc.
INFO/CARD #211

Shielded Performance Interconnects

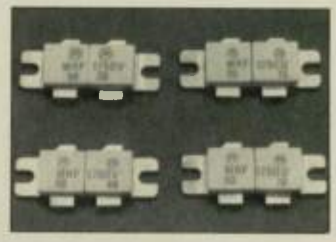
Meritec's new Shielded Performance Interconnects (SPI™) are used for fast logic, dense

package applications which require low noise crosstalk and high impedance control. The assemblies are EMI/RFI shielded and impedance controlled all the way to the PC board. The interconnects are available in straight or right angle configurations, and ground contacts are extended into connector bodies to mate first and break last, so proper grounding is ensured. The assemblies mate with 0.025 inch square or round pins and are side-to-side and end-to-end stackable on a 0.100 inch × 0.100 inch grid. Current rating is 1.0 amp/contact (continuous), and contact resistance is 10 milliohms maximum.

Meritec
A Division of Associated Enterprises
INFO/CARD #210

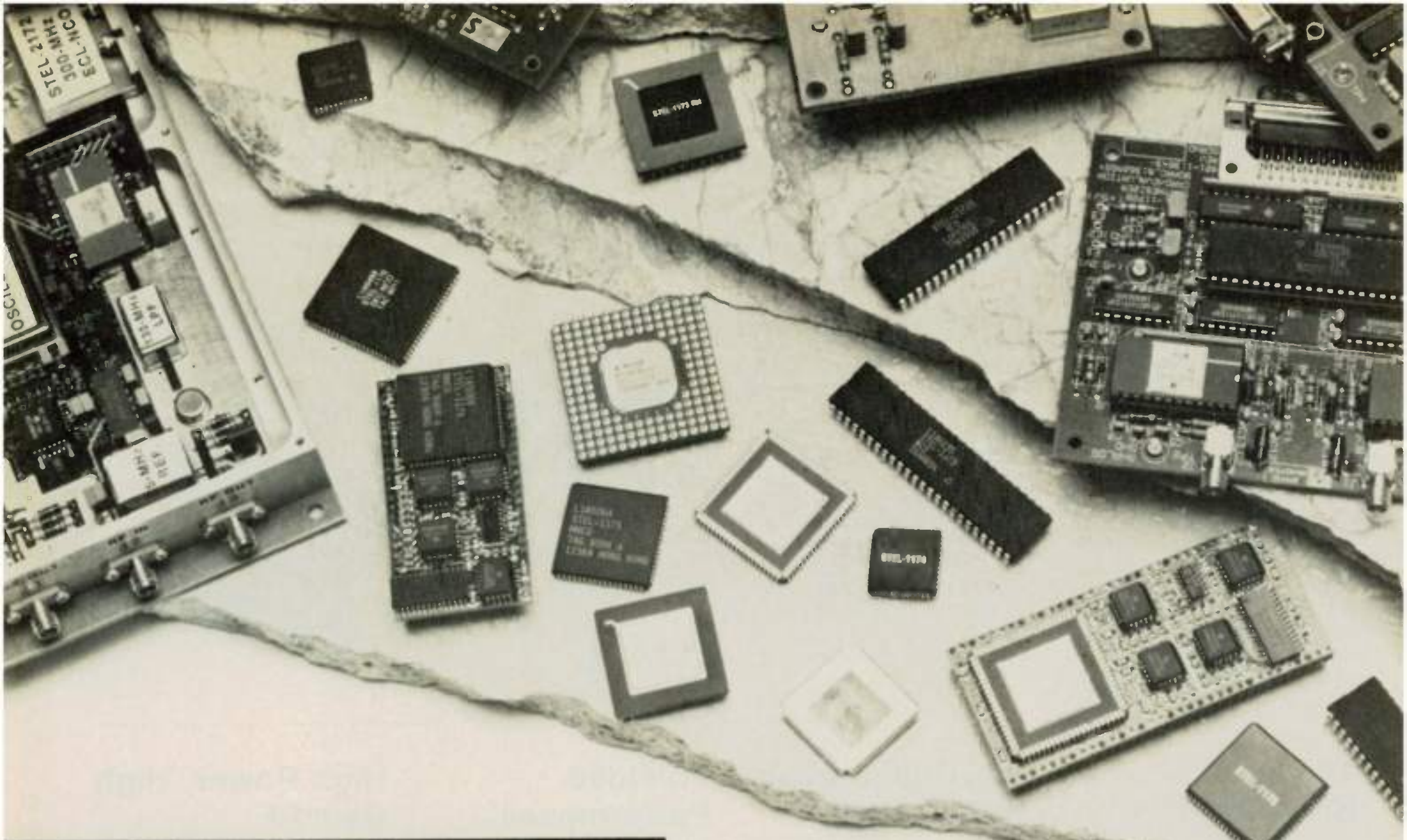
High Power, High Gain RF MOSFETs

Motorola has introduced the 28-volt MRF175GV/GU and 50-volt MRF176GV/GU, N-channel enhancement mode FETs intended for signal amplification as common source amplifiers at frequencies to 500 MHz. The GV models are characterized at 225 MHz and supply up to 200 watts at up to 17 dB gain, while the GU models are characterized at 400 MHz and deliver 150 watts at up to 14 dB gain. They also offer low thermal resistance and low C_{rss}. Designed for broadband commercial and military applications using push-pull circuits at frequencies to 500 MHz, these devices also lend themselves to applications such as solid state transmitters for FM broadcast and TV transmitters and translators, high power amplifiers for base stations, magnetic resonance equipment and sputtering



machines. Pricing in quantities of 25-99 for the MRF175 and MRF176 GV models is $118.75, and pricing for the MRF175 and MRF176 GU models is $123.75.

Motorola Inc.
INFO/CARD #209


STEL-2172
300-MHz
ECL-NCO

Current Feedback AGC Amplifier

The CLC520, a wideband current feedback AGC amplifier from Comlinear Corporation, has a high-impedance differential sig-

nal input, a high-bandwidth gain control input, and a single ended voltage output. The signal channel bandwidth is 160 MHz, with a 0.5 linear phase deviation (to 60 MHz). The gain control bandwidth is 100 MHz. The CLC520 is available in 14-pin DIP plastic and ceramic packages and is priced at $9.26 for 1000 pieces.
Comlinear Corporation
INFO/CARD #208

Dielectric Probe and Software

The HP 8507A kit, which includes a probe and software, is designed to work with a network analyzer and computer. It measures the complex permittivity, including dielectric-loss factor, of materials at RF and microwave frequencies. The kit is priced at $3,950.
Hewlett-Packard Company
INFO/CARD #207

Solid State Dual 16 × 1 Switch

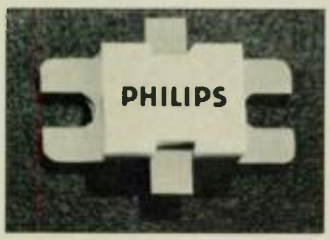
The Model 652 Dual 16 × 1 Switch, a broadband (DC to 1 GHz) switch for audio, video, IF, RF distribution, and automated test equipment applications, is now available from M/A-COM. It can be configured as a dual 16 × 1 or single 32 × 1 switch. Specifications include 4 dB nominal insertion loss, 60 dB isolation, and +27 dBm input power.
M/A-COM Government Products, Inc.
INFO/CARD #206

SAW Filter

The Siemens Y6901 SAW filter for use in satellite TV receivers features 17 dB insertion loss, 43 dB attenuation for the side lobes, and linear group delay. It is used for the second intermediate frequency of 480 MHz in satellite receiving stations and has a 3 dB bandwidth of 27 MHz.
Siemens
INFO/CARD #205

Power Transistors

Philips Components has released a series of microwave power transistors ranging from 50 W to 325 W. Using a 50 volt supply, each transistor outputs its power with a minimum power of 7 dB across the 960 MHz to 1215 MHz frequency band. Unit pricing ranges from $120 to $241 in 1,000 piece quantities and delivery is 11 weeks ARO.



Philips Components Discrete Products Division
INFO/CARD #204

RF Filters

A new line of filters has been announced by Anthony RF. Designated model ASM for surface mount options, and model ATX for TO-8 transistor packages, the product line offers highpass, lowpass, and bandpass filters in the frequency range from 60 MHz to 2.3 GHz. Prices start at $120 with delivery at 4 to 6 weeks.
Anthony RF Products, Inc.
INFO/CARD #203

HF/VHF Converter

The HF/VHF Converter Assembly, designed and manufactured by K&L Microwave, covers the 2 to 125 MHz frequency range in 17 sub-octave bands. It provides 55 dB isolation, an IF output conversion gain of +10 dB, a noise figure of 11.5 dB, rejection of 75 dB, and conforms to MIL-E-5400 and MIL-STD-883, Class 5004, Level B, requirements.
K&L Microwave Inc.
INFO/CARD #202

Thin-Film Amplifiers

Avantek has introduced two new thin-film amplifiers. The UTO/UTC-526 displays 28 dB gain over the 10 to 500 MHz range and the UTO/UTC-111 features +16.8 dBm output power and a noise figure of 1.4 dB over the 10 to 100 MHz range. Prices are $86 for the UTO-526, $156 for the UTC-526, $66 for the UTO-111, and $134 for the UTC-111.
Avantek
INFO/CARD #201

Bit Error Rate Tester

The CSA 907 Bit Error Rate Tester (BERT) from Tektronix operates at up to 700 MHz and is designed for quantifying errors that occur in high data rate digital communications. It supports both the IEEE-488.2 GPIB and the RS-232-C interfaces and can be equipped with optional 32 kbit programmable words for applications-specific pattern testing.
Tektronix
INFO/CARD #199

Low Noise and AGC Amplifiers

Miteq has just developed the model AMX-1320 low noise amplifier and a line of switchable AGC amplifiers. The AMX-1320 covers the 0.02 to 1000 MHz

bandwidth and has a typical gain of 26 dB. Miteq's line of switchable AGC amplifiers can provide 35 dB of dynamic range over the 5 to 500 MHz frequency range.
Miteq
INFO/CARD #198

INFO/CARD 46

Transimpedance Amplifiers

The ATA01500 and the ATA06210 are low power transimpedance amplifiers for use in low noise RF amplifiers, low power synchronized optical networks, and analog video receiver fields. The ATA01500 features 70 dB of dynamic range while the ATA06210 has a dynamic range of 40 dB.
Anadigics, Inc.
INFO/CARD #190

Coaxial Cable Assemblies

W. L. Gore has introduced the CX Series GORE-TEX[R] RF coaxial cable assemblies for low frequency applications up to 1000 MHz. They are 30 percent lighter than the RG type cables with a VSWR no greater than 1.2 to 1.
W. L. Gore & Associates, Inc.
INFO/CARD #189

Surface Mount Filters

K&L model 6IL10-X1800-P/P features a maximum VSWR of 1.5 to 1 and insertion loss of less than 1.0 dB. Its housing measures 1.0 × 0.375 × 0.30 inches plus tabs. The filter has a cut-off frequency of 1800 MHz and a shape factor of 1.4 to 1. 3 dB to 60 dB.

K&L Microwave, Inc.
INFO/CARD #188

EMI/RFI Test Fixture

A ferrite test fixture addressing frequencies up to 1 GHz has been released by FerriShield. The unit previews resistance properties and expected attenuation results of a ferrite assembly. The units are available from stock as part #ET28B2000.
FerriShield, Inc.
INFO/CARD #187

Low Noise Modular Amplifier

The PA779 from Phoenix Microwave features 52 dB reverse isolation and a noise figure of 1.8 dB. Small signal gain measures 39 dB typically, and output power is 13 dBm at the 1 dB compression point. The amplifier covers the 5 to 500 MHz frequency band.
Phoenix Microwave, Inc.
INFO/CARD #186

Low Power 10 Bit ADC

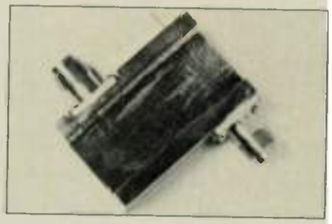
Maxim's 10 bit ADCs, the MAX173 and the MAX177, have a 5 μs conversion time with 215 mW power consumption and 8.33 μs conversion time with 180 mW power consumption respectively. The MAX177 also has on-chip track-and-hold.
Maxim Integrated Products
INFO/CARD #185

Ceramic Capacitor Design Kit

Single layer chip ceramic MIC capacitors ranging in value from 0.5 pF through 2000 pF are available in this kit from Murata Erie. The customer selects the required values in groups of 5, 10, 15, or 20 and orders the kit with the selected capacitors included.
Murata Erie North America
INFO/CARD #184

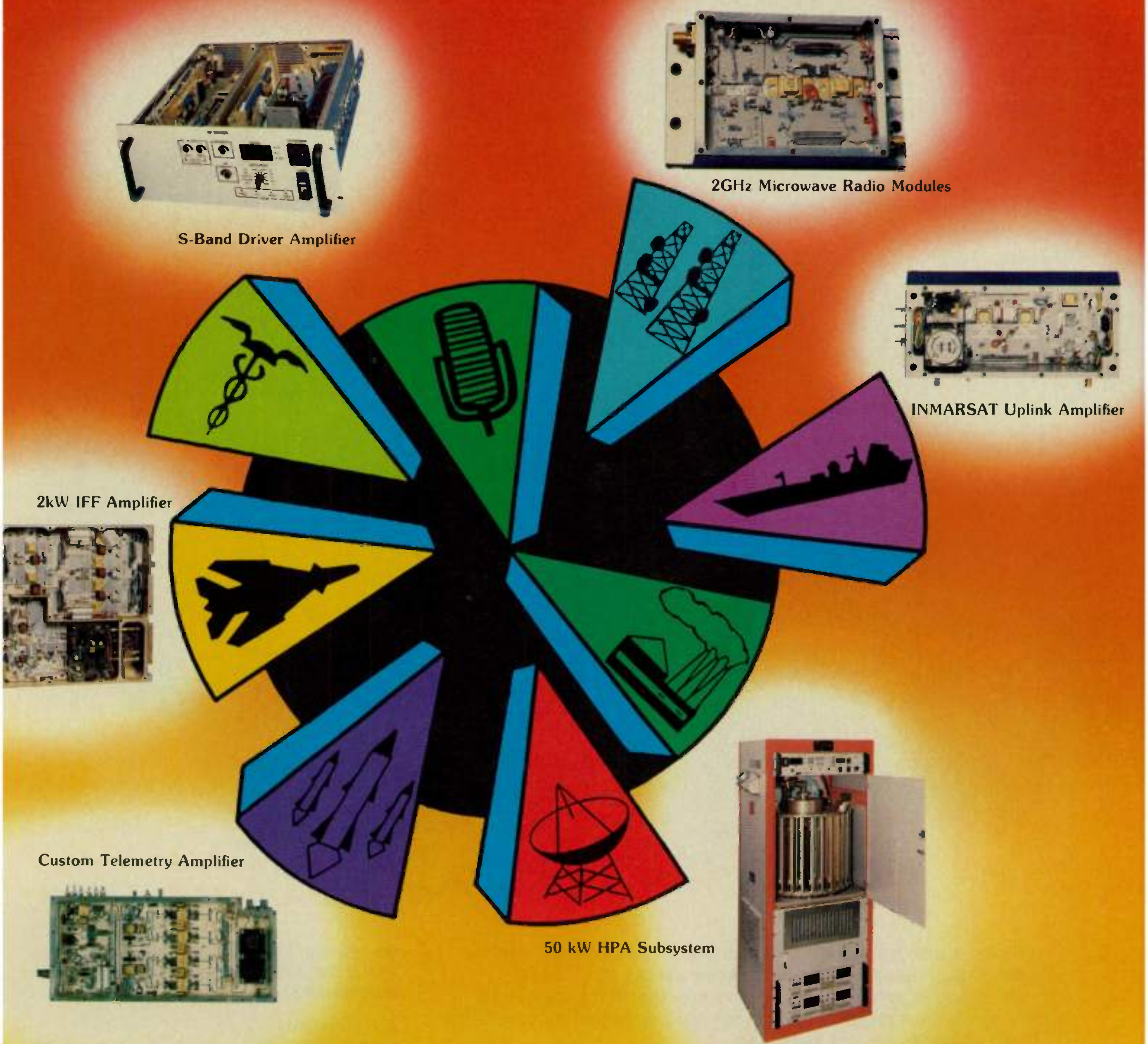
20 dB Coupler

Sage Laboratories has announced Model FC4545-2 coupler built for use at altitudes up to 70,000 feet. Typical features include insertion loss of less than 0.25 dB, from 950 - 1230 MHz and isolation of greater than 40 dB to 1500 MHz.



Sage Laboratories, Inc.
INFO/CARD #182

NO MATTER WHAT THE APPLICATION . . .



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INFO/CARD 51

Superimposing Low-Phase Noise, Low-Drift Instrumentation Techniques on RF Design

By C.M. Felton
National Institute of Standards and Technology

The information required to do good low-phase noise design is, for the most part, already in the literature under different titles. Low-noise audio design is concerned with optimizing amplitude signal-to-noise ratio. Instrumentation amplifier design isolates the desired signal using bridge configurations, (control of common mode rejection ratio (CMRR) and power supply rejection ratio (PSRR)) from interfering noise and line harmonics (1,2,3). Concerns with operating point stability at the microvolt level lead to awareness of dielectric quality, thermal stability, and bias balance requirements. At a large laboratory there are numerous sources of electromagnetic interference. Switching power supplies, clock and computer radiation, motor start-up surges, and fluorescent light spikes are as hostile an electromagnetic environment as a power utility substation. Critical applications require that such interference be considered in the basic circuit design. A balanced circuit resembles (or can be successfully encouraged to do so by the designer) a parallel, two wire transmission line, providing for rejection of external electromagnetic noise.

The focus of this paper is integrating these considerations into basic designs. A radio frequency (RF) isolation amplifier will be used to illustrate the concepts. I will discuss component selection and circuit details of the completed device and show how these affect both AM and phase noise (PM) performance.

RF Design in a Phase Noise Context

It is important to have full-time access to a relatively low-noise source (crystal oscillator), and equipment to measure amplitude and phase noise. Good low-amplitude noise design is not the same as low phase noise design, although the two are related. To aid my own visualization, I think of phase modulation occurring in series and shunt modes (Figure 1).

To the extent that a circuit element or stage is nonlinear with frequency, that stage forces a phase shift in whatever signal passes through it. Baseband noise and thermal drift, present with the desired signal, will act as variables in the modulators (Figure 1) and therefore modulate the desired signal.

Standard microwave radio frequency (RF) amplifier designs, (as presented by computers — variation on the microstrip matched, grounded emitter, capacitance coupled, single ended (class A or C configuration), present their basic characteristics as reasons for me to suspect them of being poor phase noise performers.

High-Q (≥ 1) resonant circuitry is unaesirable because a major mechanism of phase modulation is the reactive slope at any one point. The steeper the slope is, the higher the modulation efficiency and the higher the temperature coefficient.

Some form of emitter or source degeneration is crucial to obtaining low phase-noise performance. Resistance, emitter to ground, improves operating point or baseband stability and improves signal linearity. Thermal instability is a major contributor to low frequency noise, below a few hertz, and amplitude nonlinearity reduces power supply rejection as well as introducing an unstable element into the modulators (Figure 1).

Bipolar transistors have more gain at low frequencies than at radio frequencies. Capacitively coupled bipolar amplifiers can accumulate baseband noise faster than desired signal, with each succeeding stage affecting amplitude modulations (AM) to phase modulation (PM) conversion of the amplified baseband noise.

The single-ended amplifier stage has no low frequency power supply noise rejection, and no common mode noise rejection (Figure 5). This is because signal currents share the ground return with operating (B+) currents and input-to-output signal-ground currents (assuming capacitor coupling).

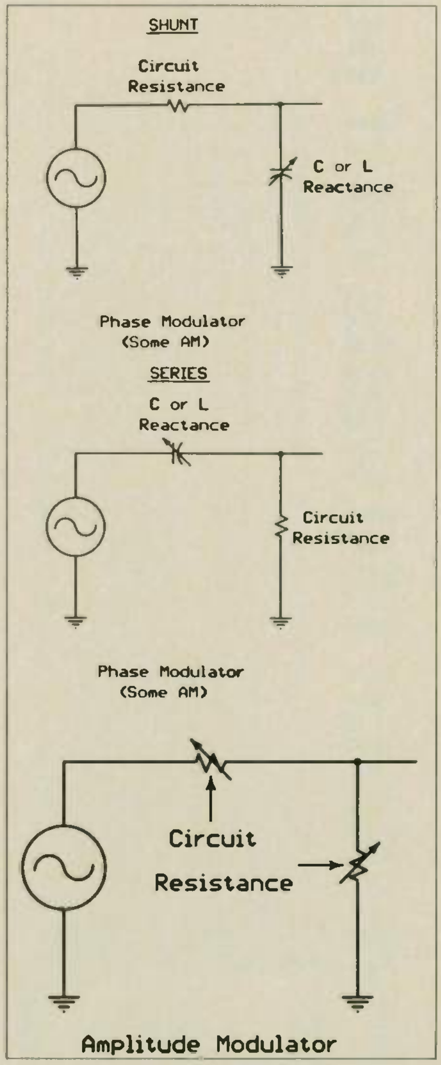


Figure 1. This is an aid to visualization. In a practical circuit, all three of these will be occurring simultaneously to one degree or another.

Transmission line transformers are a good solution for interstage coupling at radio frequencies. When impedance matched and compensated, these devices can give a flat reactive slope

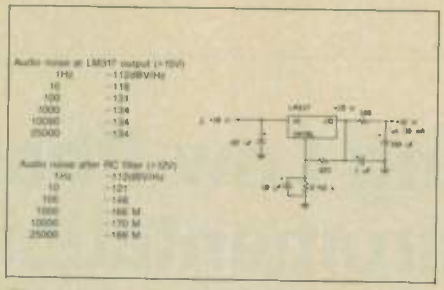


Figure 2. A simple R/C filter to reduce rail AM noise.

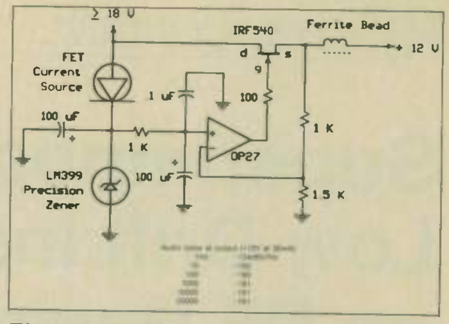


Figure 3. Phase noise reduction circuit.

around design center, while at the same time, affect impedance transformation and phase inversion, necessary for balanced amplification. Because of their transmission line construction, they also cancel external field pickup and radiation (4,5).

The balanced amplifier configuration allows use of emitter/source-coupled pairs, the basic instrumentation amplifier form which provides isolation from power supply rail noise and common mode ground plane noise (2,3). The transformer coupled push-pull pair also allows:

- Direct current paralleling of devices to reduce device generated noise.
- Common mode isolation from input to output.
- Low amplitude-distortion for a given power dissipation.
- Cancellation of even order harmonics.
- Circuit stray capacitances are in series in a push-pull stage and not direct shunts to ground. This allows wider bandwidth for a given impedance level.
- Relatively high reverse isolation from output to input.
- A large resistance or constant current source can be used in the emitter circuit without appearing in the signal path.

Ground path continuity and mass are so important that they almost cannot be used for design trade-off. When we start looking as low as 170 dB below the signal, ground path resistance and reactance, adequate for lesser dynamic ranges, can allow development of common-mode noise and signals that will compromise the noise-floor. While a balanced RF amplifier can achieve a useful degree of common-mode isolation, this reduces but does not eliminate, requirements for control of common-mode signals and noise.

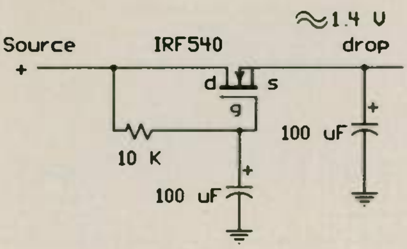
Ohm's law (E=IR) describes what happens. I will expand that a little for these purposes:

$$\frac{(CMRR)(E)}{\text{Circuit gain}} = I \times \text{(Common-mode ground path resistance + reactance)}$$

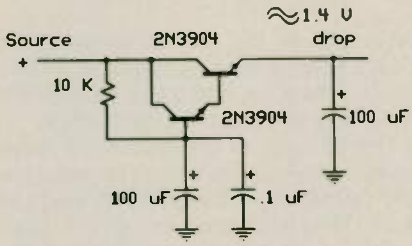
where

E = acceptable limit of interfering signal or desired circuit noise floor.
I = common mode noise current that will produce E.

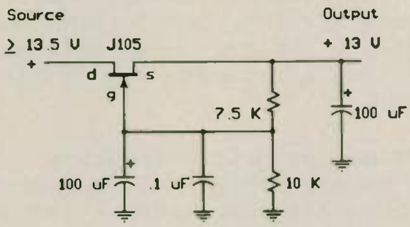
CMRR = In this case, this a complex term including, but not necessarily dominated by, a calculated figure. The amplifier physical ground path, as a percentage of the overall ground path (the path along which common mode signals are conducted), and the angular orientation of that amplifier ground path relative to noise current flow, will determine the percentage of noise signals generated by common mode currents which will be injected into the amplifier. Then, the amplifier's CMRR (if any) will act to



1Hz	−126dBV/Hz
10	−137
100	−147
1000	−163
10000	−170 M
25000	−169 M



1Hz	−127dBV/Hz
10	−146
100	−160
1000	−168 M
10000	−170 M
25000	−169 M



1Hz	−128dBV/Hz
10	−136
100	−155
1000	−169 M
10000	−170 M
25000	−169 M

Figure 4. Two low noise clean-up followers and one regulator. Noise measured at 30 mA current.

isolate the desired signal from this resultant noise. A real number for total CMRR, in this case, is more accurately arrived at experimentally.

Circuit requirements will fix the noise floor and circuit gain. Control of environment will reduce interfering signals to some unavoidable minimum. At radio frequencies, common-mode isolation is limited by relatively unstable stray reactances. After the other terms are optimized, what is left to manipulate is the found path characteristic.

For example, take three sets of points 5.08 cm (2 inches) apart. One set is connected by a printed circuit trace 1.575 mm (0.062 inches) wide. Another is connected by copper wire of 0.635 mm (0.025 inches, #22), diameter. A third set is centrally located on the unetched copper foil of a 7.62 cm (3 inch) by 12.7 cm (5 inch) printed circuit card. 100 mA of direct current and then 4.5 mA RMS at 10 MHz was applied between the three sets of printed circuit board pads to obtain approximate values for resistance and reactance.

Conclusive RF measurements across 5.08 cm (2 inches) of a continuous copper ground plane were not possible in the time available. All indications were that the reactance is very small, approximately 0.1 ohm or less at 10 MHz. Experimental estimates of the trace and wire over ground plane were not so difficult because they are much larger — 1.5 ohms and 0.5 ohm at 10 MHz.

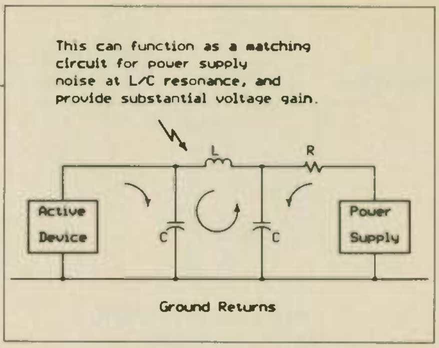


Figure 5. Capacitors used as high frequency ground returns and filters will be completely transparent at very low frequencies.

Estimates of the DC resistances are 0.0006 ohm for the ground plane, 0.0015 ohm for the wire, and 0.015 ohm for the trace. This is a relatively large trace.

The difficulty of breadboarding these measurements puts these figures in the −50 percent to +100 percent range of error. They do, however, give a good indication of the large difference between a single conductor and the continuous ground plane when it comes to controlling common-mode noise.

For example, you've got a single ended amplifier with a gain of ×10, and a maximum allowable interfering signal of 1 μV. If you have been able to get the current of common mode line harmonics down to 0.1 mA, the required total ground plane resistance would by 0.001 ohms.

Active Device Considerations

Available devices require some form of paralleling within the device structure to get a low noise corner. Large gate area in junction field effect transistors (JFET) produces the lowest noise but the highest capacitance, limiting frequency response (3). The U310 FET die is a good compromise between noise and speed. The multiple emitter site, ballasted bipolar transistor configuration, desireable for stability at micro-

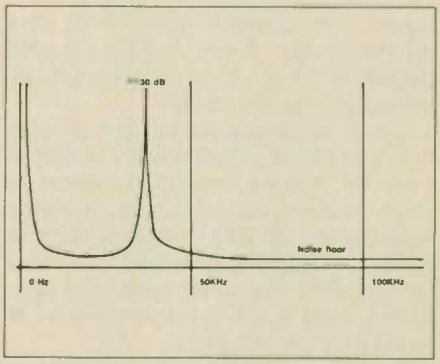


Figure 6. Noise floor peak observed during phase noise testing of circuit.

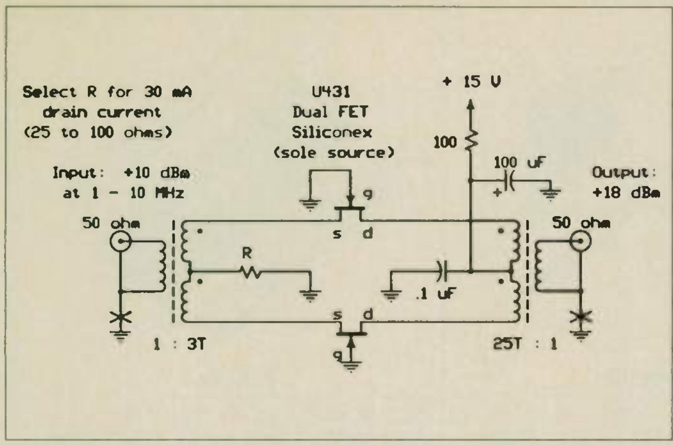


Figure 7. Isolation amplifier for lower clock frequencies.

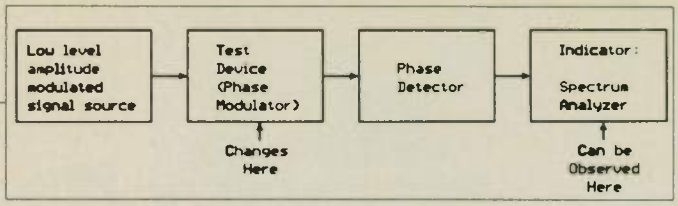


Figure 8. Real-time feedback on effects of circuit changes.

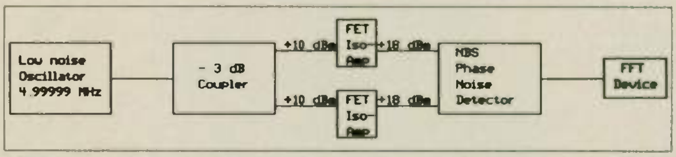


Figure 9. Block diagram of test setup for evaluation of FET iso-amplifier.

wave frequencies, can also be stable and exhibit low noise at baseband.

Since high-Q circuitry will produce a high AM to PM conversion factor and phase/temperature instability, devices with low interelectrode stray capacitances are desireable at RF. Small capacitance values can be absorbed into the compensating capacitance of the transmission line transformers allowing for the flattest possible response (4). Moderate to low operating impedances are desireable because less inductance is required for a given frequency response in transformers. I have experienced trouble obtaining flat high frequency response at the higher impedances above 400 ohms. The lower the circuit impedance, the less the effect of the unavoidable stray capacitive reactance also. Strays are by their nature unpredictable and unstable.

Junction Field Effect Transistors are limited to the common-gate configuration to keep impedances as low as practical and eliminate adverse effects of reverse transfer capacitance. Microwave bipolar transistors are most useful in the common emitter, emitter-couple pair configuration now, but better low impedance transformer designs may extend bipolar possibilities by allowing efficient use of common base configurations.

Capacitor Considerations

- Capacitance temperature stability.
- Dielectric loss temperature stability.
- Absorption (environmental stability), aging, internal and package mechanical stability (microphonics).

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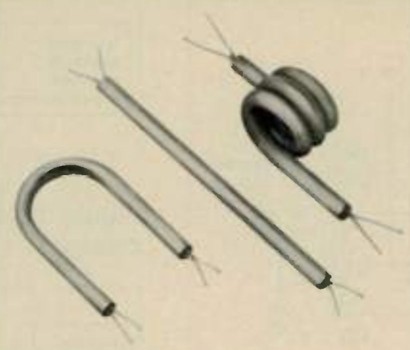

		WIRELINE	WIREPAC
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	A narrow band hybrid	HC1 & JC1 3 dB + .32 − .25 f2/f2 = 1.25 L(inches) = 1850/FMHz	KC1 & JC1 3 dB + .22 − .19 f2/f1 = 1.25 L(inches) = 1970/FMHz
	A directional coupler	A 2″ length is a 10 ± 1 dB coupler from 175 to 229 MHz	A 2″ length is a 10 ± 1 dB coupler from 186 to 244 MHz
OFFERS THESE KEY FEATURES	Low VSWR	1.2 MAX	1.1 MAX
	Good isolation	20 dB MIN	30 dB MIN
	Low insertion loss	0.3 dB MAX	0.2 dB MAX
	Handles average power	HC 100 Watts / JC 200 Watts	500 Watts
	Handles peak power	2000 Watts	2500 Watts
	Frequency range	100 MHz to 5 GHz	246 MHz to 6.5 GHz
	Outside dimensions	HC = .105″ JC = .145″	KC = .25″ dia round LC = .25″ square
	High reliability product	Used in communication satellites	Used in high power amplifiers
PLUS THESE ADVANTAGES	It's easy to use	To trim, use a razor blade and thermal strippers	Comes cut to length
	You can bend it	HC min radius of curvature .15″ JC min radius of curvature .30″	Straight lengths only
	You can buy it in bulk	Comes in 5′ lengths	Furnished only to length See below
	You can buy it cut and trimmed	Minimum length .5″	Any length .3″ to 8″
	It's inexpensive	Call us for a quotation	
	We'll send you a free sample	Send us your requirement	

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- Capacitor value reactance at frequency of interest, case and lead reactance.
- Capacitor reactance at baseband.
- For use in signal path, stacked foil Mylar, wound foil Mylar and polypropylene are low inductance and high dielectric quality.
- Use solid tantalum only where an electrolytic is required.

Inductor Considerations

- Inductance temperature stability.
- Control of radiation and rejection of external magnetic fields.
- Microphonics.
- Resonance effects at signal center frequency and baseband.
- The ferrite loaded transmission line transformer optimally applied resolved most inductor considerations and also allows implementation of a balanced, non-resonant RF amplifier.

Resistors

- Because of their superior noise and thermal performance, I use 1 percent metal film, conservatively rated resistors everywhere.

Power Supply Considerations

Three-terminal regulator broadband-noise output is approximately -135 dBV/Hz as viewed on an audio spectrum analyzer out to 400 kHz. Depending on the power supply rejection ratio and the AM to PM conversion factor of the circuit in question, this could easily set the broadband phase noise floor. Single-ended circuitry almost does not have a PSRR. Class A and C amplifiers and most forms of logic are offenders in this way (Figure 5). If the power supply situation can accommodate the additional voltage drop and power dissipation, and if the remaining close-in noise

		Frequency	Levels	
Input: +10dBm @ 5MHz		Input:		
		5MHz	+10dBm	+7dBm
Hz from the carrier	dBV/Hz	Output:		
1	-136	5MHz	+18dBm	+15dBm
10	-146	10MHz	-81dBc	-79dBc
100	-156	15MHz	-65dBc	-68dBc
1000	-166	20MHz	—Signals below—	
10000	-174	25MHz	measurement floor	
25000	-174			

Table 1. SSB phase noise and harmonic distortion data.

is not a problem, a simple resistor/capacitor (R/C) filter will reduce rail AM noise below where it will be a major contributor to circuit phase noise performance (Figure 2).

When output shunt capacitance approaches some fraction of input capacitance or there is reactance on one of the legs, three-terminal regulators can oscillate. They are, after all, gain blocks. This oscillation may not be obvious or even visible with an oscilloscope. But it will get into sensitive circuitry and cause increased noise, instability, and even intermittent thermal shut-down of the regulator. If phase noise is a major consideration, a better solution is to build a discrete regulator using a precision reference, low-noise operational amplifier, and a pass device. This can produce a power supply noise floor of approximately 160 dBV/Hz, but even here, the most critical situations will require some kind of postfiltering (Figures 3, 4).

Simple additional active low-pass filtering can be added after the regulator when current or close-in noise specifications require. This circuit also isolates the regulator from any large shunt capacitor required for a single-ended stage (Figure 4).

Baseband resonances in the B decoupling networks can generate noise peaks. Common-mode or bias currents circulate equally in the active device, decoupling circuitry, power supply, and ground path. These are all in series for low-frequency noise. Capacitors used as high frequency ground returns and filters will be completely transparent at very low frequencies (Figure 5).

Figure 6 is a representation of a noise floor peak initially observed during phase noise testing of a circuit. The same peak was observed on the power supply rail. Eliminating an accidental resonance in decoupling circuitry removed both peaks.

RF Isolation Amplifier

Here is an isolation amplifier for the lower clock frequencies (1 to 10 MHz) using readily available commercial components (Figure 7).

Input and output need not be ground referred; this allows very high input-to-output common-mode isolation.

Substituting optimized custom transformers for the commercial units can substantially expand the bandwidth.

Considerations

- Gain: +8dB, 1 to 12 MHz (−1dB, 80 kHz to 15 MHz; −3dB, 50 kHz to 26 MHz)
- Reverse Isolation: ⩾ 34dB, 10 kHz to 670 MHz
- PSRR: for drain volts, +1V, (at output 18 dBm) ⩽+1MV
- Input level for compression at 10 MHz: +11 dBm/0.1dB, +16 dBm/dB
- Phase change with temperature at 10 MHz: ⩽ 0.1 degrees/10 degrees C to 60 degrees C
- Phase noise: see Table 1.
- Linearity: see Table 1.

Testing Notes

At the lower signal levels, accidental common-mode ground noise, both coherent line harmonics and broadband noise, will probably be the biggest obstacle to a repeatable test setup. Also, slow line variations will disturb long sweep time measurements. In my own laboratory, I run all equipment involved in a particular test off one line-conditioning ferro-resonant transformer. Then, in addition to signal grounds, I run chassis-to-chassis ground straps.

After a carrier has been phase-detected, the resultant information is amplitude noise, equivalent to the phase noise. The relationship between the two is the phase-detector sensitivity (6,7). Almost any indicating device can be used after a low-noise preamplifier. Values indicated by various analyzers or even a single frequency (for example 1 Hz center frequency) operational amplifier filter (8) can be normalized to a 1 Hz bandwidth to provide interchangeability of numbers. There is a limitation in that filter bandwidth must be equal to or less than one tenth of the filter's center frequency (9). Resultant calibration can be verified using the precision noise source described in NIST paper, "Accuracy Model for Phase Noise Measurements." (10) This and some other papers relevant to phase noise analysis are listed in the references.

To observe the AM-to-PM conversion of an RF amplifier, amplitude modulate the RF signal at some low level (−80 dBc) with a high quality modulator, then measure the resultant phase noise side bands at the amplifier output. This can give real-time feedback on the effects of circuit changes (6) (Figure 8).

Figure 9 is a block diagram of the test setup used to evaluate the FET iso-amplifier. I used two iso-amplifiers to get the same conditions at both inputs of the phase detector. The resultant figure is the sum of the noise of the two amps. Phase noise coherent to the two amplifiers under test, such as phase noise induced by common power supply noise, will cancel in the phase detector. This has been known to give painfully misleading test results.

Figure 10 shows a block diagram of a common form of quadrature phase noise measurement system. Measuring original oscillator phase noise is somewhat complicated in that at least two identical oscillators that can be phase locked to each other are required (6, 10) A single oscillator and −3dB coupler will provide the two coherent signals for other tests. However, a second, non-critical oscillator will be required for calibration (7,10).

The amplitude noise test results reported for Figures 2, 3, and 4, have a repeatability range of ± 1 to 2 dB. The phase noise figures quoted for the amplifier in Figure 7 are ± 2 to 3 dB. More time with the same equipment will yield better accuracy.

Low-Amplitude-Noise Preamplifier

Figure 11 is a low-noise video preamplifier using standard parts which can be used in front of a standard or fast Fourier transform (FFT) spectrum analyzer to evaluate amplitude noise. It can also be used after a phase detector for the evaluation of phase noise.

All amplitude measurements in this paper used this pre amp. It is the limiting factor on some of them. An "M" by a figure means measurement limited.

Conclusion

When signal considerations extend 160 dB or more below the carrier, calculated incremental design solutions can reach a point of diminishing returns. Attempting to optimize as many design parameters as possible right from the start will save a lot of time. Since amplitude noise is a major source of phase noise, a good beginning is to design the lowest amplitude noise circuit possible. Then make the reactive slopes of that circuit as flat as possible, and allow some form of emitter/source degeneration.

Use of phase-noise measurement equipment to obtain real-time empirical feedback, as regards the effects of design changes, is important in this area of design that is not yet fully understood. Using this paper and the reference publications, fabrication of a basic phase-noise measuring system capable of producing verifiable documentation can be accomplished in the average analog

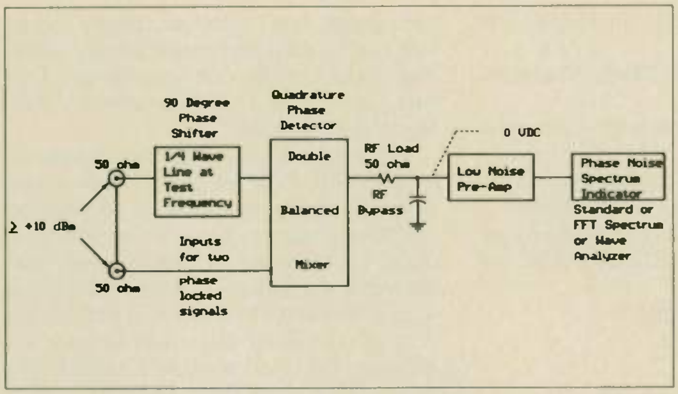

Figure 10. Block diagram of quadrature phase noise measurement system.

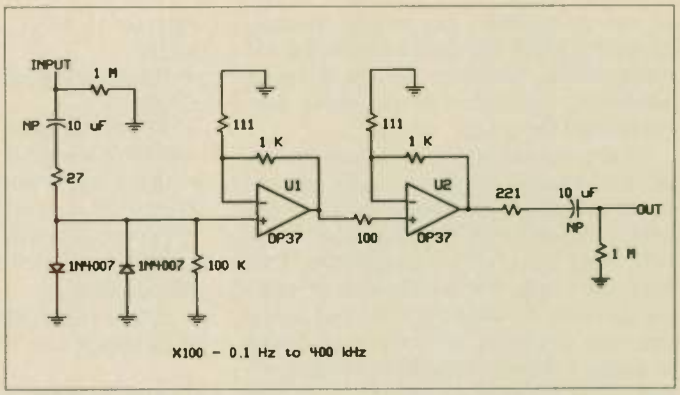

Figure 11a. Low-noise video preamplifier using standard parts.

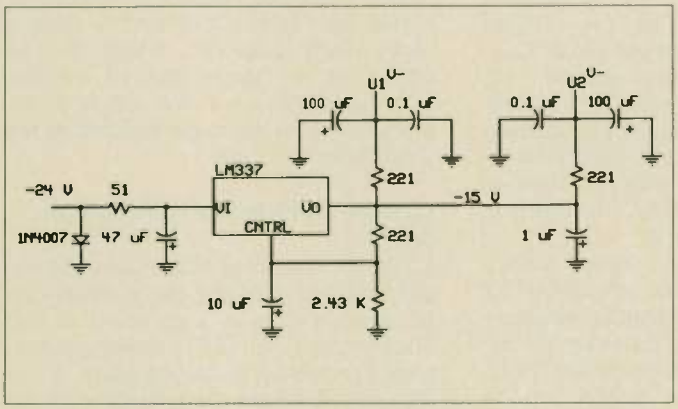

Figure 11b. Negative voltage regulator.

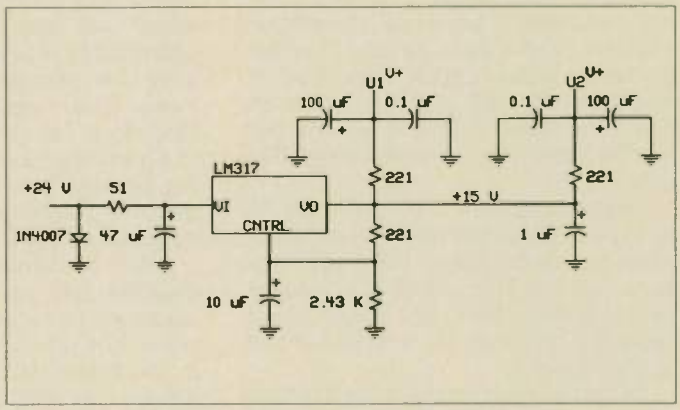

Figure 11c. Positive voltage regulator.

laboratory using existing equipment.

Initial design, component selection, layout, power supply requirements, and control of environment are each crucial in a high performance situation. Since phase noise is cumulative (multiplicative) for an entire system, system performance will be somewhat worse than the single worst gain block or device in a system. Achieving low phase-noise system performance requires careful attention to every individual function block in that system.

Acknowledgements

I thank Dr. Fred Walls for a great deal of productive discussion, and the other reviewers who guided this paper to its final form. The regulator of Figure 3 is the result of a conversation with Emmit Kyle, United States Navy.

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References

1. "Amplifier Techniques," R331-351 and "Electrical Characteristics," 61-66, C. *OP-AMP Cookbook 3rd Ed.*, Walter G. Jung, (Howard W. Sams and Co., 1986).
2. "Emitter Coupled Differential Amplifier," pp. 11-120 and "Common Mode Rejection Defined," p. 115, *GE Transistor Manual*, 7th Ed., (General Electric Co., 1964).
3. "An Introduction to FETs," 7-11 and "FETs in Balanced Mixers (U431)," 55-64, *Siliconix FET Data Book*, (Siliconix Inc., 1986).
4. Jerry Sevick, "Transformer Analyses," and all of *Transmission Line Transformers*, (American Radio Relay League, 1987).
5. *Broadband Transformer Design Information, Iron Powder and Ferrite Coil Forms* (Amidon Associates Inc., 1989).
6. F.L. Walls, C.M. Felton, A.J.D. Clements, "Accuracy Model for Phase Noise Measurements," *Proc. of the 21st Annual Precision Time and Time Interval (PTTI) Meeting*, Redondo Beach, CA, Nov. 28-30, 1989, pp. 295-310.
7. D.A. Howe, "Frequency Domain Stability Measurements: A Tutorial Introduction," NIST Tech Note 679, 1976.
8. D. Lancaster, "Multiple Feedback Bandpass Circuit," *Active Filter Cookbook*, (Howard W. Sams and Co., 1988).
9. F.L. Walls and S.R. Stein, "Accurate Measurements of Spectral Density of Phase Noise in Devices," *Proc. of the 31st Annual Frequency Control Symposium*, 1977, pp. 335-343.
10. F.L. Walls, A.J.D. Clements, C.M. Felton, M.A. Lombardi, and M.D. Vanek, "Extending the Range and Accuracy of Phase Noise Measurements," *Proc. of the 42nd Annual Frequency Control Symposium*, Baltimore, MD, June 1-4, 1988, 432-441.

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Constant Reactance Voltage Controlled Oscillator

By Raymond T. Page
Wenzel Associates, Inc.

A need exists for a very wide range voltage controlled oscillator that exhibits good frequency and amplitude stability over its entire frequency span without complex band switching. Applications include wide pull phase locked loops which incorporate a single continuously tuned VCO, broadband sweep generators with good stability at the high end of the frequency range and network analyzer oscillators with extremely flat output level over frequency.

Traditional wide-range VCOs vary only the capacitance in an oscillating tank. The reactance of this varactor and an inductor increase with frequency since the operating frequency is inversely proportional to the square root of the capacitance. Consequently, these VCOs have been limited to a tuning ratio of about 3 to 1 and the loaded Q and resulting circuit stability become degraded at the end of the frequency range. Some designs have incorporated complex switching circuits to select a more appropriate inductor as the frequency increases. Such circuits do not tune continuously from one end to the other. Varactors combined with saturable core inductors have also been used to obtain better than 3 to 1 tuning ranges, however, these circuits have been found to be hopelessly unstable, noisy and exhibit substantial hysteresis due to core magnetization.

A new approach in VCO design, a Constant Reactance VCO, (CRVCO) can be realized which exhibits the stability of a varactor-only tuned VCO while providing the wide continuous tuning range (7.5 to 1) of a varactor/saturable core reactor VCO. By actively holding the inductor's reactance constant in a feedback system that tracks the tuning varactor, high Q and exceptionally constant output power are maintained over frequency.

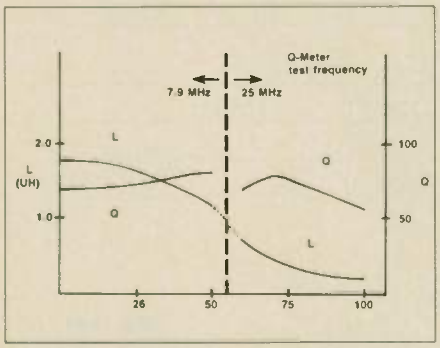

Figure 1. Q and inductance of a ferrite inductor in a magnetic field.

The saturable core reactor consists of a ferrite toroidal inductor placed in the field of an ordinary electro-magnet. As the magnetic flux increases, the 4C4 core loses permeability without significant changes in Q (Figure 1). This CRVCO employs a modified Wabash reed relay (P/N: 208-31-1) with a soft iron rod replacing the switch to direct the saturating magnetic field to the VCO coil, which uses seven turns of 30 gauge wire on a Ferroxcube core (P/N: 135T050-4C4). This combination requires less than 100 mA to fully saturate the inductor.

The MC 1648 is selected as the VCO because it contains an automatic gain control which precisely sets the voltage across the tank, allowing the inductor's reactance to be determined by measuring its current. This current is metered by connecting the ground end of the coil to the synthetic ground at the collector of a grounded base stage. A voltage proportional to the emitter current appears at the collector which is amplified and detected. The low impedance collector resistor and MMIC amplifier provide very flat wide-band response.

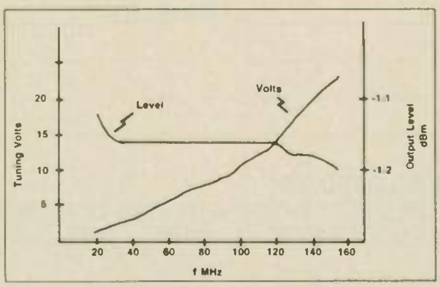

Figure 2. CRVCO's frequency and amplitude characteristics.

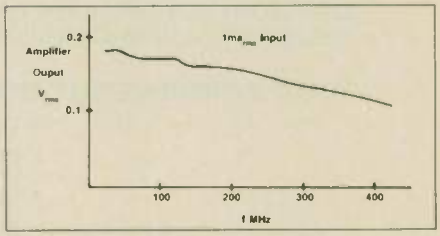

Figure 3. Transresistance amplifier frequency response.

Once detected, the inductor current results in a DC voltage which is scaled by a 50 kilo-ohm pot before it is applied to the reference pin of a TL431 shunt regulator. In this unique application the TL431 modulates the current into its cathode in an attempt to keep the reference pin at 2.5 volts DC.

As an increasing voltage is applied to the varactors, the VCO's frequency begins to rise which makes the inductor current start to drop. Since this drop in inductor current shows up as a proportionate drop in RF voltage at the detector, the voltage at the reference pin of the TL431 will attempt to increase causing the cathode to sink more current. More current through the electromagnet increases the saturation of the saturable core reactor which lowers its inductance bringing the current back up to its preset level thereby satisfying the feedback loop. The compensation network consisting of a 620 ohm resistor in series with a 0.001 μF capacitor assures that the frequency response of the TL431 is slower than the frequency response of the electromagnet for good loop stability.

Performance Data

With a tuning voltage of 1 volt to 24 volts, the CRVCO tunes from 20 MHz to 150 MHz - an incredible 7.5 to 1 tuning ratio (Figure 2)! Nearly as impressive is the output flatness, a barely detectable ± 0.04 dBm from end to end (Figure 2).

The combined performance of the grounded base stage and MMIC stage play a crucial role in just how well the saturable core reactor's reactance can be regulated. Figure 3 testifies to the transresistance amplifier's capability of being used out to 400 MHz.

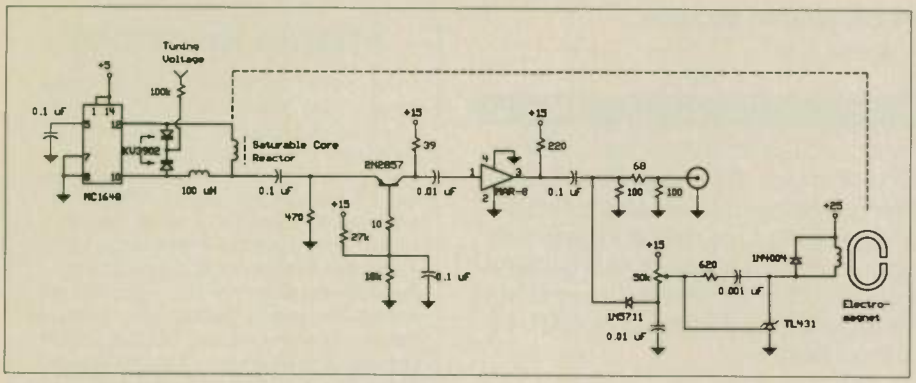

Figure 4. 20 MHz to 150 MHz CRVCO.

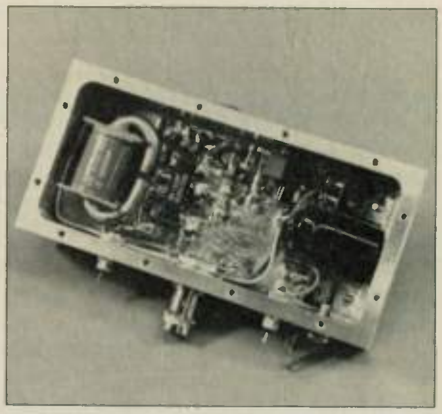

Figure 5. Photograph of CRVCO.

Summary

This CRVCO implementation need not be restricted to high ratio tuning applications. Smaller ratio designs can still benefit from its inherent stability. Other applications of the tracking saturable core reactor include high Q tracking filters or tanks with a fixed resonant frequency which alter the components' reactances. Insightful applications of this technique should lead to some very promising circuit solutions. *RF*

About the Author

Raymond Page is a design engineer for Wenzel Associates, Inc. He as done extensive work with production oscillators and special application oscillators. He can be reached at Wenzel Associates, Inc., 14050 Summit Drive, Suite 119, Austin, TX 78728. His phone number is (512) 244-7741.

SPECIAL COURSES AT RFEE

NOVEMBER 12, 13, 14 AND 15

RF expo EAST November 13-15, 1990 MARRIOTT's Orlando World Center Orlando, Florida

Preregistration is required for the following special courses.

Fundamentals of RF Circuit Design: Part I — Nov. 12

This highly popular course provides an introduction to RF circuit concepts without an intimidating amount of complex mathematics. RF component models are reviewed first, explaining parasitic effects, progressing to resonant circuits, filters and impedance matching principles, comparing analytical and graphical (Smith Chart) techniques. Scattering (s-) parameters, unilateral and bilateral small-signal/low noise amplifier design methods, stability conditions, constant gain circles are illustrated by the use of video-projected interactive CAD. Instructor: Les Besser, president, Besser Associates Inc.

Fundamentals of RF Circuit Design: Part II — Nov. 13

A sequel to Part I, this newly revised course begins with microstrip transmission line applications in RF circuits. Transmission line and transformer type power dividers and combiners, wide-band "multifilar" ferrite-core autotransformers (rod and toroid) are examined under "real life" conditions, considering balance, isolation and impedance transformation. PIN diode switches and attenuators are analyzed by linear circuit simulators. Broadband feedback and high-power amplifiers are reviewed; the effects bias, temperature, parasitics and losses are considered, and an introduction to tolerance analysis is presented. Instructor: Les Besser, president, Besser Associates Inc.

Computer-Aided Filter Design — Nov. 12

This course covers L-C filter design and analysis, with emphasis on principles and solving practical problems using the personal computer. The historical development of filter disign introduces the course, followed by discussions of the modern lowpass prototype, its transformation to highpass, bandpass and bandstop configurations, and the transfer function amplitude and delay characteristics of each. Additional topics include elliptic transfer function filters, determination of required filter order, effects of component and Q parasitics, filters as matching networks, and comments on distributed (transmission line) filters. Instructor: Randy Rhea, Eagleware/Circuit Busters.

Oscillator Design Principles — Nov. 14

First time offered at Expo East. Learn the fundamentals of oscillator design. Historically, oscillator design has been obscured with pages of equations for particular configurations. In this course, basic concepts are applied to design various oscillators using a unified approach. Attendees learn how to evaluate oscillator designs accurately. L-C distributed element, SAW and crystal oscillators are studied. Also considered are output level, starting time, harmonic levels and phase noise performance. Instructor: Randy Rhea, Eagleware/Circuit Busters.

Introduction to Modern CAD Techniques — Nov. 15

This new course offers a complete overview of the various forms of computer-aided design techniques used by RF/MW circuit and system designers. DC, AC time-domain, harmonic-balance and transient analysis principles are reviewed, including statistical and worse-case considerations. Matching network and filter synthesis are compared for both lumped and distributed elements. Circuit optimization, design centering and system analysis concepts are introduced through illustrative examples. The session closes with a discussion of software/hardware combinations to meet various budget considerations. Textbook: Computer-Aided Design of Electronic Circuits. Instructor: Les Besser, president, Besser Associates Inc.

RF EXPO EAST is sponsored by *RF Design* magazine.

RFEE '90 EXHIBITORS

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Please use the registration card on pg. 91.

RF Expo East Features an Outstanding Technical Program

RF Expo East will be held November 13-15, 1990 at Marriott's Orlando World Center in Orlando, Florida. This year's Program Chairman, Dr. Frederick H. Raab of Green Mountain Radio Research Co., has organized an outstanding program, covering both traditional and advanced RF topics. Overall participation is at an all-time high, including more international speakers than any previous Expo. With these papers, and the addition of a fifth day-long short course (see facing page), attending engineers will find RF Expo East 1990 to be a stimulating and rewarding experience.

Tuesday, November 13 — 8:30 to 11:30 a.m.

Session A-1: Receivers I (Tutorial)
Chair: Peter Chadwick, Plessey Semiconductor

Design of Receivers for Electronic Warfare
Sherman R. Vincent, Raytheon
This tutorial provides a review of the characteristics of the five basic EW receiver architectures and a review of the basic analysis equations and calculations used by the EW receiver designer.

Session A-2: Power Amplifiers
Chair: Steven J. Samay, Trontech

VSWR Performance of Transistor RF Power Amplifiers
Richard W. Brounley, RF Engineering Consultant
The ability of an RF power amplifier to operate into a SWR depends upon a number of factors including the reflection coefficient, magnitude and phase, transistor power dissipation, and amplifier stability. These factors, along with protection methods, will be discussed with emphasis on applications which have severe VSWR requirements.

A Novel Technique for Analyzing High-Efficiency Switched-Mode Amplifiers
Kazimierz Siwiak, Motorola
A novel circuit analysis technique was developed for investigating the performance of high efficiency amplifiers operating in the switched mode. The analysis gives insight into the practical implementations of high efficiency RF amplifiers, particularly at high frequencies.

RF Power Transistors for 200 W Multicarrier Cellular Base Station
Korne Vennema, Philips Components
The new generation of cellular systems requires multi-channel amplifiers with a high peak power capability. This paper describes the design and application of new common-emitter class-AB transistors with output power levels up to 200 W for 860-960 MHz base-station transmitters.

Session A-3: PLLs and Synthesizers I
Chair: Rob Gilmore, Qualcomm

The "Approximation Method" of Frequency Synthesis
Albert D. Helfrick, Tel-Instrument Electronics Corp.
There is a method of frequency synthesis which uses a phase locked loop with a reference frequency significantly greater than the minimum frequency resolution. The improvement in resolution is achieved using a unique method of direct digital synthesis to vary the reference frequency of the phase locked loop by minute amounts.

A Comparison of Techniques for Phase-Stability Measurement
Lisa M. Moder, Erbtec Engineering
Phase shift across a pulse in an amplifier offers a measurement challenge. This paper compares three techniques for making such a measurement.

Ten-Bit 350 MHz DAC for Direct Digital Synthesis
Perry Jordan, Analog Devices
A ten bit 300 MHz DAC has been tailored to the Direct Digital Synthesis (DDS) Market. This DAC combined with a 300 MHz phase accumulator and the appropriate RAM will yield a complete DDS system.

Session A-4: Microwaves
Chair: R.W. Livingston, Rockwell International

System Design Considerations for Line-of-Sight Microwave Radio Transmission
G.M. Kizer, Rockwell (Dallas)
This tutorial will focus on four major areas: System performance objectives, both national and international; Analog and digital radio transmitter/receiver performance characteristics; Site location considerations such as frequency planning and antenna characteristics; and Path Considerations.

Phase Shifter Based Upon Reflectively Terminated Multiport Coupler
M.H. Kori, Centre for Development of Telematics (India)
A reflection phase shifter, which is comprised of a reflection circuit and coupler, conventionally has the two parts designed separately. A comprehensive analysis which takes both units together reveals that the coupler also introduces phase error, making the design of a reflection phase shifter a delicate task of balancing the various parameters to obtain optimal performance.

Reflectivity Measurement Instrumentation
D.J. Kozakoff, C.W. Sirles, D.A. Thompson and R.S. Banks, Millimeter Wave Technology
This paper focuses on the design criteria implemented to develop a portable reflectometer instrument.

Tuesday, November 13 — 1:30 to 4:30 p.m.

Session B-1: Receivers II
Chair: David Krautheimer, RHG Electronics

Spread Spectrum with Digital Signal Processing
Robert J. Zavrel, Jr., Stanford Telecom
This paper will explain how several existing custom ASIC devices perform in spread spectrum systems. Although several SS techniques will be discussed, the direct sequence method is the most applicable to this design solution.

GLONASS: The Soviet L-band Spread Spectrum Navigation System
James Danaher, Structured Systems & Software
The operation of GLONASS, details of the GLONASS spread spectrum signal structure, comparison between GLONASS and GPS, and results of using GLONASS/GPS signals from satellites currently in orbit will be discussed.

Detection and Sorting of Frequency-Hopped Signals
J. Eric Dunn and Steve F. Russell, Iowa State University
Advances in high speed digitizers and processors make feasible a digital system designed to detect and dehop or "sort" frequency hopping signals. A theoretical system is developed where signal detection is accomplished using a combination of wide and narrowband FFTs.

Session B-2: MMICS

Chair: Sheryl Johnson, Motorola

GaAs MMIC Switch Products - Daily Applications
Michael Smith, Anzac
A simple overview of GaAs MMIC devices, their packaging styles, applications, and configurations will be presented. In particular, low cost switches, configurations and their replacement of pin diode circuits.

Silicon MMICs: 35 dB - 35dBm - $35
T.E. Boles, D. Osika, and M. Deiss, SGS-Thomson
SGS-Thomson has developed a line of a combination of silicon MMICs with a discrete output device to achieve the technical goals of 35 dB of RF gain and an output power level of 35dBm. This was accomplished while staying within the market driven cost goal of $35.

Some Design Considerations for L-Band Power MMICs
Robert Weber, ISU Microelectronics Research Center
It should be possible to produce high power (>10 Watts) MMICs. However, several design constraints and tradeoffs concerning thermal limitations, chip size, available components, market, etc. are considerations whenever a power MMIC is considered.

Session B-3: Filters

Chair: Maura Fox, Phonon

SAW Coupled Resonator Filter Capabilities and Applications
Allan Coon, RF Monolithics
Problems associated with SAW Coupled Resonator filters are addressed with a practical selection guide of filter technologies in the VHF and UHF frequency ranges. Generalized guidelines are developed for the optimal selection of filter technology during system design.

At Long Last: Modular, Digitally Tuned RF Filters as Easy as Amplifiers and Mixers
E.A. Janning, Pole-Zero
The design of a new family of digitally tuned bandpass filters covering 10 MHz to 1 GHz is discussed. Their excellent selectivity and wide dynamic range make them ideally suited for receiver preselection, synthesizer postselection, or transmitter noise cleanup.

Narrow Band SAW Filters for IF Applications
B. Horine and S. Gopani, Sawtek
Because of the wide selection of narrowband SAW techniques now available, the receiver design can flow smoothly from system requirements to choice of architecture and filter specifications. Several different typical receiver requirements will be discussed and SAW solutions developed for each.

Session B-4: Antennas and Propagation

Chair: Alan Victor, Monicor Electronics

Large Loop Antenna Variations
Robert P. Haviland, Mini Lab Instruments
This paper examines loop antennas of large size using various geometries and feed methods. Larger loops, arrays, and non-planar configurations are also discussed.

VHF Multipath Propagation Causes and Cures
D.R. Dorsey, Jr., DocSoft Enterprises
This paper will explore the phenomenon of MultiPath Propagation at VHF frequencies and above. It will attempt to define the basic physical causes of multipath propagation and some of the means that may be used to overcome it on line-of-sight radio links.

Radio Frequency Identification Systems for Commercial and Industrial Applications
James Eagleson, Allen-Bradley Company
RF systems can avoid problems that can prevent proper operation of other methods of ID "tagging," such as bar codes: obstructions, distance, or environmental effects. Methods currently used to implement RFID systems are presented, including performance characteristics, advantages, and difficulties.

Wednesday, November 14 — 8:30 to 11:30 a.m.

Session C-1: Receivers III
Chair: M.A. Belkerdid, Univ. of Central Florida

IF Frequency-Response Considerations for the Digital Radio Environment
Richard Roberts and M.A. Webster, Harris
This presentation includes a review of Nyquist filtering, eye patterns, and SER curves and their use in digital radio systems. Following this introduction, the relationships between IF bandpass performance and intersymbol interference are discussed, including effects of phase and amplitude, group delay, impulse response, and symmetry.

Signal Digitization for Radio Receivers
Steve Russell and J. Eric Dunn, Iowa State University
Digital radio theory and techniques are becoming increasingly important. The basic design issues involved in choosing a digitization method will be presented and an important new technique called sigma-delta analog-to-digital converters will be described.

A DSP PSK Modem for Satcom SCPC Voice/Data
Y.S. Rao, R. Asokan, K. Reeta, C-DOT (India)
A hybrid approach is presented for implementation of a DSP modulator directly at 45 MHz and brought to the 52-88 MHz range and the demodulator through a DSP at 20 kHz (Baseband frequency) after a single down conversion.

Session C-2: Transmitters
Chair: Paul Finman, LCF Enterprises

Architecture of HF-VHF Radio Transmitters
M.A. Sivers and S.V. Tomashevitch, Leningrad Electrotechnical Institute of Communications (USSR)

Digital-Feedback Techniques for a Pulse-Width-Modulated RF Power Amplifier
Harry Direen, Erhorn Technological Operations
The output of an RF power supply will vary with load variations, AC line variations, duty cycle of pulse width modulation, temperature, and other factors. This paper presents a microprocessor based feedback loop that stabilizes the RF power output at any given level.

Increasing the Efficiency of SSB Transmitters by Envelope-Tracking RF Power Amplifier
Leonid Voronov, Leningrad Electrotechnical Institute of Communications (USSR)
The method of envelope-tracking improves the efficiency of a linear RF power amplifier. This paper is concerned with the problem of achieving potential efficiency of envelope-tracking RF PA with the required IMD level.

Session C-3: SAW Tutorial
Chair: James Yolda, U.S. Army Center for Signals Warfare

Surface Acoustic Wave (SAW) Technology
C.A. Erikson, Jr., Oakmont
This 3-hour tutorial provides an overview of the fascinating technology of surface acoustic wave devices. It is geared to a practical understanding of all aspects of SAW device design, fabrication and testing.

Session C-4: RF Systems for Research in Particle Physics
Chair: Otward Mueller, General Electric Co.

RF Systems for the Advanced Photon Source
James F. Bridges, Argonne National Laboratory
The Advanced Photon Source (APS) is a positron storage ring from which x-ray beams of energies up to hundreds of keV are emitted. The RF system will be described as well as several lower-power systems at frequencies of 9.8 MHz, 117 MHz and 2.8 GHz.

RF Applications in Particle Accelerators
C. Hovater, Continuous Electron Beam Accelerator Facility
Most particle accelerators, either for physics research or medical applications, use RF fields to accelerate the charged particles. This paper discusses RF control systems and the RF circuits employed by the various types of particle accelerators.

A Fully Digital RF Synthesis and Phase Control for Acceleration in COSY
Hermann Meuth, Forschungszentrum KFA Julich
For carrier frequencies up to 2 MHz and maximum clock and sampling rates of about 40 MSPS, a fully digital real time RF signal synthesis, phase control and processing system is being designed for use on the new cooler synchrotron accelerator ring, COSY.

Wednesday, November 14 — 1:30 to 4:30 p.m.

Session D-1: Receivers IV
Chair: Mahesh Kumar, AEL

Dynamic Evaluation of High-Speed, High-Resolution D/A Converters
James Colotti, CSD/Telephonics
Although most manufacturers provide a comprehensive set of data, often devices will not be specified under the conditions called for in the application. However, dynamic D/A evaluation can uncover the necessary performance information under the appropriate conditions.

TV Demodulator to Evaluate TV Transmission Quality
P.R.M. Correa, (Brasil)
This work is based on the development of a synchronous demodulator for use in television service. Its main purpose is to obtain a demodulation of TV signals, which could assure all measurements, or the utilization of that signal in any other service.

Digital Signal Processing Based Spectrum Monitoring System for the European Broadcasting Area
Istvan Novak, Design Automation, Technical University of Budapest
This paper describes a spectrum monitoring system for the 0.1 to 30 MHz frequency range. The system is based on a high-performance, synthesizer tuned receiver and the digital signal processing (FFT) of its IF output signal.

Session D-2: Components
Chair: Sam M. Richie, Univ. of Central Florida

Impedance-Matching Transformers for RF Power Amplifiers
David N. Haupt, Erbtec Engineering
Impedance matching transformers are attractive for many applications. Unfortunately, transformer behavior at RF, and especially transmission line transformers, are poorly understood topics to many designers.

Temperature Compensating Attenuators
Perry F. Hamlyn, ANZAC
This paper will describe the use of passive positive and negative coefficient thermistors in simple resistive networks to compensate for signal level variations over temperature.

Useful Network Transformations in Filter Design
William B. Lurie, Consultant
To get practical element values in filters, exact or approximate transformations, or equivalences, can be used to achieve realizable designs.

Session D-3: Quartz Crystals and Applications
Chair: Murat Eron, Compact Software

Vibrational Sensitivity and Phase Noise in Crystal Oscillators
G. Kurzenknabe, Piezo Crystal
A growing concern in the radar, ECM and communications community is the effect of vibration on the phase noise of crystal oscillators as it degrades systems performance. This paper will review what phase noise is and why it is degraded with vibration.

Quartz-Crystal Filters: A Review of Current Issues
M.D. Howard and R.C. Smythe
This paper discusses some of the issues facing both users and manufacturers of crystal filters, including performance required for new applications, requirements for wide bandwidths, monolithic dual resonators, plus phase and amplitude matching.

Frequency Correlation of Quartz-Crystal Resonators
Bruce Long, Piezo Crystal
Quartz Crystal resonators for oscillator applications must be specified for oscillator load capacitance. Otherwise a considerable difference between the crystal frequency and the frequency of oscillation can occur.

Session D-4: Modulation
Chair: Brian D. May, NASA LeRC

New Method of Linear Amplitude Modulation
M. Lee, L. Gan and S. Zhang, Wuhan University (PRC)
Deriving from the conventional non-linear modulation method, this paper suggests a linear amplitude modulation method with mini-signals. The analysis and the experiments show that the method can be applied to any oscillator.

4-Ghz Multiplied Source for Digital Modulation
D. Balusek, Rockwell (Dallas)
This paper describes a multiplied 4 GHz source with very low microphonic susceptibility. This source is suitable for use in Digital Radio Systems using 64 Quadrature Amplitude Modulation.

Techniques in Voice Compression and Synthesis
Paul G. Beaty, Erbtec Engineering
There are several methods for compressing and synthesizing voice. The quality of speech varies from being suitable for children's toys to being suitable for a telephone conversation. This paper discusses the implementation details of such methods.

Thursday, November 15 — 8:30 to 11:30 a.m.

Session E-1: Noise Tutorial
Chair: Michael J. Willis, Georgia Tech Research Institute

Noise Fundamentals
Frank Perkins and Albert J. Ward III, RF Monolithics/Avantek
This tutorial paper discusses the nature of RF noise and reviews the concepts of noise power, noise bandwidth, noise factor, noise figure, and noise temperature. Noise calculations for cascaded RF stages are reviewed in the context of RF system design. Noise measurement techniques are discussed along with facts that affect measurement accuracy.

Session E-2: CAD and Simulation
Chair: M. Abdollahain, GTE Laboratories

Spice Modeling and Simulation of an 800 MHz, Class-AB Push-Pull Amplifier
R.Y. LaLau, Mobile Data
A design example of a Class-AB amplifier is used to illustrate the methodology and results of modeling RF amplifiers using SPICE and SPICE-based computer tools.

Computer Programs Design and Optimize High-Efficiency Switching-Mode RF Power Amplifiers
Nathan Sokal and Istvan Novak, Design Automation
Single-ended switching-mode RF power amplifiers are difficult to design accurately for wideband operation or when using non-ideal components. Complicated interactions among the component parameters and design variables yield a set of nonlinear implicit design equations which can be solved only by computer.

A Quasi-linear Determination of UHF Power Device Operation From a Spice Simulated Nonlinear BJT Model
P.E. D'Anna, MMD

Session E-3: PLLs and Synthesizers II
Chair: W.A. Davis, Virginia Polytechnic Institute

Designing With Direct Digital Frequency Synthesizers
F. Cercas, A. Albuquerque and M. Tomlinson, Institute Superior Tecnico (Portugal) and Plymouth Polytechnic (England)
A complete characterization of Direct Digital Frequency Synthesizers is made in both the time and frequency domain. As an application example of the derived expression for the power spectrum density with phase quantization, an extremely simple algorithm is described that sequentially computes the frequency and magnitude of each component and gives exactly the same result as an FFT.

Direct Digital Waveform Generation Using Advanced Multi-Mode Digital Modulation
B.G. Goldberg, Sciteq
This presentation defines an optimum waveform generation device, the performance of which has just been validated. In one square inch, it is a complete DDS (with DAC), that covers up to 10 MHz with -65dBc spurs, yet provides true digital AM, PM and FSK - while consuming a bit over one watt.

Optimum PLL Design for Low Phase Noise Performance
Stan Goldman, E-Systems
In designing a PLL, the general practice has been to select damping factor and loop bandwidth for switching time. But, switching time design goals are different from low phase noise level design goals. Optimum damping factor and bandwidth goals for low phase noise PLL design will be determined.

Session E-4: Test and Measurement
Chair: Sara Mussman, Wavetek

Design and Development of an RF Data Acquisition System
Thomas H. Jones and Madjid A Belkerdid, University of Central Florida
Accurate measurements of scattering parameters using an automatic network analyzer and S-parameter test set is a viable tool. There are several limitations to using a network analyzer however. These problems can be solved by developing a completely computer controlled data acquisition system.

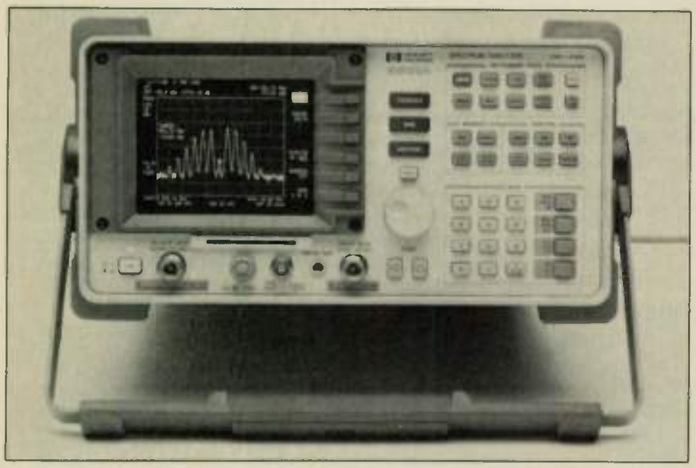
Handheld Probing Techniques for RF PCB and Hybrid Circuit Characterization
Young Dae Kim, Hewlett-Packard
This paper will address the issues related to handheld probing in RF network analysis such as source of error, calibration, and practical performance limitations.

Using the VXIbus for RF Test Equipment
M. Levy, Racal-Dana
New ATE standards such as the VXIbus are ideal for RF test systems as they allow the measurement devices, switches and interfaces to sit in one small compact unit. VXIbus RF chassis performance, RF modules for use in the chassis and interfaces suitable for test systems up to 18 GHz will be discussed.

★ ★ ★ ★ ★ ★ ★ ★ ★ **RF Design Awards Contest** ★ ★ ★ ★ ★ ★ ★ ★ ★

Prize Announcement

Grand Prize Design Contest

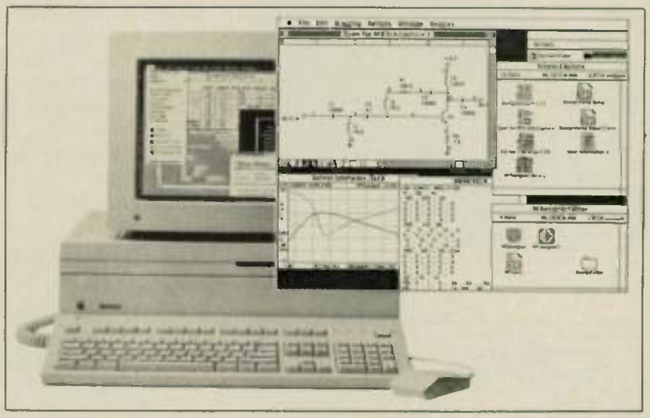


HP 8591A Spectrum Analyzer!

The design Grand Prize is a HP 8591A portable spectrum analyzer for design, production or field service. A few key specs include 9 kHz to 1.8 GHz coverage, stable synthesized LO, −115 dBm noise floor, and 1 kHz to 3 MHz resolution bandwidth. This prize is provided by **Hewlett-Packard Company.**

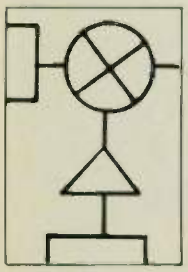
Grand Prize PC Software Contest

A Macintosh computer system with RFDesigner™ software!

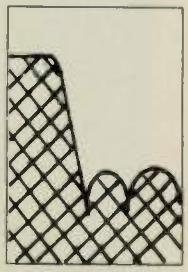


The software Grand Prize includes a complete Macintosh SE/30 computer system with 2 MB RAM, 40 MB hard disk, and ImageWriter II printer — Plus: RFDesigner analysis, synthesis and optimization software, including schematic capture and CAD software, plus auxiliary software for word processing, spreadsheet analysis, and more. This prize is provided by **ingSOFT Limited.**

★ ★ ★ Second Prizes ★ ★ ★



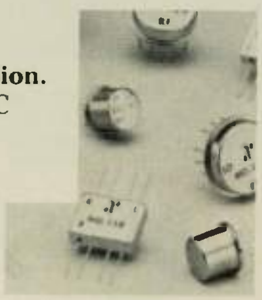
Design —
You can speed up your RF system design with this software package provided by **TESOFT** — TESS block diagram simulator plus the MODGEN model generator option. Accessories include OrCAD/SDT III schematic capture software and Microsoft's FORTRAN compiler.



Software —
Design filters faster and easier with software donated by **DGS Associates** — the student version of their Passive/Microwave filter package, which includes S/FILSYN, passive module, and utilities.

Stock your lab with this RF component package provided by **Adams-Russell, ANZAC Division.** An assortment of popular ANZAC components will be awarded to the third place winners in both categories.

Third Prize Both Contests



Every engineer who enters will receive a special RF Design Awards T-shirt. Just include your size with your entry. This special reward for all entrants is compliments of **TESOFT.**

★ ★ ★ ★ ★ ★ ★ ★ ★ **See August 1990 *RF Design*, pg. 50 for complete entry rules** ★ ★ ★ ★ ★ ★ ★ ★ ★

RF software

Smith Chart Program Upgrade

Smithsoft Plus is an enhancement of the previously released Smithsoft program. Improvements to the original include network analysis; circuit cut/paste/tune; component parasitics; Z-theta chart; H, S, Y, Z, and ABCD parameter conversions; S-parameter translation for CB, CE, and CC; and other additions. It runs on any IBM or compatible with an EGA or better display, more than 64K of screen memory, a Microsoft compatible mouse, at least 512K of memory and running DOS-2.1 or later. The price is $259 with discounts for purchases in quantity.
Somersoft
INFO/CARD #218

RF Circuit Analysis Software

Lightwave Technologies, Incorporated has released Personal RF Lab, a low cost, general purpose, linear simulation software program that includes features such as schematic capture, multiple output windows and online help. The program uses nodal analysis, and an optional optimizer is available. Measurements that are available include scattering parameters, gain and stability circles, and other parameters as well. Circuit documentation capabilities such as the ability to export schematics, graphs, and tables to page layout and spreadsheet software are supported. Prices start at $995.
Lightwave Technologies, Inc.
INFO/CARD #217

Signal Creating Software

The HP 8791 Model 100 precision signal generator is a software package for the HP 8791 frequency-agile signal simulator (10 MHz to 3 GHz). It creates precise and complex signals modulated with AM (to 20 MHz), FM (to 20 MHz deviation), phase modulation (to 20 MHz rates) or with frequency hopping speed less than 250 nanoseconds. The software works on instrument-on-a-disk architecture for front panel-like operation. All modulations may be used simultaneously, along with other user-defined formats. The price is $6,000.
Hewlett-Packard Company
INFO/CARD #216

RF Subsystem Evaluator

STRAN is used to calculate the cascaded noise figure and dynamic range of up to seventeen elements making up an RF subsystem. It can perform the cascaded calculation at any time after data has been entered on an element and can compare the calculation with a previously performed calculation.
Joseph C. Thornwall
INFO/CARD #214

PLL Prototyping Boards

RF Prototype Systems has announced a full product line brochure that provides photos, block diagrams, and other pertinent information. Completely updated, the brochure contains the company's latest designs, including the PLL Universal Serial Synthesizer Controller Board (PLLCNTRL1).
RF Prototype Systems
INFO/CARD #230

LISN Catalog

Schaffner EMC has introduced a catalog describing their Schwarzbeck Line Impedance Stabilization Networks (LISN's). These instruments are required for accurate measurements of equipment conducted emissions, RFI noise conducted back onto the AC power line from equipment under test. These units present a stabilized 50 ohm impedance over the 0.01 to 30 MHz frequency range, and can be used up to 300 MHz.
Schaffner EMC, Inc.
INFO/CARD #229

Frequency Synthesizers

Properties, specifications, applications, and prices of the complete synthesizer line spanning 0.1 to 500 MHz are given in this catalog from Programmed Test Sources. Also included in this catalog are descriptions of the options and accessories available to match customer specifications.
Programmed Test Sources, Inc.
INFO/CARD #228

SMT Chip Inductors

An eight page bulletin describing a line of SMT chip inductors is no available from Sprague-Goodman Electronics. Among the items specified in the charts are inductance, Q, self-resonant frequency, rated current, and DC resistance. The bulletin, SG-800B, also includes sections on reel and carrier specifications.
Sprague-Goodman Engineering, Inc.
INFO/CARD #227

RF Capabilities Brochure

Richardson Electronics, Ltd. now offers a brochure listing the dimensions, specifications, pricing and applications of its line of RF products. Products featured include transistors, power FETs, power modules, amplifiers, microwave transistors, microwave and RF passive power products, and semiconductors.
Richardson Electronics, Ltd.
INFO/CARD #226

RF Design Software Service

Computer programs from *RF Design*, provided on disk for your convenience
All disks are MS-DOS/PC-DOS compatible, unless otherwise noted

Disk RFD-1090: October 1990
"Microstrip CAD Program," by Thomas Cefalo of MITRE Corp. Computes microstrip impedance, delay, inductance, capacitance, and other factors. (BASIC, compiled)

Disk RFD-0990: September 1990
"Split Tee Power Divider" from article by S. Rosloniec. Performs matrix computations for analysis of this type of circuit (BASIC)

Disk RFD-DR90: Directory Issue
"Noise Bandwidth Calculations" from article by Richard Bain. Computes filter noise bandwidth by integrating data from passband graph. (QuickBasic, compiled)

Still Available: RFD-1989-SET
All 11 disks from 1989 issues of *RF Design* — $74.00 (5¼") or $82.00 (3½")
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Questions and comments should be directed to *RF Design* magazine

INFO/CARD 66

RF literature *continued*

Monolithic Ceramic Capacitors

Catalog C-01-A from Murata Erie North America provides complete electrical, mechanical, and environmental specifications on the Murata Erie line of chip, axial and radial leaded monolithic ceramic capacitors. Also included is detailed information on the company's line of monolithic ceramic capacitors designed to replace aluminum and tantalum electrolytic devices.
Murata Erie North America
INFO/CARD #225

Low Noise/Medium Power Amplifiers

Miteq has released a brochure describing selected models of its AFS Series of amplifiers. Features include: ultra miniaturization in size, ultra low noise to medium power, moderate to wide bandwidth, low power consumption, and appropriate packaging styles for different uses.
Miteq
INFO/CARD #224

Guide to RF Connectors

A new catalog from AMP Incorporated covers its complete product line and offers information on connector selection, theory and application. Included are BNC, TNC, N, C, SHV, UHF, SMA, SMB, and SMC connectors, blindmate connectors, triax connectors, and twin-ax connectors. The catalog also contains information on basic RF theory and cable and connector types.
AMP Incorporated
INFO/CARD #223

Test Instruments

Hewlett-Packard Company has released HP Direct, a catalog of test instruments and accessories. Listed are oscilloscopes, frequency counters, function generators, cables, attenuators, and other equipment.
Hewlett-Packard Co.
INFO/CARD #222

RF Amplifiers

Featuring the newest solid state amplifiers for NMR spectroscopy and magnetic resonance imaging, ENI's RF power amplifiers catalog provides specifications and information on RF products for industrial, medical, and research applications. New sections on impedance matching transformers and broadband power multicouplers are also included.
ENI
INFO/CARD #221

Advertising Index

DISTRIBUTION REDEFINED:

imprisonment and reformatory discipline; in the U. S., usually, a State prison; also, in the *Rom. Cath. Ch.*, an officer appointed to deal with cases of conscience reserved for the bishop of a diocese or for the papal court; also, an office of the papal court (presided over by the 'cardinal grand penitentiary') having jurisdiction over such cases.

pen-i-tent-ly (pen′i-tent-li), *adv.* In a penitent manner.

pen-knife (pen′nīf), *n.*; pl. *-knives* (-nīvz). A small pocket-knife, orig. one for making and mending quill pens.

pen-man (pen′man), *n.*; pl. *-men.* One who uses a pen, as in writing; one skilled in the use of the pen; also, a writer or author.—**pen′man-ship,** *n.*

pen-na (pen′ä), *n.*; pl. *pennæ* (-ē). [L., feather: see *pen*².] In *ornith.*, a contour-feather, as distinguished from a down-feather, plume, etc.

pen-name (pen′nām), *n.* A nom de plume. See *nom.*

pen-nant (pen′ant), *n.* [Var. of *pendant*, associated also with *pennon.*] A flag of distinctive form (as long and tapering, short and swallow-tailed, or triangular) and special significance, borne on naval or other vessels or used in signaling, etc.; any flag serving as an emblem, as of success in an athletic contest; also, in *music*, a hook (stroke attached to the stem of an eighth-note, etc.).

pen-nate (pen′āt), *a.* [L. *pennatus*, winged, < *penna*, feather.] Winged; feathered. Also **pen-nat-ed** (pen′ā-ted).

pen-nat-u-la (pe-nat′ū-lä), *n.*; pl. *-las* or *-læ* (-lē). [NL., prop. fem. of LL. *pennatulus*, dim. of L. *pennatus*, winged: see *pennate.*] A sea-pen (polyp) of the genus *Pennatula.*

pen-ner (pen′ėr), *n.* One who pens or writes something.

pen-ni-less (pen′i-les), *a.* Without a penny; destitute of money.—**pen′ni-less-ly,** *adv.*—**pen′ni-less-ness,** *n.*

pen-non (pen′on), *n.* [OF. F. *penon*, < *penne*, < L. *penna*, feather.] A distinctive flag in various forms (tapering, triangular, swallow-tailed, etc.), orig. one borne on the lance of a knight below the rank of banneret; a pennant; any flag or banner; also, a wing or pinion (poetic: as, "Fluttering his *pennons* vain, plumb down he drops Ten thousand fathom deep," Milton's "Paradise Lost," ii. 933).

Medieval Knight's Pennon.

pen-non-cel (pen′on-sel), *n.* [OF. *penoncel*, dim. of *penon*, E. *pennon.*] A small pennon; a pencel. [Archaic.]

pen-noned (pen′ond), *a.* Bearing a pennon.

Penn-syl-va-ni-a (pen-sil-vā′ni-ä) **Dutch.** See under *Dutch, n.*

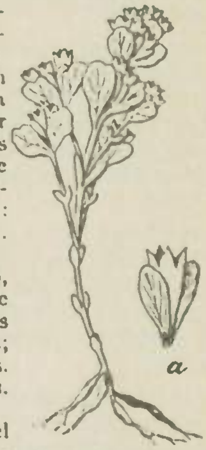
Penn-syl-va-ni-an (pen-sil-vā′ni-an). **I.** *a.* Of or pertaining to the State of Pennsylvania; in *geol.*, noting or pertaining to a geological period or a system of rocks which comprises the upper or later portion of the Carboniferous period or system in North America. **II.** *n.* A native or inhabitant of Pennsylvania; in *geol.*, the Pennsylvanian period or system.

pen-ny (pen′i), *n.*; pl. *pennies* (pen′iz) (individual coins) or *pence* (pens) (a sum or amount in this denomination). [AS. *penig, pening, pending*, = D. *penning* = G. *pfennig* = Icel. *peningr* = Sw. *penning*, penny.] An English bronze coin equal to one twelfth of a shilling, or about 2 U. S. cents; any of various coins of other countries, as the Roman denarius (see Luke, xx. 24) or the U. S. cent; in general, a coin; a piece of money; a sum of money (small or large: as, a pretty *penny*, that is, a considerable sum). Also used in composition to form adjectives denoting price or value, as in *fourpenny, fivepenny*, etc. (as used in *fourpenny nails, fivepenny nails*, etc., formerly meaning nails costing fourpence, fivepence, etc., a hundred, but now nails of certain arbitrary sizes).—**pen′ny-a-lin′er** (-a-lī′nėr), *n.* One who writes, as for a newspaper, at a penny a line or some low rate; a hack writer.—**pen′ny-an′te,** *n.* The game of poker when the amount of the ante is limited to one penny (one cent).

American Pennyroyal (*Hedeoma pulegioides*).

pen-ny-roy-al (pen-i-roi′al), *n.* [Appar. a corruption of obs. *puliol royal* (OF. *puliol*, dim. < L. *pulegium*, pennyroyal).] A European mint, *Mentha pulegium*; also, an American menthaceous plant, *Hedeoma pulegioides*, used medicinally and yielding a pungently aromatic oil (see cut).

pen-ny-wort (pen′i-wėrt), *n.* Any of several plants with round or roundish leaves, as the navelwort, *Cotyledon umbilicus*, and the Kenilworth ivy, *Cymbalaria cymbalaria* (see *ivy*), and a small American plant, *Obolaria virginica*, of the gentian family.



Pennywort (*Obolaria virginica*).—*a*, a flower.

pen-ny-worth (pen′i-wėrth), *n.* As much as may be bought for a penny; hence, a small quantity or amount; also, value for the money given, or return for one's money or trouble (as, "Have once more with hail shot. I will have some *pennyworth*, I will not lese [lose] all": Udall's "Ralph Roister Doister," iv. 7); a bargain (good, bad, etc.).

pe-nol-o-gy (pē-nol′ǭ-ji), *n.* [Gr. ποινή, fine, penalty: see *-logy.*] The science of the punishment of crime, in both its deterrent and its reformatory aspects; the science of the management of prisons.—**pe-no-log-i-cal** (pē-nǭ-loj′i-kal), *a.*—**pe-nol′o-gist,** *n.*

pen-point (pen′point), *n.* A small steel or other pen, for insertion in a penholder. [Prov., Eng. and U. S.]

pen-sion (pen′shon), *n.* [OF. F. *pension*, < L. *pensio(n-)*, payment, < *pendere* (*pendĕre*), weigh, pay: cf. *pend.*] A payment made or exacted†; also, a fixed periodical payment made in consideration of past services, injury or loss sustained, merit, poverty, etc.; an allowance or annuity; also (F. pon-syôn), in France and elsewhere on the Continent, a boarding-house or boarding-school.—**pen′sion,** *v. t.* To grant a pension to; cause to retire on a pension (with *off*).—**pen′sion-a-ble,** *a.* Entitled or entitling to a pension.—**pen′sion-a-ry** (-ā-ri). [ML. *pensionarius.*] **I.** *a.* Of the nature of a pension; also, receiving a pension; hence, hireling. **II.** *n.*; pl. *-ries* (-riz). A pensioner; in the Netherlands, formerly, the chief magistrate of a city (as, "Jean Sersanders, the *pensionary* of Ghent": J. F. Kirk's "Charles the Bold," iii. 1); specif. (usually 'grand pensionary'), the chief minister of the state.—**pen′sion-er,** *n.* One who receives a pension; hence, a hireling; also, a member of a body-guard†; a gentleman-at-arms†; also, at Cambridge University, a student who pays for his commons, etc., and is not supported by any foundation.

pen-sive (pen′siv), *a.* [OF. F. *pensif*, < *penser*, think, < L. *pensare*, weigh, ponder, freq. of *pendere*, weigh: see *pension.*] Deeply, seriously, or sadly thoughtful (as, "Their hearts . . . with thoughts of vanished years Were *pensive*": W. Morris's "Jason," x. 555); grave; sober; melancholy; also, expressing or inducing thoughtfulness and sadness (as, "the *pensive* shade of the Italian ruins": G. W. Curtis's "Prue and I," ii.).—**pen′sive-ly,** *adv.*—**pen′sive-ness,** *n.*

pen-stab (pen′stab), *n.* An article for a writing-desk, commonly a small vessel containing a brush with the bristles turned upward, for thrusting a pen into after using.

pen·stock **(pen′stok), *n.* [See *pen*¹] Technical value added RF & microwave components distributor with over $6,000,000 inventory of Avantek, Amphenol, AVX, Comlinear, EZ Form, FEI Microwave, Hewlett-Packard, Johanson, EF Johnson, Lucas Weinschel, Mini-Circuits, Omni Spectra, Penstock Engineering, Precision Tube Company, Sawtek, Toko American, and Tusonix. In Stock: Amplifiers, Attenuators, Cable Assemblies, Capacitors, Connectors, Couplers, Detectors, Diodes, Filters, Limiters, Mixers, MMIC Components, Oscillators, Power Splitters/Combiners, Semiconductors, Semi-Rigid Cable, Switches, Transformers, Transistors, Value Added Engineering. For more information call (800) PENSTOCK or circle reader service number. Sales offices throughout the U.S. and western Canada.**

fat, fāte, fär, fall, ask, fāre; net, mē, hėr; pin, pīne; not, nōte, möve, nôr; up, lūte, pull; oi, oil; ou, out; (lightened) aviāry, ēlect, agǫny, intǫ, ūnite; (obscured) errant, operā, ardent, actor, natūre; ch, chip; g, go; th, thin; ᴛʜ, then; y, you;