rf design

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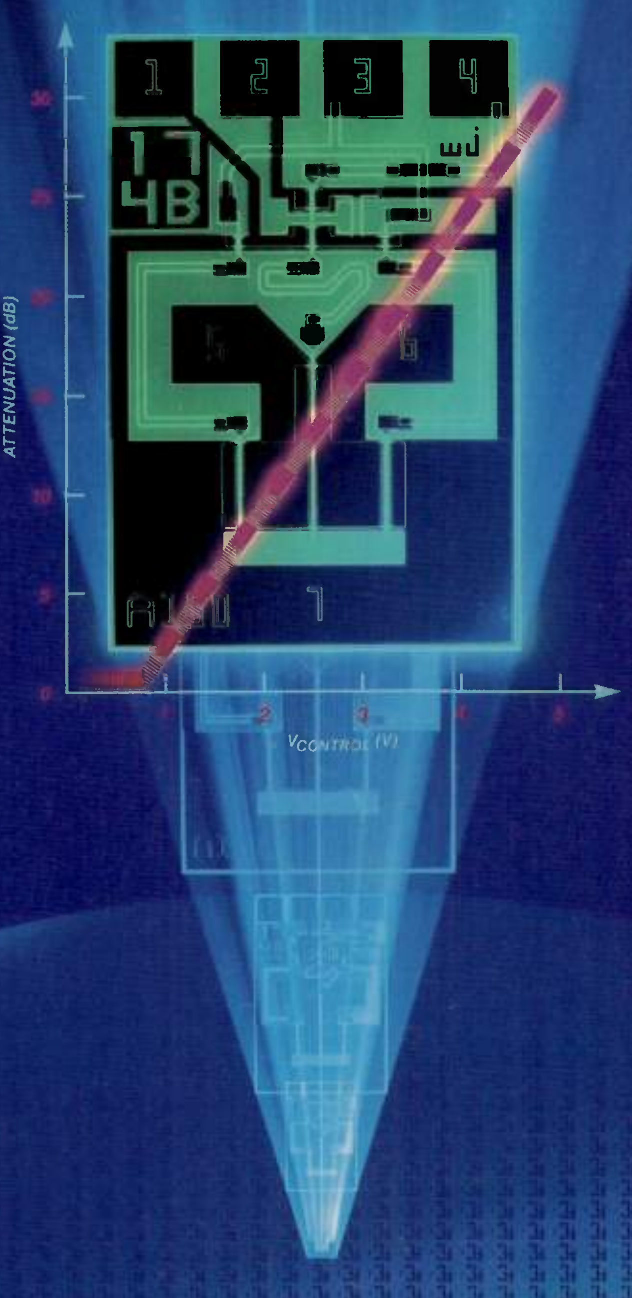
October 1987



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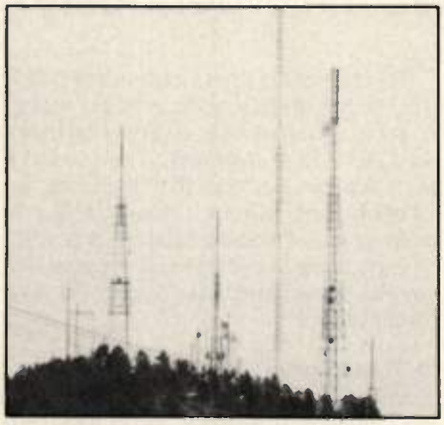
INFO/CARD 3

rf design

October 1987



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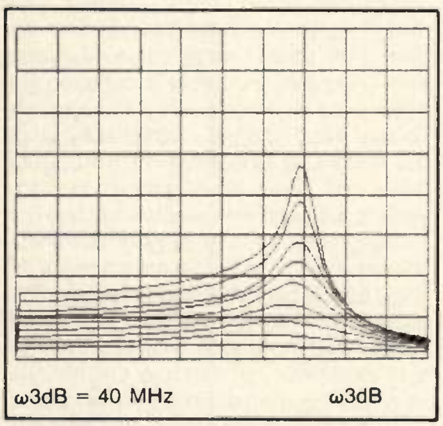

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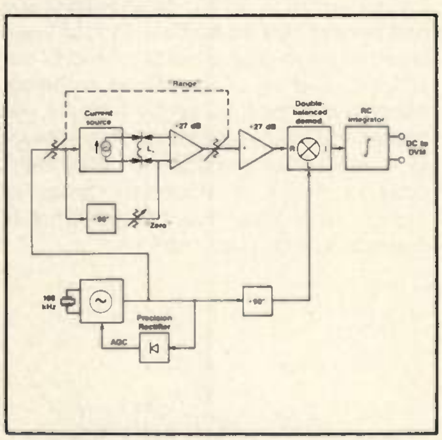

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rf editorial

Education — A Job We Take Seriously

Gary A. Breed
Editor

Among the articles in this issue is a summary of the technical program for this November's RF Expo East. Please take note of the papers to be presented, then do your best to get to Boston and take part!

With a lot of hard work, and with the able assistance of Dick Wainwright, we have developed a program that we are unable to keep quiet about. Here's what's so exciting:

Basic tutorials on power amplifier design, operational amplifiers, computer-aided filter design, phase locked loop principles and test systems.

Advanced techniques for high-efficiency amplifiers, A/D conversion, time domain analysis, network synthesis and phase noise measurements.

Practical case histories, including our contest-winning frequency multiplier, high power solid-state amplifiers, receiver IC applications, plus EMC tests and measurements.

A panel discussion on superconductivity, with examples of recent developments that are beginning to reap benefits in the world of RF.

The authors of these papers are justifiably proud of their work, and are willing to stand up before their engineering peers and share their expertise. They deserve your support, but more than that, they are offering their unique understanding to help other engineers (that means *you*). The education contained in three days of an RF Expo cannot be duplicated anywhere else.

A Re-Dedication

With this issue, *RF Design* completes nine years of publication. As we begin our tenth year, we have taken time to re-examine just what it is that makes *RF Design* valuable to our readers (and therefore, to our advertisers). The answer is the same now as it was nine years ago — we give engineers information that helps them do a better job. Although technology has changed dramatically since the November/December 1978 inaugural issue, the need for engineers to know what is going on with technology has not.

The greater effort that has gone into the development of technical programs for RF Expo East is being continued for next February's RF Technology Expo and for *RF Design* magazine itself. This effort reflects a re-dedication to our role of providing engineering education and information.

To help us do the best job possible, there are two things you can do. First, send us your comments on any aspect of the magazine, or on any other subject you feel is important. In addition to your feedback, we need your expertise. Most of our articles, and all of our Expo technical papers, are contributed by readers. No matter how many articles we may receive to consider for publication, they can't possibly cover all important areas of design. Your idea may be just what is needed. Let us hear from you.

Gary A. Breed

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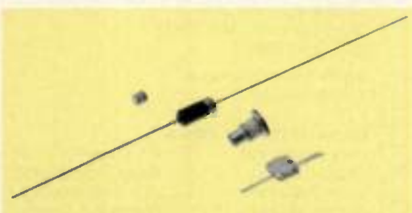

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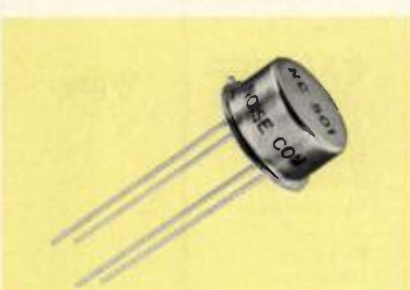

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NC 504	up to 3 GHz
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NC 506	up to 5 GHz

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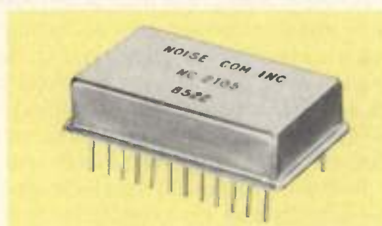

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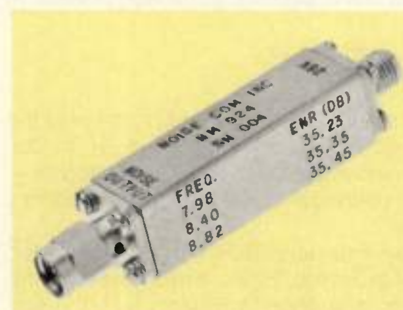

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INFO/CARD 5

Come to the (RF) Fair

By Keith Aldrich
Publisher

In January 1985, this magazine held the first RF Technology Expo — at the Disneyland Hotel, Anaheim, California — and opened a kind of gladsome Pandora's Box.

By February 1987 we had replicated that event four times; three times in Anaheim, and once in Boston, with the first RF Expo East, last November. Now as we approach the second RF Expo East — to be held November 11-13, Boston World Trade Center — it is possible to discern the emerging outlines of a somewhat festive tradition.

From the opening minutes of the first RF Expo, when we arrived to find 200 people lined up waiting for admission, it appeared clear that the Expos would be successful in one of their earliest stated objectives: to create a sense of "community" or "hometown" for RF engineers. "Not too digital" and "not too microwave," as one attendee put it, each of the Expos has attracted an "in" crowd of between 1,100 and 1,700 RF design practitioners, hungry for sessions and product exhibits which are totally relevant to their work. Tending toward youth, advanced degrees, personal computers and handheld radios, attendees seem to thrive on each other's company and the exchange of engineering ideas. Cocktails served on the exhibit hall floor the second evening of the show are already a convivial tradition.

There have been hitches, of course. At the first Expo East the exhibit hall was on a different floor of the Boston Copley Hotel than the sessions, and many attendees did not get to both floors (sessions and exhibits will be on the same level of the Boston World Trade Center next month). Some papers at some Expos have not measured up to the general high standard. (Editor Gary Breed has applied a rigorous screening procedure in developing the program for RF Expo East next month, and in future Expos his efforts will be augmented by an honorary program chairman, selected from among leaders of the industry.) Hitches and glitches are an essential element in the development of any tradition; indeed, one could hardly have a tradition without a few war stories.

As the RF Expo tradition develops we can see these parameters emerging:

- Engineering attendance will surpass 2,000 in RF Expo East next month and at RF Technology Expo 88 next February in Anaheim (based on registrations now coming in). I predict an attendance level of 3,000 to 4,000 on both coasts within a couple of years. While these are large-ish numbers, they are still "in-crowdish" compared to the multitudes that swarm into the general electronics conventions.
- In November, 1988, RF Expo East will be held in Philadelphia rather than Boston and will alternate between Northern and Central East Coast cities from then on, given a successful show in Philadelphia. In February 1989, RF Technology Expo 89 will be held in Santa Clara rather than Anaheim and will alternate between Northern and Southern California cities from then on, given a successful show in Santa Clara. In this way the RF Expos can reach a greater number of RF engineers without requiring them to travel long distances.

You may be among those who have yet to attend one of the RF Expos. If so, you will be amazed at the new world — your own world — that will open up when you get there.

Come to the RF fairs!

Keith Aldrich

rf design

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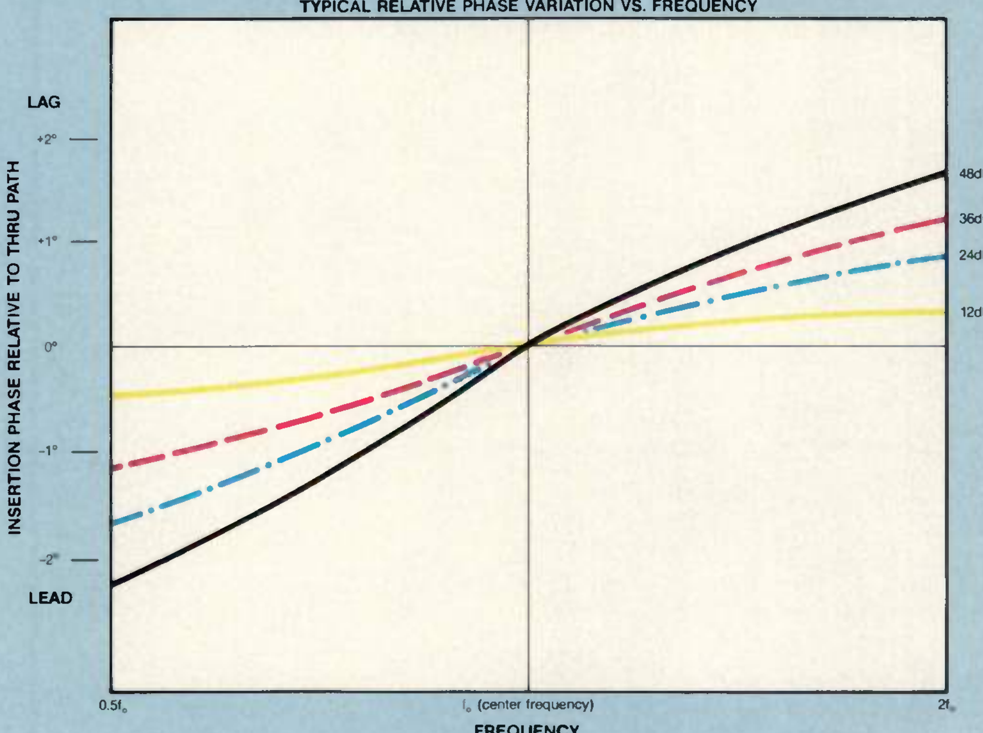

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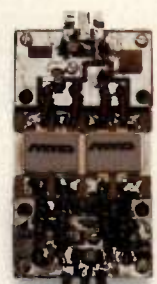

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Letters should be addressed to: Editor, *RF Design*, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111.

An Omission

The software listings in the September issue failed to include a valuable contributor to RF engineers' computing needs:

E.E. Public Domain Library
36 Irene Lane East
Plainview, NY 11803

We suggest that interested readers write directly to proprietor Gerald Harrison at the above address for the latest listing of available software. — *Editor*

"The Engineering Personality" Reactions

Editor:

I want to congratulate Keith Aldrich for recognizing and courageously stating that engineers are not complete "social nerds." Perhaps we should be more colorful, social and assertive to regain the "renaissance man" image. However, our positive traits: dedication, loyalty, artistic sensitivity and dependability, more than offset our "nerdishness." With additional training in the areas of political, economic and social awareness, we can truly be the lovable, outgoing and involved individuals needed to create the better world we all want.

I am proud to be one of us!

Les Besser
Besser Associates Inc.
Palo Alto, CA

Editor:

Thank you for your editorial in the August 1987 issue. It is nice to receive a compliment every so often, even though we "shy" types would avoid that in public.

Please remember, however, that the name "nurd" (*National Lampoon* spelling) was given to engineers for a reason. I believe the reason is that many engineers are so very narrow in their outside interests. Beware of the engineer who builds computers as work, then goes home to write technical software on his personal computer. This man may be a genius, but hardly the type who would be included in high-level marketing or goal-making decisions.

On the other hand, there are those of us who have so many outside interests and hobbies that it sometimes seems that we do not have enough time or energy to go to work (my boss won't see this letter!). These other interests do not include designing electronic devices. Some of us are even interested in history and current world affairs.

Changing the college curriculum to include more humanities courses is not the answer to the problem . . . Don't apply more pressure to a curriculum already trying you pull you under with technical courses.

One last point: college may be too late to see that there are other things going on in the world that should be of concern an interest. People must be subjected to as many different concepts as possible while as young in age as possible. This includes real-world concepts, too, not just academic ideas. How many parents or teachers discuss the business world with young children? When my second grade son single-handedly won the school trivia championship for his class, I was more proud of him than if he had won the school spelling bee.

Fred Gribbell
Merrel-Dow
Cincinnati, OH

New Book Covers HF Broadband Transformers

Transmission Line Transformers by Dr. Jerry Sevick, W2FMI, offers experimental and theoretical information on high frequency RF transformers useful to experienced engineers and hobbyists alike. Among the author's noteworthy contributions are experimental results on twisted vs. parallel windings and wire vs. coaxial cable windings. Also included is valuable data on the relationships between impedance levels and transformer bandwidth.

In addition, the text covers core materials, winding methods, fractional-ratio windings, multiple windings, series transformers, baluns, and limitations at high impedance levels. The chapters include analyses, low frequency characterization, high frequency characterization, transformer characterization, and simple test equipment. The book represents an excellent value, priced at only $10 (hardbound), available from the American Radio Relay League, Inc., 225 Main St., Newington, CT 06111.

UL Opens EMI Test Facility

Underwriters Laboratories Inc. (UL) has begun operation of an EMI test facility at its Northbrook, IL headquarters. UL conducts compliance testing to FCC Parts 15 and 18 as well as to EMI Standards used by VDE in Germany. Parts 15 and 18 of the FCC rules and regulations cover products such as computing devices, television and radio receivers, walkie-talkies, garage door openers, ultrasonic equipment, microwave ovens, plus industrial, scientific and medical equipment.

Study to Focus on Superconducting Ceramics

Gorham Advanced Materials Institute, a subsidiary of Gorham International, Inc., is planning to conduct a multiclient program of research in superconducting ceramics. The program, *A Global Assessment of the Business Impacts of High Transition Temperature Superconducting Ceramics on Permanent Magnet Producers, Users, and Raw Materials Suppliers,* will be an investigation and assessment of the magnetic and current-carrying systems presently being used, and will determine which systems will benefit from or be affected by superconducting ceramics. The program will also provide an identification of new systems and products which may evolve.

Physicists have announced unprecedented achievements in superconducting ceramics over the past seven months, raising transition temperatures to above 95K and current densities to over 1×10^5 A/cm^2. A Japanese government laboratory recently announced evidence of superconductivity in a ceramic oxide compound at 323K (50 degrees). For additional information including a prospectus detailing the study, contact: Gregory L. Perron, Manager, Market Research and Business Planning, Gorham Advanced Materials Institute, P.O. Box 250, Gorham, ME 04038-0250, Tel: (207) 892-5445.

Motorola to Discontinue 19 Products

The special functions operation of Motorola's MOS Digital-Analog Integrated Circuits Division will end the manufacture of all versions of the following devices: MC6190, MC6191, MC6192, MC6193, MC6194, MC6195, and MC6196 NMOS phase-locked loop (PLL) frequency synthesizers; MC14444 CMOS A/D converter; MC14457 remote control transmitter; MC14458 remote control receiver; MC14460 automotive speed control processor; MC14466 low-cost smoke detector: MC145029 remote control decoder; MC145104, MC145107, MC145109, MC145112, MC145143, and MC145144 PLL frequency synthesizers. These devices will be available for lifetime buy orders for a six month period ending December 31, 1987. Contact your Motorola representative for more information.

Frequency Electronics Acquires TRW Microwave

TRW Microwave, a subsidiary of TRW Inc. of Sunnyvale, California has been acquired by Frequency Electronics, Inc. of Mitchell Field, New York. Under its new affiliation, TRW Microwave will become FEI Microwave, Inc., and operate as a wholly owned subsidiary of Frequency Electronics. According to Peter O. Clark, President of FEI Microwave, the company plans to continue all operations at its present three building site in Sunnyvale.

Profits Drop at Grumman

Grumman Corporation, an aerospace contractor, has posted a 34 percent profit drop for the second quarter. This translates to a profit of 32 cents a share versus 50 cents a share a year ago of which 11 cents was from the sale of a Data Systems division subsidiary. Excluding that gain, the decline would have been 18 percent. Also, during the first half of the year, Grumman eliminated 1500 jobs at its Long Island facilities due to a falloff in F-14 Navy fighter production. According to John Bierwirth, chairman and chief executive, the company will suffer a further decline in the third quarter followed by an anticipated recovery in the fourth quarter.

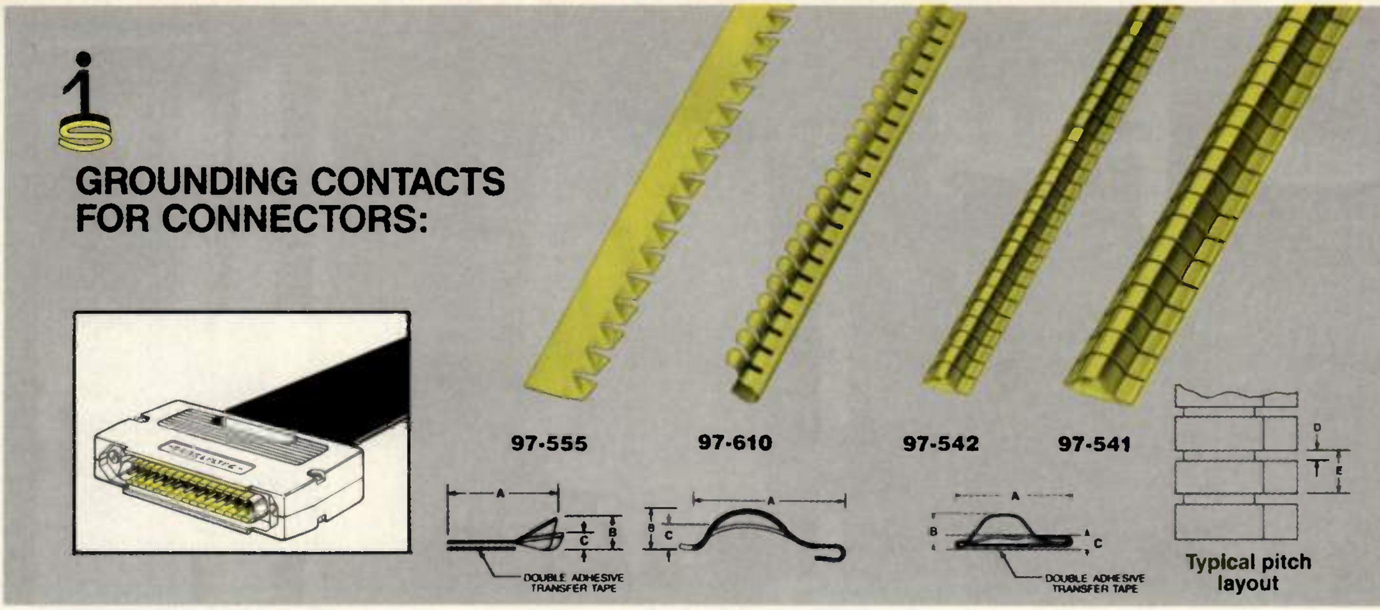
KDI Acquires Triangle Microwave

KDI Corporation announced that it has completed the acquisition of Triangle Microwave, Inc. where it will be operated as a wholly-owned subsidiary. KDI Electronics is a wholly-owned subsidiary of KDI corporation. The merger is valued in excess of $35 million.

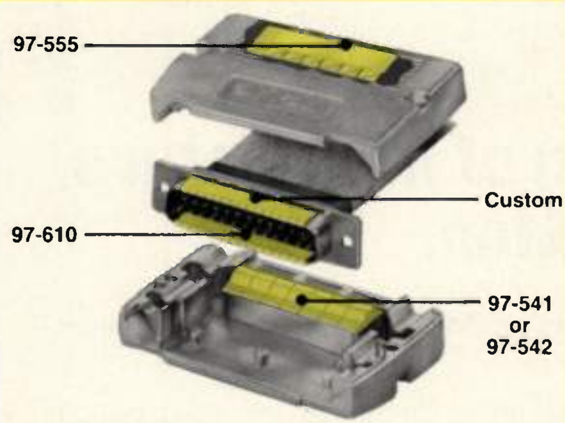
TRAK Acquires Operation in Scotland

TRAK Microwave Corporation has acquired Channel Microwave (Scotland) Ltd. of Dundee, Scotland. Channel manufactures ferrite isolators and circulators for commercial applications such as cellular radio base stations and microwave links. Channel will continue as a wholly-owned subsidiary of TRAK.

TRAK is also establishing TRAK Microwave Ltd. which will be located in a separate facility adjacent to Channel Microwave, to produce coaxial couplers, rotary joints, isolators, circulators, and other passive microwave products. TRAK Microwave Corp. is based in Houston.



Which Instrument Specialties contact strip will solve your connector grounding problem?



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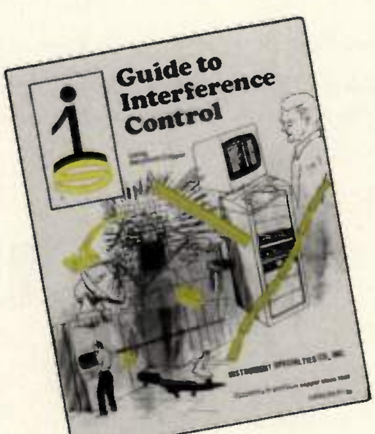

More complete descriptions of these strips and other shielding products can be found on pages 10 and 11 of our Guide to Interference Control. Write for your free copy. Address: Dept. RFD-35.

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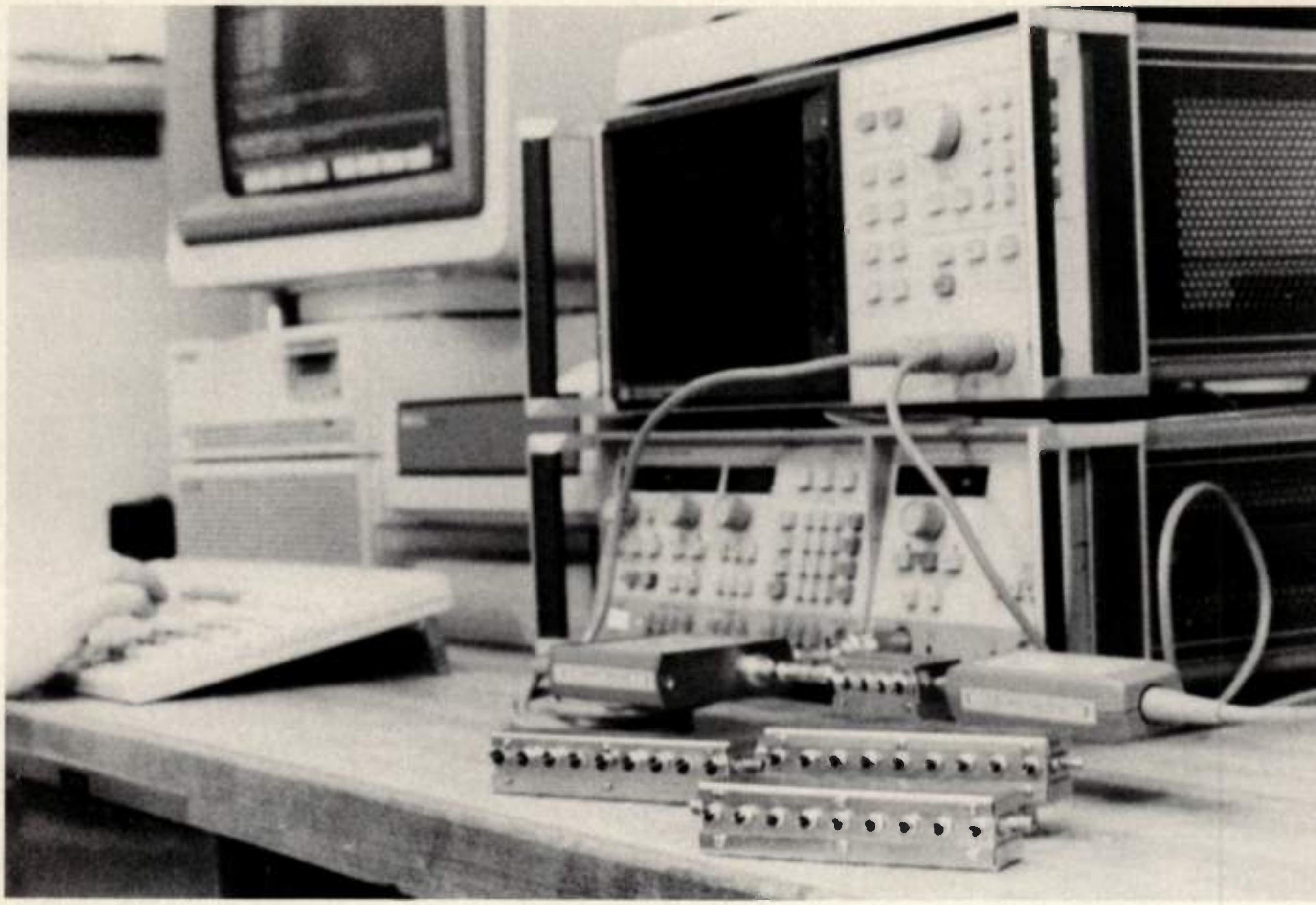

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INFO/CARD 11

Innotec Acquires Eratron

Innotec Group Inc. announces that it has acquired the assets and business interests of Eratron Inc. of Campbell, CA. Eratron designs and manufacturers DC and RF plasma power supplies including medium frequency RF generators used in semiconductor epitaxial systems, AC power controllers, and magnetic components.

Scientific-Atlanta Receives $2.2M

Scientific-Atlanta, Inc., has received a $2.2 million order from McDonnell Douglas Aircraft Company, St. Louis, Missouri, for a pulsed radar cross section measurement system and a Series 5750 Compact Range.

Marine Corps Awards Bid To Gould

Gould Inc. announced that its Test & Measurement Group has been awarded an order from the U.S. Marine Corps for high- performance digital oscilloscopes. Valued at approximately $1 million, these 100-MHz digital oscilloscopes will be used as general test equipment in repair and service.

AEL Awarded $27.9M

American Electronic Laboratories, Inc. announces that it has been awarded a $27.9 million contract by the U.S. Army to produce 15 additional AN/MLQ-34 TACJAM systems. The new award increases the value of TACJAM contracts issued to AEL since May 1983 by the U.S. Army's Center for Signal Warfare Laboratory at Vint Hill Farms Station, Warrenton, VA, to $168,843,332. The AN/MLQ-34, an electronic warfare system mounted on a tracked vehicle, combines computer control with multiple jamming capabilities. The TACJAM antenna can be retracted rapidly and the entire system can be moved quickly over virtually any type of terrain for redeployment.

Diagnostic/Retrieval Systems Wins $14.6M in Contracts

Diagnostic/Retrieval Systems (DRS) has received three contracts totalling $14.6 million. Two contracts are from the Naval Sea Systems Command (NAVSEA) and one from Magnavox Government and Industrial Electronics Company. NAVSEA awarded DRS a $9.8 million contract for additional quantities of AN/SQR-17A sonar signal processing sets and support services. The AN/SQR-17A is a highly sensitive antisubmarine warfare detection device that aids sonar operators in target direction, analysis and classification. The second contract from Naval Sea Systems

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INFO/CARD 13


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Command, valued at $1.3 million, was received to provide additional quantities of AN/SQR-17/18A interface kits and engineering support services. DRS also received a $3.5 million contract from Magnavox Government and Industrial Electronics Company for display generator modification kits.

Cincinnati Electronics and American Systems Team Awarded $4.8M

Cincinnati Electronics Corporation (CE) has been awarded a contract from American Systems Corporation (ASC) for the U.S. Air Force Sentinel Bright II program. The $4.8 million contract to CE is for the construction of a series of radar signal analysis trainers which will enable students to learn the operation of an ELINT collection system via simulation. The trainer provides several displays including an angle-of-arrival (AOA) PPI, RF Spectrum, IF Spectrum, oscilloscope and frequency counter. The system also provides audio signal recognition training.

Solid State Relays From Kodak

Eastman Kodak Company announced plans to market solid-state relays for use in the commercial and industrial markets which are manufactured at the Kodak Apparatus Division in Rochester, NY. According to John Calver, Product Manager of the Solid State Relay Group, Kodak's relays have a failure rate of only 0.05 per million hours of operation — claimed to be 2,000 times more reliable than conventional relays.

Submarine Signal Division Receives $9M

Raytheon Company's Submarine Signal Division has won a U.S. Navy contract totaling $9 million for production of transducers for advanced submarine sonar acoustic arrays. These transducers convert electric energy to acoustic energy, and both send and receive underwater signals. The contract runs for 39 months and calls for the manufacture of 5,400 transducers. Production deliveries are scheduled to begin in mid-1989.

Interstate Electronics Awarded SDI Contract

Interstate Electronics Corporation has been awarded a $3 million contract from the U.S. Air Force Armament Division, Eglin Air Force Base, for the development of a global positioning system (GPS) frequency translator to be used for tracking the exoatmospheric reentry-vehicle interceptor subsystem (ERIS) and its reentry vehicle target in support of the SDI program. The contract calls for a total of 44 units with deliveries starting in September 1988 and with options for deliveries through December 1990.

Datel Completes Buyout from GE

Datel, Inc. announces that it had completed the purchase of the Datel Division of General Electric Company by a management group led by President Nicholas G. Tagaris and Vice President Leif D. Jacobsen, top officers of the Datel Division. This announcement finalizes the agreement in principle released in March 1987, between Datel and General Electric officials in Research Triangle Park, NC.

Headquartered in a 180,000 square foot facility in Mansfield, MA, Datel has subsidiaries in England, France, West Germany and Japan. U.S. direct sales offices are located in New England and California.

rf courses

Besser Associates

Principles of RF Design — Theory and Application

December 14, 15, 16, 1987, Santa Clara, CA

Information: Les Besser, Besser Associates, Inc., 3975 East Bayshore Rd., Palo Alto, CA 94303; Tel: (415) 969-3400

The George Washington University

Introduction to Receivers

October 19-20, 1897, Washington, DC

Modern Receiver Design

October 21-23, 1987, Washington, DC

Global Positioning System: Principles and Practice

November 4-6, 1987, Washington, DC

HF Communications Technology

November 16-20, 1987, Washington, DC

Modern Communications and Signal Processing

November 16-20, 1987, Washington, DC

Tools for Evaluating Command, Control, and Communication Systems

December 2-4, 1987, Washington, DC

Wideband Communications Systems

December 7-11, 1987, Washington, DC

Modern Digital Signal Processing and Applications

December 14-18, 1987, Washington, DC

Fiber-Optics System Design

Feb 29-Mar 2, 1988, Washington, DC

Information: Shirley Forlenzo, Continuing Education Program, George Washington University, Washington, DC 20052; Tel: (800) 424-9773, (202) 994-8530

UCLA Extension

Kalman Filtering II

October 26-30, 1987, Los Angeles, CA

Smart Armament/Missile Systems and Technology

October 27-29, 1987, Los Angeles, CA

Information: UCLA Extension, P.O. Box 24901, Los Angeles, CA 90024; Tel: (213) 825-1901; (213) 825-1047; (213) 825-3344

Interference Control Technologies, Inc

Grounding and Shielding

October 20-23, 1987, Boston, MA
November 3-6, 1987, Philadelphia, PA
November 17-20, 1987, San Jose, CA
December 1-4, 1987, Las Vegas, NV

Tempest Facilities

October 20-23, 1987, Washington, DC

RFI Design and Measurement

October 26-30, 1987, Philadelphia, PA

Practical EMI Fixes

November 10-13, 1987, San Jose, CA

Tempest Design

November 17-20, 1987, Mountain View, CA

Information: Penny Caran, Registrar, Interference Control Technologies, Inc., State Route 625, P.O. Box D, Gainsville, VA 22056; Tel: (703) 347-0030

Integrated Computer Systems

Digital Signal Processing

October 27-30, 1987, Anaheim, CA
December 1-4, 1987, Washington, DC
December 8-11, 1987, Boston, MA
January 26-29, 1987, Washington, DC

Image Processing and Machine Vision

October 27-30, 1987, Palo Alto, CA
November 3-6, 1987, Toronto, Canada
December 1-4, 1987, Washington, DC
January 19-22, 1987, Los Angeles, CA
February 9-12, 1987, Washington, DC

Hands-On Programming in C

October 27-30, 1987, Boston, MA
November 3-6, 1987, Los Angeles, CA
November 17-20, 1987, Washington, DC
December 8-11, 1987, Palo Alto, CA
December 15-18, 1987, Washington, DC

Hands-On Advanced Programming in C

December 8-11, 1987, Los Angeles, CA
January 19-22, 1988, Washington, DC
February 23-26, 1988, San Diego, CA

Fiber Optic Communication

November 3-6, 1987, Los Angeles, CA
November 3-6, 1987, Washington, DC
November 17-20, 1987, Boston, MA
December 1-4, 1987, Toronto, Canada
December 8-11, 1987, Palo Alto, CA
December 15-18, 1987, Washington, DC

Information: Barbara Fischer, Integrated Computer Systems, 5800 Hannum Avenue, P.O. Box 3614, Culver City, CA 90321-3614; Tel: (800) 421-8166, (213) 417-8888

Colorado State University

Computer Aided Design and Drafting

October 27, 1987, Colorado Springs, CO
November 3, 1987, Northglenn, CO

Information: Pat Brown, Division of Continuing Education, Colorado State University, Fort Collins, CO 80532. Tel: (303) 491-8410

Georgia Institute of Technology

Phased Array Antennas: Theory, Design, and Technology

November 17-20, 1987, Atlanta, GA

Information: Deidre Mercer, Department of Continuing Education-R, Georgia Institute of Technology, Atlanta, GA 30332-0385. Tel: (404) 894-2547

Norand Corporation

MIL-STD 461B/C and 462 Regulations and Design Criteria

October 13-14, 1987, Cedar Rapids, IA

RF Susceptibility and ESD Testing

November 3-4, 1987, Cedar Rapids, IA

Information: Bev Reynoldson, Norand Corporation, 550 2nd St S.E., Cedar Rapids, IA 52401; Tel: (319) 846-2415

Compliance Engineering

Compliance Seminars: EMI, Safety, ESD, Telecom

October 27-30, 1987, Boston, MA
December 1-4, 1987, San Diego, CA

Information: Compliance Engineering, 593 Massachusetts Avenue, Boxborough, MA 01719. Tel: (617) 264-4208

R & B Enterprises

Electromagnetic Pulse (EMP) Design and Test

November 17-18, 1987, Washington, DC
December 7-8, 1987, Philadelphia, PA

Understanding and Applying MIL-STD-461C

November 17-18, 1987, Washington, DC
December 14-15, 1987, Philadelphia, PA

MIL-STD-461C Praxis (Workshop)

December 16-17, 1987, Philadelphia, PA

Information: Greg Gore, Director of Training, R & B Enterprises, 20 Clipper Road, West Conshohocken, PA 19428. Tel: (215) 825-1960

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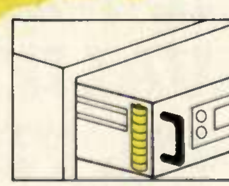
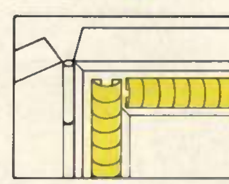
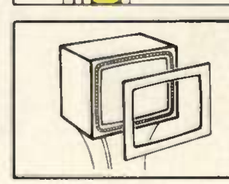
<u>Heat is on computer manufacturers</u> to comply with FCC emission standards. At stake are amounts of electromagnetic radiation that disrupt communications. Recent FCC test showed that half of 29 models examined failed to meet limits. Agency plans to ask Justice to crack down on offenders with fines of $10,000 for those who fail to comply, and that includes fixing machines already sold.

— as reported by Research Institute of America







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October 19-21, 1987
The Twentieth Annual Connectors and Interconnection Technology Symposium
Franklin Plaza Hotel, Philadelphia, PA
Information: Electronic Connector Study Group, Inc., P.O. Box 167, Fort Washington, PA 19034-0167; Tel: (215) 825-3840

October 26-30, 1987
FOC/LAN 87, Eleventh International Fiber Optic Communication and Local Area Networks Exposition
Anaheim Convention Center, Anaheim, CA
Information: Renee Farrington, Information Gatekeepers, Inc., 214 Harvard Avenue, Boston, MA 02134; Tel: (617) 232-3111

November 10-12, 1987
1987 ITEA Symposium
Park Plaza Hotel, Boston, MA
Information: Howard L. Graves, Raytheon Company, Public Relations, 141 Spring Street, Lexington, MA 02173; Tel: (617) 470-6027

November 10-14, 1987
Productronica 87
Trade Fair Center, Munich, West Germany
Information: Muchener Messeund Ausstellungsgesellschaft mbH, Messegelande, Postfach 12 10 09, D-8000 Munchen 12; Tel: (89) 5107-0

November 11-13, 1987
RF Expo East '87
World Trade Center, Boston, MA
Information: Linda Fortunato, Cardiff Publishing Company, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111; Tel: (303) 220-0600; (800) 525-9154

November 12-13, 1987
Challenges Facing Aerospace and Defense Leaders in the 1990's
Vista Hilton International Hotel, Washington, DC
Information: Alvin J. Babkow, Aviation Week and Space Technology, 43rd Floor, 1221 Avenue of the Americas, New York, NY 10020; Tel: (212) 512-2231

November 12-13, 1987
1987 Quality in Electronics Conference
Viscount Hotel, Los Angeles Airport, CA
Information: Tina Doty, AVW Electronic Systems, Inc., 2233 E. Grand Ave., El Segundo, CA 90245. Tel: (213) 548-8604

November 17-19, 1987
Electrical Product Safety Seminar
Cincinnati Commonwealth Hilton, Cincinnati, OH
Information: MIRA Corporation, 2301 Glenheath Drive, Kettering, OH 45440-1905; Tel: (513) 434-7127

December 3-4, 1987
30th ARFTG
Crowne Plaza Holiday Inn, Dallas, TX
Information: Ken Bradley, M/S 255, Texas Instruments, P.O. Box 660246, Dallas, TX 75266; Tel: (214) 995-6158

January 11-14, 1988
SMART IV
Westin Bonaventure, Los Angeles, CA
Information: EIA, 2001 Eye St., N.W., Washington, DC 20006; Tel: (202) 457-4932

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Output				
Phase Noise @ f_0 ±10 kHz (dBc/Hz max)	−110	−100	−90	−90
Pushing @ ±1V (±kHz max)	5	10	20	20
Pulling @ 2:1 all phases (±kHz max)	200	300	500	500

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INFO/CARD 19

A Linear GaAs MMIC Variable Attenuator

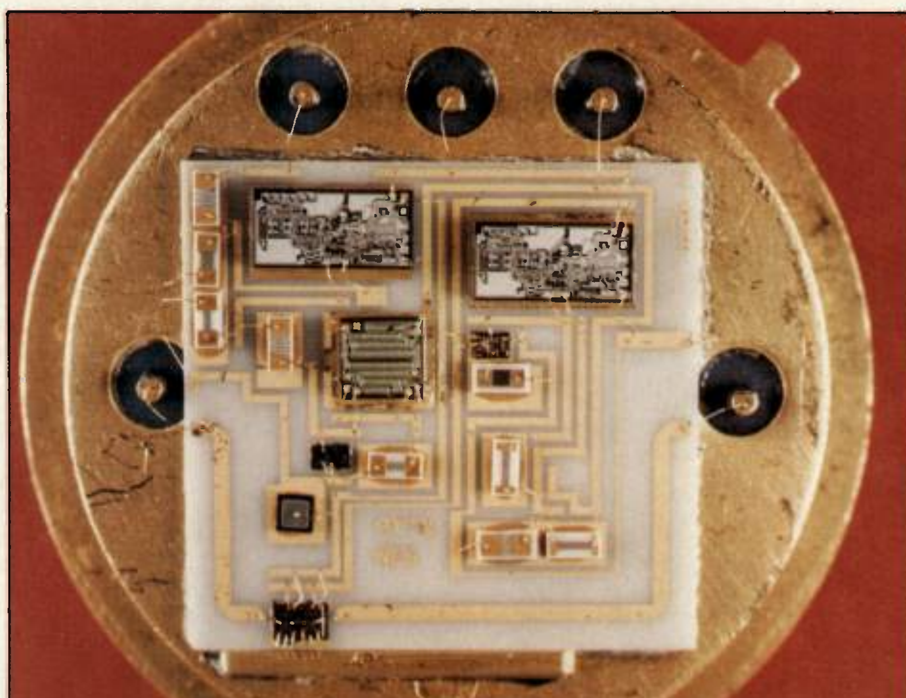
FET Attenuator Can Solve Problems Common to PIN Diode Attenuators

By David Fisher, Thomas Kritzer, and Salvatore Algeri
Watkins-Johnson Company

Electronically variable attenuators are some of the most versatile and widely applied signal-processing components. However, conventional (PIN diode) attenuators have several limitations which complicate design, limiting their applications. This article describes a new GaAs monolithic microwave integrated circuit (MMIC) that overcomes these limitations. Among the advantages GaAs FET attenuator ICs offer over PIN diode attenuators is that DC and RF resistances are, for practical purposes, equal — a characteristic which simplifies impedance matching and linearization circuits. MMIC technology allows the MESFET devices to be located on a single chip to reduce parasitic elements that would otherwise limit performance.

PIN diode attenuators have non-linear attenuation-versus-control voltage characteristics and are very sensitive to control voltage at high attenuation levels (see Figure 1). A complicated linearizing circuit with several breakpoints is required for linear operation. A MMIC attenuator can have a linear attenuation-versus-control voltage characteristic. This simplifies AGC loop and programmable attenuator design. It also allows the designer to generate a linear attenuation-versus-temperature characteristic with the addition of a silicon temperature-transducer IC for temperature-compensation networks.

Another major advantage of FET attenuators over PIN diode attenuators is that the control port (the gate) is intrinsically decoupled from the RF signal path and requires only microamps of current drive. This makes broadband operation and operation down to DC straightforward. With PIN diodes, the decoupling is provided by an external choke (or quarter-wave stub at higher frequencies). Even with a large choke to decouple the RF signal, significant distortion can result at low frequencies from rectification unless extremely long carrier lifetime diodes are employed.



The WJ-RF45 is supplied in a TO-8B package specified to 4 GHz. Higher frequency packaging is being developed.

Operation over temperature is critical in successful system design. Since PIN diode attenuators are current-controlled devices and, since the knee voltage varies over temperature, careful attention is required to maintain a constant level of attenuation for a given control voltage as the temperature changes. The constant voltage sources required by the FET-based attenuator are much easier to design than the constant current sources required by PIN diode attenuators.

The MMIC attenuator is extremely stable over the full military temperature range of −55C to +125C. Figure 2 shows that for a fixed control voltage the attenuation changes less than 0.5 dB over this range. This is a particular advantage in military systems where these wide temperature extremes are frequently encountered.

Fabrication and Design of the Attenuator

The attenuator chip measures 420 microns × 610 microns (17 mils × 25 mils) and is fabricated with a 1-micron gate geometry to increase uniformity and yield.

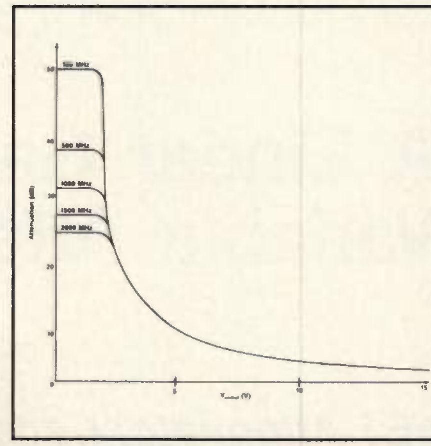


Figure 1. Typical PIN diode attenuator characteristic.

Sub-micron gates would offer little if any performance advantage, since the MESFETs are used in a common-gate configuration. The gates are aluminum and are directly printed using contact lithography. The starting material uses silicon ions directly implanted into a chrome-doped LEC substrate with a subsequent capless anneal in an arsenic overpressure. The doping profile is an n+ on n structure with an n-layer doping level of 3×10^{17} cm^{-3}.

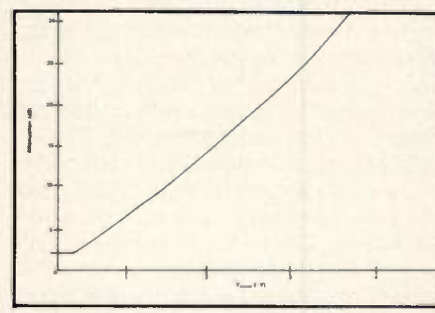


Figure 2. WJ-RG45 linearity.

The attenuator uses three MESFETs as voltage-variable resistors in a PI configuration. Several factors must be considered when using FETs as resistors. The FET

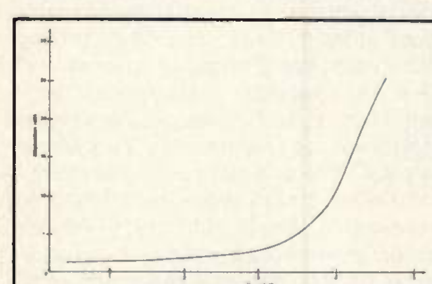


Figure 5. MMIC attenuator characteristic without linearizing circuit.

can be modeled as a variable resistor in parallel with a capacitance (C_{gs} in series with the parallel combination of C_{gd} and C_{ds}). For a given material doping level, as the gate width increases, the minimum resistance will decrease and the parasitic capacitance will increase proportionally. For a PI attenuator, the minimum resistance of the series FET largely determines minimum insertion loss. The parasitic capacitance of the series FET allows the signal to shunt around the FET resistance at high frequencies and, thus, limits the series FET impedance. The result is that the attenuation range is reduced at high frequencies. Gate widths must be chosen that are wide enough to obtain a low insertion loss at the minimum insertion-loss state, but narrow enough to limit the parasitic capacitance to achieve sufficient attenuation range at high frequencies. To evaluate this trade-off of minimum insertion loss-versus-attenuation range, several attenuators with differing series FET gate widths were fabricated and tested. Based on this study, the series gate width was chosen to be 150 microns.

The small size and layout of the chip have significantly reduced additional parasitic elements to yield excellent broadband performance (see Figure 3). The minimum insertion loss is less than 2.0 dB at 10 GHz and 2.75 dB at 20 GHz. The attenuation range is 12 dB with less than 1-dB change in flatness from DC to 20 GHz. Over the more limited bandwidth of DC to 10 GHz, the attenuation range is better than 14 dB; from DC to 2 GHz, greater than 25 dB is achieved.

Control Circuitry

The function of the control circuitry is to apply the correct voltages to the series and shunt FET gates to provide both linear (dB) attenuation-versus-control voltage and a 50-ohm match. An important feature of the attenuator chip is the addition of critical control circuitry on the chip. Two external op-amps and silicon bipolar transistors are also used.

The impedance match was achieved using a technique previously reported by Barta, et al. (1). It is shown schematically in Figure 4. Because the DC and RF resistances are essentially equal (note that this condition does not exist for PIN diodes), a separate on-chip reference attenuator is used at DC to establish the correct shunt FET gate voltage for a given series FET gate voltage. A voltage divider sets a constant voltage corresponding to the 50-ohm reference resistor, R_{ref}, at the non-inverting input to the op-amp. Any change in resistance of the series FET induces a change in the voltage at the in-

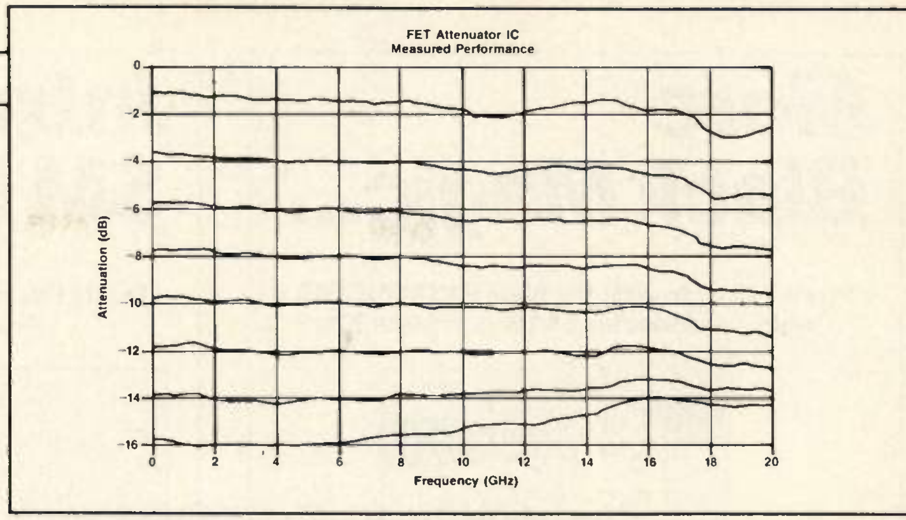


Figure 3. MMIC attenuator chip performance.

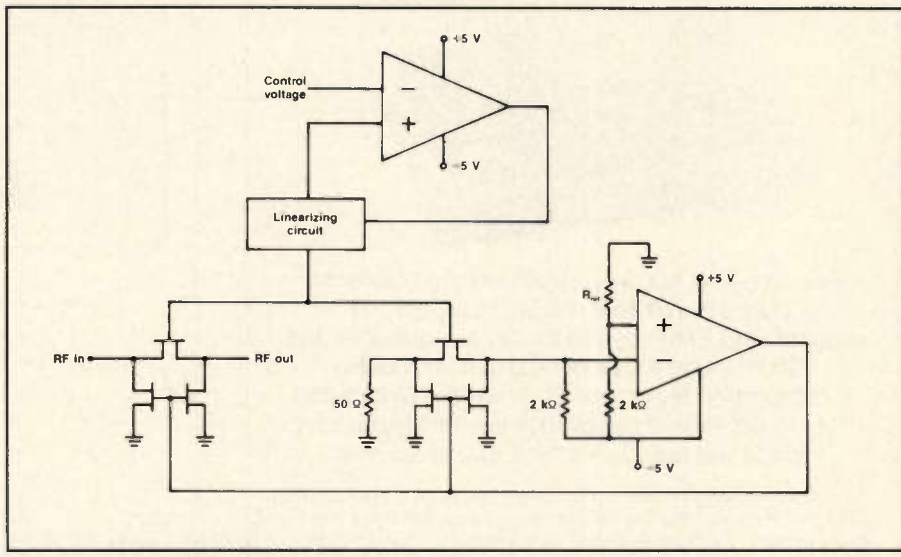


Figure 4. WJ-RG45 control circuitry.

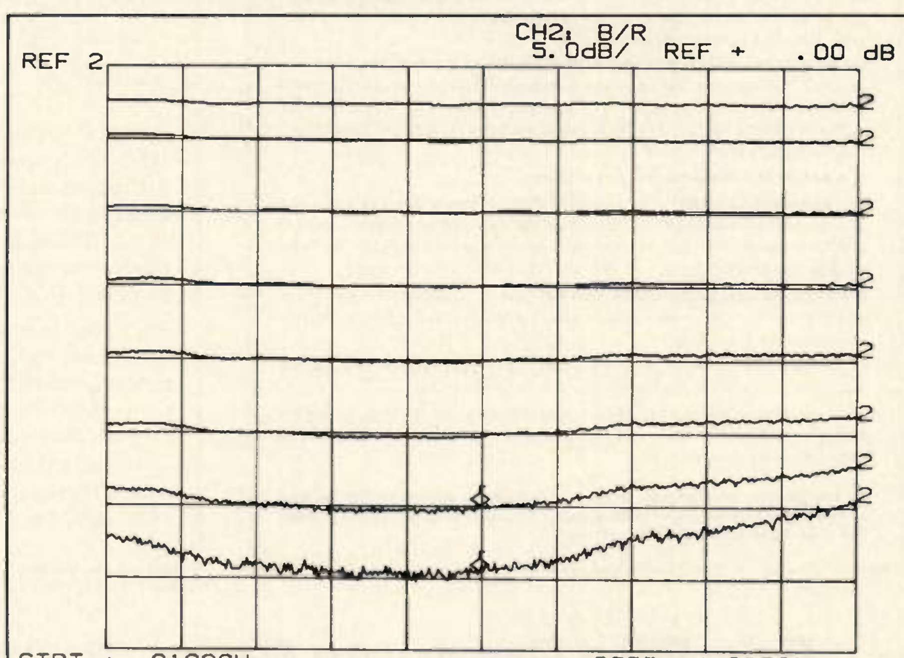


Figure 6. WJ-RG45 attenuator performance.

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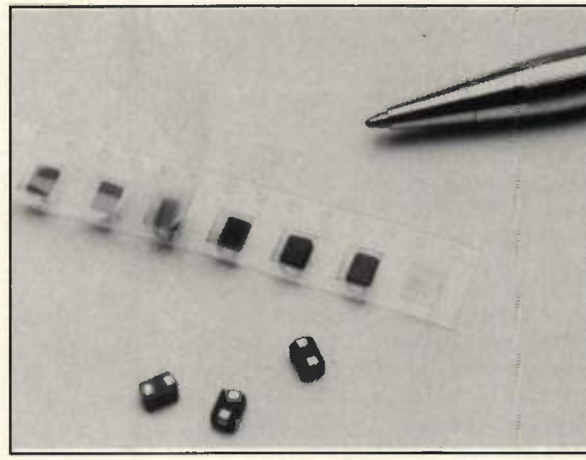
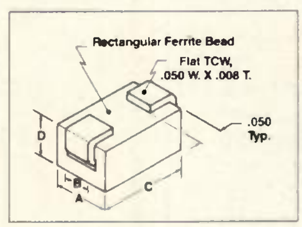
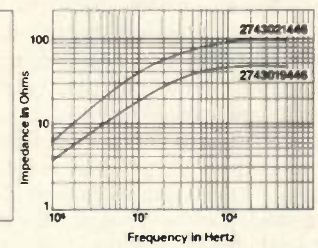
Ferrite EMI suppressors expressly for use with Surface Mount Technology







Fair-Rite Part No.	A Dim	B Dim	C Dim	D Dim	Z @ 25 MHz*	Z @ 100 MHz*	DC Resistance Ohms
2743019446	.115 / .125	.055 / .060	.150 / .170	.095 / .105	30 ohms	45 ohms	< 6 Milliohms
2743021446	.115 / .125	.055 / .060	.325 / .345	.095 / .105	60 ohms	90 ohms	< 9 Milliohms
2743022446	.050	.030	.080	.040	8 ohms	12 ohms	< 1.2 Milliohms

Surface Mount Technology is fast becoming the preferred method of PC Board assembly. Recognizing the need for surface mount EMI suppressors, Fair-Rite Products is introducing a line of Surface Mount Shield Beads (Patent applied for) to supplement our current array of EMI/RFI Suppressor elements. Two of the parts available at present offer equivalent impedances to our most popular "beads-on-leads"; all can be used in place of the older technology.

The construction of these SM Beads™ is such that they offer maximum current carrying capacity, through solid flat copper conductors rather than metal plating, limited only by the saturation characteristics of the ferrite core material, and thus are highly resistant to mechanical or magnetic failure. These parts are available taped and reeled on carriers, per EIA Standard EIA-481A, at a price that makes them a most attractive method of designing EMI protection into circuitry from its inception.

** Typical impedance measured on a Hewlett-Packard 4191A RF Impedance Analyzer.*

INFO/CARD 21

INFO/CARD 57

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verting input of the op-amp. The op-amp acts to adjust the resistance of the shunt FETs, thus maintaining a 50-ohm environment.

Recognition that attenuation is linearly proportional to series FET resistance provides the basis of the linearizing circuit design. Without the linearizing circuit, the attenuation-versus-control voltage characteristic is quasi-exponential, due to the relationship of FET resistance to gate voltage near pinchoff. At high attenuation levels, as shown in Figure 5, very small changes in the series FET gate voltage produce large changes in attenuation. This quasi-exponential characteristic presents a problem for most users. The control circuit which linearizes this characteristic is simple and flexible so that the slope of the attenuation-versus-control voltage characteristic and the input control-voltage range may be changed by changing only two resistor values.

The matching and linearization techniques using the op-amps are invariant to process variation and non-uniformity, provided that the reference attenuator and linearizing circuit closely match the RF attenuator. For this reason, the reference attenuator and critical elements of the linearizing circuit are placed on the chip with the RF attenuator. This also reduces the complexity of the final hybrid circuit and simplifies assembly.

Implementation and Performance

The final product, WJ-RG45, is an RF and microwave variable attenuator that combines the performance of GaAs ICs with conventional silicon ICs to provide linear attenuation with control voltage. The component cascades two GaAs MMIC attenuator chips to obtain better than 30 dB attenuation range with an 8-dB/volt slope (see Figures 2 and 6). It is stable over the −55C to +125C temperature range and has less than 2.2 dB minimum insertion loss with 14 dB minimum return loss (1.5:1 VSWR) from DC to 5 GHz. The attenuator is extremely linear up to +10 dBm input power levels and saturates above +20 dBm. The heart of the WJ-RG45 is a GaAs MMIC attenuator with greater than 12 dB attenuation from DC to 20 GHz. The device is enclosed in a TO-8B package (see photo) which is specified to 4 GHz, although development of a higher frequency performance package is in progress.

The combination of linear attenuation control, flat frequency response and temperature stability makes the MMIC device ideal for a variety of system applications. Work is ongoing to introduce a product which can take full advantage of the GaAs MMIC attenuator chip to 18 GHz. **For more information, please circle INFO/CARD #174.**

Reference

1. Gary S. Barta, Keith E. Jones, Geoffrey C. Herrick, and Eric W. Strid, "A 2 to 8 GHz Leveling Loop Using A GaAs MMIC Active Splitter and Attenuator," 1986 IEEE Microwave & Millimeter-Wave Monolithic Circuits Symposium Digest of Papers, p. 75-79.

About the Author

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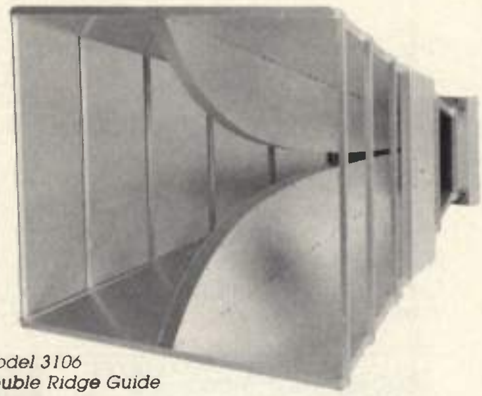
Model 3115 Double Ridge Guide
1–18 GHz
Model 3116 Double Ridge Guide
18–40 GHz



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Double Ridge Guide
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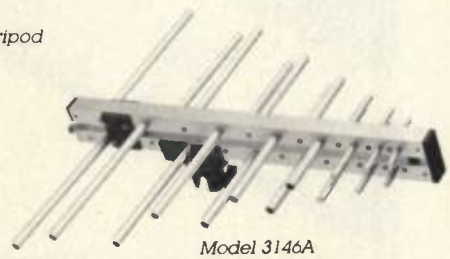
Model TR3 Non-Metallic Tripod
22.68 kg capacity



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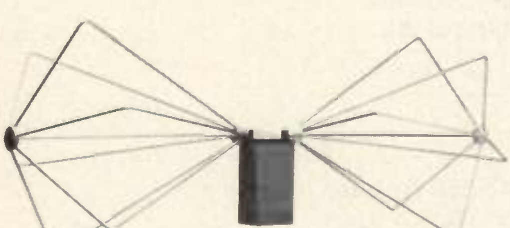

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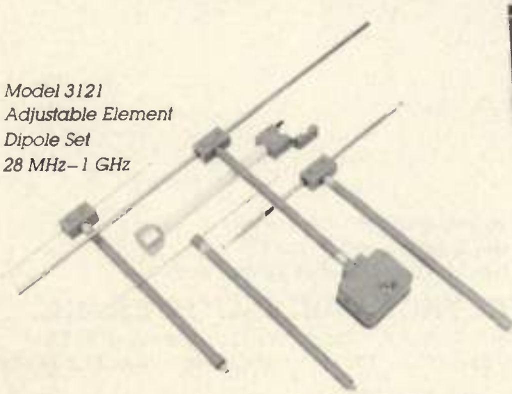

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INFO/CARD 23

RF Radiation Hazards: An Update on Standards and Regulations

By Mark Gomez, Assistant Editor,
and Gary A. Breed, Editor

The issue of human exposure to radio frequency (RF) radiation is an environmental topic that has seen growing concern over the past several years. In response to that concern, the American National Standards Institute (ANSI) developed a standard (C95.1-1982) containing recommended safety levels for human exposure to RF electromagnetic fields. This report reviews the technical and regulatory aspects of the current standard. Also presented are summaries of recent studies which measured radiation levels near broadcast facilities, plus information on changes under consideration by ANSI for a revised RF radiation exposure standard.

The National Environmental Policy Act of 1969 (NEPA) requires that all agencies of the Federal Government evaluate the potential impact of their actions on the quality of the human environment. To comply with this provision in the area of RF radiation, some Federal agencies have adopted C95.1-1982. In addition, many local and state governmental bodies have legislation or pending legislation based on the recommendations set forth in the standard.

In 1985, the FCC adopted a *Report and Order* amending part 1, subpart I, of the FCC Rules and Regulations to provide for analysis of the environmental impact of RF radiation. The amendment stated that future applications submitted to the commission will be subject to environmental evaluation as outlined in the rules if the facility or operation in question could cause human exposure to RF radiation in excess of specified guidelines (1).

Agencies such as the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) intend to establish (or have already established) a standard in accordance with ANSI C95.1-1982. The Navy's Combat Readiness Electromagnetic Analysis and Measurement (CREAM) program includes RADHAZ which is a radiation hazard test set designed for the ANSI standard.

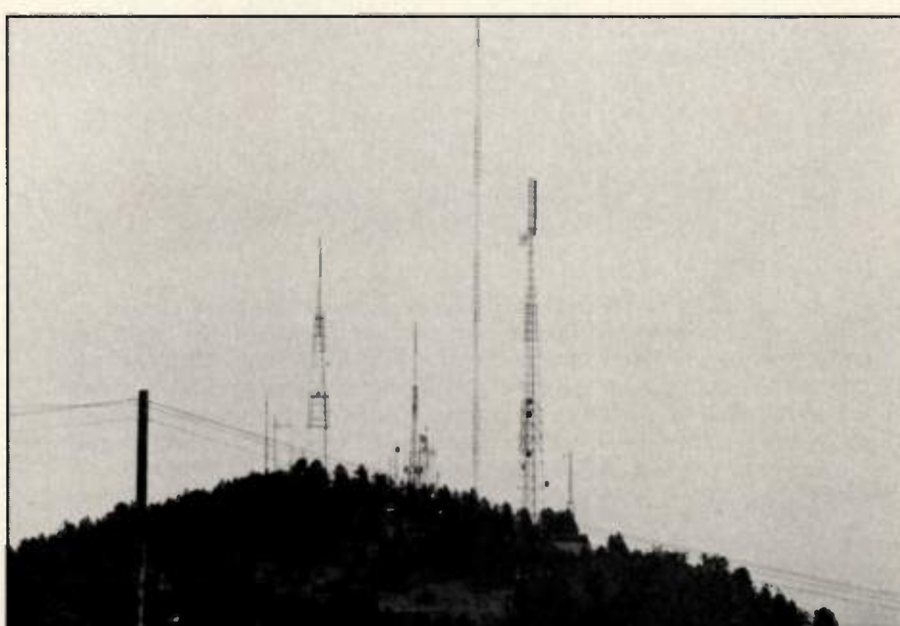
Other organizations have either drafted or approved guidelines which are *lower* the ANSI standard for public exposure, occupational exposure or both. These include the International Radiation Protection Association (IRPA) and the National Council on Radiation Protection and Measurements (NCRP).

Technical Definition of the Standard

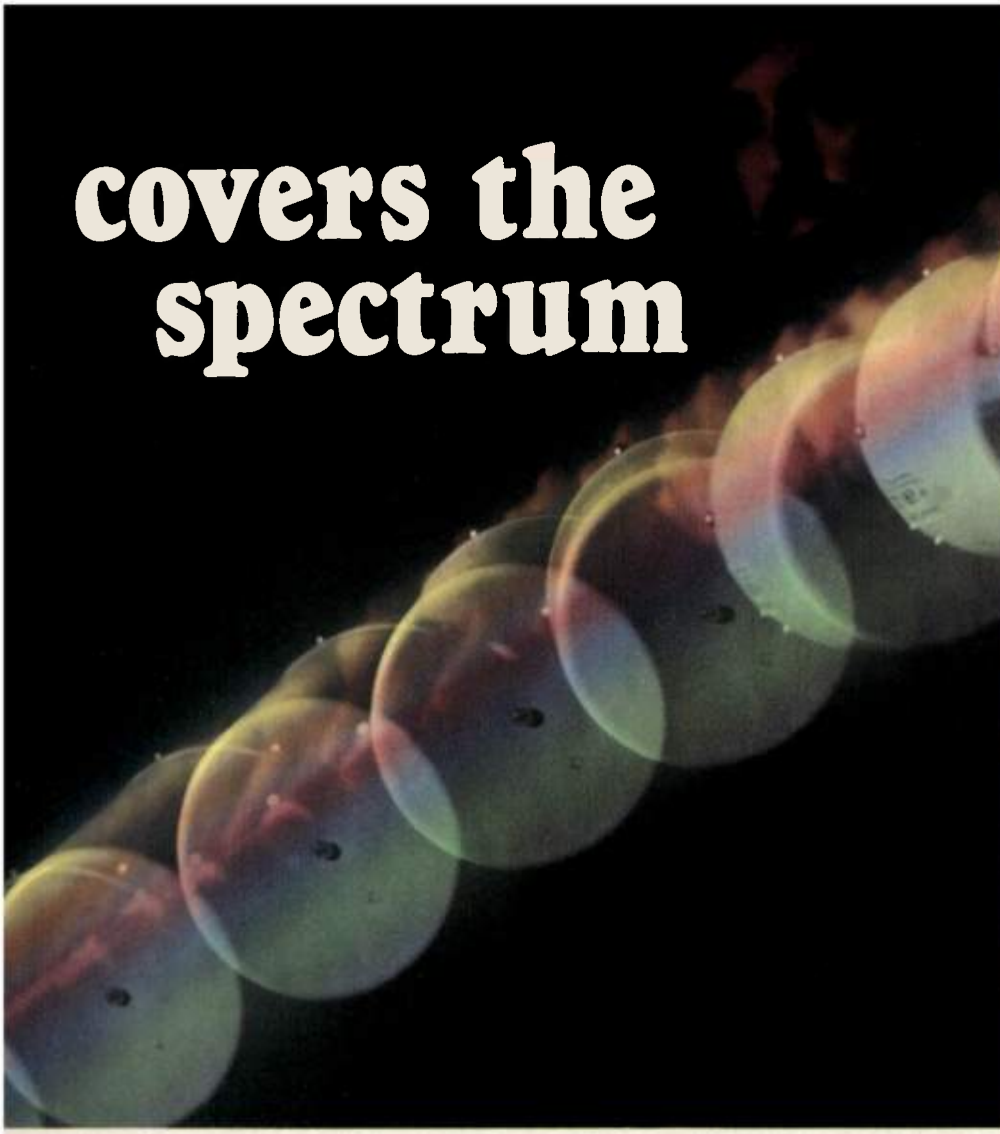
The ANSI radio frequency protection guides (RFPG) are frequency-dependent limits recommended for safe exposure to RF radiation. The guideline covers 300 kHz to 100 GHz with the limits given in terms of RMS electric and magnetic field strength and in terms of plane-wave or free space power density. Equation 1 shows the relationship between the H (magnetic field in A/m), E (electric field in V/m) and S (power density in mW/cm^2).

$$S = \frac{E^2}{3770} = 37.7H^2 \qquad (1)$$

The most restrictive limits are recommended where the human body's absorption is the greatest, i.e., 30-300 MHz. Absorption is lowest from 300 kHz to 3 MHz, hence, the least restrictive limits apply here. Different limits are recommended for frequencies in other frequency ranges. The ANSI curve (see Table 1) is a mirror image of the RF absorption curve which is defined by the specific absorption rate (SAR). ANSI's RPG states that the SAR cannot exceed 0.4 W/kg when averaged over the entire body mass. SAR is the rate of energy absorption per mass of tissue and is expressed in W/kg. Equation 2



Lookout Mountain's antenna farm is home to most of the Denver, Colorado, area FM and TV stations.



Safety personnel with no specialized RF expertise can, for the first time, perform fast, easy, accurate measurements over the frequency spectrum from 300 KHz to 1500 MHz (exposure levels of RFPG contained in ANSI C95.1-1982). The Narda Model 8682 ANSI Standard Radiation Monitor conformal probe can be used with either 8611 and 8616 metering instruments. Both direct reading meters permit measurement with excellent resolution over the 30 dB dynamic range. This monitoring system features: direct readings in percent of ANSI exposure limit; operation even in multiple signal environments; true RMS indications regardless of modulation; isotropic response; and compatibility with existing meters.

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INFO/CARD 24

Radiation Monitors

Narda has developed radiation monitoring systems consisting of a variety of field sensitive probes and metering instruments. These probes are interchangeable to provide electric and magnetic field measurements. The metering instruments are also usable for applications from 0.3 MHz to 26 GHz.

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Three meter styles are available. Each performs specific requirements. Model 8616 is our full-featured instrument and is calibrated in average equivalent power density. While the 8619 is identical in size, it is calibrated in mean squared electric and magnetic field strengths. Both accommodate all probes. Model 8611 is a compact unit with the same readout as 8616 and accommodates all probes.

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Radio Frequency Protection Guide (RFPG)			
Frequency Range (MHz)	E^2 (V^2/m^2)	H^2 (A^2/m^2)	Power Density (mW/cm^2)
0.3-3	400,000	2.5	100
3-30	4,000 ($900/f^2$)	0.025 ($900/f^2$)	$900/f^2$
30-300	4,000	0.025	1.0
300-1,500	4,000 ($f/300$)	0.025 ($f/300$)	$f/300$
1,500-100,000	20,000	0.125	5.0

Note: f is the frequency, in Megahertz (MHz)

Table 1. RFPG in accordance with ANSI C95.1-1982.

defines SAR in radiometric terms:

$$SAR = [\sigma/2(\varrho_t)]\ E_t^2 \qquad (2)$$

Where ϱ is the density of the tissue in kg/m^3, σ is tissue conductivity in s/m, and E_t is the magnitude of the sinusoidally varying electric field.

SAR can also be calculated from thermal considerations in terms of the time rate of change of the exposed tissue assuming no thermal losses or metabolic heating exists (see equation 3). c is the specific heat capacity in J/kg/°C.

$$SAR = c(dT/dt) \qquad (3)$$

Time averaged exposure can be used for determining compliance with the FCC *Report and Order* where personnel may be intermittently exposed to relatively in-

Frequency range	RMS Electric field strength (V/m)	RMS Magnetic field strength (A/m)	Power density (mW/cm^2)
AM Radio	632	1.58	100
FM Radio and VHF-TV	63.2	0.158	1
UHF-TV			
ch-14	79.2	0.200	1.57
ch-69	103	0.258	2.67

Table 2. FCC maximum permissible exposure levels over 6 minutes, in accordance with ANSI C95.1-1982.

tense fields. The FCC rules require that the broadcast station license applicants determine that RF emissions from their facilities do not expose employees or the general public in access of the ANSI radiation protection guide. Table 2 shows the maximum power densities and magnetic field strengths based on the ANSI RPG.

A significant aspect defined by ANSI is time averaging over a six minute period. This means that the product of power density and time cannot exceed 6 $mW\cdot min/cm^2$ as shown in equation 4 and demonstrated in Table 3. In graphical form, the area under a radiation versus time curve cannot exceed 6 $mW.min/cm^2$ for any 6 minute period.

$$S(mW/cm^2)t(min) \leqslant 6\ mW/cm^2 \qquad (4)$$

Recent Developments

Between September 22 and 26, 1986, an investigation of radio frequency radiation levels was conducted at Lookout Mountain, Jefferson County, Colorado by engineers from the EPA and FCC (2). Lookout Mountain is the location for broadcast antennas for many of the television and FM radio stations that serve the Denver area. The number of stations and their close proximity to one another and to residential areas make the Lookout

Exposure level (mW/cm^2)	Exposure time allowed	Time out of field
1.0	6 min.	—
1.5	4 min.	2 min.
2.0	3 min.	3 min.
3.0	2 min.	4 min.
5.0	1 min. 12 sec.	4 min. 48 sec.
10.0	36 sec.	5 min. 24 sec.

Table 3. Time averaged exposure at various power levels.

Mountain antenna farm unusual. Interference to consumer electronic devices and subsequent concern over possible health effects led the residents and the Jefferson County Planning Commission to request a survey of RF radiation levels.

RF field strength is usually measured using either broadband isotropic electric or magnetic field strength meters or tunable field strength meters connected to appropriate antennas. Broadband equipment is used to determine the total RF field at a point while narrowband equipment provides details of the RF field intensity at any particular frequency. This study at Lookout Mountain employed both types of equipment.

Near the base of one tower (KYGO-FM), power densities reach 10,000 uW/cm^2 in a publicly accessible area. This exceeds the FCC's 1000 uW/cm^2 guideline for FM frequencies. However, none of the measurements made inside the main building of the compound exceeded 100 uW/cm^2. The maximum power density near another tower (KOSI-FM) was 580 uW/cm^2, lower than the FCC standard. The spatially averaged power density within an area of about 1000 square feet near the tower does exceed the 200 uW/cm^2 NCRP and IRPA standards. Typical power densities at several residences on Lookout Mountain did not exceed 100 uW/cm^2. Higher power densities of limited extent were found near field enhancing metal objects.

Healy Heights, Portland, Oregon, the location of another study (3), is one of the few places in the nation where AM and many FM broadcast antennas can be found in close proximity to one another, with six of the seven FM broadcast antennas mounted on a single tower. There are also two major towers located within a residential neighborhood.

As the study began, KBOO-FM began transmitting from a new antenna that is higher on the tower than the old antenna. With the new modification, the power density guideline of 1000 uW/cm^2 was not exceeded around the KXL tower, which had higher levels prior to KBOO's move. Typical values found inside the KXL residence were below 70 uW/cm^2 although a few localized values were found between 100 uW/cm^2 and 200 uW/cm^2. Data collected in other selected residential areas around Portland found no power densities approaching the FCC guideline.

It should be noted that the City of Portland and the Portland Planning Commission have instituted guidelines that are significantly lower than the ANSI standard. In some instances, these guidelines are one-tenth the power density of C95.1-1982.

Other radiation sources of concern include amateur radio, radar and satellite uplinks. Although it is possible for amateur radio facilities to generate power densities exceeding the ANSI standard, the FCC considers the problem to be almost negligible. Most amateur radio operators do not have large enough systems to generate radiation above the guidelines, and operation tends to be intermittent with a relatively low duty cycle.

Satellite uplinks pose virtually no problem as the satellite main beam is directed skyward and the public rarely has access to transmitting dishes. The exposure to satellite dish microwave radiation can cause adverse health effects if an individual were to stand directly in the microwave beam, especially for any extended period of time. Radiation from satellite uplinks is something birds should be worried about (but only if they linger in the beam).

Updating the Standards

A standing subcommittee has been working for the last five years to study and revise the ANSI C95.1-1982 standard. The subcommittee will eventually present its proposal to the parent committee which, in turn, will present its revised version to ANSI. The parent committee is comprised of representatives from various organizations of which the Navy is the secretariat. The subcommittee, on the other hand, is made up of 125 scientists (biologists, physicists, etc.) and 25 to 30 engineers. The subcommittee is chaired by Dr. F. Kristian Storm of the University of Wisconsin with Dr. John Osepchuck of Raytheon Research as the secretary.

The proposals outlined here are preliminary and subject to debate and voting. The major proposal for the revised ANSI standard is to tackle the problem of occupational and public exposure separately. This could result in different standards for the two categories. New rules for RF shock and burn are proposed, with limits on induced current and stringent regulations on low frequency electric field exposure where no specific means of mitigation are employed. The low end of the revised standard is proposed at 3 kHz while the high end may be set to 300 GHz. A proposal to relax the magnetic field rules below 1 MHz where human susceptibility is low is also being reviewed.

There is intent to change the concept of time-averaging so that it is more accurate at the various frequency ranges. Discussions are underway to change and implement new measurement techniques so that the interpretation will be more accurate. One reason for the change in the measurement technique is that localized hot spots will not be interpreted as whole body exposure.

After the subcommittee has voted and agreed on the new regulations, the parent committee will vote and possibly change the wording as needed before submitting the finalized proposal to ANSI for evaluation and publication. The standard, if approved, will take at least two to three years before it is finalized and issued.

Conclusion

The majority of broadcast stations do not create situations where the public can be exposed to levels in excess of the ANSI protection guide. In the few cases where public exposure may be a problem, several options are available to minimize or eliminate the problem. The simplest is by restricting access to the area by using fences or warning signs. Another solution would be to redesign or use a different antenna to minimize downward radiation. Altering the spacing in an FM array may be a positive step. The most expensive solutions would be to increase the height of the antenna or relocate the tower.

Broadcast facilities represent the most common source of high electromagnetic fields. RF engineers and technicians working on communication systems need to be aware of regulations for his or her own safety as well as public safety. Regulatory compliance of equipment being installed is another requirement. Finally, with the growing public awareness and concern about RF radiation, RF engineers will be called on to respond to public inquiry when it arises.

The ANSI standard itself is voluntary, although it can be used as a guideline when regulation is needed. Regulation is normally imposed by individual cities or counties, various governmental organizations, and organizations with health and environmental concerns. A significant number of these governmental or regulatory bodies have adopted, or are considering, requirements which are lower than the current ANSI standard. rf

References

1. Robert F. Cleveland, Jr., "Radiofrequency radiation and FCC Actions Under the National Environmental Policy Act," *1986 NAB Engineering Conference Proceedings*, p. 379-387, April 1986.

2. "An Investigation of Radiofrequency Radiation Levels on Lookout Mountain, Jefferson County, Colorado, September 22-26, 1986," Electromagnetics Branch, Office of Radiation Programs, U.S. Environmental Protection Agency, P.O. Box 18416, Las Vegas, NV 89114-8416, February 1987.

3. "An Investigation of Radiofrequency Radiation Levels on Healy Heights, Portland Oregon, July 28-August 1, 1986," (same source as ref. 2), January 1987.

Chebyshev & Butterworth Filter Group Delay and Delay Distortion

By Robert C. Kane
Motorola, Inc.

In the course of development of a typical communication system, it is necessary to consider signal selectivity at the input of the system receiver. The commonly used method of incorporating the desired degree of selectivity is through the use of a narrow band-pass filter network (see Figure 1). Such a preselector will have the effect of passing a limited range or band of desired frequencies while rejecting all others which may produce an interfering signal in the receiver.

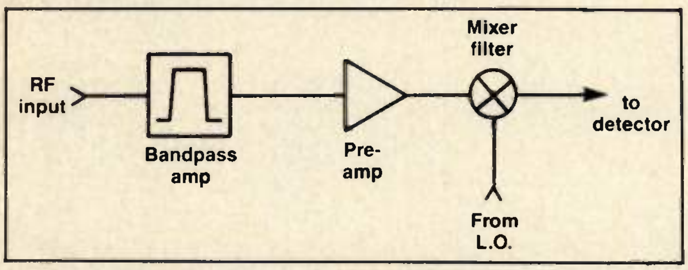

Figure 1. Block diagram of a bandpass filter network.

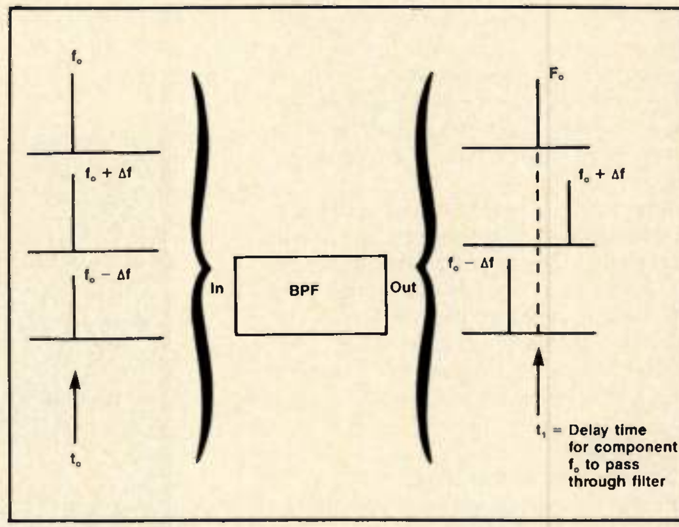

Figure 2. Propagation delays before and after the band-pass filter.

In addition to the desired effect of rejecting signals at frequencies falling outside of the filter pass-band region, it is found that the filter network will introduce a level of distortion to those signals which pass through the filter to the subsequent receiver circuitry. This added distortion is explained by considering that the propagation of energy within the filter is a function of the frequency of that energy. That is, when energy consisting of more than a single spectral component is being passed through a filter, the components will not propagate at the same velocity.

Generally, received information will not be of single sinusoidal composition but consists of sinusoidal components of a finite bandwidth or complex waveshapes which are composed of sinusoidal components.

When considering propagation of each of the discrete frequency components through the filter network, it becomes apparent that due to the frequency dependency of propagation velocity, the individual spectral components will begin to spread out and propagate through the filter at different rates. The result is seen as a distorted reproduction of the original signal when viewed at the output of the filter (see Figure 2). This distortion is termed delay distortion as it is introduced by the unequal delay of the spectral components of energy being passed through the filter.

In many communication applications where the integrity of the received signal must be faithfully preserved, additional circuitry will be added to compensate for this distortion. The method of compensation is generally to introduce a phase shift exactly opposite to that which was originally encountered in the preselector filter. The difficulty encountered in accomplishing this step in the overall processing of the signal is primarily due to the fact that it is not easy to accurately predict the actual distortion component.

Available information which provides graphical data for direct use or tabular data which may be used to determine the delay response are restricted to a few select variations of parameters. In the case of Butterworth filters, this is not an impediment as the required delay information may be obtained directly from commonly available graphs by scaling. However, in instances when Chebyshev filters are being evaluated, direct scaling is not an option and one is usually placed in a position of selecting a best approximation for determining the delay response and delay distortion of a particular filter. This is true for Chebyshev filters because the delay is a function of the pass-band ripple as well as bandwidth.

In the following, a systematic method for determining the delay distortion in and near the pass-band region for Chebyshev filters of order 2 through 10 is developed. This development is based on determination of the actual delay of energy spectral components through the filter, commonly referred to as the group delay.

Chebyshev Delay Response

The well-known expression for group delay is:

$$T_d = \frac{d\Theta}{d\omega} \tag{1}$$

It relates the change in phase delay of the input signal through the filter to the input signal spectral components. Θ may be ex-

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SPD-4	500-1500 MHz	1.0 dB	15 dB

*Above 3.0 dB Theoretical split loss.

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SPD-C1-2	850-960 MHz	1.0 dB	20 dB	$10.75
SPD-C3	700-1000 MHz	1.0 dB	15 dB	$17.50
SPD-C4	500-1500 MHz	1.0 dB	15 dB	$22.75

*Above 3.0 dB Theoretical split loss.

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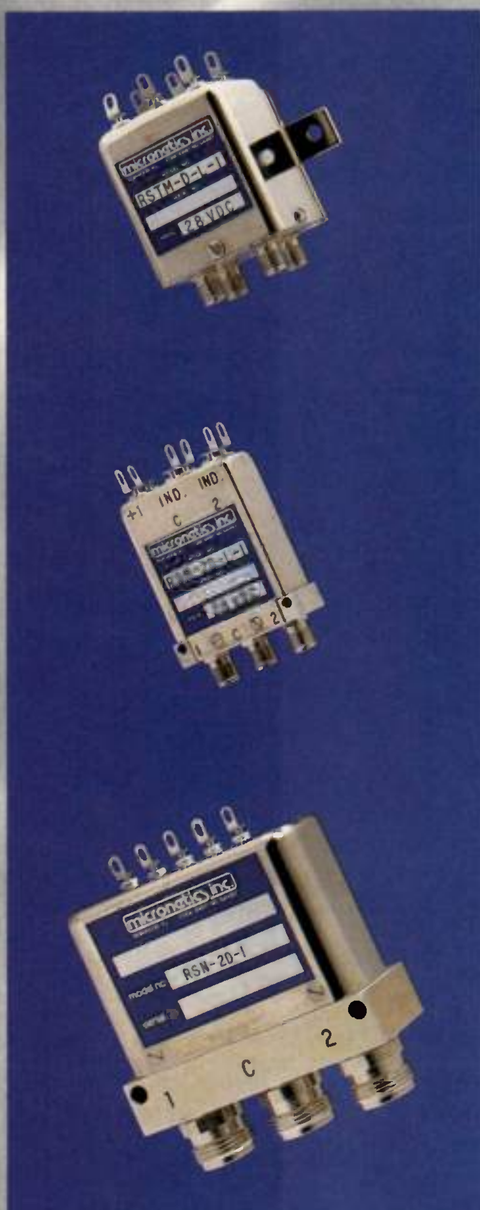

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SPDT Switch DC-18 GHz/RSM Series/SMA Type		
Model	Operating Voltage**	Mode
RSM-2-D-TTL	28V DC	Failsafe TTL
RSM-2-D-L-TTL	28V DC	Latching TTL

SPDT Switch DC-12.4 GHz/RSN Series/N-Type		
Model	Operating Voltage**	Mode
RSN2-D-TTL	28V DC	Failsafe TTL
RSN2-D-L-TTL	28V DC	Latching TTL

Transfer Switch DC-18 GHz/RSTM Series/SMA-Type		
Model	Operating Voltage**	Mode
RSTM-D-TTL	28V DC	Failsafe TTL
RSTM-D-L-TTL	28V DC	Latching TTL

*Most types are now available off the shelf
**Operating voltages as low as 10V DC are also available

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pressed as:

$$\Theta = \tan^{-1}\left[\frac{I_m(H_{j\omega})}{R_e(H_{j\omega})}\right] \qquad (2)$$

In order to calculate group delay of the filter transfer function, Matthaei (1) states that:

For N>= 3 and odd:

$$P_n = C(P+X)\prod_{m=1}^{(m-1)/2}\left[P^2+\left(2X\text{Cos}\frac{\pi m}{2}\right)P+X^2+\text{Sin}^2\left(\frac{\pi m}{n}\right)\right] \qquad (3)$$

Note: The π symbol stands for a multiplication of terms of the expansion. — Ed.

For n even:

$$P_n = C\prod_{m=1}^{n/2}\left[P^2-\left(2X\text{Cos}\frac{\pi(2m-1)}{2n}\right)P+X^2+\text{Sin}^2\left(\frac{\pi(2m-1)}{2n}\right)\right] \qquad (4)$$

In the above, C is a proportionality constant used to determine the minimum atenuation. As will be shown, the value of this constant does not enter into this particular calculation and can be neglected.

$$\text{where } X=\text{Sinh}\left[\frac{1}{n}\text{Sinh}^{-1}\left(\frac{1}{10^{r/10}-1}\right)^{1/2}\right] \qquad (5)$$

and r is the pass band ripple in dB

Also,

$$\text{Sinh}^{-1}(Y) = \text{Ln}(Y+\sqrt{Y^2+1}) \qquad (6)$$

$$\text{Sinh}(Y) = \frac{e^{y} - e^{-y}}{2} \qquad (7)$$

The variable p is the representation for complex frequency, which we take for the lossless case to be:

$$p \equiv j\omega \qquad (8)$$

Where ω is the frequency of interest with respect to the normalized ripple bandwidth, ω_1'.

Given that ω_1 is the 3-dB bandwidth of the filter

$$\omega_1' = \frac{1}{\text{Cosh } A}\,\omega_1 \qquad (9)$$

$$A = \frac{1}{n}\,\text{Cosh}^{-1}\left(\frac{1}{\varepsilon}\right) \qquad (10)$$

$$\varepsilon = (10^{r/10} - 1)^{1/2} \qquad (11)$$

From (1) and (2) it follows that:

$$T_d = \frac{D'C - C'D}{C^2 + D^2} \qquad (12)$$

Where:

$$D = I_m[P_n] \qquad (13)$$

$$C = R_e[P_n] \qquad (14)$$

$$D' = \frac{d(I_m[P_n])}{d\omega} \qquad (15)$$

$$C' = \frac{d(R_e[P_n])}{d\omega} \qquad (16)$$

As an example, expansion of the transfer function polynomial for the case of n = 5 results in the following for D, D', C, and C'.

n = 5

$$D=\omega^5-(5.236X^2+1.25)\omega^3+(3.236X^4+2.926X^2+.3125)\omega \qquad (17)$$

$$D' = 5\omega^4-(15.708X^2+3.75)\omega^2+(3.236X^4+2.926X^2+.3125) \qquad (18)$$

$$C = 3.236X\omega^4-(5.236X^3+2.926X)\omega^2+(X^5+1.25X^3+.3125X) \qquad (19)$$

$$C' = 12.944X\omega^3-(10.472X^3+5.852X)\omega \qquad (20)$$

A program in BASIC incorporating these relationships for Chebyshev filters of order 2 through 10 is shown in Figure 3. Note that for the sake of completeness the program has been written to include the capability of determining the delay and distortion of the Butterworth type filter in addition to the Chebyshev type.

Example

A Chebyshev filter with n = 5, .003 dB ripple and 28 MHz BW_{rip} is calculated.

Since n is odd we select:

$$P_n=C(P+X)\prod_{m=1}^{(n-1)/2}\left[P^2+2X\text{Cos}\left(\frac{\pi m}{n}\right)P+X^2+\text{Sin}^2\left(\frac{\pi m}{n}\right)\right] \qquad (21)$$

Performing the indicated operrations yields the expanded form:

$$\begin{aligned}&j\omega^5+3.236X\omega^4-j(5.236X^2+1.25)\omega^3-(5.236X^3+2.926X)\omega^2\\&+j(3.326X^4+2.926X^2+.3125)\omega+(X^5+1.25X^3+.3125X)\end{aligned} \qquad (22)$$

Separating the above into its real and imaginary components yields:

$$D=I_m[P_n]=\omega^5-(5.236X^2+1.25)\omega^3+(3.236X^4+2.926X^2+.3125)\omega \qquad (23)$$

$$C=R_e[P_n]=3.236X\omega^4-(5.236X^3+2.926X)\omega^2+(X^5-1.25X^3+.3125X) \qquad (24)$$

Recalling that group delay is a function of the derivative of the phase delay:

$$\frac{d\theta}{d\omega} = \frac{d\tan^{-1}\left[\frac{I_m(P_n)}{R_e(P_n)}\right]}{d\omega} = \frac{\dfrac{d\left[\frac{I_m[P_n]}{R_e[P_n]}\right]}{d\omega}}{1+\left[\frac{I_m(P_n)}{R_e(P_n)}\right]^2} \qquad (25)$$

Performing the indicated differentiation on (23) and (24) yields:

$$D'=\frac{dI_m[P_n]}{d\omega}=5\omega^4-(15.708X^2+3.75)\omega^2+(3.236X^4+2.926X^2+.3125) \qquad (26)$$

$$C'=\frac{dR_e[P_n]}{d\omega}=12.944\omega^3-(10.472X^3+5.852X)\omega \qquad (27)$$

At this point, solving for X:

$$X = \text{Sinh}\left[\frac{1}{5}\,\text{Sinh}^{-1}\left(\frac{1}{10^{0.003/10}-1}\right)^{1/2}\right] = .9789 \qquad (28)$$

For the filter under consideration:

Chebyshev, n = 5, .003 dB ripple, 28 MHz BW_{rip}.

$$T_d = \frac{d\theta}{d\omega} = \frac{D'C - C'D}{C^2 + D^2} \qquad (29)$$

The above will yield the group delay at the normalized low pass frequency ω. The delay distortion can then be calculated by subtracting the group delay at the center frequency of the pass band (for the band pass application) from the calculated group delay at the frequency of interest. Note, ω_1' for this consideration is the normalized ripple bandwidth not the 3 dB BW.

Figure 4 shows the results of the above filter when the parameters are entered into the program.

Notice that the data and graph have been renormalized to a 3 dB BW, which may be conveniently calculated from information given in the preceeding development for the Chebyshev delay response. rf

References

1. Matthaei, G.L., Young, L., Jones, E., Microwave Filters, Impedance-Matching Networks, and Coupling Structures, McGraw-Hill, Inc., 1964, p. 114-115.

About the Author

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Figure 3. This program calculates the delay distortion.

```
10     !•••••••••••••••••••••••••DELAY-DISTORTION•••••••••••••••••••••••••••••
20     !
30     DIM L(400)
40     BEEP 300,.3
50     INPUT "ENTER 1 FOR BUTTERWORTH ; 2 FOR CHEBYSHEV",T
60     GOSUB Bandwidth
70     BEEP 300,.3
80     INPUT "ENTER NUMBER OF POLES (FROM 2 TO 10) ",N
90     R=0
100    OUTPUT 701;"fp"
110    Coh=1
120    IF T=2 THEN GOSUB Ripple
130    IF T=1 THEN
140      OUTPUT 701;N;"-POLE BUTTERWORTH FILTER, ";Bw;" MHz 3dB BW"
150      ELSE
160      IF Bs=1 THEN
170      OUTPUT 701;N;"-POLE CHEBYSHEV FILTER ";R1;" dB RIPPLE ";Bw;" MHz 3dB BW"
180      ELSE
190      OUTPUT 701;N;"-POLE CHEBYSHEV FILTER ";R1;"dB RIPPLE ";Bw;" MHz 3dB BW"
200      END IF
210    END IF
220    IF T=2 THEN
230           IF Bs=1 THEN GOSUB Calc1
240           IF Bs=2 THEN GOSUB Calc2
250    END IF
260    FOR W=.01 TO 8.0 STEP .02
261    IF W>1.5•Coh THEN GOTO 340
270    R=R+1
280    GOSUB Delay
290    Td=((D1•C-D•C1)/(C^2+D^2))
300    Td=(INT((Td/(Bw•10^6•2•PI)•1.E+9)•1000))/1000
310    L(R)=Td
320    GOSUB Print
330    NEXT W
340    GOSUB Graph
350    GOTO End
360 Delay:   ! EVALUATE AT W
370    IF T=1 THEN
380           SELECT N
390             CASE 2
400               D=1.414•W
410               D1=1.414
420               C=1-W^2
430               C1=-2•W
440             CASE 3
450               D=-W^3+2•W
460               D1=-3•W^2+2
470               C=-2•W^2+1
480               C1=-4•W
490             CASE 4
500               D=-2.613•W^3+2.613•W
510               D1=-7.839•W^2+2.613
520               C=W^4-3.414•W^2+1
530               C1=4•W^3-6.818•W
540             CASE 5
550               D=W^5-5.236•W^3+3.236•W
```

```
560            D1=5•W^4-15.708•W^2+3.236
570            C=3.236•W^4-5.236•W^2+1
580            C1=12.944•W^3-10.472•W
590          CASE 6
600            D=3.864•W^5-9.134•W^3+3.864•W
610            D1=19.32•W^4-27.402•W^2+3.864
620            C=-W^6+7.45•W^4-7.452•W^2+1
630            C1=-6•W^5+29.8•W^3-14.9•W
640          CASE 7
650            D=-W^7+10.1•W^5-14.61•W^3+4.495•W
660            D1=-7•W^6+50.5•W^4-43.82•W^2+4.495
670            C=-4.495•W^6+14.61•W^4-10.1•W^2+1
680            C1=-26.97•W^5+58.4•W^3-20.2•W
690          CASE 8
700            D=-5.12•W^7+21.8•W^5-21.81•W^3+5.12•W
710            D1=-35.84•W^6+109.05•W^4-65.43•W^2+5.12
720            C=W^8-13.1•W^6+25.65•W^4-13.11•W^2+1
730            C1=8•W^7-78.6•W^5+102.6•W^3-26.22•W
740          CASE 9
750            D=W^9-16.58•W^7+41.96•W^5-31.15•W^3+5.76•W
760            D1=9•W^8-116.06•W^6+209.8•W^4-93.45•W^2+5.76
770            C=5.76•W^8-31.15•W^6+41.96•W^4-16.58•W^2+1
780            C1=46.08•W^7-186.9•W^5+167.8•W^3-33.16•W
790          CASE 10
800            D=6.39•W^9-42.79•W^7+74.2•W^5-42.79•W^3+6.39•W
810            D1=57.51•W^8-299.5•W^6+371•W^4-128.4•W^2+6.39
820            C=-W^10+20.42•W^8-64.86•W^6+64.85•W^4-20.42•W^2+1
830            C1=-10•W^9+163.36•W^7-389.2•W^5+259.4•W^3-40.82•W
840      END SELECT
850      ELSE
860        SELECT N
870          CASE 2
880            D=1.414•X•W
890            D1=1.414•X
900            C=-W^2+X^2+.5
910            C1=-2•W
920          CASE 3
930            D=-W^3+2•X^2•W+.75•W
940            D1=-3•W^2+2•X^2+.75
950            C=-2•X•W^2+X^3+.75•X
960            C1=-4•X•W
970          CASE 4
980            D=-2.615•X•W^3+(2.615•X^3+1.69•X)•W
990            D1=-7.845•X•W^2+2.615•X^3+1.69•X
1000           C=W^4-(3.42•X^2+1)•W^2+X^4+X^2+.125
1010           C1=4•W^3-(6.84•X^2+2)•W
1020         CASE 5
1030           D=W^5-(5.236•X^2+1.25)•W^3+(3.236•X^4+2.926•X^2+.3125)•W
1040           D1=5•W^4-3•(5.236•X^2+1.25)•W^2+(3.236•X^4+2.926•X^2+.3125)
1050           C=3.236•X•W^4-(5.236•X^3+2.926•X)•W^2+(X^5+1.25•X^3+.3125•X)
1060           C1=4•3.236•X•W^3-2•(5.236•X^3+2.926•X)•W
1070         CASE 6
1080           D=3.86•X•W^5-(9.13•X^3+4.47•X)•W^3+(3.86•X^5+4.47•X^3+1.01•X)•W
1090           Da=19.3•X•W^4-(27.39•X^3+13.41•X)•W^2
1100           Db=(3.86•X^5+4.47•X^3+1.01•X)
1110           D1=Da+Db
1120           Ca=-W^6+(7.45•X^2+1.497)•W^4-(7.45•X^4+6.09•X^2+.562)•W^2
1130           Cb=(X^6+1.5•X^4+.56•X^2+.031)
1140           C=Ca+Cb
1150           C1=-6•W^5+(29.8•X^2+5.988)•W^3-(14.9•X^4+12.2•X^2+1.12)•W
1160         CASE 7
1170           Da=-W^7+(10.1•X^2+1.748)•W^5-(14.61•X^4+10.82•X^2+.873)•W^3
1180           Db=(4.495•X^6+6.34•X^4+2.191•X^2+.109)•W
1190           D=Da+Db
1200           Da=-7•W^6+(50.5•X^2+8.74)•W^4-(43.83•X^4+32.46•X^2+2.62)•W^2
1210           Db=(4.495•X^6+6.34•X^4+2.191•X^2+.109)
1220           D1=Da+Db
1230           Ca=-4.495•X•W^6+(14.61•X^3+6.34•X)•W^4
1240           Cb=-(10.1•X^5+10.8•X^3+2.19•X)•W^2+X^7+1.75•X^5+.873•X^3+.11•X
1250           C=Ca+Cb
1260           Ca=-26.97•X•W^5+(58.4•X^3+25.35•X)•W^3
1270           Cb=-(20.2•X^5+21.64•X^3+4.38•X)•W
1280           C1=Ca+Cb
1290         CASE 8
1300           Da=-5.12•X•W^7+(21.8•X^3+8.5•X)•W^5
1310           Db=-(21.8•X^5+21.7•X^3+3.97•X)•W^3
1320           Dc=(5.12•X^7+8.5•X^5+3.97•X^3+.46•X)•W
1330           D=Da+Db+Dc
1340           Da=-35.8•X•W^6+(109•X^3+42.5•X)•W^4
1350           Db=-(65.4•X^5+65.1•X^3+11.9•X)•W^2
1360           Dc=(5.12•X^7+8.43•X^5+3.95•X^3+.459•X)
1370           D1=Da+Db+Dc
1380           Ca=W^8-(13.11•X^2+2)•W^6+(25.6•X^4+17.4•X^2+1.24)•W^4
1390           Cb=-(13.11•X^6+17.4•X^4+5.54•X^2+.25)•W^2
```

```
1400            Cc=(X^8+2•X^6+1.24•X^4+.25•X^2+.008)
1410            C=Ca+Cb+Cc
1420            Ca=8•W^7-(78.66•X^2+12)•W^5+(102•X^4+69.6•X^2+4.96)•W^3
1430            Cb=-(26.22•X^6+34.8•X^4+11.08•X^2+.5)•W
1440            C1=Ca+Cb
1450          CASE 9
1460            Da=W^9-(16.578•X^2+2.25)•W^7+(41.978•X^4+26.132•X^2+1.6876)•W^5
1470            Db=-(31.157•X^6+38.766•X^4+11.501•X^2+.4686)•W^3
1480            Dc=(5.758•X^8+11.015•X^6+6.529•X^4+1.223•X^2+.0351)•W
1490            D=Da+Db+Dc
1500            Da=9•W^8-(116.05•X^2+15.75)•W^6
1510            Db=(209.89•X^4+130.66•X^2+8.438)•W^4
1520            Dc=-(93.471•X^6+116.3•X^4+34.5•X^2+1.406)•W^2
1530            Dd=(5.758•X^8+11.015•X^6+6.529•X^4+1.223•X^2+.0351)
1540            D1=Da+Db+Dc+Dd
1550            Ca=5.758•X•W^8-(31.157•X^3+11.016•X)•W^6
1560            Cb=(41.977•X^5+38.768•X^3+6.5286•X)•W^4
1570            Cc=-(16.579•X^7+26.129•X^5+11.501•X^3+1.223•X)•W^2
1580            Cd=(X^9+2.25•X^7+1.688•X^5+.4686•X^3+.0351•X)
1590            C=Ca+Cb+Cc+Cd
1600            Ca=46.064•X•W^7-(186.94•X^3+66.096•X)•W^5
1610            Cb=(167.91•X^5+155.072•X^3+26.114•X)•W^3
1620            Cc=-(33.158•X^7+52.258•X^5+23.002•X^3+2.446•X)•W
1630            C1=Ca+Cb+Cc
1640          CASE 10
1650            Da=6.3925•X•W^9-(42.802•X^3+13.832•X)•W^7
1660            Db=(74.235•X^5+64.007•X^3+9.9121•X)•W^5
1670            Dc=-(42.802•X^7+64.007•X^5+26.465•X^3+2.6077•X)•W^3
1680            Dd=(6.3925•X^9+13.832•X^7+9.9121•X^5+2.6077•X^3+.18293•X)•W
1690            D=Da+Db+Dc+Dd
1700            Da=57.5325•X•W^8-(299.61•X^3+96.824•X)•W^6
1710            Db=(371.18•X^5+320.04•X^3+49.561•X)•W^4
1720            Dc=-(128.41•X^7+192.02•X^5+79.395•X^3+7.8231•X)•W^2
1730            Dd=(6.3925•X^9+13.832•X^7+9.9121•X^5+2.6077•X^3+.18293•X)
1740            D1=Da+Db+Dc+Dd
1750            Ca=-(W^10)+(20.4315•X^2+2.5)•W^8
1760            Cb=-(64.883•X^4+37.343•X^2+2.1875)•W^6
1770            Cc=(64.883•X^6+76.016•X^4+20.977•X^2+.78125)•W^4
1780            Cd=-(20.4315•X^8+37.343•X^6+20.977•X^4+3.6838•X^2+.09765)•W^2
1790            Ce=(X^10+2.5•X^8+2.1875•X^6+.78125•X^4+.09765•X^2+.00195)
1800            C=Ca+Cb+Cc+Cd+Ce
1810            Ca=-10•W^9+(163.45•X^2+20)•W^7
1820            Cb=-(389.3•X^4+224.06•X^2+13.125)•W^5
1830            Cc=(259.53•X^6+304.06•X^4+83.908•X^2+3.125)•W^3
1840            Cd=-(40.863•X^8+74.686•X^6+41.954•X^4+7.3676•X^2+.1953)•W
1850            C1=Ca+Cb+Cc+Cd
1860        END SELECT
1870  END IF
1890  RETURN
1900 Bandwidth:   !
1910        IF T=1 THEN
1920              INPUT "ENTER 3dB BANDWIDTH__MHz",Bw
1930              ELSE
1940              INPUT "SELECT 3dB BW (1) OR RIPPLE BW (2) ENTER 1 OR 2",Bs
1950              IF Bs=1 THEN INPUT "ENTER 3dB BANDWIDTH__MHz",Bw
1960              IF Bs=2 THEN INPUT "ENTER RIPPLE BANDWIDTH___MHz",Bw
1970        END IF
1980 RETURN
1990 Ripple: !
2000      INPUT "ENTER PASS-BAND RIPPLE___dB",Ri
2010      E=2.7182818
2020      Q=10^(Ri/10)-1
2030      Y=SQR(1/Q)
2040      Z=LOG(Y+SQR(Y^2+1))
2050      S=Z/N
2060      X=(E^S-1/(E^S))/2
2070 RETURN
2080 Print: !
2090      IF W=.01 THEN
2100      OUTPUT 701
2110      OUTPUT 701;"       W'/W       ";"      Td    nSEC.";"    DELTA Td "
2120      OUTPUT 701
2130      END IF
2140      OUTPUT 701;"       ";W;"            ";L(R);"       ";L(R)-L(1)
2150 RETURN
2160 Graph: !
2170          GCLEAR
2171          OUTPUT 701;"%"
2180          Scale=(20/(Coh•Bw)•T)
2190          CSIZE 4,.5
2200          FOR K=20 TO 120 STEP 10
2210          MOVE K,20
2220          DRAW K,100
2230          NEXT K
2240          FOR K=20 TO 100 STEP 10
2250          MOVE 20,K
```

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```
2260        DRAW 120,K
2270        NEXT K
2280        MOVE 98,16
2290        LABEL "wl"
2300        MOVE 10,10
2310        LABEL "wl ( w3dB ) = ";(INT((Bw*Con)*100))/100;" MHz"
2320        FOR K=18 TO 98 STEP 10
2330        MOVE 1,K
2340        LABEL INT((K-18)*2*Scale);"nSEC"
2350        NEXT K
2360        MOVE 20,20
2370        FOR K=1 TO 400
2380        DRAW (20-.35/Con+K/Con/.7143),1/Scale*L(K)/2+20
2390        IF (20+K/Con/.7143)>120 THEN GOTO 2420
2400        NEXT K
2410        OUTPUT 701
2420        DUMP GRAPHICS
2430 RETURN
2440 Calc1: !
2450           GOSUB Cosh
2460           Bw=1/Con*Bw
2470           OUTPUT 701;" RIPPLE BANDWIDTH IS ";Bw;"MHz"
2480 RETURN
2490 Calc2: !
2500           GOSUB Cosh
2510           Bw3=Con*Bw
2520           OUTPUT 701;"3dB BANDWIDTH IS ";Bw3;"MHz"
2530 RETURN
2540 Cosh: !
2550          Zc=LOG(Y+SQR(Y^2-1))
2560          A=Zc/N
2570          Con=(E^A+1/(E^A))/2
2580 RETURN
2590 End: END
```

Figure 4. These are the results for the filter in the example.

5-POLE CHEBYSHEV FILTER .003dB RIPPLE 28 MHz 3dB BW
3dB BANDWIDTH IS 39.1812212029MHz

W'/W	Td nSEC.	DELTA Td
.01	14.555	0
.03	14.557	.002
.05	14.561	.006
.07	14.567	.012
.09	14.575	.02
.11	14.585	.03
.13	14.597	.042
.15	14.612	.057
.17	14.629	.074
.19	14.648	.093
.21	14.67	.115
.23	14.695	.14
.25	14.723	.168
.27	14.754	.199
.29	14.787	.232
.31	14.825	.27
.33	14.865	.31
.35	14.909	.354
.37	14.956	.401
.39	15.007	.452
.41	15.062	.507
.43	15.12	.565
.45	15.182	.627
.47	15.247	.692
.49	15.317	.762
.51	15.39	.835
.53	15.467	.912
.55	15.549	.994
.57	15.634	1.079
.59	15.723	1.168
.61	15.817	1.262
.63	15.916	1.361
.65	16.019	1.464
.67	16.128	1.573
.69	16.243	1.688
.71	16.364	1.809
.73	16.493	1.938
.75	16.629	2.074
.77	16.776	2.221
.79	16.932	2.377
.81	17.101	2.546
.83	17.284	2.729
.85	17.482	2.927
.87	17.697	3.142
.89	17.933	3.378
.91	18.19	3.635
.93	18.473	3.918
.95	18.782	4.227
.97	19.122	4.567
.99	19.493	4.938
1.01	19.899	5.344
1.03	20.341	5.786
1.05	20.819	6.264
1.07	21.335	6.78
1.09	21.885	7.33
1.11	22.465	7.91
1.13	23.071	8.516
1.15	23.693	9.138
1.17	24.317	9.762
1.19	24.928	10.373
1.21	25.507	10.952
1.23	26.031	11.476
1.25	26.475	11.92
1.27	26.815	12.26
1.29	27.028	12.473
1.31	27.097	12.542
1.33	27.008	12.453
1.35	26.758	12.203
1.37	26.352	11.797
1.39	25.8	11.245
1.41	25.121	10.566
1.43	24.339	9.784
1.45	23.479	8.924
1.47	22.564	8.009
1.49	21.619	7.064
1.51	20.664	6.109
1.53	19.715	5.16
1.55	18.786	4.231
1.57	17.887	3.332
1.59	17.024	2.469
1.61	16.202	1.647
1.63	15.424	.869
1.65	14.689	.134
1.67	13.999	-.556
1.69	13.35	-1.205
1.71	12.743	-1.812
1.73	12.175	-2.38
1.75	11.643	-2.912
1.77	11.146	-3.409
1.79	10.681	-3.874
1.81	10.245	-4.31
1.83	9.837	-4.718
1.85	9.454	-5.101

continued on p. 49

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167 LP	2000 W	10-86 MHz	60 dB gain	$13,990
164 HP	500 W	80-200 MHz	55 dB gain	$7,990
166 HP	1000 W	80-200 MHz	55 dB gain	$9,990
164 UP	300 W	200-400 MHz	55 dB gain	$6,990
166 UP	600 W	200-400 MHz	55 dB gain	$8,990
164 SP	250 W	400-500 MHz	55 dB gain	$6,990
168 LP	4000 W	10-60 MHz	60 dB gain	$20,990

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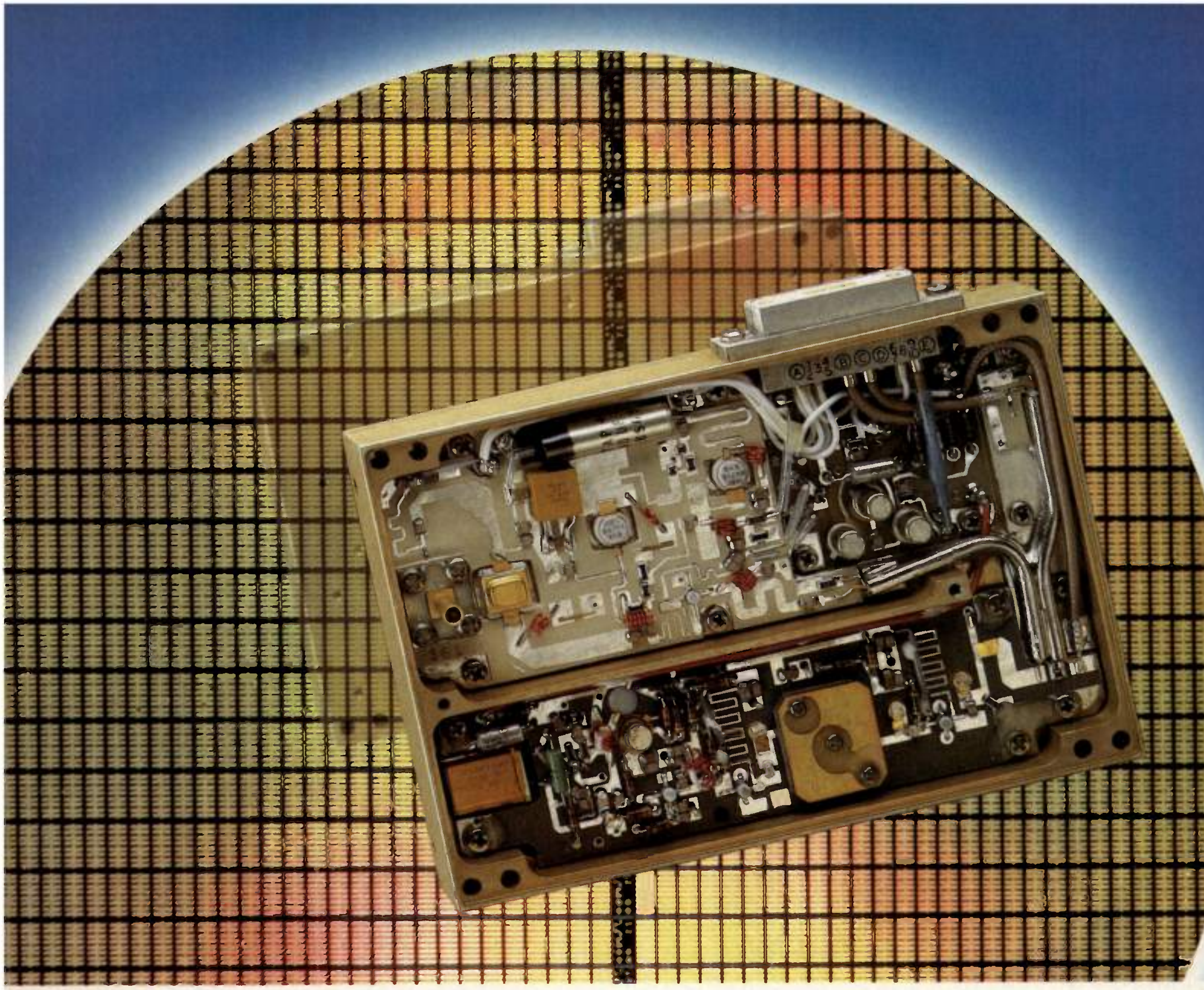

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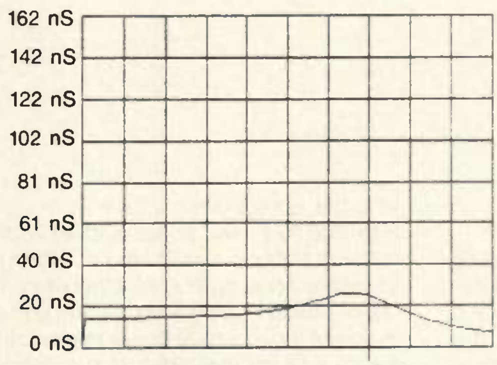
1.87	9.095	-5.46
1.89	8.758	-5.797
1.91	8.44	-6.115
1.93	8.142	-6.413
1.95	7.86	-6.695
1.97	7.594	-6.961
1.99	7.344	-7.211
2.01	7.106	-7.449
2.03	6.882	-7.673
2.05	6.668	-7.887
2.07	6.466	-8.089
2.09	6.274	-8.281



ω3dB = 39.18 MHz ω3dB

2-POLE CHEBYSHEV FILTER .003 dB RIPPLE 40 MHz 3dB BW
RIPPLE BANDWIDTH IS 9.05341214491MHz

3-POLE CHEBYSHEV FILTER .003 dB RIPPLE 40 MHz 3dB BW
RIPPLE BANDWIDTH IS 17.8845813409MHz

4-POLE CHEBYSHEV FILTER .003 dB RIPPLE 40 MHz 3dB BW
RIPPLE BANDWIDTH IS 24.3022522176MHz

5-POLE CHEBYSHEV FILTER .003 dB RIPPLE 40 MHz 3dB BW
RIPPLE BANDWIDTH IS 28.5851223013MHz

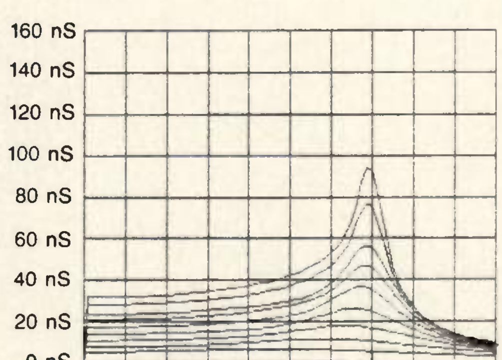
6-POLE CHEBYSHEV FILTER .003 dB RIPPLE 40 MHz 3dB BW
RIPPLE BANDWIDTH IS 31.4436482999MHz

7-POLE CHEBYSHEV FILTER .003 dB RIPPLE 40 MHz 3dB BW
RIPPLE BANDWIDTH IS 33.3987623935MHz

8-POLE CHEBYSHEV FILTER .0003 dB RIPPLE 40 MHz 3dB BW
RIPPLE BANDWIDTH IS 32.1483461404MHz

9-POLE CHEBYSHEV FILTER .003 dB RIPPLE 40 MHz 3dB BW
RIPPLE BANDWIDTH IS 35.7757666307MHz

10-POLE CHEBYSHEV FILTER .003 dB RIPPLE 40 MHz 3dB BW
RIPPLE BANDWIDTH IS 36.5199402062MHz



ω3dB = 40 MHz ω3dB

2-POLE CHEBYSHEV FILTER .05 dB RIPPLE 40 MHz 3dB BW
RIPPLE BANDWIDTH IS 17.6320984067MHz

3-POLE CHEBYSHEV FILTER .05 dB RIPPLE 40 MHz 3dB BW
RIPPLE BANDWIDTH IS 26.4533072415MHz

4-POLE CHEBYSHEV FILTER .05 dB RIPPLE 40 MHz 3dB BW
RIPPLE BANDWIDTH IS 31.2892226257MHz

5-POLE CHEBYSHEV FILTER .05 dB RIPPLE 40 MHz 3dB BW
RIPPLE BANDWIDTH IS 34.031882112MHz

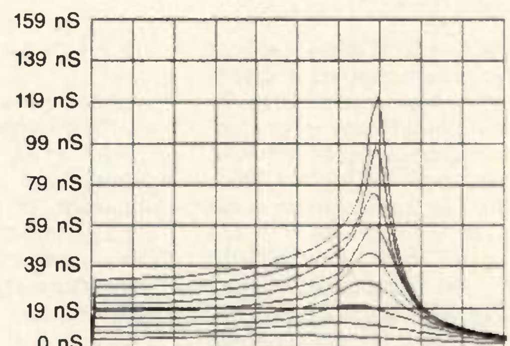
6-POLE CHEBYSHEV FILTER .05 dB RIPPLE 40 MHz 3dB BW
RIPPLE BANDWIDTH IS 35.6908324336MHz

7-POLE CHEBYSHEV FILTER .05 dB RIPPLE 40 MHz 3dB BW
RIPPLE BANDWIDTH IS 36.7565152838MHz

8-POLE CHEBYSHEV FILTER .05 dB RIPPLE 40 MHz 3dB BW
RIPPLE BANDWIDTH IS 37.4766218281MHz

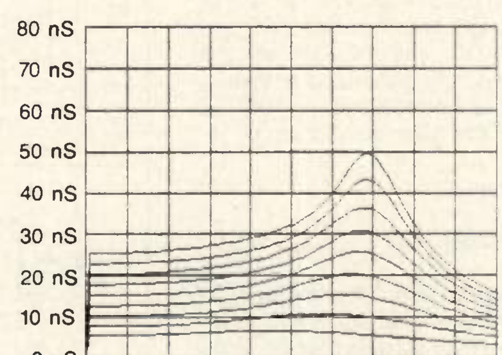
9-POLE CHEBYSHEV FILTER .05 dB RIPPLE 40 MHz 3dB BW
RIPPLE BANDWIDTH IS 37.9839231009MHz

10-POLE CHEBYSHEV FILTER .05 dB RIPPLE 40 MHz 3dB BW
RIPPLE BANDWIDTH IS 38.353815781MHz



ω3dB = 40 MHz ω3dB

2-POLE BUTTERWORTH FILTER, 40 MHz 3dB BW
3-POLE BUTTERWORTH FILTER, 40 MHz 3dB BW
4-POLE BUTTERWORTH FILTER, 40 MHz 3dB BW
5-POLE BUTTERWORTH FILTER, 40 MHz 3dB BW
6-POLE BUTTERWORTH FILTER, 40 MHz 3dB BW
7-POLE BUTTERWORTH FILTER, 40 MHz 3dB BW
8-POLE BUTTERWORTH FILTER, 40 MHz 3dB BW
9-POLE BUTTERWORTH FILTER, 40 MHz 3dB BW
10-POLE BUTTERWORTH FILTER, 40 MHz 3dB BW



ω3dB = 40 MHz ω3dB

Simple Digital Inductance Meter With 0.1 nH Resolution

By Roger A. Williams
LTX Corporation

The personal computer and the advent of inexpensive circuit analysis and synthesis software have made the RF engineer's job easier in many ways. Construction and component issues, however, have become more important than miniaturization. The broadband networks in modern RF circuits have more elements than their narrowband predecessors. Hence, the designer must take care to fully characterize them. At frequencies below 1 GHz, this involves accurate measurement of inductances and capacitances of both components and circuit board strays. Chip capacitors and tiny air-wound coils demand resolutions of about 0.1 pF and less than 1 nH.

Accurate low-cost portable digital capacitance meters proliferate, but inexpensive inductance bridges have a resolution of only about 100 nH. This article takes a look at the design of the high resolution digital inductance meter which won the author a copy of Superstar in the RF Design Awards Contest.

The inductance meter operates by forcing a constant 100 kHz sinusoidal current through the inductor (L_x) and measuring the magnitude of the quadrature voltage generated across it. This voltage leads the current by 90°, as indicated by the basic relationship:

$$V(t) = L_x \cdot di/dt$$

$$= L_x \cdot a_1 \omega \cos(\omega t), \text{ if } i(t) = a_1 \sin(\omega t)$$

This works out to about 2.5 mV for a 20 mA, 100 kHz current through a 200 nH inductor, or 25 uV for a 2 nH inductor. Since the test fixture and every coil will have some series resistance, R_s, the total voltage across the inductor can be represented as:

$$V(t) = L_x \cdot a_1 \omega \cos(\omega t) + R_s \cdot a_1 \sin(\omega t)$$

Observe the importance of measuring just the quadrature component: for 20 mA current, an R_s of only 125 milliohms will generate a 0° component of 2.5 mV, the amplitude of the full-scale quadrature signal. (Note that the inductor cannot be conveniently measured by applying a constant shunt voltage and measuring the series current, as this current becomes infinite as the inductance goes to zero, and is 16 A for a 10 nH coil with a 100 mV, 100 kHz excitation.)

The amplitude of the quadrature component of the voltage across L_x may be recovered by synchronous demodulation, with the demodulator's reference signal provided by a +90° phase-shifted version of the currrent source's signal. When the demodulator's output is integrated, the out-of-phase components cancel and the in-phase (quadrature) components add to create a DC signal which is proportional to the peak amplitude of the in-phase component.

Description

The reference sine wave is generated by a 100 kHz crystal-controlled oscillator (Figure 1) with AGC to maintain a constant output level. This signal provides a reference to the demodulator, and after amplitude scaling by the range switch, to

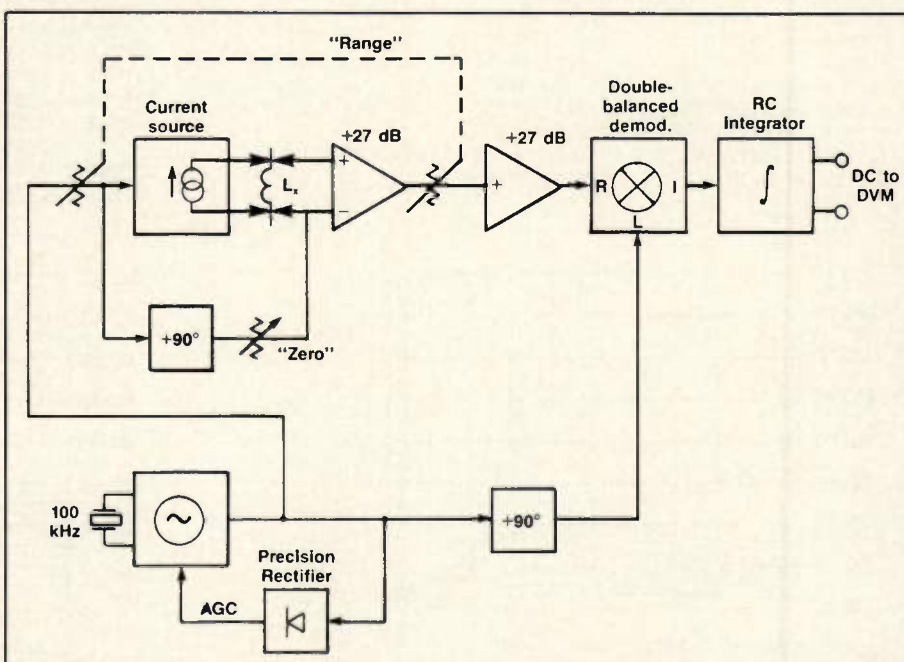


Figure 1. Block diagram of inductance meter.

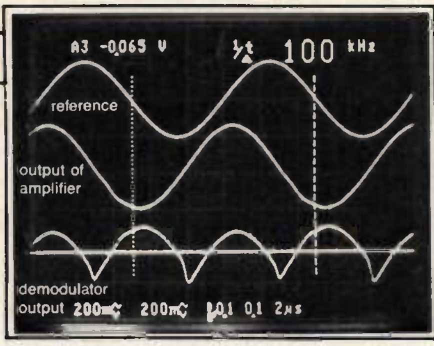


Figure 2. Inductance meter waveforms when measuring 1.8 uH coil on 2 uH range.

the voltage-controlled current source which drives the inductor.

The current source forces 20 mA p-p through L_x on the 200 nH and 2 uH ranges, 2 mA on the 20 uH and 200 uH ranges, and 200 uA on the 2 mH range. (These currents are low enough to not cause saturation of sensitive ferrite-core toroidal inductors.) The voltage generated across the inductor is amplified by two 27 dB low-phase-shift amplifiers separated by a range-switched attenuator. The signal is attenuated by 20 dB on the 2 uH and 20 uH ranges, and by 40 dB on the 200 uH and 2 mH ranges.

The signal, at a single full-scale value for all ranges, drives the signal input (RF) port of an active double-balanced modulator (mixer). The reference (LO) port of this modulator is driven into saturation by a +90° phase-shifted reference signal. The output (IF) of the modulator (Figures 2 and 3) is integrated by an R-C low-pass filter. The resulting DC signal is the scaled (0-200 mV) signal which drives the digital voltmeter.

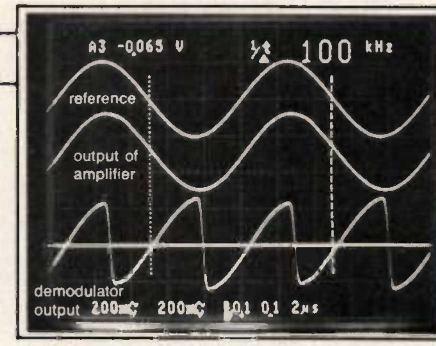


Figure 3. Inductance meter waveforms when measuring 1Ω resistor on 2 uH range.

Circuit Description

The complete circuit diagram is shown in Figure 4. The oscillator is op amp U_{1a}, which is gain-stailized by precision rectifier U_{1b} and N-channel FET Q_1. Q_1 is placed in U_{1a}'s feedback path so that as negative gate drive increases (R_{ds} in-

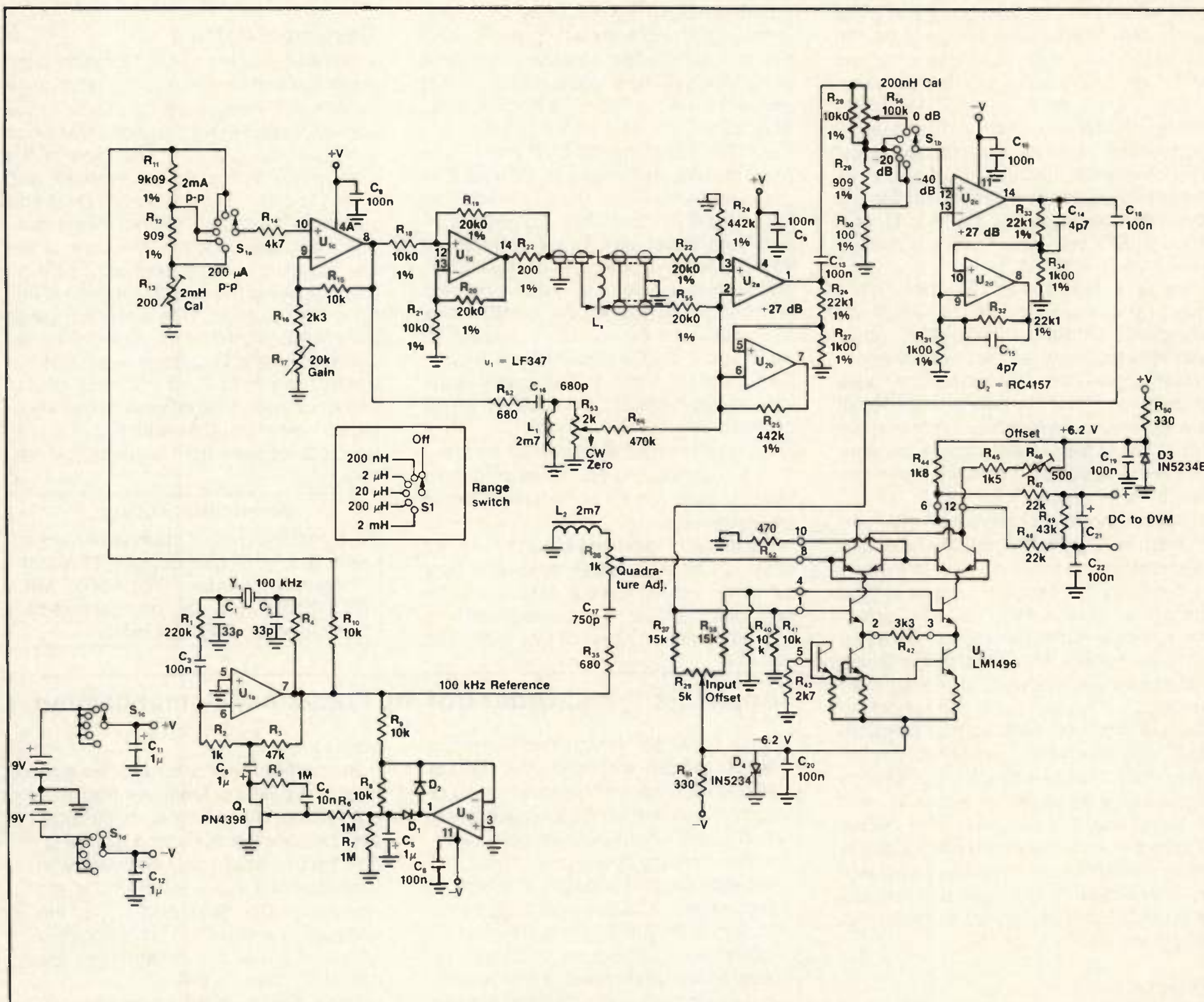


Figure 4. Circuit diagram of inductance meter.

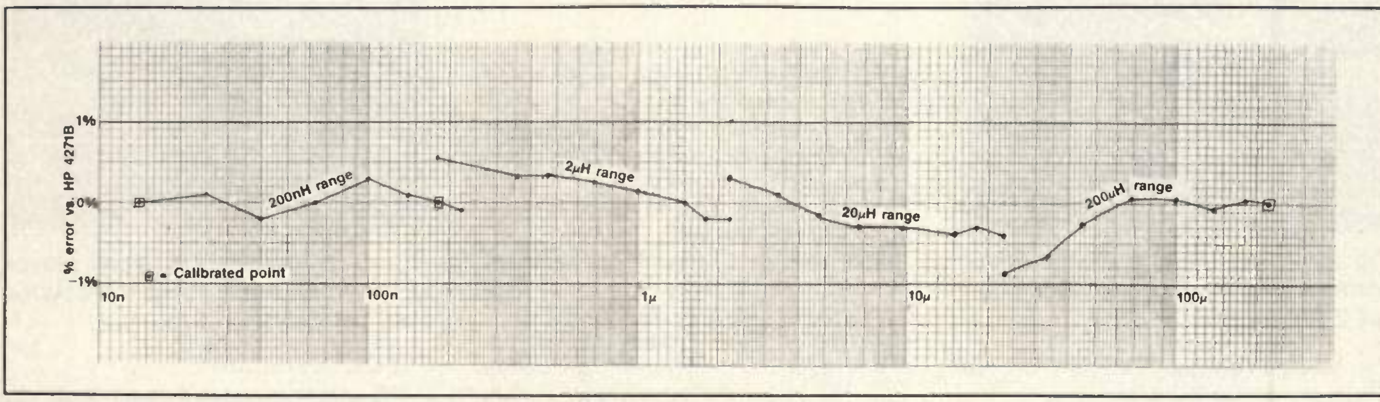


Figure 6. Correlation of inductance meter with HP 4271B.

creases), the op amp gain will decrease. The values of R_2 and R_3 are chosen so that unity gain is reached in the FET's high-slope R_{ds} region near V_{gs}(off) (pinch-off). As the pinchoff voltage of a JFET is very nearly temperature-independent, the oscillator's amplitude (and frequency, due to Y_1) are very stable over temperature.

U_{1c} is a buffer to drive U_{1d}, which is configured as a current source. It is important that 1 percent (or matched) resistors be used in the current source, as its output conductance is proportional to the mismatch between R_{19} and R_{20}. U_1 is a quad Bi-FET op amp, chosen for its high slew rate limit (11 V/us).

U_2 is a high-speed (18 MHz GBW) quad op amp configured as two 27 dB low-phase-shift-amplifiers. The novel amplifier topology, referred to as *Second-Order Frequency-Compensation*, was chosen to extend the phase response of the amplifier a decade beyond that which could be achieved with single op amp amplifiers. Appendix 1 contains a description of its operation.

Synchronous demodulation is performed by U_3, an RF double-balanced modulator/demodulator. A reference signal from the oscillator, phase-shifted through a passive RLC network, drives the top differential pairs into saturation, while the bottom differential pair is driven linearly by the amplified signal V_x from across L_x. The top pairs' output collectors are cross-coupled so that full-wave multiplication of the phase-shifted reference and V_x occurs. Since the reference signal is the same frequency as V_x, and is saturating the top pairs, the output (Figures 2 and 3) of the demodulator is a function of the amplitude and phase of V_x. The output of U_3, used differentially to avoid DC drift problems, is filtered and drives the digital voltmeter.

Performance

The circuit was built on a small piece of ground-plane broadboard material, and was installed with the rotary Range/power switch, Zero-set potentiometer, inductor test clip, and two 9 V transistor batteries into a 130 × 150 × 50 mm slope-front aluminum box. The 0-200 mV DC signal to the digital voltmeter was brought out of the box with a two-conductor shielded cable. A Kelvin-type test clip was used to eliminate errors from test clip stray inductors.

An HP 4271B digital LCR meter was used to calibrate the circuit. Comparison measurements were made on the first four ranges (through 200 uH) and the inductance meter was found to track the 4271B to within 0.5 percent on the 200 nH and 2 uH ranges and to within 1 percent on the other two ranges. As the 4271B has a specified accuracy of 1 percent of reading to 1 uH, 0.6 percent to 10 uH, and 0.2 percent to 1 mH, the accuracy of the inductance meter circuit is better than 1.6 percent.

The system gain (scale error) and zero drift are almost independent of supply voltage. They are also almost unaffected by temperature.

For measuring printed circuit traces, the drive (current source) and measure (amplifier inputs) coaxial cables may be extended to at least 1 m in length without degrading the accuracy of the meter. The circuit draws less than 25 mA from each supply. With 9 V alkaline batteries (550 mAh), continuous operation of over 25 hours can be obtained.

Recommendations

Several changes could be made to improve the performance of the inductance meters. If it were mated with one of the common ratiometric 3½-digit DVM chips available, the gain drift and most of the zero drift errors could be removed, and it could be built into a standard DVM-size package. This circuit cannot measure inductances above 2 mH because of the low inductor currents that would be required to keep the inductor voltage within the dynamic range of the amplifiers. Large inductances could be measured if the circuit were made to operate at a lower frequency (such as 1 or 10 kHz) for the higher ranges. A negative-voltage switching converter could be added to allow the circuit to operate from a single 9 V battery.

About the Author

Roger Williams is applications engineer at LTX Corporation, LTX Park at University Avenue, Westwood, MA 02090-2306. He can be reached by telephone at (617) 329-7550.

Appendix 1: 2nd-Order OpAmp Frequency Compensation

In a conventional single non-inverting operational amplifier, the output phase rolls off with frequency more quickly than the closed-loop gain does, and is −6° at 10 percent gain bandwidth. In many applications this is not acceptable and requires the use of high-speed op amps operating below their gain-frequency limits. The technique of using a second (matched) op amp to provide second-order frequency compensation was developed to extend this phase response by several octaves.

In any feedback amplifier, we may refer to the ratio of feedback from output to input as β. For our discussion, approximate the open-loop gain of an op amp by a single-pole response with time constant A_o/ω_τ, where A_o is the open-loop DC gain and ω_τ is the unity-gain bandwidth. This is accurate so long as $A_{o\beta} >> 1$ and we are operating below $\omega t/10$.

For a single op amp non-inverting amplifier,

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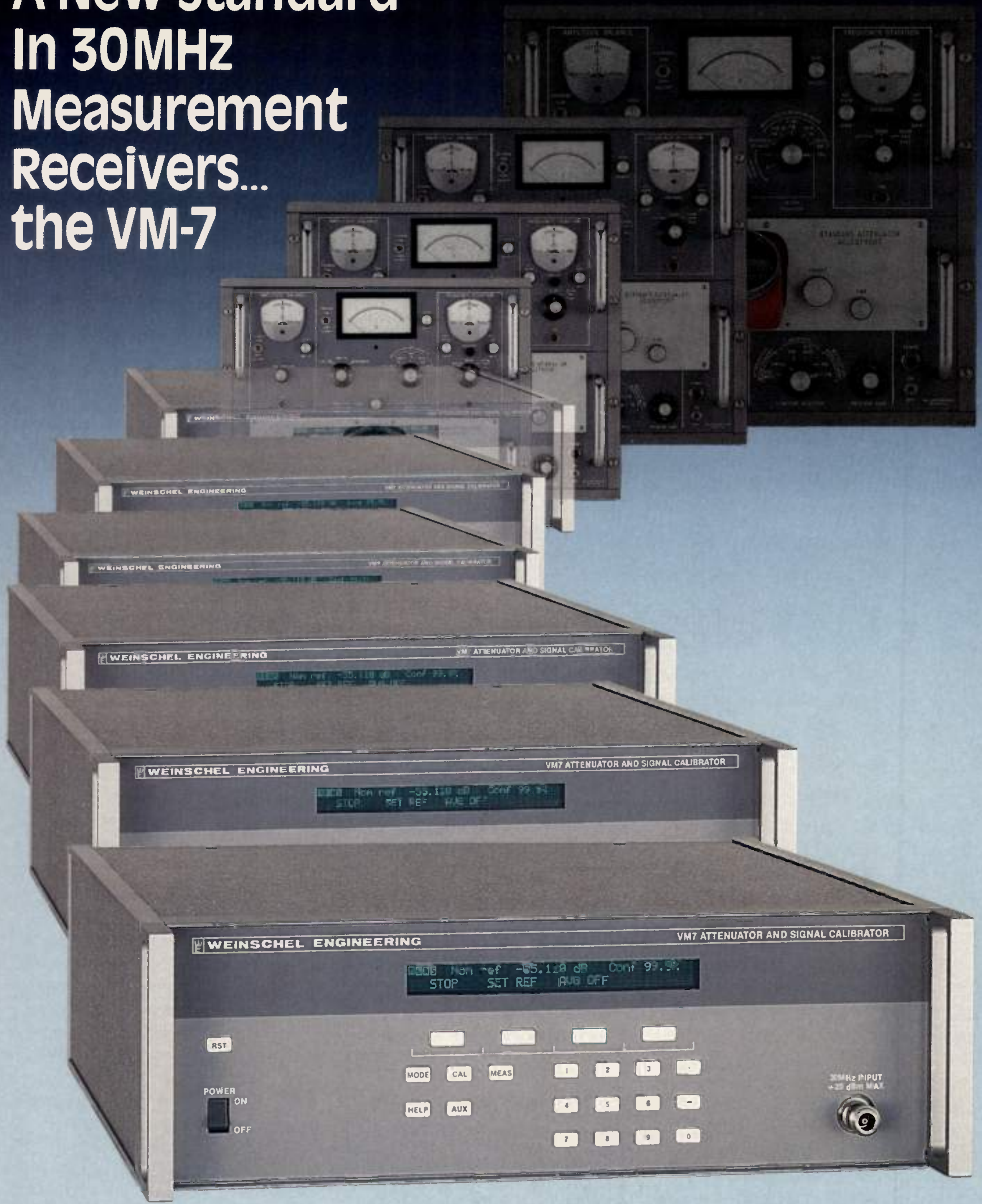


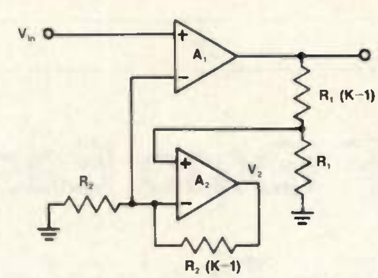
INFO/CARD 37

Closed-loop gain $\triangleq \dfrac{1}{\beta}\,\dfrac{1}{1+\dfrac{1}{\beta\omega_T}s}$

and thus (by small-angle equivalence), phase-error $= -\omega/\beta\omega_T$. If a second op amp of identical characters is available (i.e. monolithic dual or quad op amp), its frequency characteristics may be used to compensate those of the main amplifier.

At low frequencies, A1 forces V_2/K to be equal to V_{in}. A_2 forces V_o/K to be equal to V_2/K. Thus, the DC gain is K. Assume that the two op amps have matched gain bandwidths and that open-loop gain $\triangleq \omega_T/s$. The transfer equation (V_o/V_{in}) can then be determined from the loop equations for A_1 and A_2.

$$\frac{V_o}{V_{in}} = K\left[\frac{1 - j\left(\dfrac{\omega}{\beta\omega_T}\right)^3}{1 - \left(\dfrac{\omega}{\beta\omega_T}\right)^2 + \left(\dfrac{\omega}{\beta\omega_T}\right)^4}\right]$$



Thus, the phase error has been reduced to approximately $-(\omega/\beta\omega_T)^3$. For $\omega/\beta\omega_T < 0.1$, phase error is reduced since the two op amp compensated circuit has less than 0.1° error at $\omega/\beta\omega_T = 0.1$, compared to the 6° of the uncompensated circuit.

Reference

1. Precision Monolithics Inc., 1986 Analog Applications Seminar.

Appendix 2: Parts List

Description & Part Number	Qty	Manufacturer	Component Designations
Res, 220k ohm, ¼W 5% CF	1	various	R1
Res, 1k ohm, ¼W 5% CF	1	various	R2
Res, 47k ohm, ¼W 5% CF	1	various	R3
Res, 100k ohm, ¼W 5% CF	1	various	R4
Res, 1M ohm, ¼W 5% CF	3	various	R5,6,7
Res, 10k ohm, ¼W 5% CF	6	various	R8,9,10,15,40,41
Res, 9.09k ohm, ¼W 1% MF, RN55D	1	various	R11
Res, 909 ohm, ¼W 1% MF, RN55D	2	various	R12,29
Res, 200 ohm variable, 4t cermet	1	various	R13
Res, 4.7k ohm, ¼W 5% CF	1	various	R14
Res, 3.3k ohm, ¼W 5% CF	2	various	R16,42
Res, 20k ohm variable, 4t cermet	1	various	R17
Res, 10.0k ohm, ¼W 1% MF, RN55D	3	various	R18,21,28
Res, 20.0k ohm, ¼W 1% MF, RN55D	4	various	R19,20,23,55
Res, 200 ohm, ¼W 1% MF, RN55D	1	various	R22
Res, 442k ohm, ¼W 1% MF, RN55D	2	various	R24,25
Res, 1.00k ohm, ¼W 1% MF, RN55D	3	various	R27,31,34
Res, 22.1k ohm, ¼W 1% MF, RN55D	3	various	R26,32,33
Res, 100 ohm, ¼W 1% MF, RN55D	1	various	R30
Res, 100k ohm variable, 4t cermet	1	various	R56
Res, 680 ohm, ¼W 5% CF	2	various	R35,52
Res, 1k ohm variable, 4t cermet	1	various	R36
Res, 15k ohm, ¼W 5% CF	2	various	R37,38
Res, 5k ohm variable, 4t cermet	1	various	R39
Res, 2.7k ohm, ¼W 5% CF	1	various	R43
Res, 1.8k ohm, ¼W 5% CF	1	various	R44
Res, 1.5k ohm, ¼W 5% CF	1	various	R45
Res, 500 ohm variable, 4t cermet	1	various	R46
Res, 22k ohm, ¼W 5% CF	2	various	R47,48
Res, 43k ohm, ¼W 5% CF	1	various	R49
Res, 330 ohm, ¼W 5% CF	2	various	R50,51
Res, 2k ohm variable, type 3520	1	Bourns	R53
type 535		Spectrol	
Res, 470k ohm, ¼W 5% CF	1	various	R54
Cap, 33 pF, NPO monolithic ceramic	2	various	C1,2
Cap, 100 nF, X7R monolithic ceramic	10	various	C3,7,8,9,10,13,18,19,20,22
Cap, 10 nF, X7R monolithic ceramic	1	various	C4
Cap, 1 uF, dipped tantalum	5	various	C5,6,11,12,21
Cap, 4.7 pF, NPO monolithic ceramic	2	various	C14,15
Cap, 680 pF, NPO monolithic ceramic	1	various	C16
Cap, 750 pF, NPO monolithic ceramic	1	various	C17
IC, quad BiFet opamp, LF347	1	National	U1
IC, quad H/S opamp, RC4157	1	Raytheon	U2
IC, demodulator, DIP, LM1496N	1	National	U3
MC1496L		Motorola	
NE1496		Signetics	
Trn, N-ch JFET, PN4393	1	Siliconix	Q1
		National	
Diode, switching, 1N4148	2	various	D1,2
Diode, 6.2 V zener, 1N5234B	2	various	D3,4
Inductor, 2.7 mH choke, 10%	2	various	L1,2
Crystal, 100 kHz miniature tuning fork, CX-1V	1	Statek	Y1
Switch, 4-pole 6-pos rotary	1	various	S1
Test clip, 4-terminal Kelvin	1	various	

RF Expo East — The Technical Program

An Engineering "Curriculum" Including Tutorials, Case Histories, and a Panel on Superconductivity.

RF Expo East, November 11-13, 1987 at Boston's World Trade Center, offers engineers an opportunity to take part in an exchange of ideas that cannot be found anywhere else. Papers have been specifically sought out to supplement those freely offered, to create balanced coverage of important topics. The result is a program broad enough to offer every engineer something of value and deep enough to satisfy the most rigorous theoretician.

Fundamentals of RF Circuit Design
Les Besser, Besser Associates

A One-Day Short Course: Tuesday, November 10, or Wednesday, November 11

Once again, this popular course in RF design fundamentals is being offered to RF Expo East attendees. The course covers component behavior at radio frequencies, reviews the Smith chart and S-parameters, and presents basics of amplifier design using manual and CAD techniques.

An additional fee of $125 is charged for this course, and advance registration is strictly required.

WEDNESDAY — 8:30 to 11:30 a.m.

A-1 — RF Power Amplifier Tutorial Chair: Sam Klein, Microwave Modules and Devices

RF Circuit Design Practices
Dan Moline, Motorola

This paper presents fundamental RF power amplifier design principles, including device selection, circuit configuration, board layout, distributed and lumped-element component choices, stability analysis, and test procedures.

RF Combining and Protection Techniques
Joe Johnson, Microwave Modules and Devices

Power amplifier integration into a system often requires the combination of more than one amplifier. A complete system must also include protection circuitry at the individual amplifier and system-wide levels. This paper covers combining and protection methods for power amplifiers operating at HF through UHF.

Requirements for Envelope-Elimination-and-Restoration (EER) Systems
Frederick H. Raab, Green Mountain Radio Research

Class D RF power amplifiers (PAs) with kilowatt power output at HF have been recently been demonstrated. Such amplifiers, however, are not usable for linear amplification. Class S (pulse-width modulated) PAs are well established in high-efficiency amplitude modulated systems. Envelope elimination and restoration (EER) combines these two PAs into a high efficiency linear PA system. This paper covers the basic principles and techniques required for a high efficiency linear EER system.

Session B-1 — Digital/ RF Applications

RF versus Digital — The Intelligent Allocation of Resources
Sara M. Mussmann, Wavetek RF Products

Sophisticated design now requires that RF circuits interface with microprocessor control circuitry. Due to the lack of "cross pollination" between analog and digital, there are many pitfalls that can hamper an integrated RF/digital design. This paper discusses some of the ways in which a hardware intensive analog design can be transferred with no loss of functionality to digital software control. Included is information on software development time estimation and code space allocation.

Digital Dynamic A/D Evaluation Technique
James Colotti, Eaton Corporation

Data sheet specifications of A/D converter systems can be difficult to interpret when selecting a device for a specific application. This paper describes a software method for evaluating A/D converter performance under specific test conditions. The system is based on Discrete Fourier Transform (DFT) and Fast Fourier Transform (FFT) analysis.

Precision IC Test System with Sub-nanosecond Speed
Karl Zadel & Richard Davis, Harris Microwave Semiconductor
An evaluation and test system for high speed GaAs digital integrated circuits is described. This system was developed to provide engineers with a means of evaluating these GHz-speed devices.

Session C-1 — Oscillators and Multipliers
Chair: Carl Erickson, McCoy Electronics

Getting the Most Out of the Familiar Colpitts Oscillator
Brian Rose, Q-Tech
This paper presents results of experiments and analysis of the "old familiar" Colpitts oscillator. Gain margin, stability, and pullability as a VCXO are examined.

New Topology Multiplier Generates Odd Harmonics
Charles Wenzel, Wenzel Associates
Winner of the Second Annual RF Design Awards Contest, this paper describes an odd-order frequency multiplier using a Schottky diode-based square wave converter. Also covered are basics of phase noise measurement for oscillator and multiplier evaluation.

The Numerically-Controlled Modulated Oscillator
Earl McCune, Digital RF Solutions
Direct digital frequency synthesis is becoming an important method available to RF designers. This paper describes a system with digital control of amplitude, phase and frequency of the output signal. Various methods of modulation and control of the synthesizer are discussed.

WEDNESDAY — 1:30 to 4:30 p.m.

Session D-2 – RFI/EMC Techniques
Chair: Mike Howard, Norand Corp.

Type Acceptance Tests for Radio Transmitters
Mike Howard, Norand Corp.
Before marketing radio transmitters, manufacturers must receive proper approval from the proper governmental agency in the country it is to be sold in. In the U.S., the Federal Communications Commission is the responsible agency, and in Canada, it is the Department of Communications. Aspects of test methods used to obtain equipment approval by these agencies is reviewed in this paper.

RF Radiation Hazards: Power Density Prediction for Communications Systems
Gary Breed, RF Design
This paper reviews ANSI standard C95.1-1982, and its impact on governmental regulation of RF radiation levels, with regard to public safety. Methods of predicting power density levels in areas near communications facilities are shown. Included are estimates based on isotropic and hemispherical RF source models, plus more precise computations based on computer-modeled field intensities.

GPS Antenna Gain/ Pattern Measurements on an Open Field Test Range
Mike Howard, Norand Corp.
Described is a method to evaluate Global Positioning System (GPS) antenna gain/radiation pattern characteristics above 1 GHz in an economical and timely manner. Although a majority of antenna measurements above 1 GHz are performed within absorber-lined chambers with specialized positioners and towers, this paper details site considerations and test methodology used on an existing open-field range normally utilized for FCC Part 15 Subpart J (computing devices) measurements.

Session E-2 — RF Power Devices
Chair: Howard Hench, Amperex

Power Transistors for Radar Applications
Jim Curtis, M/A COM PHI
Solid state radars are being deployed in place of tube type systems as performance and cost of solid state devices improves. This paper describes the general requirements for high power bipolar transistors which are applicable for use in radar systems. It presents a summary of transistor characteristics which are generally required (or desired) for radar applications. Specific transistor types are examined for use in UHF through S-band systems. Finally, present performance limits are outlined, and a forecast of developments in coming years is presented.

Passive Components for RF Power
Jim Meador, Acrian
High power RF passive components are discussed, for applications in combiners and ballasted circuits. The paper will cover related design elements, trade-

offs and advantages of developing resistors, attenuators and terminations with up to 500 watts dissipation.

A Linear FET for L-Band Radar and Communications Applications
Hanan Zurkowski, M/A COM PHI

This paper describes the application of a new broadband, high power FET with an F/subscr T/ of 4 GHz. This FET offers 65 watts power at 1.45 GHz with 7.5 dB gain. The FETs linear common source operation makes possible simple gain and power output control as well as linear broadband amplification of complex waveforms. Ease of bias and lack of thermal runaway problems are discussed.

Session F-2 — RF Components
Chair: Gene Niemec, Merrimac Industries

A Single-Chip VHF Narrowband Receiver
Jon Stillwell, Motorola

A single channel 50 MHz narrowband receiver is presented, using Motorola's new MC3363 bipolar analog IC. The MC3363 is a complete VHF dual conversion FM receiver, including RF amplifier, two mixers, two local oscillators, limiting IF and quadrature detection, squelch, RSSI and a comparator for FSK data recovery. The part has a bandwidth of 160 MHz using the internal local oscillator, and over 450 MHz with an external LO. Basic receiver performance in the 50 MHz application and alternate configurations are discussed.

Lifetime Effects in PIN Diodes
Peter Sahjani, SDI Microwave

Carrier lifetime governs switching speed, ON resistance and low frequency distortion characteristics of a diode. The lifetime depends on I region length, forward bias current density, composition and contamination introduced during processing. A mathematical model is presented to compute ON resistance by estimating lifetime under certain conditions.

Low Power IF Integrated Circuits Provide Simple Design Solutions
Don Anderson, Signetics

This paper discusses recently developed IF integrated circuits for reception of FM and various methods of digital communication, as well as other applications. Design techniques and performance of these low power components in single conversion schemes with intermediate frequencies of 10.7 MHz and higher will be discussed.

THURSDAY — 8:30 to 11:30 a.m.

Session G-3 — Filter Design Tutorial
Chair: Dick Wainwright, QRS

Computer-Aided Filter Design — A Tutorial
Randall Rhea, Circuit Busters

This session reviews modern LC filter design in three segments of approximately one hour each. Part I begins with a definition of some common terminology and background material, Part II deals with typical applications and problems of the real world, and Part III, by empirical methods, demonstrates the development of special filter solutions.

The overall purpose is to introduce the beginning engineer to modern methods of LC filters, as well as offer the journeyman additional ideas and methods.

Session H-3 — CAD/ CAE Techniques
Chair: Ray Sicotte, American Microwave Corp.

A Method for Introducing Active Sources to Ladder Analysis Programs
Grainger C. Goodman, Northern Microwave Systems

This paper will present a method of including a voltage-dependent current source and a current-dependent voltage source in a ladder analysis program with S-parameter output. This increases the usefulness of ladder programs from only passive analysis to active/passive analysis. The method is explained from the mathematics through an example modeling a bipolar transistor using an updated version of a program presented at RF Technology Expo 87, and published in those Proceedings.

A Program for Synthesizing Broadband Networks of Arbitrary Structure
Steven Sussman-Fort, State University of New York, Stony Brook

A matching network synthesis option has been added to the program CIAO, whose features include microwave circuit analysis and optimization. The synthesis algorithm is an adaptation of the recently developed iterative analysis method. The synthesis program handles a choice of elements (lumped or distributed, lossless or lossy), real or complex source and load, and arbitrary structure and gain shape (S_{21}) across the specified band.

Creating Custom Models for Integration in Linear Simulator Software
Dane Collins, EEsof

Linear simulation software makes use of mathematical models of circuit elements to simulate the small signal electrical performance of linear circuits. Touchstone is one such software tool, containing over 120 models of circuit elements. Touchstone Sr. is a program that can use custom models to meet the most stringent or unique design situations. This paper discusses the creation of a custom Schottky diode model based on process-related dimensional and semiconductor parameters.

Session I-3 — Filter Design
Chair: Richard Snyder, R.S. Microwave

RF and Microwave Filter Technology: Past, Present and Future
Ali Atia, Comsat

Evaluation of methods of filter designs and synthesis procedures are traced: from classical image parameters and ladder networks, to modern insertion loss theory approaches and computer aided design to specifications.

Filter designs for various frequency bands, bandwidths and types (lowpass, highpass, bandpass, bandstop) are discussed, along with suitable components or transmission media. Future trends in filter design will also be noted, including high power, materials and optical applications.

Electrical, Environmental and Packaging Parameters of Filters — How are They Related?
Richard Snyder, R.S. Microwave

An early mentor of the author indelibly impressed the statement that only two parameters are intrinsically incapable of proper realization in an integrated format: *high power and low loss.* This paper explores the current validity of these presuppositions in an effort to assist users and designers of filters in the selection of packaging which is compatible with the intended application. Isolation, power handling, losses and their relationship to volume, temperature, packaging and transmission medium will be examined.

Microwave Filters Containing High Dielectric Constant Materials
Kawthar A. Zaki, University of Maryland

High dielectric constant materials with excellent temperature stability are now being used in such applications as filters and oscillators. The paper reviews the state of the art in dielectric resonator filters, and covers the need for accurate knowledge of resonant frequency, coupling to other resonators and to the transmission line. Also reviewed are the complex electromagnetic boundary value problems required for these designs. Recent results and promising new low cost structures are presented.

THURSDAY — 1:30 to 4:30 p.m.

Session J-4 — RF Test Systems
Chair: Malcolm Levy, Racal-Dana

Programmable Switching Systems
Paul Dhillon, Racal-Dana

When setting up an automated test system, all instruments and devices under test must be interfaced with each other. The interface normally consists of a switching system and/or coax cables for RF frequencies. However, there are problems associated with such switching systems, especially at radio frequencies. Identification of these problem areas allows the engineer to avoid or overcome them. The paper discusses signal integrity, configurations and solutions for RF switching tasks.

Accuracy Considerations in RF Network Measurements
Lorenzo Freschet, Hewlett-Packard

Most engineers understand the basic concepts behind RF measurements such as gain, loss, VSWR, etc. But how many understand all the factors that add uncertainty to these measurements, sometimes to the point of making them useless. This paper will quantify the common sources of error and give examples on how to summarize them to determine measurement accuracy.

A Phase Noise Calibration System
Guy Love and Kevin Lindell, Norden Systems

Spectral purity of RF signal sources is often the limiting factor in the performance of radar and communications systems. Performance is usually specified in terms of phase noise, a measurement of the regular or random variations in phase from an ideal sinusoid.

This paper presents a method of calibrating phase noise measuring systems using a known phase modulation created by switching between two transmission paths (coaxial cables).

Session K-4 — High Power RF
Chair: Tawna Wilsey, Varian Associates

Multi-Kilowatt RF Pulse Power Amplifier
Otward Mueller, General Electric

A high power RF amplifier system for magnetic resonance imaging applications is described in this paper. Design, construction, power output, pulsed characteristics, and cooling techniques are discussed.

60 kW UHF Solid State Power Source
C. Davis, M. Lynch, D. Reid, Westinghouse Defense Group

A very high power RF amplifier system for driving Radio Frequency Quadrupole (RFQ) accelerators is the subject of this presentation. Los Alamos National Laboratories and Westinghouse Electric Corp. engineers borrowed from solid state radar designs for this UHF system, used in a 1 MeV RFQ.

Thermal Considerations in Amplifier Design
Gregg Hollingsworth, Acrian

Higher power in smaller packages is a major push in the RF amplifier marketplace right now. Electrical design receives much attention, but thermal design is often only touched upon. This paper discusses aspect of thermal design, starting with the die, packaging materials and methods, and concluding with system heat exchangers. This is intended to familiarize engineers with the major design considerations for thermally rugged and reliable amplifiers.

Session L-4 — Superconducting Technologies
Chair: Dick Wainwright, QRS

This session is a panel discussion, including short presentations by researchers and engineers. Recent developments in high temperature superconducting materials promises to make possible many "ideal" RF circuits and components. Practical realization of these devices would cause a dramatic change in the design and performance of all types of electronics. Participants in the panel include:

Dr. Kawthar A. Zaki, Univ. of Maryland
Dr. Joseph White, M/A COM
Dr. Rene Bonetti, Comsat
Dr. Ali Atia, Comsat
Dr. Richard Snyder, R.S. Microwave

FRIDAY — 8:30 to 11:30 a.m.

Session M-5 — Phase-Locked Loops — A Tutorial
Chair: Peter Lacy, Wiltron Company

Phase Locked Loop Design Fundamentals
Russell Brown, Wiltron Company

This paper is an introduction to basic phase locked loop concepts and design techniques. It illustrates the performance advantages of phase locked sources and describes some commonly used circuits. Simple approaches to calculation of loop dynamics and noise performance are included in this tutorial.

Basic Phase Noise Analysis Principles
Dale Teets, Locus, Inc.

In the usual low noise PLL design process, the output phase noise of the loop is predicted using the reference and VCO phase noise spectra. Particularly in low noise designs, this method is not reliable since the noise generated inside the PLL circuitry can dominate the output phase noise spectrum. A method is presented to aid in the optimization of PLL noise performance, and prediction of PLL residual noise. The paper includes a brief tutorial on phase noise, with emphasis on the calculation of phase jitter from the noise spectrum.

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Newton refracts light through a glass prism, circa 1672. "The Bettmann Archive."

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PLL Analysis Including Sampling-Time of Digital Phase Detectors
Jeff Blake, Fairchild Weston Systems

Classical continuous-time (Laplace transform) analysis commonly used for PLL synthesizers only yields results that are accurate for loop bandwidths less than 1 per cent of the reference frequency. This is not sufficient for today's high performance, frequency-agile synthesizers that require much wider bandwidths. To take into account the discrete-time (sampling) of digital phase detectors, a new and simple technique has been developed that avoids approximations and is applicable fo· any loop bandwidth.

Session N-5 — Filter Topics
Chair: Dr. Kawthar A. Zaki, Univ. of Maryland

Design of Space-Coupled "Irisless" Dual-Mode Ceramic Resonator Filters
K. Zaki, Univ. of Maryland

(Title not Available)
Rene Bonetti, A.E. Williams, Comsat

Session O-5 — Analog Design Principles
Chair: Al Haun, Analog Devices

High Speed Operational Amplifier Suits DC and AC Coupled Applications
Roy Gosser and Tom Gratzek, Analog Devices

To best illustrate the virtues of a new high-speed amplifier, this paper will compare both DC- and AC-coupled amplifiers, the characteristics and specifications that differentiate then, and the traditional applications for each. The AD9611 amplifier's performance will be discussed in detail, with attention to AC-coupled applications, where noise and distortion are of key concern, as well as the traditional DC-coupled applications where this type amplifier is typically used.

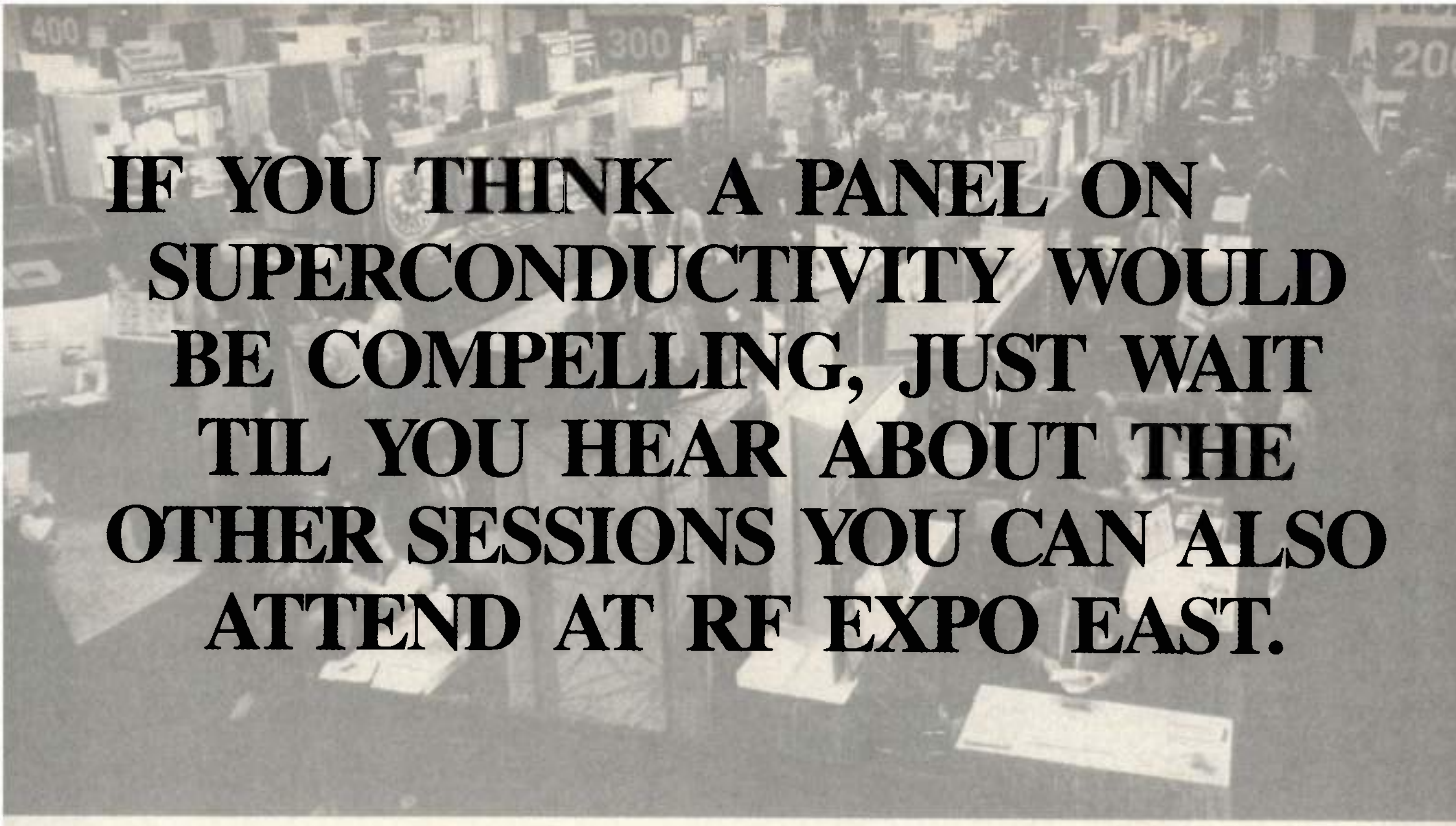
Bandwidth and Compensation Considerations for Operational Amplifiers
Michael J. Willis, Texas Instruments

Operational amplifiers are often employed in the design of video or baseband applications within an RF system, for their "ideal amplifier" characteristics. However, when the video bandwidth system specification is greater than several MHz, problems occur in op amp designs.

This paper explores the frequency limitations of op amps by analyzing the classical closed-loop model in both inverting and non-inverting modes. Also covered is frequency compensation configurations and their impact of op amp parameters.

Time Domain Analysis Provides Insight Into RF Networks
Lorenzo Freschet, Hewlett-Packard

Stimulus/response measurements in the frequency domain are the most common way to characterize RF circuits and components. Unfortunately, this method does not determine *why* the circuit behaves as it does. Time domain analysis allows identification of the components that make up a circuit and provides insight for troubleshooting purposes. Examples are discussed with a tutorial on the basics of time domain measurements.



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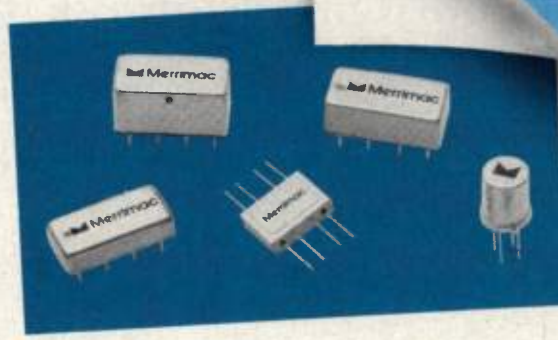

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/1-01S /1-01N	DMS-2-100/57855S DMS-2-100/57855N	0.05-200	DC-200	+4 min. +7 typ. +13 max.	6.5 typ. 8.5 max.	6.5	45 35	40 30	N/A N/A	0.05-30 30-200	+2	0	neg.
/1-02S /1-02N	117A/57834S 117A/57834N	5-500	DC-500	+4 min. +7 typ. +13 max.	7.0 typ. 9.0 max.	7.0	45 35	40 25	N/A N/A	5-50 50-500	+2	0	neg.
/1-03S /1-03N	DMS-2-250/57852S DMS-2-250/57852N	0.5-500	DC-500	+7 typ.	7.0 typ. 8.5 max.	7.0	35 30 25	30 25 20	N/A N/A N/A	0.5-1 1-250 250-500	+2	0	neg.
/1-04S /1-04N	DMS-8-500/57835S DMS-8-500/57835N	RF 2-400 LO 2-500	DC-800	+10 min. +20 typ. +23 max.	7.0 typ. 9.0 max.	7.5	40 35 25	40 35 25	N/A N/A N/A	2-32 32-100 100-500	+16	+14	pos.
/1-09S /1-09N	M119/57836S M119/57836N	1-750	DC-750	+7 typ.	7.5 typ. 8.5 max.	7.5	45 30 25	30 25 20	N/A N/A N/A	1-2 2-375 375-750	+2	0	pos.
/1-10S /1-10N	DMS-4-250/57853S DMS-4-250/57853N	0.4-500	DC-500	+7 min. +13 typ. +17 max.	7.0 typ. 9.0 max.	7.0	45 25	40 25	N/A N/A	0.4-50 50-500	+11	+8	neg.
/1-11S /1-11N	DMS-8-250/57837S DMS-8-250/57837N	1-500	DC-500	+23 typ.	7.5 typ. 9.5 max.	7.5	50 40 30 20	40 30 20 20	25 20 20 20	1-100 100-200 200-300 300-500	+16	+14	neg.
/1-12S /1-12N	DMS-2-25/57838S DMS-2-25/57838N	0.002-12	DC-12	+4 min. +7 typ. +13 max.	6.0 typ. 8.0 max.	6.0	45 40	40 30	N/A N/A	0.002-5 5-12	+2	0	neg.
/2-01S /2-01N	DMF-2A-505/57839S DMF-2A-505/57839N	5-1000	DC-1000	+10 min. +10 typ. +17 max.	7.0 typ. 8.0 max.	7.0	40 30	40 25	30 15	5-100 100-1000	+2	0	pos.
/2-02S /2-02N	DMF-2A-700/57840S DMF-2A-700/57840N	10-1500	DC-1000	+4 min. +7 typ. +13 max.	7.0 typ. 9.5 max.	7.0	30 25 25	30 20 18	N/A N/A N/A	10-600 600-1200 1200-1500	+2	0	neg.
/2-04S /2-04N	DMF-2A-250/57841S DMF-2A-250/57841N	0.5-500	DC-500	+7 min. +7 typ. +17 max.	7.0 typ. 8.0 max.	7.0	40 35	30 20	23 20	0.5-300 0.5-500	+2	0	pos.
/2-05S /2-05N	DMF-2A-250/57854S DMF-2A-250/57854N	0.5-500	DC-500 (IF-1 & IF-2)	+7 min. +7 typ. +13 max.	6.5 typ. 7.0 max.	6.5	35 30 25	30 25 20	25 20 15	0.5-10 10-200 200-500	+2	0	neg.
/7-01S /7-01N	M109/57832S M109/57832N	10-500	DC-500	+7 typ.	7.0 typ. 9.0 max.	7.0	40 35 30 25	35 30 25 15	25 20 15 10	10-50 50-100 100-200 200-500	+2	0	neg.
/7-02S /7-02N	M109/57833S M109/57833N	350-500	DC-500	+7 typ.	7.0 typ. 9.0 max.	7.0	25	15	10	350-500	+2	0	neg.

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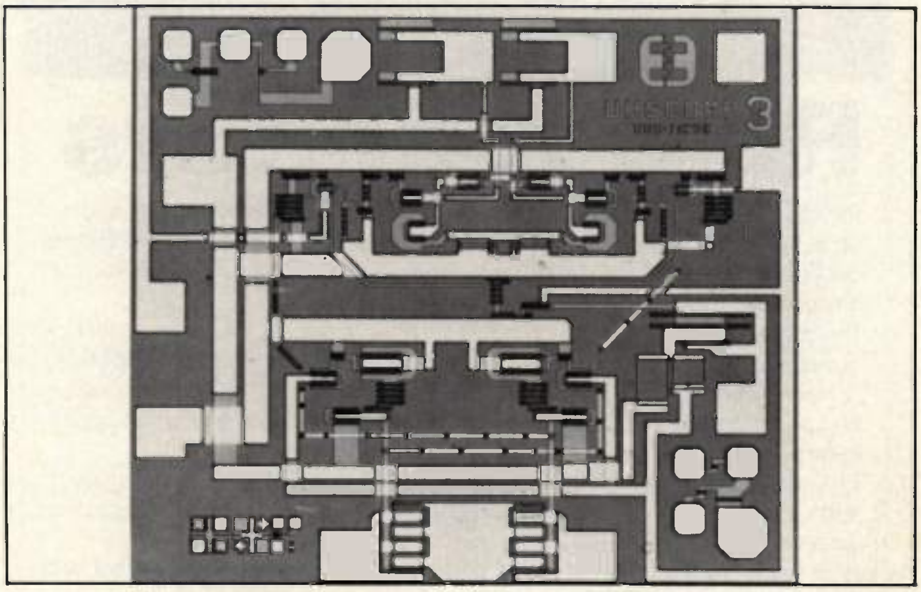
The upgraded EMC-30 unit features front panel controls which are directly computer accessible via the IEEE-488 (GPIB) interface bus. Simplified data input/output command formats facilitate computer-controlled operation of the receiver.

The unit's high visibility light-emitting diode frequency display is accurate to ±0.1 percent, and its amplitude display (including attenuation) is accurate to ±2 dB. A front panel analog meter and a beat-frequency oscillator are also included to facilitate tuning CW signals.

In addition to quasi-peak, advanced detector circuits in the EMC-30 provide true average, direct peak and slideback detection capability. The unit is priced at $42,900. **Electro-Metrics, Amsterdam, NY. INFO/CARD #205.**

Harris Introduces a Comparator With DC to 2.0 G/bps Data Rate



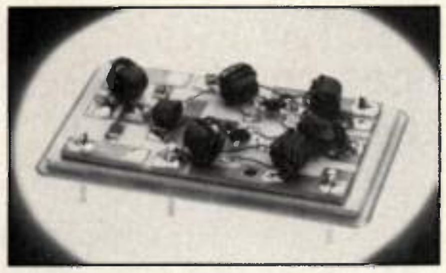
The HMD-11685-2 is an ECL compatible GaAs comparator that features a typical input data rate of 2.0 G/bps and propagation delay of 500 ps. The chip operates at processing rates four times faster than equivalent ECL devices. Its typical power dissipation is 1.25 W with latch setup time being 500 ps.

The HMD-11685-2 can be used in line driver, line receiver, system clock driver, pulse driver, buffer amplifier, differential amplifier, and high speed sampling applications. It can also be cascaded for analog to digital applications and has a typical transition time of 125 ps. With the output loading capacitance being 2 pF, the low to high output transition time is 150 ps and the high to low output transition time is 220 ps. Other specifications include a differential input voltage of ±200 mV and a single-ended sensitivity of 600 mV at 2 GHz.

The comparator's output capability is adequate for driving a fan-out of three into a 50 ohm terminated transmission line. In addition, the HMD-11685-2 provides a latch function for use in a sample and hold mode. It functions normally when the latch enable input is held at a logic high. The outputs are locked in their existing logical status at the time of the latch input transition when the latch enable is driven low. Minimum latch enable pulse width is 150 ps. The device features a Ti/Pt/Au metallization system and operates from −55C to +85C and comes with an input resistance of 60 k ohms. In quantities of 100, the HMD-11685-2 costs $155 and comes in a 16-pin hermetic flatpac. **Harris Microwave Semiconductor, Milpitas, CA. Please circle INFO/CARD #204.**

Quadraphase Modulator

The Model MOP-101 quadraphase modulator is a thick film MIC subassembly consisting of two bi-phase modulators, a 90 degree quadrature hybrid and an in phase power divider. This assembly accepts an RF carrier at 2.8 MHz and two data inputs at ±30 mA for phase modulation typically used in satellite data modem applications. Specifications include a



modulation bandwidth of 10 percent minimum, RF output amplitude balance of 0.4 dB maximum, output phase tolerance at band center of 1.5 degrees maximum, and insertion loss of 5 dB maximum. The specified RF input level is +17 dBm maximum and output harmonics suppression is 40 dB minimum. The unit is designed for MIL-STD-883 environmental conditions and is contained in a package 1.5" × 1.0" × 0.5". The MOP-101 is priced at $175. **KDI Electronics, Whippany, NJ. INFO/CARD #203.**

Low Noise Signal Generator

Marconi Instruments has added a portable signal generator offering frequency, phase, and amplitude modulation over the frequency range of 10 kHz to 1 GHz. The Model 2022A features an output flatness

of ±0.5 dB with FM noise of 7 Hz, carrier harmonics of −35 dBc, FM distortion of 0.5 percent, and FM bandwidth of 50 kHz. The RF output is settable to 0.1 dB steps from −127 to +6 dBm with up to seven calibration units that are user selectable. RF offsets of ±2 dB are possible to compensate for external losses. **Marconi Instruments, Allendale, NJ. Please circle INFO/CARD #202.**

DC-8 MHz Direct Digital Frequency Synthesizer

Pentek's Model 1080 direct digital frequency synthesizer features sub-microsecond, phase-continuous frequency switching with 0.001 Hz resolution throughout the DC to 8 MHz range. The

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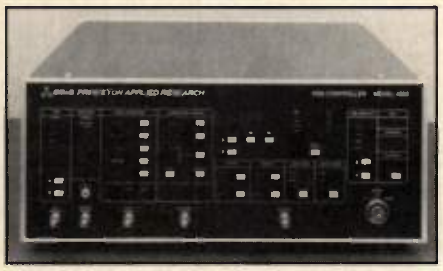
INFO/CARD 48

sinewave output drives 50 ohms at 500 mV, with spurious and harmonic components below −50 dBc. The case measures 4.0" × 5.5" × 0.5". Other features include TTL square wave outputs, BCD frequency programming, and output phase reset control. The cost is $990 when purchased in 100's. **Pentek, Inc., Rockleigh, NJ. INFO/CARD #201.**

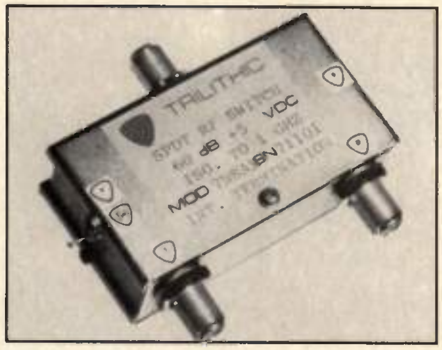
Superconductivity Measurements with Magnetometer

EG&G introduces the Model 4500 vibrating sample magnetometer. Measurements can be made over a 1050 C span and a cryogenic version allows sample temperatures to be varied from 1.5 K to 300 K. A choice of front panel operation or full IEEE control is provided together with comprehensive applications software. **EG&G Princeton Applied Research, Princeton, NJ. Please circle INFO/CARD #200.**



Programmable RF Switch

Models 7LSAB and 7NSAB are electronically controlled latching and non-latching A/B switches. The return loss is measured at 20 dB min while the maximum insertion loss is 0.2 dB. It operates from DC to 1000 MHz. **Trilithic, Indianapolis, IN. INFO/CARD #199.**



rf products Continued

Digital Storage Oscilloscopes

The DS-6612 digital storage oscilloscope offers a 60 MHz analog bandwidth, a 60 MHz digital storage bandwidth for repetitive signals, dual 20 MS/s A/D converters, and deep 16K wave form memory.

The DS-6411 has a 40 MHz analog bandwidth plus dual 10 MS/s A/D converters. Both scopes have menu driven operations. **Iwatsu Instruments, Carlstadt, NJ. INFO/CARD #198.**

0.5 nS GaAs Comparator

A voltage comparator featuring up to 0.5 ns propagation delays is available from Anadigics. The device features differential inputs, ECL-compatible outputs, and a voltage gain of 100 at 1 GHz. At 20 mV overdrive, the ACP10010 has a switching speed of 1 ns which increases to 0.5 ns at higher drive levels. Also, the comparator exhibits less than 7 mV of hysterisis. It is priced at $19.50 each when purchased in quantities of 1,000. **Anadigics, Inc., Warren, NJ. INFO/CARD #197.**

Triple Video DAC

Intech introduces a 4-bit video digital to analog converter, the RGBDAC3405S. The device combines three video speed DACs, there static ram arrays organized 32x4, internal temperature compensated reference and all the control lines necessary for a full graphics/color monitor interface. The price ranges from $19.20 to $73.25 in 100 piece lots. **Intech Advanced Analog, Santa Clara, CA. Please circle INFO/CARD #196.**

1500 V PIN Chips

The Model CSB3779 features 1500 volts minimum at 10 uA, low resistance, low thermal impedance, and hermeticity on the chip level. Specifications include a maximum power dissipation of 35 W, and a carrier lifetime of 6 us. **Alpha Industries, Inc., Woburn, MA. Please circle INFO/CARD #195.**

Fast Comparators

Plessey Semiconductors has announced the availability of a family of subnanosecond comparators. Designated the SP938XX, the family offers typical propagation delays of 950 ns. The three versions available are the SP93808 octal, the SP93804 quad, and SP93802 dual devices. All devices are available in surface mount packages. In 1000 quantities, the cost ranges from $26.56 to $69.05 each. **Plessey Semiconductors, Irvine, CA. INFO/CARD #194.**

Noise Generator

The NC8109 is a 1 W broadband noise generator that covers the 1 MHz to 300 MHz range with RF output of −55 dBm/Hz ±2 dB. The output impedance is 50 ohms and it has a crest factor of 5.1. The instrument has a built-in attenuator with a range of 100 dB in 10 dB steps. The NC 8109 costs $5600. **Noise Com, Inc., Hackensack, NJ. INFO/CARD #193.**

High Speed DMOS FETs

The SST211, SST213, and SST215 FETs, fabricated with an oxide-isolated silicon gate DMOS process, provide performance features that bridge the gap between conventional FETs and GaAs devices. The switching time is 1 ns and SOT-143 packaging is utilized. The feedback capacitance is less than 0.3 pF. **Siliconix, Inc., Santa Clara, CA. INFO/CARD #192.**

RF Power Amplifier

This 500 W unit has a frequency range of 10 to 200 MHz. Application for the PA5-200/PS228 include communications, RFI/EMI, linear accelerators, medical diathermy, and CAT scan. **Intech, Inc., Santa Clara, CA. INFO/CARD #191.**

Miniature Crystal Oscillator

Piezo Crystal introduces the Model 2850038 crystal oscillator. It features an aging rate of 5 x 10^{-10} per day and a noise floor of −153 dBc/Hz. The device is available in standard frequencies of 10.00 MHz or 10.23 MHz, and special frequencies in the 8 to 14 MHz range. It measured 3 cubic inches. **Piezo Crystal Company, Carlisle, PA. INFO/CARD #190.**

Low Profile Molded RF Inductors

With an overall height of .30", Coilcraft's 148 Series of tuneable coils are ideal for

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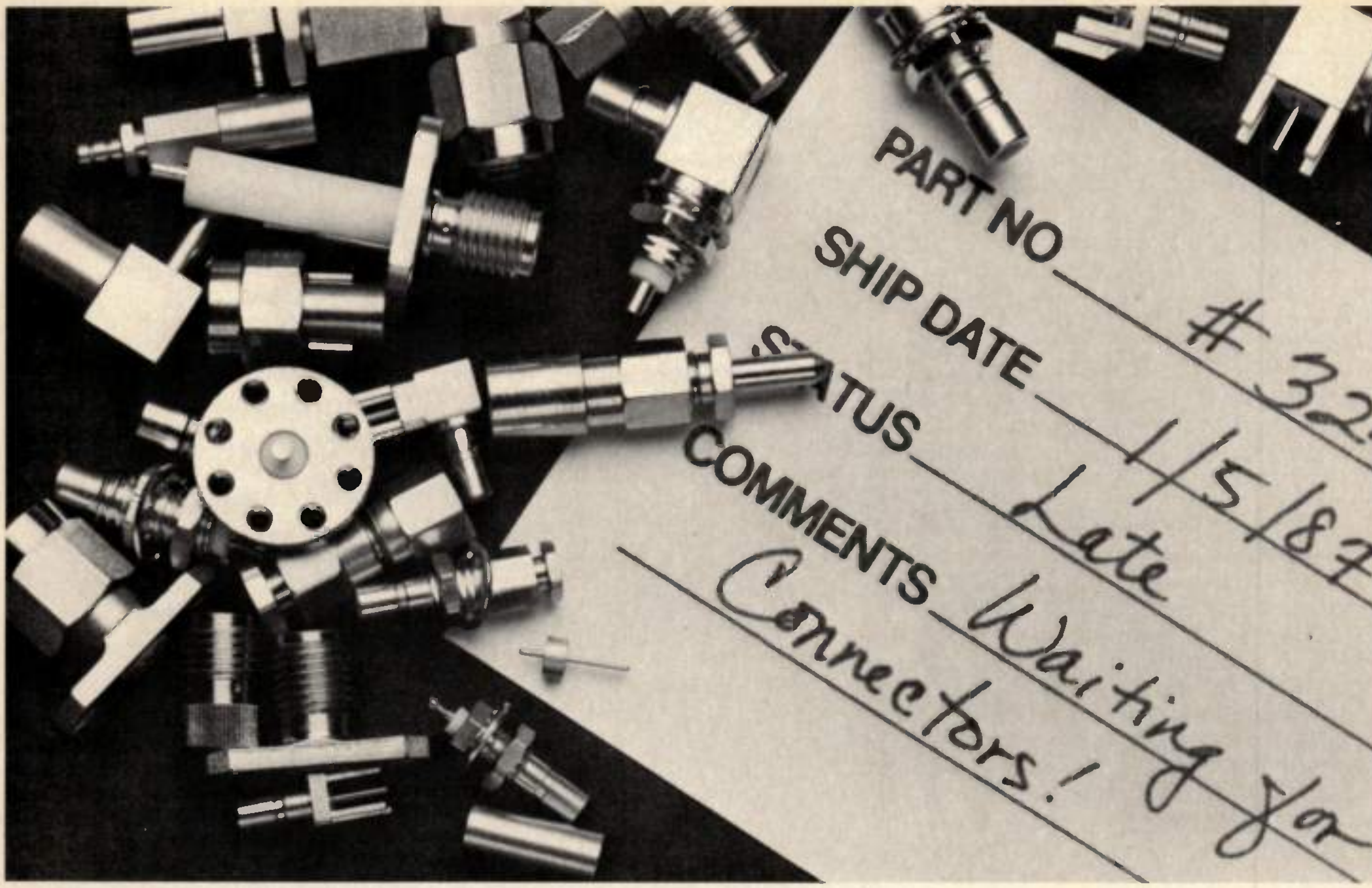

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INFO/CARD 54

low profile circuit boards. They have a constant winding pitch with tuning done by means of a threaded Carbonyl J core. Ferrite or aluminum cores are also available. Nominal inductance ratings range from 39 to 540 nH with Q values from 64 to 112. In 10,000 piece quantities, the inductors are $0.10. **Coilcraft, Cary, IL. INFO/CARD #189.**

Frequency Synthesized Down Converter

The Model 8711 frequency synthesized down converter has a frequency range of 20 to 1100 MHz. Its features include a synthesizer speed of less than 10 ms, IF output frequency of 160 MHz, selectable gain of 25 dB ±3 and 45 dB ±3dB, and a LO phase noise of −105 dBc/Hz at 100 kHz. **Interad Ltd., Gaithersburg, MD. Please circle INFO/CARD #188.**

BiMOS Op Amp

The CA5422 consists of 2 op-amps with different operating characteristics. Amplifier A features a guardbanding technique for reducing the normal doubling of leakage at each 10 C temperature increase up to 85 C. Amplifier B's overall gain is 300. Nonlinear current mirrors allow this amplifier to deliver 2 mA (typical) to the load. In quantities of 1,000, the device is $1.50 each. **GE/RCA Solid State Division, Somerville, NJ. Please circle INFO/CARD #187.**

Miniature Inductor Sample/Prototype Kits

Three coil experimenting/prototype sample kits are being introduced by Toko America. The kits contain a wide variety of coils in 7mm or 10mm sizes. The molded coil sample kit contains 82 values (123 parts), covering frequencies from 30 MHz to 150 MHz with inductances ranging from 0.0393 to 1.173 uH. The 7mm sample kit contains 54 values (108 parts), covering frequencies from 70 kHz to 50 MHz and inductances from 0.1 to 22 mH. The 10 mm sample kit contains 68 values (136 parts) covering frequencies from 79 kHz to 75 MHz, and inductances from 0.08 uH to 56 mH. The kits are priced at $39. **Toko America, Inc., Mt. Prospect, IL. Please circle INFO/CARD #186.**

Noise Figure Test Sets

The Model 8419A noise figure test set is capable of measuring receiver noise figures from 2 to 32 dB between 10 kHz to 40 GHz. The unit has a built-in continuously variable IF preselector. Operation is from the receiver IF output or video output. **S.T. Research Corp., Newington, VA. INFO/CARD #185.**

Image Processor

The 67117 image enhancer is an image enhancement system built around the OEI image and video signal processing modules. The image processing unit consists of expansion, compression, and colorization. These functions can be used together or separately in systems requiring information extraction or interpretation from video signals. The output is NTSC. It is priced at $6,858. **Optical Electronics, Inc., Tucson, AZ. INFO/CARD #184.**

RS232C Optical Fiber Link

A optical fiber link between two RS232C connectors for data transmission is available from Automatic Connector. The Model 40- 97003-000 has a transmission capability of 2 km with a repetition rate of 64 k-bits/sec. Output power level is -23 dBm while time delay is 20 us plus 5 ns for each additional meter of fiber. **Automatic Connector, Inc., Commack, NY. INFO/CARD #179.**

Shielded Enclosures

Pacific West Electronics has introduced a line of shielded enclosures for Tempest applications. The features include zinc plated sheet steel, heavy duty doors, and handles with beryllium copper contacts, and are available with a line of accessories. Shielding effectiveness above 10 GHz is provided. **Pacific West Electronics, Costa Mesa, CA. INFO/CARD #178.**

Contrast Enhancement Filter

Chromerics has designed an EMI shielded contrast filter which consists of an anti-reflective coated glass with blackened wire mesh embedded throughout. The assembly is terminated with a corrosion resistant conductive elastomer EMI gasket on one surface, and non-conductive elastomer on the other surface, to provide environmental sealing. It provides 55 dB of attenuation at frequencies up to 1 GHz. **Chomerics, Inc., Woburn, MA. INFO/CARD #182.**

Hybrid Video Digitizer

This hybrid video digitizer accepts RS-170, NTSC, or PAL signals from a CCD or vidicon camera and produces an 8-bit digital output with 256 gray scale levels. The AD9502 can digitize images with resolutions in excess of 512 × 512 pixels. It contains a video amplifier, sample/hold, sync detector and separator, phase-locked pixel oscillator, and an 8-bit flash A/D converter. The price ranges from $289 to $508 (24 qty.). **Analog Devices, Norwood, MA. INFO/CARD #181.**

rf literature

Programming the HP 8770S Signal-Simulator System

Effective Use of the HP 8770S Signal Simulator System offers programming help with the HP 11776A Waveform Generation Language (WGL). The document reviews principles of digital synthesis, and provides some product specific information on features and operation of the HP 8770S. It than shows how to program six waveforms from sine waves to frequency-hopped to multiple tone carriers. Another section is devoted to pulsed waveforms, pulsed carriers and those with phase tagging, variable rep rates and jitter, and pulsed trains with AM and scan characteristics. Finally, seven appendices review more technical detail on truncation noise and chapter examples. **Hewlett-Packard Company, Palo Alto, CA. INFO/CARD #215.**

Silicon and GaAs Components Guide

The guide covers the full line of MSC components, amplifiers, sub-systems, and noise sources. It includes a section on standard and custom power MMICs and foundry service options available at MSC. Other features include sections on power GaAs FETs, integrated fiber optic components, VHF/UHF silicon power transistors, silicon bipolar transistors, and various other devices. **Microwave Semiconductor Corp., Somerset, NJ. Please circle INFO/CARD #219.**

Hybrid Amplifiers Application Note

An application note entitled *Introduction to the General Parameters for Understanding the Performance of Hybrid Amplifiers* is available from Aydin Vector Division. It reviews the general terminology used in describing the performance characteristics of hybrid amplifiers. **Aydin Vector Division, Newton, PA. INFO/CARD #216.**

Analog Applications Handbook

A 1987 Analog Applications Seminar Handbook is available from Maxim. It covers CMOS data converters, video amplifiers and multiplexers, low power DC/DC converters, switched capacitor filters, operational amplifiers, and microprocessor support devices. A section on surface mount packaging is included. **Maxim Integrated Products, Sunnyvale, CA. INFO/CARD #213.**

Brochure Describes Signal Generator

Marconi Instruments introduces a brochure on a portable low cost signal generator, the Model 2022A. It details specification and operational features of the device which include non-volatile memory, and automatic monitoring. **Marconi Instruments, Allendale, NJ. INFO/CARD #212.**

PLL Frequency Synthesizer Application Note

Motorola introduces an application note for the MC145159 phase-locked loop frequency synthesizer with analog phase detector. The device contains a digital frequency steering phase comparator for coarse adjustment of loop frequency, separate power supply pins for the analog phase detector, a lock detect output, and on-chip logic for control of the dual-modulus prescalar. **Motorola, Inc., Phoenix, AZ. INFO/CARD #211.**

Instrumentation Catalog

This catalog from Rohde & Schwarz-Polarad details over 20 instruments suitable for both bench and ATE requirements. Included are signal generators, synthesized oscillators, spectrum/network analyzers, RF voltmeters and power meters, test receivers, sweep generators, vector analyzers, and mobile communications test sets. **Rohde & Schwarz - Polarad, Lake Success, NY. INFO/CARD #210.**

Advertiser Index

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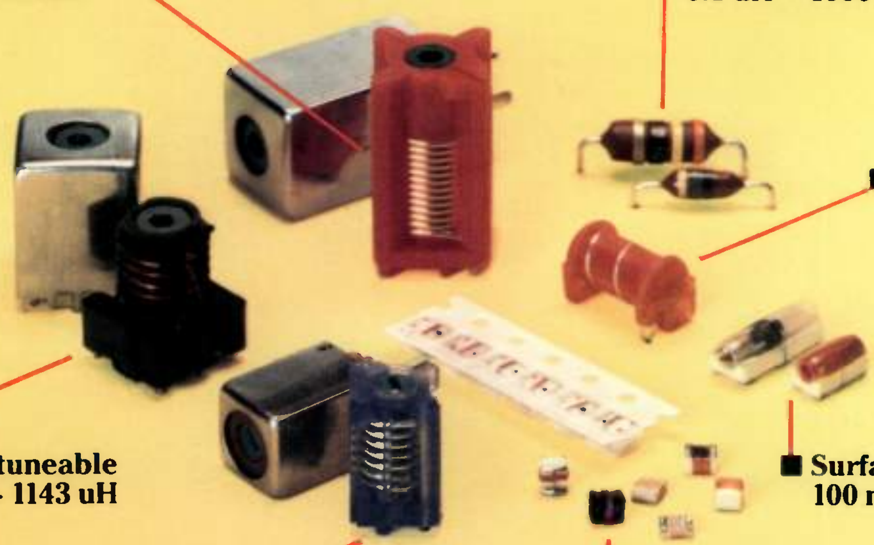

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Kit C100 $125	Kit C101 $50

Fixed inductors

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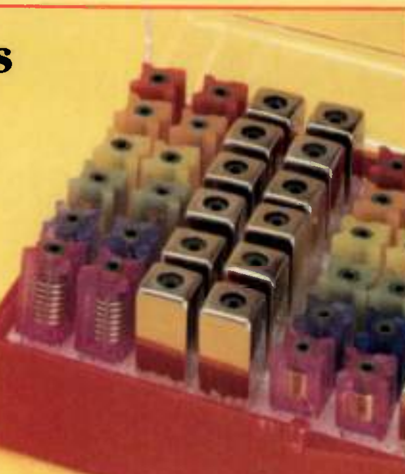
0.1 uH-1000 uH	31.5 nH-720 nH
25 values (5 of each)	20 values (6 of each)
Kit F101 $50	Kit F100 $50



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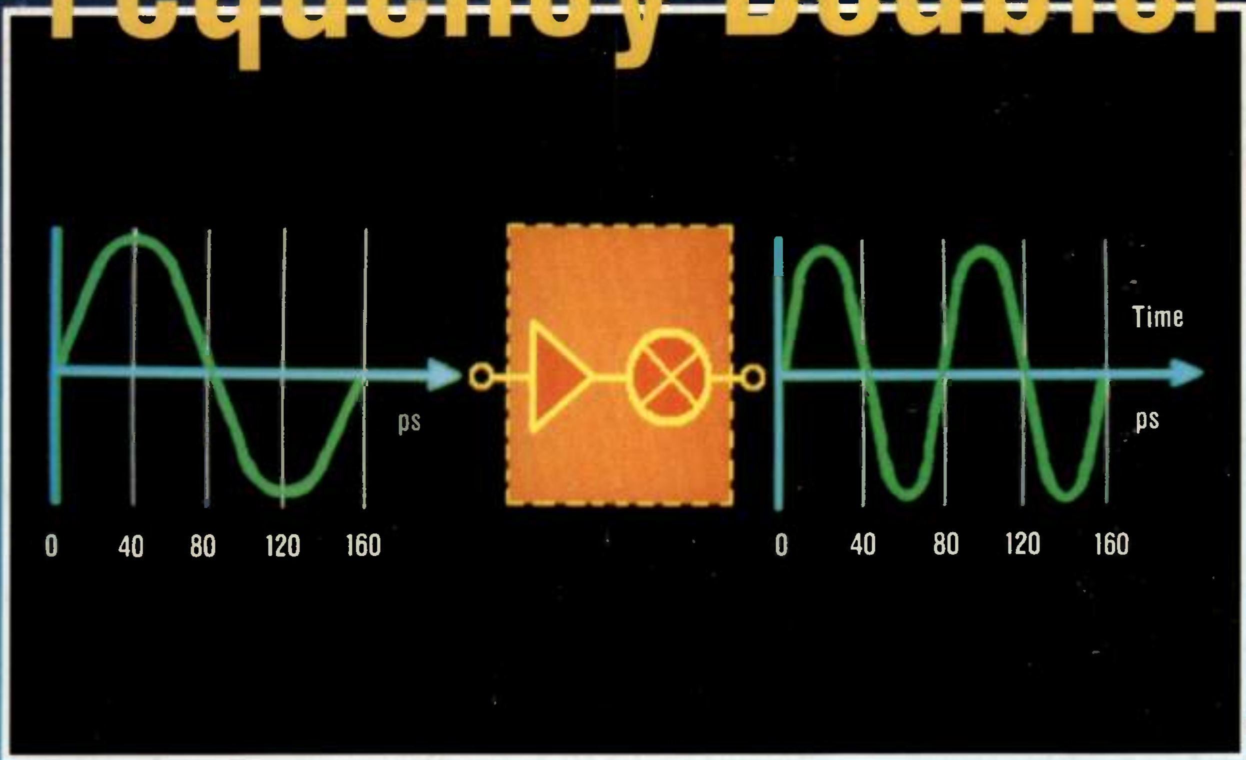

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0.02-2.0	6242-0902	1.0	-7 to -1	15	44
0.1-2.5	6242-0903	1.0	+8 to +10	15	63
0.2-4.5	6243-0904	6.0	-5 to -2	15	233
4.0-16.0	6242-0905	0.0	-5 to 0	5	60

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