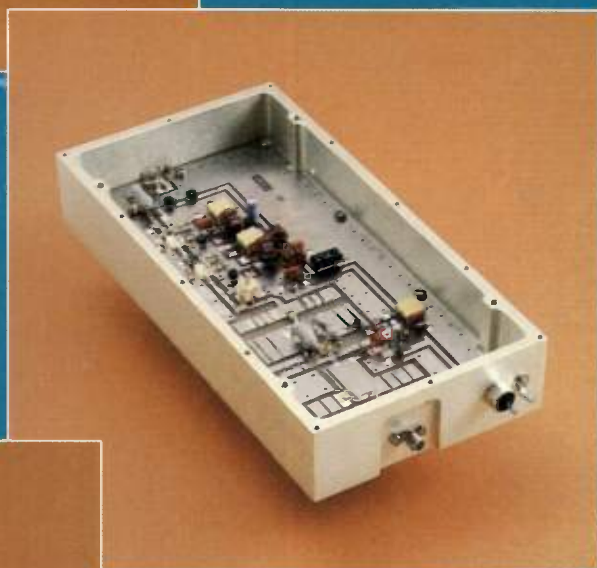
rf design

engineering principles and practices

January 1989

Low-Cost Performance From New MOSFET Amplifier Line.

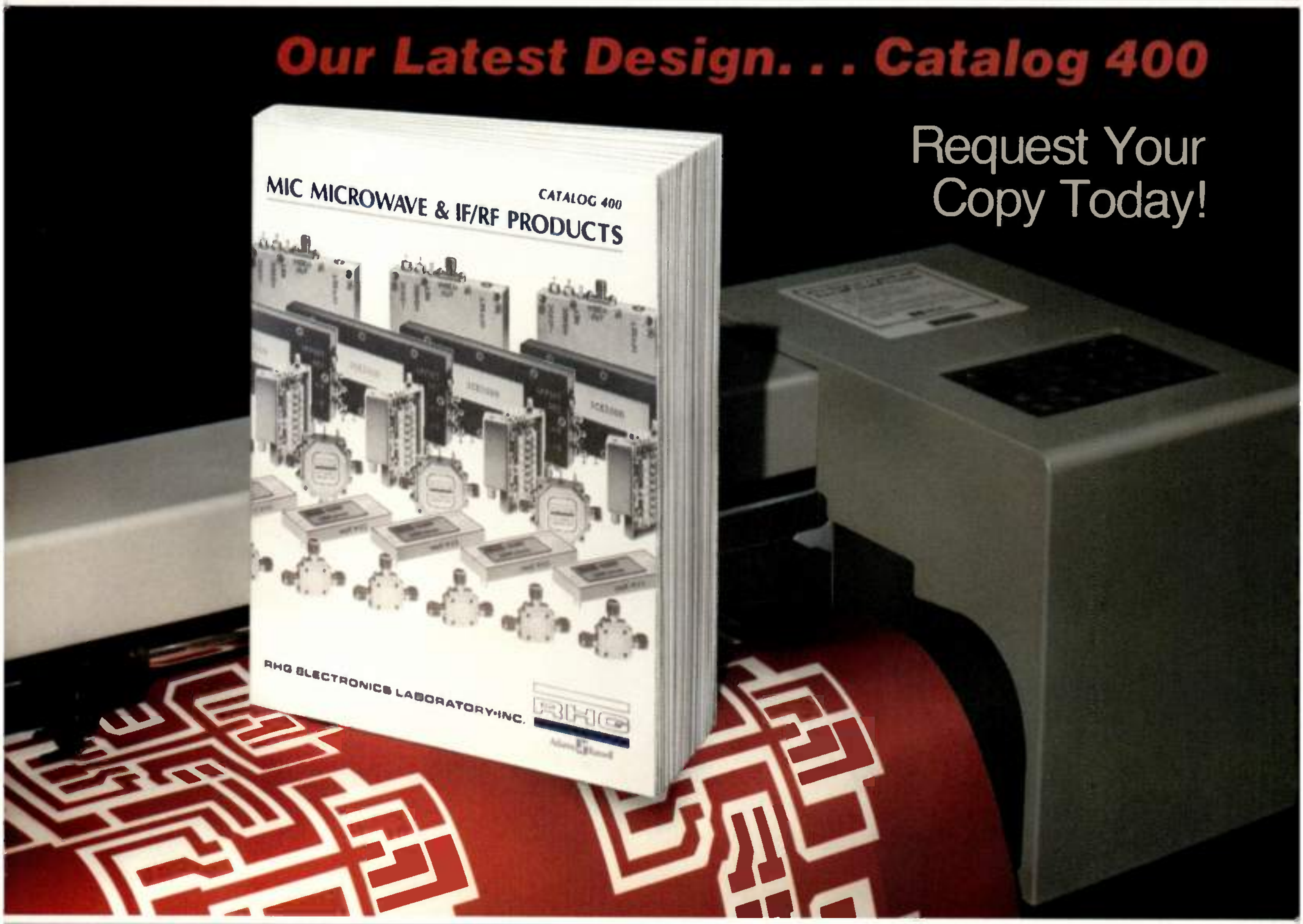
Industry Insight —
Trends in Test Equipment



Featured Technology
RF Power Amplifiers

plus **the RF Expo 89 Technical Program**

RHG. . . For Microwave and IF/RF Products



RHG's catalogs have been more than simple listings of products and specifications. They're sources of useful information about the microwave components and subsystems we make, how to specify them, and how to incorporate them into your systems.

Complete Information

Catalog 400 continues in that tradition. It contains the most current information on our broad line of IF/RF products, mixer and mixer preamps, components, and subsystems. It includes many of the applications articles that specifiers have found so valuable in the past.

Easy To Use

The catalog is easy to use, organized into key technology areas, such as IF/RF products, microwave mixers, and microwave receivers. Helpful product summaries are included for each area to speed the search for a particular product. Just refer to your area of interest, and you'll find complete specifications, outline drawings and prices.

Catalog 400 features many new designs, as RHG continues to pack better performance into smaller packages. Just a few examples are:

- A 1 GHz log amp with 1 nsec rise time.
- 750 and 1000 MHz delay line discriminators with 5 nsec rise time.
- A biasable hermetic mixer that spans 2 to 26 GHz.
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Custom Capabilities

RHG's new catalog also details our custom capabilities, for those who need that "special" design. Find out how our experienced design staff can help you with those hard-to-meet requirements, quickly and economically.

Application Notes

In short, Catalog 400 is an invaluable reference guide to high-quality MIC components and subsystems, custom capabilities, and application information. Don't be left without it; reserve your copy today.

RHG

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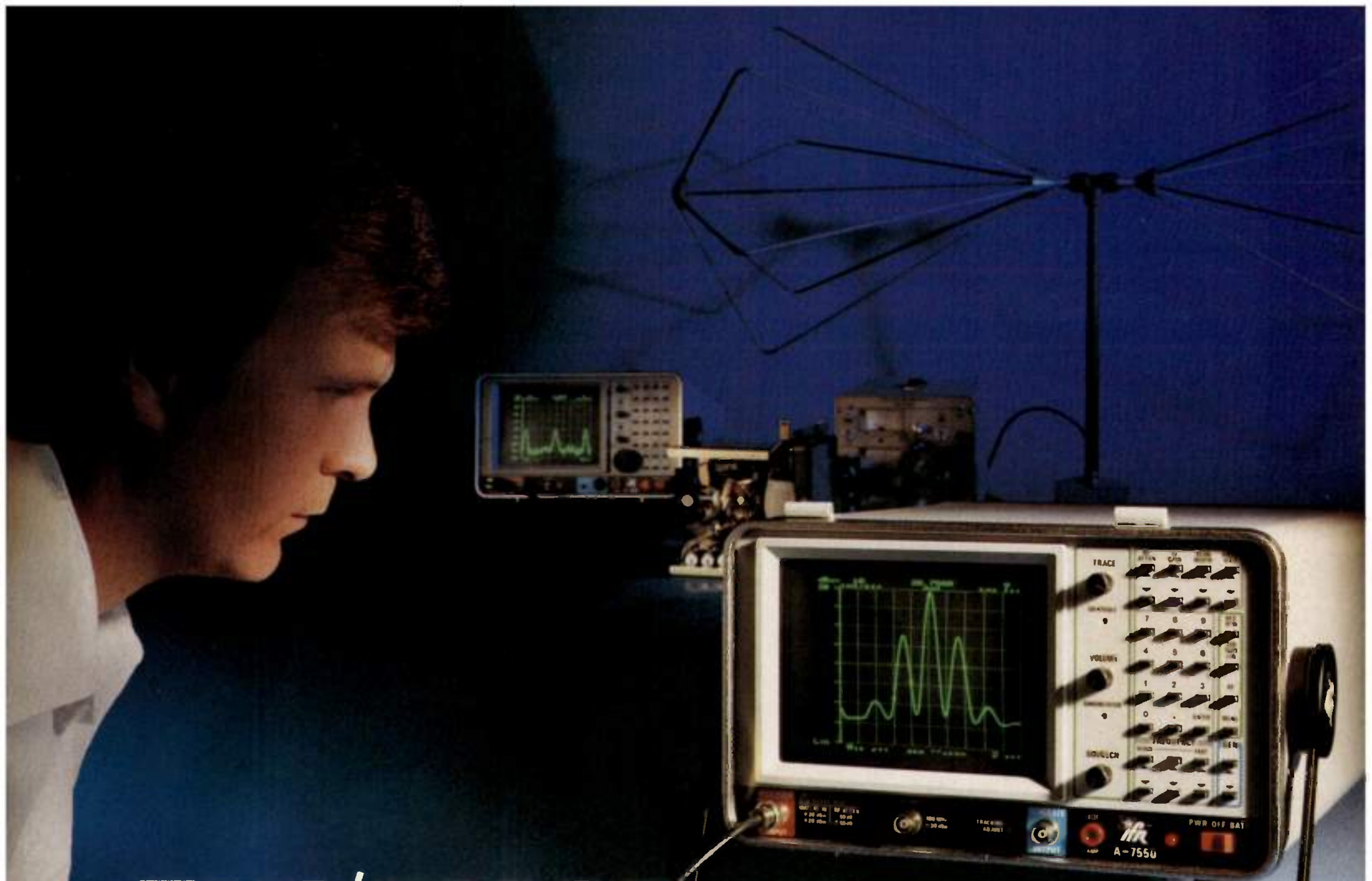
INFO/CARD 1



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A-7550 Spectrum Analyzer with Quasi-Peak Detector for under $7800*

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

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For more information or a demonstration contact your local IFR distributor or representative, or contact IFR directly at 316/522-4981.

*U.S.A. Trade Net Price

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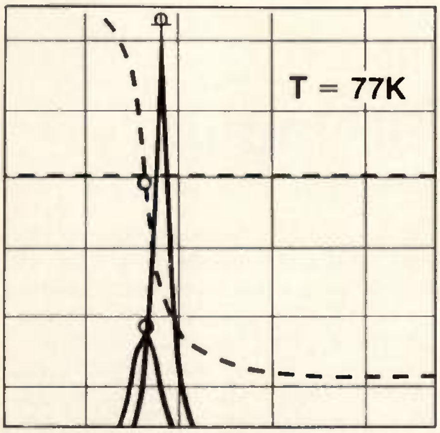
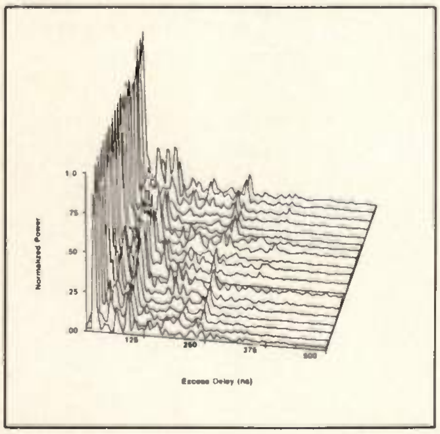
January 1989



Page 29 — RF at Low Temperatures

Page 59 — The RF Expo Program



Page 67 — Factory Communications

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rf editorial

The State of the RF Industry

By Gary A. Breed
Editor

The RF industry has plenty of problems to tackle in 1989.

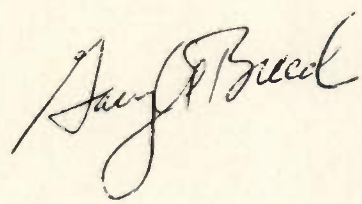
On the political front, the astronomical size of the national debt will force the Bush administration to keep a lid on spending. Large strategic programs like SDI will likely be slowed down, but systems which promise eventual cost and/or manpower savings will get more attention. Existing system upgrades, smart weapons, radar enhancements, unmanned aircraft, and robot land vehicles should be strong areas.

Regulatory matters are another concern. The FCC will certainly continue its course of deregulation, letting the marketplace of consumers and manufacturers decide what performance/cost tradeoffs are acceptable. Hopefully, they will demonstrate the responsibility to protect "innocent bystanders" in the area of RF interference and susceptibility, and remain aware of foreign efforts in areas of new technology.

Candidate Bush vowed support of the environment. If he follows through as President, we may see increased attention to the subject of hazardous radiation. There is a lot of public concern with high-voltage power distribution lines, and RF energy could become the next target of media attention. The RF industry should take a look at these concerns in the context of both public and occupational safety.

There is some good news, too. The U.S. economic difficulties have reduced the value of the dollar relative to foreign currencies. RF companies focusing on export sales have better price competitiveness than just a few years ago. Consumers will see increasing prices for imports, so domestic market opportunities are improving, too. To get these advantages, fast action will be required, before everyone gets accustomed to the situation.

Most of these observations are no different than we have seen for the past several years. And like the recent past, innovation in technology and cost will have an edge, along with those companies with intelligent marketing capabilities. It's not going to be a year to just run with the rest of the RF pack.



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Parameter	What they needed	What NCI delivered
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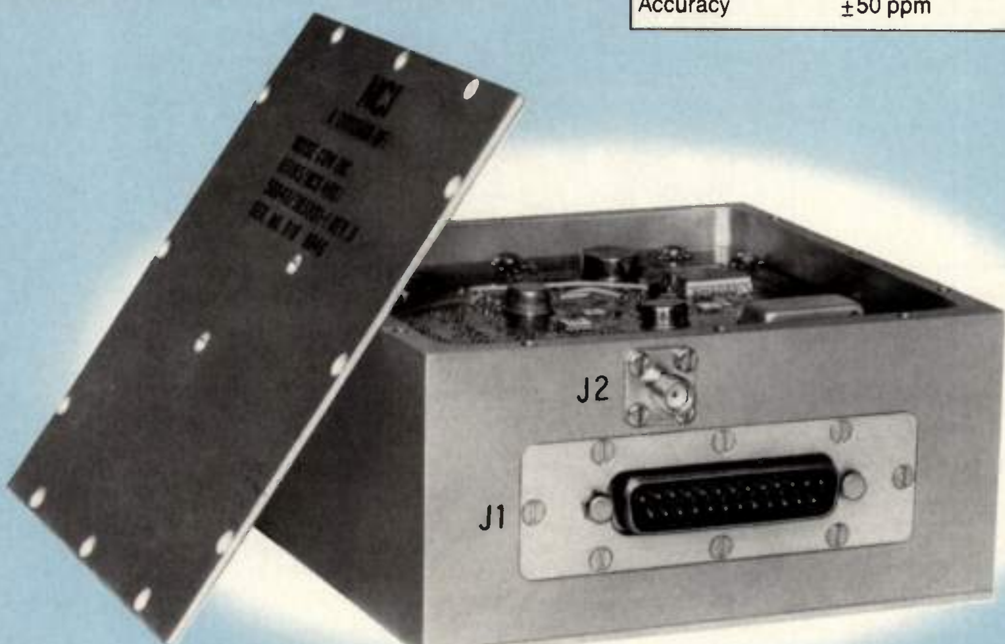
Output power	0 dBm	+4 dBm
Flatness	±1.5 dB	±1 dB
Power consumption	41 W maximum	8 W typical
Size		4 in. × 4 in. × 4 in.
Environmental	−35 to +70 C, 10,000 ft., 12 G shock. Vibration and humidity to MIL-STD 810D	
DTO		
Stability	±0.2%	±0.04%
Accuracy	±100 MHz	±1 MHz
Settling time	1 s	200 ms
SYNTHESIZER 1 MHz resolution, 10 Hz to 1 MHz modulation		
Stability	±0.03%	50 ppm
Accuracy	±50 ppm	±10 ppm



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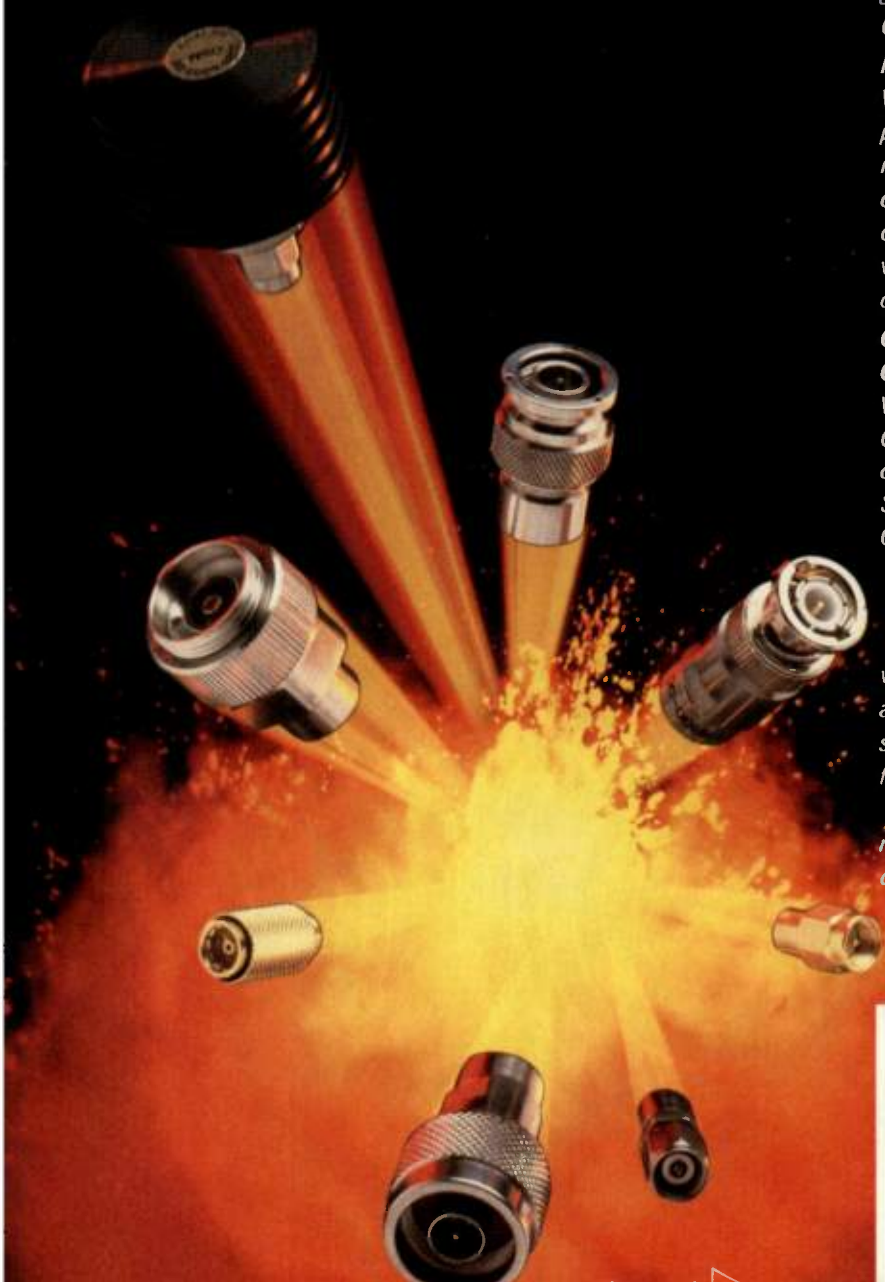

If you need coaxial terminations for any type of requirement, M/A-COM Omni Spectra is the choice for you.

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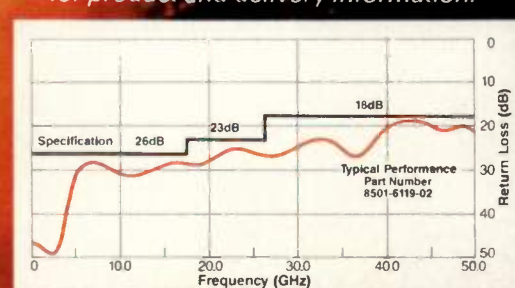

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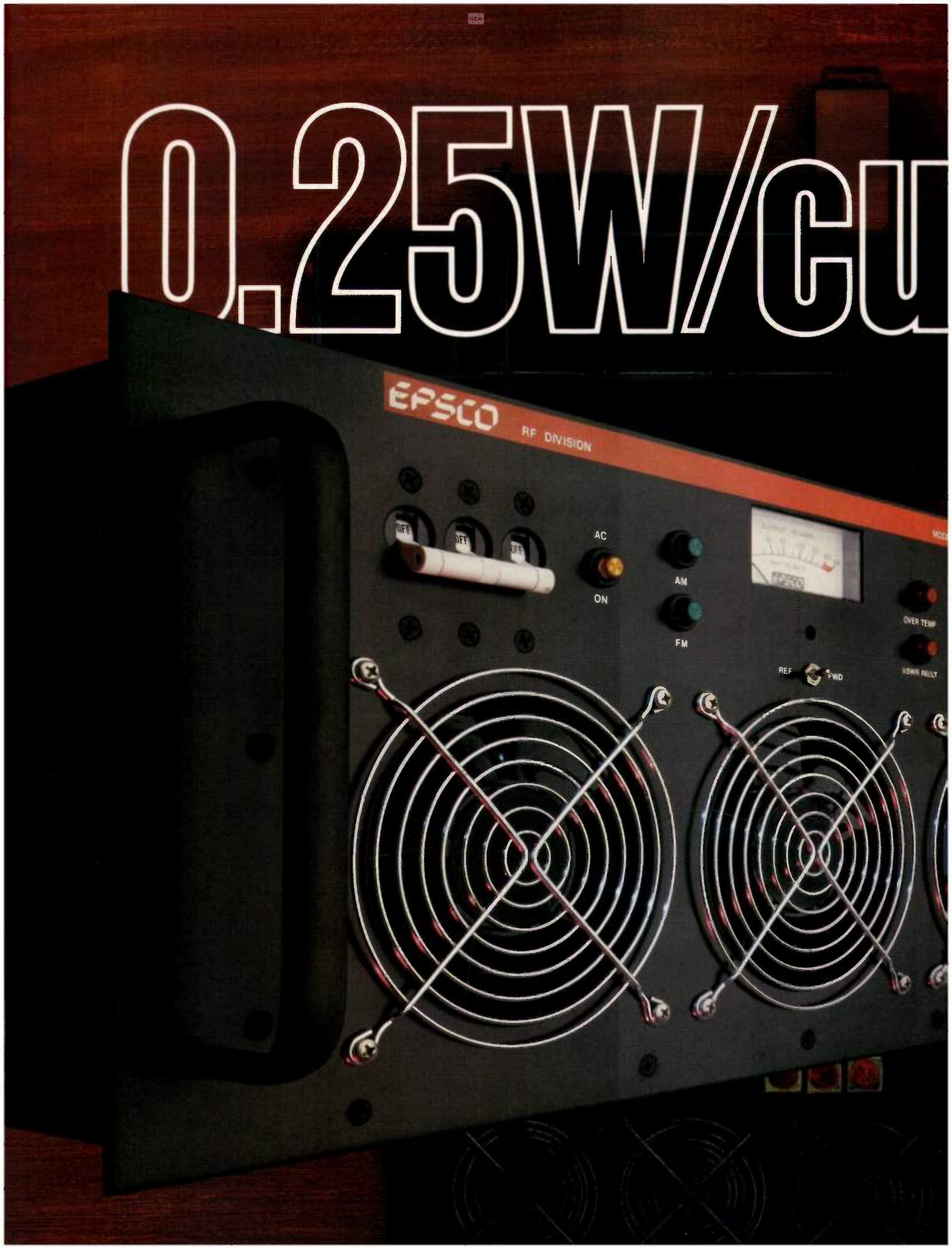

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rf letters

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

Editorial Feedback

Editor:

Thank you for your timely editorial in September's issue addressing the susceptibility problem in the consumer electronics marketplace. I agree that the lack of action on the part of the FCC is clearly irresponsible. The "let the marketplace decide" approach of the commission is one which places an unfair burden on the consumer.

To hope that an educated consumer is going to pick and choose the better product places an unrealistic burden on those consumers who, by human nature and financial restrictions, will in many cases purchase a "low-end" item only to find its performance to be unreliable and highly susceptible in our growing RF environment.

Walter A. Poggi
Retlif Testing Laboratories
Ronkonkoma, NY

A Suggestion on Content

Editor:

Since A/D and D/A components are making fast inroads in RF designs, how about providing more feature articles and notices of upcoming seminars/meetings on this new RF technology?

Adolfo A. Garcia
Avantek Inc.
Newark, CA

A Vote for HDTV

Editor:

Regarding your November 1988 editorial "Making Room for HDTV" — here we go again, stuck with an inferior system because the "powers" (FCC and U.S. industry?) want compatibility. We got stuck with NTSC when those same powers forced compatibility at the beginning of color TV, although both PAL and SECAM present superior video. We had to wait behind the rest of the world for stereo TV because of arguments over method. Many manufacturers have monitors and televisions on the market now that are "multiscan" (scan as necessary to suit the signal coming in). I own a television that plays both NTSC and PAL, and it even switches automatically. So being able to receive HDTV and the current system is not a problem. HDTV broadcast stations will be slow coming on the air anyway.

I vote for full HDTV! And forget about compatibility. "Go for the gold!"

Eugene B. Simmons, Jr.
Harvest, AL

Software-Generated Artwork

Editor:

I have noticed that your magazine recently has been using computer-drawn schematic diagrams. What software do you use?

My company has been looking for this kind of documentation package.

J. Tellus
Arlington, VA.

Our schematics are drawn using HiWIRE™ from Wintek Corporation, 1801 South Street, Lafayette, IN 47904-2993, (800) 742-6809. —Editor

rf calendar

January 24-26, 1989
ATE and Instrumentation West '89
Disneyland Hotel, Anaheim, CA
Information: MG Expositions Group, 1050 Commonwealth Avenue, Boston, MA 02215. Tel: (800) 223-7126; (617) 232-3976

January 30-31, 1989
Electronic Warfare
The Catamaran Hotel, San Diego, CA
Information: Susan Call, Frost & Sullivan, Inc., 106 Fulton Street, New York, NY 10038-2786. Tel: (212) 233-1080

February 12-17, 1989
IEEE 1989 Aerospace Applications Conference
Breckenridge, CO
Information: Harvey Endler, 15137 Gilmore Street, Van Nuys, CA 91411.

February 14-16, 1989
RF Technology Expo 89
Santa Clara Convention Center, Santa Clara, CA
Information: Linda Fortunato, Cardiff Publishing Company, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel: (303) 220-0600; (800) 525-9154

March 1-3, 1989
EMC Japan '89
Sunshine City Convention Center, Tokyo, Japan
Information: Hirotaka Suzuki, Japanese Management Association, 3-1-22, Shiba-Koen, Minato-ku, Tokyo 105, Japan. Tel: (03) 434-1377; Fax: (03) 434-1836; Telex: J25870

March 6-9, 1989
Advanced Materials Conference
Embassy Suites Hotel, Denver, CO
Information: Dr. Jerome Morse, Advanced Materials Institute, Colorado School of Mines, Golden, CO 80401. Tel: (303) 273-3852

March 21-23, 1989
3rd European Frequency and Time Forum
Le Kursaal, Place Granvelle, Besancon, France
Information: A. Remond, 41bis, avenue de l'Observatoire, 25044 Besancon Cedex, France. Tel: 81.80.22.66

March 29, 1989
EMC MINI-CON '89
Inland Meeting Center, Westmont, IL
Information: Radiometrics Midwest Corp., 2200 Main Street, Lombard, IL 60148. Tel: (312) 932-7262

April 4-7, 1989
6th International Conference on Antennas and Propagation
Coventry, England
Information: ICAP 89 Secretariat, Conference Services, IEE, Savoy Place, London WC2R OBL, England.

April 29-May 2, 1989
National Association of Broadcasters Annual Convention
Las Vegas Convention Center, Las Vegas, NV
Information: NAB, Conventions and Meetings, 1771 N Street, N.W., Washington, DC 20036. Tel: (202) 429-5300

rf courses

The George Washington University

Modern Radar System Analysis
January 23-27, 1989, San Diego, CA
Intelligent Automated Target Recognition Systems
January 25-27, 1989, Washington, DC
Numerical Techniques in Electromagnetics
January 30-February 2, 1989, Washington, DC
Introduction to Electronic Warfare Receivers
February 1-3, 1989, Washington, DC
Radar Operation and Design
February 1-3, 1989, Washington, DC
Specifying, Testing and Evaluating Communication and Data Transmission System
February 6-8, 1989, Washington, DC
Broadband Communications Systems
February 13-17, 1989, Washington, DC
Electromagnetic Pulse and Its Effects on Systems
February 27-March 1, 1989, Washington, DC
Introduction to Receivers
March 6-7, 1989, London, England
Electromagnetic Interference and Control
March 6-10, 1989, Washington, DC
Modern Receiver Design
March 8-10, 1989, London, England

Information: Misael Rodriguez, Continuing Engineering Education, George Washington University, Washington, DC 20052. Tel: (800) 424-9773; (202) 994-6106

Southeastern Center for Electrical Engineering Education (SCEEE)

Antennas: Principles, Design and Measurements
March 15-18, 1989, Saint Cloud, FL

Information: Kelly DuVuyst, SCEEE, 1101 Massachusetts Avenue, Saint Cloud, FL 32769. Tel: (305) 892-6146

Georgia Tech Education Extension

Principles of Pulse Doppler Radar
February 14-16, 1989, Atlanta, GA
Antenna Engineering
February 28-March 3, 1989, Atlanta, GA

Information: Education Extension, Georgia Institute of Technology, Atlanta, GA 30332-0385. Tel: (404) 894-2547

Integrated Computer Systems

Fiber Optic Communication Systems
January 31-February 3, 1989, Boston, MA
February 21-24, 1989, San Francisco, CA
Digital Signal Processing: Techniques and Applications
January 31-February 3, 1989, San Francisco, CA
February 7-10, 1989, Washington, DC
CASE: Computer-Aided Software Engineering
January 24-27, 1989, Washington, DC
January 31-February 3, 1989, Los Angeles, CA
Image Processing and Machine Vision
January 24-27, 1989, Toronto, Ontario, Canada
February 21-24, 1989, Los Angeles, CA

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

Interference Control Technologies, Inc.

Practical EMI Fixes
January 30-February 3, 1989, Orlando, FL
February 13-17, 1989, Palo Alto, CA
EMC Design and Measurement
January 23-27, 1989, Palo Alto, CA
February 6-10, 1989, Washington, DC
Grounding and Shielding
January 24-27, 1989, Orlando, FL
February 7-10, 1989, San Diego, CA
Intro to EMI/RFI/EMC
February 7-9, 1989, Orlando, FL
April 18-20, 1989, San Diego, CA
TEMPEST Design and Measurement
February 21-24, 1989, Washington, DC
March 7-10, 1989, Palo Alto, CA

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

UCLA Extension

Superconductive Electronics
February 7-9, 1989, Los Angeles, CA
Power Electronic Circuits
March 6-10, 1989, Los Angeles, CA
Introduction to Automatic Testing and ATE Engineering
March 13-16, 1989, Los Angeles, CA
Modern Microwave Techniques
March 13-16, 1989, Los Angeles, CA

Information: UCLA Extension, P.O. Box 24901, Los Angeles, CA 90024-0901. Tel: (213) 825-1047

Compliance Engineering

EMI
February 14, 1989, San Diego, CA
Safety
February 15, 1989, San Diego, CA
ESD
February 16, 1989, San Diego, CA
Telecom
February 17, 1989, San Diego, CA

Information: Compliance Engineering, 271 Great Road, Acton, MA 01720. Tel: (508) 264-4208.

Technology Dynamics Institute

Optical Fiber Communications Systems
January 23-25, 1989, San Diego, CA

Information: Technology Dynamics Institute, 140 North Vista Street, Los Angeles, CA 90036. Tel: (213) 935-4649

Liberty Labs, Inc.

EMC Laboratory Quality Assurance and Assessment
February 21-23, 1989, San Diego, CA

Information: Liberty Labs, Inc., 4920 Johnson Avenue N.W., P.O. Box 8268, Cedar Rapids, IA 52408. Tel: (319) 390-3646

Reports Predict HDTV Impact on U.S. Industry

U.S. semiconductor, personal computer and factory automation firms stand to lose significant world market shares in the next 20 years if the United States is not a strong participant in the emerging High Definition Television (HDTV) market. This is the prediction of a report released by the American Electronics Association (AEA) Advanced Television (ATV) Task Force.

The study predicts the consequences of U.S. non-participation in the anticipated $20 billion domestic HDTV market. The U.S. semiconductor world market share of 41 percent will shrink to 21 percent by the year 2010 if the U.S. share of the domestic HDTV market is 10 percent or less. The task force estimates that a 50 percent or better HDTV market portion will be needed to maintain the present U.S. share of the world chip market. With a weak presence in the HDTV marketplace, the U.S. corner on the world personal computer market will drop (from its current 70 percent) to 35 percent, and American automated manufacturing equipment makers will lose approximately 7 percent of their current market share.

The study also concludes that non-participation in the HDTV market means a decreased ability on the part of U.S. electronics firms to compete in terms of cost, technology, design and manufacturing. "Non-participation," says AEA Vice President Pat Hill Hubbard, "means a loss of both broad technological know-how and an expanded potential for skilled electronics employment." The end result will be felt throughout the U.S. electronics industry, and, the report warns, "The United States will cease to be the primary innovator in significant end-use equipment electronics markets."

U.S. shares of selected electronics segments, year 2010, based on degree of U.S. participation in HDTV market

U.S. Share of HDTV Market, 2010	Projected Sales For U.S. Industry Segments	Total World Market, 2010	U.S. Share*
Automated Manufacturing Equipment			
50% or more	$ 48.7 billion	$116.0 billion	42%
30%	$ 40.6 billion	$116.0 billion	35%
10% or less	$ 32.5 billion	$116.0 billion	28%
Personal Computers			
50% or more	$220.5 billion	$315.0 billion	70%
30%	$176.4 billion	$315.0 billion	56%
10% or less	$110.3 billion	$315.0 billion	35%
Semiconductors			
50% or more	$124.3 billion	$303.2 billion	41%
30%	$ 99.4 billion	$303.2 billion	33%
10% or less	$ 62.2 billion	$303.2 billion	21%

* Consensus of electronics industry executives
Information courtesy of American Electronics Association

Another report, released by the Electronic Industries Association (EIA), also discusses the potential impact of HDTV on the U.S. economy. The EIA study, prepared by Robert R. Nathan Associates Inc. (RRNA) of Washington, D.C., predicts that the first HDTV sets to hit the U.S. market will appear in 1993, and that more than 13 million sets will be purchased by American consumers in the year 2003. Of these, 92 percent will be manufactured in the United States. The report anticipates that domestic HDTV production and sales will contribute $6.2 billion to the U.S. economy in 2003. Additionally, HDTV will have a beneficial impact on the development of communication transmission equipment and delivery systems.

In conjunction with the release of the RRNA study, the EIA announced the formation of its HDTV Information Center, which will serve as "a clearinghouse for information on HDTV developments," and will help in the coordination of research into HDTV technology.

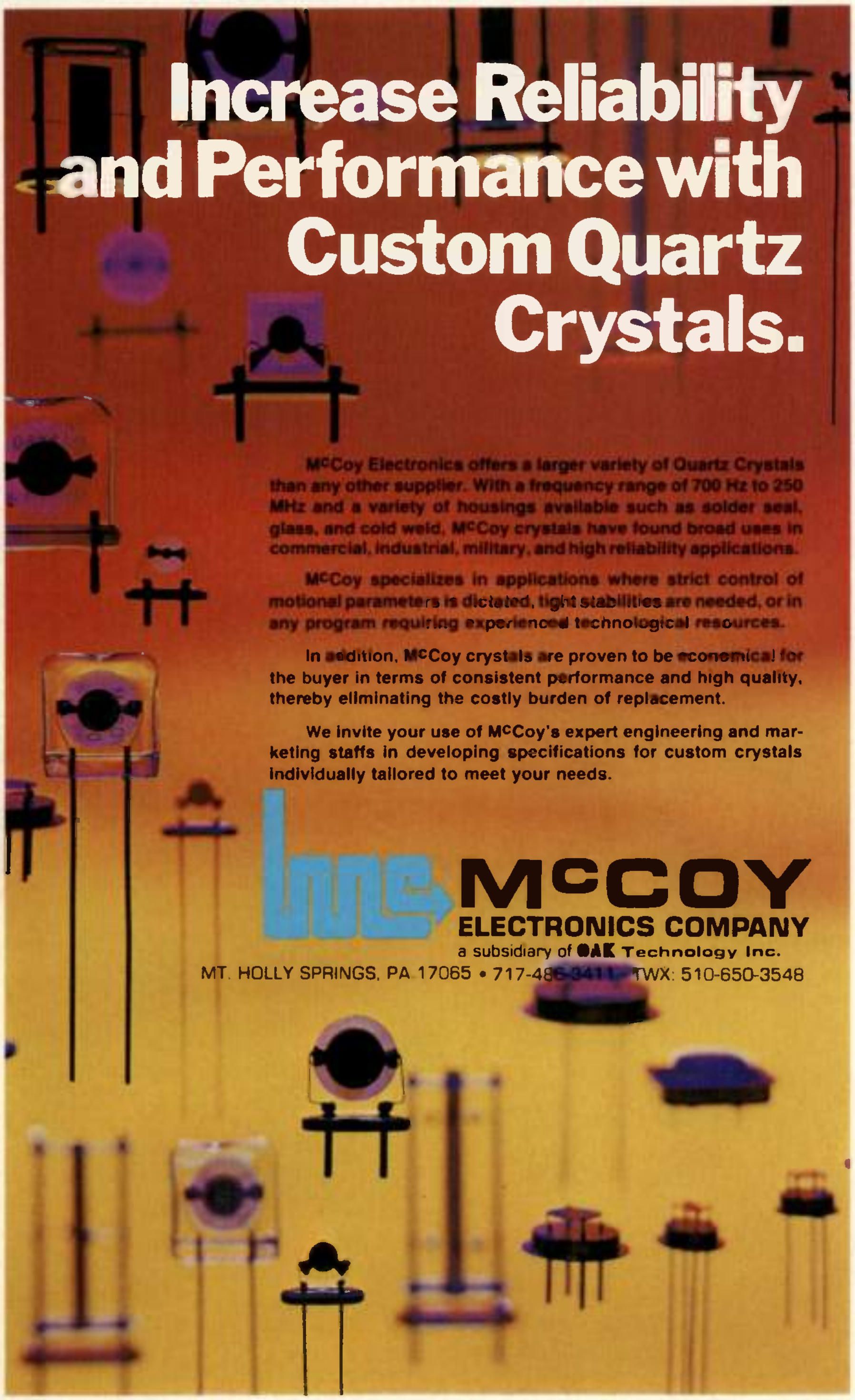
NRAO Green Bank Radio Telescope Collapses—A 300-foot-diameter radio telescope, in operation at the National Radio Astronomy Observatory (NRAO), Green Bank, W.Va., collapsed on November 15, 1988, leaving little of the instrument salvageable. The telescope, a partially steerable parabolic radio antenna able to operate at wavelengths as short as 6 cm, had been in operation for 26 years. The two supporting towers failed without warning, allowing the dish to fall to the ground, damaging it beyond repair. The nearby control building was also damaged by the falling dish. The electronics, however, were unharmed by the accident.

The cause of the antenna's collapse is being investigated by two committees, an internal NRAO group and one co-sponsored by the National Science Foundation and Associated Universities Inc. Electrical engineers at the facility will continue their work with the observatory's four other telescopes (three 85-foot scopes and a 140-foot, fully steerable antenna), and hope that funding can be found to replace the collapsed antenna with more modern equipment.

New Semiconductor Technology From Georgia Tech—Researchers at the Georgia Institute of Technology believe they have discovered the basis for a new class of semiconductor devices based on the use of electron waves. Both faster and smaller than existing semiconductor devices, the structures proposed by the Georgia Tech researchers could be combined into guided electron wave ICs. The new devices would be related to the ballistic transistors currently under development by researchers at IBM and AT&T. Such transistors attempt to use ballistic electrons — electrons that do not undergo collisions — to produce faster conventional transistors. Due to their ballistic nature, however, the electrons act as waves, creating reflection and interference effects that tend to disrupt the device's intended operation.

The Georgia Tech research group believes that these "troublesome" wave effects can be turned to advantage, reducing the size of the circuitry by at least one order of magnitude over conventional wire-based integrated circuits. This could in turn permit the operating speed of the new circuits to increase by a corresponding amount. Furthermore, the new technology would for the first time allow fabrication of guided electron wave devices with general purpose capabilities that could operate at picosecond (10^{-12} second) speeds and allow "optical-like parallel processing."

Devices which could be developed from the electron wave theory include low pass filters, high pass filters, notch filters (narrow band and wide band), bandpass filters (narrow band and wide band), impedance transformers (antireflection coatings), high reflectance surfaces, modulators, switches and deflectors. The filter devices, according to the research group, could have Butterworth, Chebyshev and elliptic functions. Narrow band filters could be incorporated monolithically to produce picosecond speed transistors.



INFO/CARD 15

SMART V Conference to Convene in New Orleans—On January 9-12, 1989, the Electronic Industries Association (EIA) and the Institute for Interconnecting and Packaging Electronic Circuits (IPC) will co-sponsor SMART V (Surface Mounting and Advanced Related Technologies). The conference, to be held in New Orleans, La., will focus on three main areas of technology — Packaging and Interconnection (P/I), Component, and Equipment Technology. Eighteen technical sessions, featuring both papers and panel discussions, will cover these topics in depth. Also scheduled are presentations on Fine Pitch Technology detailing trends in IC Interconnections, Tape Automated Bonding, Multi-Chip Modules, and Packaging for the 1990s. An expanded exhibition area will feature a wide range of surface mount devices, equipment and services.

New Zycad Division Wins $8 Million Subcontract—Zycad Corp. has launched its new Federal Services Group to aid the armed services in meeting new requirements for interoperability of all electronic components developed by military subcontractors. The new requirements, contained in the 1987 Defense Appropriations Act, are designed to ensure the successful and economic integration of electronic subsystems from multiple vendors.

The Zycad group, based in Morristown, N.J., has been awarded an $8 million, two-year subcontract from Veda Inc., prime contractor to the Air Force under the Demonstration of Avionics Module Exchangeability via Simulation (DAMES) program. The DAMES program supports the efforts of the Joint Integrated Avionics Working Group (JIAWG), established in 1987 in response to a Congressional mandate requiring common avionics for the Air Force's Advanced Tactical Fighter (ATF), the Navy's Advanced Tactical Aircraft (ATA), and the Army's light helicopter (LHX).

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AU-1189	1-100	30	0.5	1.3	2:1	+2	30	$250.
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AU-1263	5-200	43	0.5	2.0	1.5:1	+20	120	$350.
AU-2A-1045	100-450	29	0.5	1.6	1.5:1	+8	55	$300.
AU-1054	1-500	29	0.5	1.6	2:1	+8	55	$250.
AUP-1224	5-500	31	0.75	3.0	2:1	+20	160	$495.
AM-1052	1-1000	25	0.75	2.0	2:1	+6	45	$300.
AM-3A-000110	1-1000	35	0.75	2.0	2:1	+9	85	$400.
AM-2A-0510	500-1000	22	0.5	1.8	2:1	0	45	$335.
AM-3A-0510	500-1000	35	0.5	1.8	2:1	+8	80	$395.
AM-2A-1015	1000-1500	19	0.5	2.2	2:1	+3	50	$350.
AM-3A-1015	1000-1500	30	0.5	2.2	2:1	+10	75	$400.
AM-2A-0515	500-1500	19	0.75	2.2	2:1	−5	50	$350.
AM-3A-0515	500-1500	30	0.75	2.2	2:1	+4	75	$425.
AM-2A-0420	400-2000	19	0.75	2.5	2:1	−5	50	$450.
AM-3A-0420	400-2000	30	0.75	2.5	2:1	+5	75	$525.
AM-2A-1020	1000-2000	19	0.5	2.5	2:1	+3	50	$375.
AM-3A-1020	1000-2000	30	0.5	2.5	2:1	+10	75	$450.
AMMIC-1022-100	50-2000	16	1.0	2.5	2:1	+5	50	$470.
AMMIC-1022-101	50-2000	16	1.0	5.0	2:1	+15	100	$470.
AMMIC-1047	50-2000	34	1.0	2.5	2:1	+15	150	$580.

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INFO/CARD 16

By simulating multiple vendors' gate-level models of modules or circuitry, Zycad will test avionics module and companion bus interface designs for true inter-operability and identify any ambiguities in the design specifications. By eliminating specification or design flaws before expensive prototyping of actual hardware and software begins, the DAMES program is expected to economically speed development of avionics systems for the ATF, the ATA and the LHX.

Harris Corp. Acquires GE Solid State—In a $206 million cash transaction, Harris Corp. has completed its acquisition of GE Solid State. The GE Division has produced semiconductor products under the GE, RCA and Intersil brand names. Its operations will now become part of the Harris Semiconductor Sector, headquartered in Melbourne, Fla., making Harris Semiconductor the sixth largest merchant semiconductor manufacturer in the United States.

NOAA Contract to TIW Systems—The National Oceanic and Atmospheric Administration (NOAA) has awarded a $2.5 million contract to TIW Systems of Sunnyvale, Calif. According to the contract, TIW Systems will provide a 45-foot, X-Y antenna system which operates at S, L and VHF frequency bands. The antenna system will be installed at NOAA's National Environmental Satellite, Data and Information Service (NESDIS) CDA Station at Wallops Station, Va. NOAA plans to use the TIW antenna system to collect satellite imagery from the Geostationary Operational Environmental Satellite (GOES) and from the Polar Orbiting, Advanced TIROS Meteorological Satellites.

New MIT Technology Licensed to ASC—The Massachusetts Institute of Technology (MIT) has exclusively licensed a newly patented technology, the oxidation of metallic precursors, to American Superconductor Corp. (ASC) of Cambridge, Mass. The patent applies to any process in which the metallic constituents of a ceramic superconductor are first combined with a noble metal (such as silver) and then reacted with oxygen to produce a microcomposite of superconducting oxide and a noble metal. Such microcomposites have been shown to be tougher (at least five to ten times), more durable, and more readily connected to sources of electricity than superconducting oxides produced by conventional methods.

In a related move, ASC and the Oak Ridge National Laboratory have announced a collaborative program for development of manufacturing processes that will improve the current-carrying capacity of high-temperature superconducting oxides, including the newly patented MIT technology.

AEG to Acquire Siliconix Shares—AEG A.G. of West Germany has announced that it will purchase a 39 percent interest in Siliconix Inc. common shares, as part of a cooperative agreement between the two companies. Under terms of the agreement, Siliconix will grant AEG certain patent licenses for the design and manufacture of semiconductor products.

INFO/CARD 18

INFO/CARD 19

Test Equipment Consumers to Benefit in '89

The general market trend is towards lower costs and better capabilities

By Mark Gomez
Technical Editor

From the sales point of view, 1989 should be a year of increase for the number of instruments sold. "A growth in unit volume is evident for 1989 but a growth in dollar volume is left to be seen," said Tom Dideum, marketing manager of IFR Systems. Prices on spectrum analyzers are experiencing a downward trend since consumers are demanding units which are not as high-performance and precise as previously available. "High-end capabilities are nice but not everyone has use for them," added Dideum. IFR has centered its products around a core set of features required by 80 to 90 percent of customers. Together with the general list of features, a list of options that can be built in is available. Products include synthesizers, tracking generators and quasi-peak detectors. Dideum pointed out that volume growth is due to forecasted surge in areas such as mobile communications and EMI testing. However, the growth in dollar volume is unknown due to the apparent drop in price.

The trend in instrumentation has always been towards better performance, capabilities and reliability. This has been evident in the past and 1989 should be no exception. Gil Reeser, group marketing manager of microwave and communications at Hewlett-Packard, believes that the increasing use of monolithic microwave integrated circuits (MMICs) is driving performance and capabilities up. "The use of microprocessors in these units is driving prices down," notes Reeser. In 1989 the RF and microwave consumer will see more options available, and options with greater complexity will be built into units. Another trend that will be seen in '89 for test equipment is down-loadable firmware characteristics that will convert equipment characteristics so consumers will be able to use the same instrument for various tasks.

Reeser also pointed out that he has seen a price drop every three or four years of about one-third for an equivalent performance unit. He believes that 1988 was a weak year due to a cut in DoD funding and that 1989 should proceed with a reasonably modest growth rate.

As for standardization in the test equipment market, 1989 could be the year for the VXI bus. Malcolm Levy, marketing manager of Racal-Dana sees a significant interest in VXI technology. "VXI could be the strongest interesting factor," he notes. He also sees prices dropping and attributes this to better manufacturing which in turn leads to better reliability. Levy predicts a smaller growth in 1989 than in the past.

"Pricing, as always, will be governed by accuracy levels," said Bill Kail, director of domestic sales at Bird Electronics, "and there should be no major change in price to the existing line." For market trends Kail sees a lot more activity overseas, especially in third world countries where there is growing awareness of RF. Domestically, there are areas like medical electronics where new RF uses are being discovered, for example "surgical scalpels" that use RF power of about 400 to 500 watts. Other potential uses for power meters include RF sputtering equipment in the semiconductor industry.

As far as RF and microwave counters are concerned there is a demand to create less expensive and faster units. "Too many functions are being incorporated into counters as standard equipment," notes Richard P. Swift, president of XL Microwave, "since, as convenience gadgets are incorporated, price traditionally goes up." There is a current need for faster counters as well. "An example of a growing need is to be able to make chirp radar and burst measurements in real time," said Swift. He added that a price drop is forecast due to the flat economy and more aggressive competition.

As more companies, both local and foreign, are penetrating the spectrum analyzer market, prices are bound to drop due to more aggressive competition. According to John Heitman, national sales manager for Advantest America, the competitiveness in the spectrum analyzer market will drive prices down. He sees new units that are more software-intensive with improved performance and lower price tags being introduced for 1989. "Advantest sees a share market growth in 1989 due to various factors such as aggressive competition and new products," said Heitman.

With greater crack-downs of non-compliant equipment as far as emissions is concerned, there is increasing awareness in the susceptibility arena. "The market for susceptibility testing will increase in 1989 due to greater awareness and increase of ambient noise," notes Glen Watkins, vice-president of marketing and sales at The Electro-Mechanics Company (EMCO). Watkins sees two major areas of growth in his market: the first is products tailored to the entry-level person and the second is the experienced user demanding greater accuracy and more sophisticated functions. "Around June consumers could see a five percent increase in price," said Watkins. He added that the market may see more custom requests for 1989.

The year 1989 seems to be the year for the customer. Most companies foresee a price drop with increased performance. Even companies that see a price increase indicate a level that is very marginal. Consumers should also see more "user-friendly" equipment and equipment that will help make more accurate measurements. In conclusion, 1989 indicates an upward trend for test and measurement. rf

MOSFET Amplifiers Offer Wide Bandwidth and Low Cost

Up to 18 Octave Coverage is Available in a Single Instrument.

Economy has never been the primary word in the language of power amplifiers, but as device technology has progressed, it is now possible to make lower-cost amplifiers with the kind of performance RF engineers are accustomed to. This issue's cover features a new line of MOSFET amplifiers from Kalmus Engineering, designed with cost in mind, but keeping the high gain and wide bandwidth demanded for laboratory applications.

Headlining the new amplifier line is the Model 700LC, with 18-octave coverage (0.003 to 1000 MHz), 33 dB gain, and 1.5 watt output power. The cost is only $1295. Like the entire line, the Model 700LC has VSWR and temperature protection and a built-in 90-255 VAC power supply. All models meet VDE/IEC/CEE and ECMA requirements.

On the cover is the Model 706FC and its two internal amplifier modules. This amplifier has 37 dB gain, and provides 6 to 10 watts output over 0.5-1000 MHz, for a price of $1995. The larger Model 707FC has a full 12 watts output over the same frequency range. Other models in the line include:

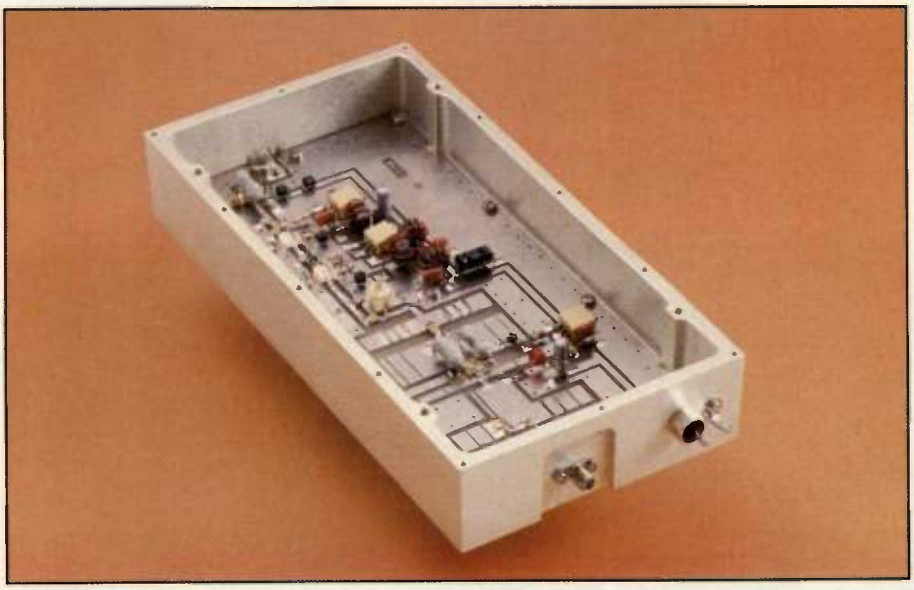
Model 505FC, covering 0.5-525 MHz with five watts output and 40 dB gain, for $1325.

Model 510FC, also covering 0.5-525 MHz, but with 45 dB gain and 10 watts power output. It is priced at $1995.

Model 520FC, a 20-watt amplifier with 45 dB gain, for the 1-525 MHz frequency range, priced at $2885; and

Model 550FC, for higher power applications. This amplifier has 50 watts output and 50 dB gain over the 50-512 MHz range, and has a price of $3995.

These amplifiers are now available for ordering, with delivery times of six to ten weeks, depending on the model.



MOSFET design keeps performance high, cost low in new amplifier line.

All of the "Econo-Line" models take advantage of the high reliability and linearity of thin-film hybrid microcircuits. In addition to these advantages, they also provide excellent noise figure and input matching, in sizes many times smaller than conventional circuitry.

The drivers and output stages consist of silicon gold-metalized "gigafets," capable of extremely high gain and very wide bandwidth. Their relatively high input and output impedances ideally lend themselves to use in these high-performance systems. The gigafets are used in a very conservative circuit design, resulting in virtual immunity to load mismatches.

Circuit simplicity and its subsequent reduction in production assembly time reduces costs, along with a "no tune" final test checkout. These savings are reflected in the low cost of the final product.

These new laboratory amplifier products represent an interesting trend in the test equipment market: Lower cost for the same performance. Manufacturing techniques, component technology, and creative design are now seen at work at nearly every instrument manufacturer. As a result, the consumer (commercial or military) is given new choices. One choice is simply to save money or to put it into another area. The other, more interesting, choice is to find new applications that were not previously considered, because the cost was too high.

For more information on this line of laboratory amplifiers from Kalmus Engineering International, circle Info/Card #150.

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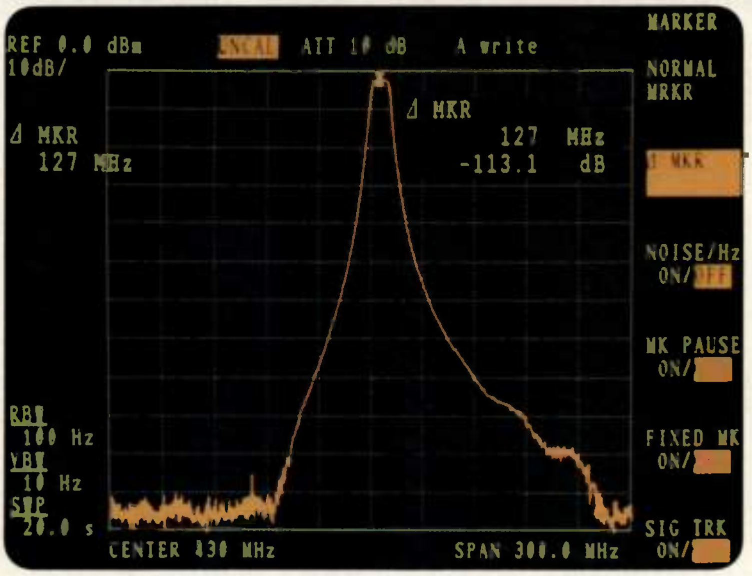

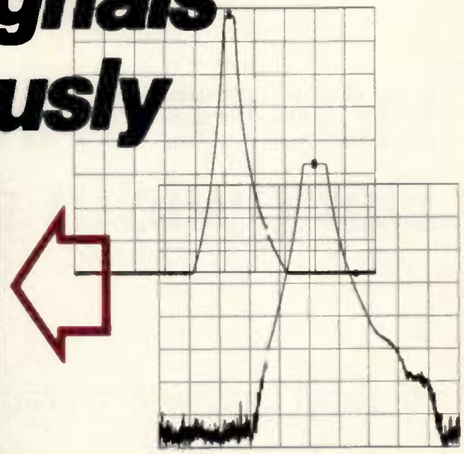

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INFO/CARD 22

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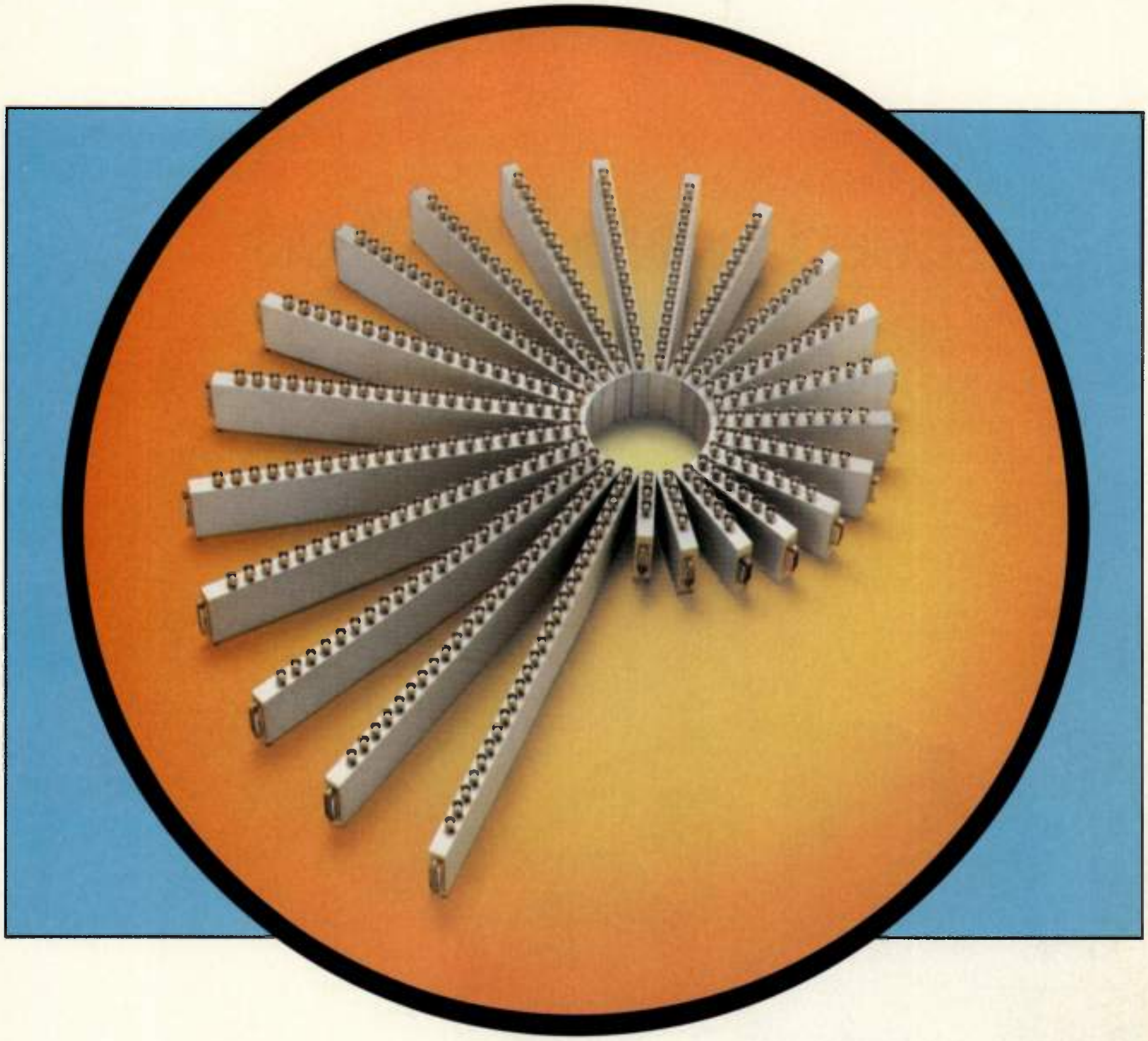

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INFO/CARD 25

RF Components at Low Temperatures

By Otward Mueller
GE Corporate Research and Development

The worldwide hectic search for high-temperature superconductors (HTS) will, if successful, have a great impact on the way electronic equipment in general and RF systems in particular are designed in the future. As soon as HTS devices are available, designers may not limit themselves to their use only but will implement complete electronic systems in a liquid-nitrogen-cooled environment. This article reviews the properties of electronic components as a result of cooling.

As long as HTS research and development is considered worthwhile, one should also investigate the general area of LTE (low temperature electronics). Even without special HTS devices it may become feasible and advantageous to consider cooling a large part of suitable electronic systems — for example, in magnetic resonance imaging and spectroscopy systems where liquid nitrogen cryogenics is available. The fact that properties of many electronic components improve if they are cooled (1-3) can then be exploited.

Electronic Conductors

It is a well-known fact that the resistance of metals decreases at lower temperatures. For example, the electrical DC resistivities of ideally pure elements such as aluminum and copper are reduced by factors of nearly 11 and 8 respectively, if these materials are cooled down from 295 K to 80 K (4). The improvement is less but not negligible at higher frequencies where skin effect is of importance. Figure 1 shows the parallel resonance impedance of a 100 uH copper wire coil and an 8200 pF high-Q mica capacitor at 300 K (room) and 77 K (liquid nitrogen). The parallel resistance increases from 2.87 kohms to 7.24 kohms if cooled. This corresponds to a Q enhancement by a factor of 2.5. The coil was just dipped into a bath of liquid nitrogen contained in a styrofoam box. A dewar cannot be used for this measurement because the metal would change the properties of the coil due to induced eddy currents. Similar Q improvement factors were obtained at higher frequencies with NMR receive coils (64, 26 MHz). In Figure 2 the insertion loss (IL) reduction by liquid nitrogen cooling is demonstrated for a five-cavity mobile radio helical filter with a center frequency of 160 MHz. The loss decreases from 4.96 dB to 2.635 dB, a 2.32 dB improvement and a significant amount if a low-noise receiver front-end is to be protected by such a filter. A seven-pole, 450 MHz Motorola miniature ceramic filter has also been measured. Its insertion loss went down from 2.38 dB to 1.78 dB, a 0.6 dB improvement. RF filters made with high-temperature superconductors should provide even better performance. The conductivity of semiconductor materials also increases with decreasing temperature. The best example is the reduction of the drain-source ON-resistance of a MOSFET or junction FET, to be discussed later.

Thermal Conductors

One of the most promising facts of low-temperature electronics is the drastic increase in thermal conductivity of some electronic materials. It seems that this feature has not yet been exploited fully. For example, the thermal conductivity of n-type silicon at liquid nitrogen temperature is about six times larger than that at ambient. Similar factors occur in germanium and gallium arsenide. For beryllia and alumina the improvement factor is about 4, depending on purity. Natural type-A2 diamond exhibits the highest thermal conductivity

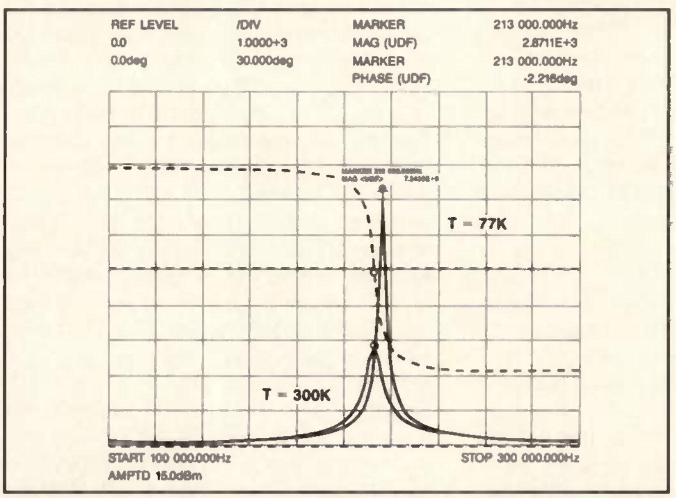

Figure 1. Q-increase of 100 μH inductor by cooling.

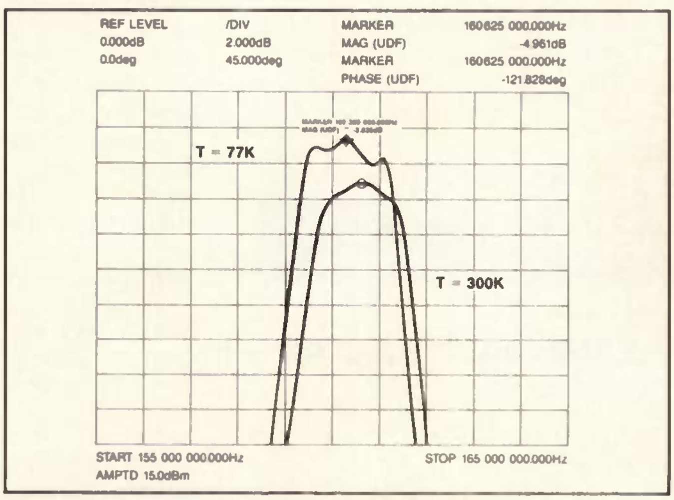

Figure 2. Helical 5-cavity 160 MHz filter.

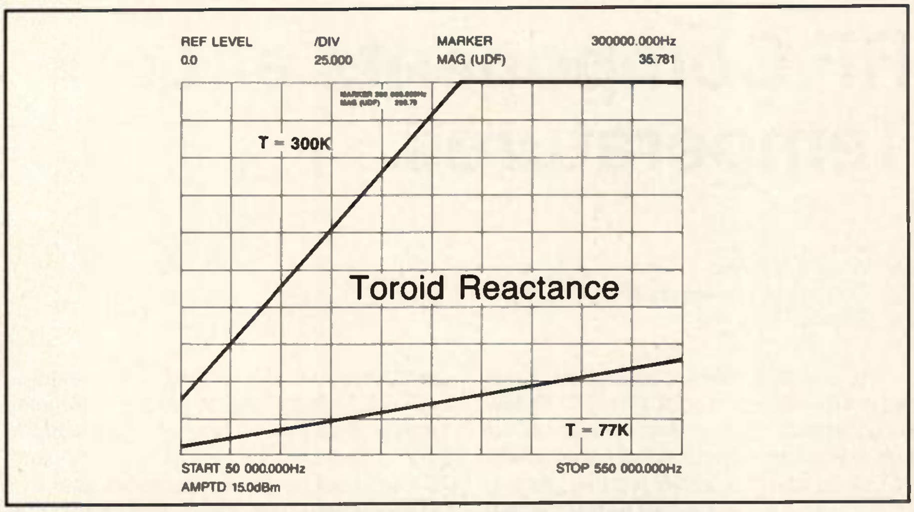

Figure 3. Reactance of ferrite toroid coil versus frequency.

of any known material (20 W/cm degree C) at room temperature. It reaches a five times higher maximum (100 watts/cm degrees C) at around 80 K (1, 5, 10). The conclusion is that much higher power levels can be obtained from cooled semiconductor devices. Though cooled low-noise preamplifiers for astronomy and cooled logic circuits for computers have been used, LTE is not yet applied to the field of electronic power generation (2,3,6,7,8). The latter should make sense in all high-efficiency and low duty cycle pulsed applications (9-15).

Magnetic Conductors

Ferrites are widely used in electronic circuits. The bad news is that they do not work well at low temperatures (19). Their permeability drops drastically as shown by the measurements of Figure 3. The inductive reactance of a ferrite toroid coil decreased from 230 ohms at room temperature down to 35 ohms at 77 K at 300 kHz while the losses increased. The good news is that nickel-iron powdered magnetic materials behave much better. As pointed out by Stevens (19), some of the insulating materials used in magnetics show substantial improvements in dielectric strength if cooled.

Semiconductors

Since the mobility of electrons and holes in semiconductors increases with decreasing temperature, one can expect that the performance of all majority carrier devices improves by cooling. Therefore, all field-effect transistors (JFETs, MESFETs, MOSFETs) are quite suitable for cryogenic operation. Bipolar transistors operate on the basis of minority carrier injection. Their DC current gain drops drastically to a value close to unity or less at 77 K. Therefore, they are not useful at low temperatures in all applications where the DC current gain is important.

Low-Noise GaAs MESFET Preamplifier at 77 K

Preamplifiers have been designed (18) using GaAs MESFETs for 0.5, 1.5, 2 and 4 Tesla magnetic resonance imaging/spectroscopy systems. They can exhibit very low noise figure (0.3 dB) at room temperature if carefully constructed. The key to such low noise performance is a high-Q input matching network implemented by a helical inductor in a relatively large cavity in combination with a low-noise transistor. The performance of a circuit for a 0.5 Tesla system operating at 21 MHz is presented in Figure 4. Curves are shown for room, freezer (-10 degrees C) and liquid nitrogen (77 K) temperatures. In the latter case the circuit was mounted on a heat sink which was then partially immersed in the cooling fluid. An almost "noise-free" amplifier was obtained. The measurements were made with the Hewlett-Packard HP 8970A noise figure meter in combination with the 346A noise source. (Never use the noise source 346B with GaAs MESFETs!) Another advantage of GaAs MESFETs is their larger dynamic range. The test results demonstrate that these microwave devices work well even at cryogenic temperatures and in the low RF range (10-100 MHz), where they are not normally used (6,7,20). MOSFETs are also very suitable devices for cryogenic applications. This is shown in the following section.

Pulsed RF Power Amplifier: An Experiment

A 2 kW RF linear pulse power amplifier using 2 MRF154 MOSFETs and bias gating has been designed for a 0.5 Tesla, 21 MHz magnetic resonance imaging system. The output network consists of a 1:32 transmission line impedance transformer (TLT). The input matching is done by a 9:1 TLT.

An interesting experiment was carried out with this circuit. It was cooled by immersing its heat sink into a liquid nitrogen bath (77 K). Figure 5 shows the RF output power as a function of the supply voltage (warm and cold). The input drive power was kept constant at 35 W. The biasing voltage was set for the same average (gated) current for both environments. A sync-pulse (sinx/x) of 1.5 msec duration and a repetition rate of 50 msec were applied. A remarkable result was obtained: The RF pulsed output power increased by 50 percent. At 50 and 60 VDC, 3 kW and 4 kW were generated in the cooled condition versus 2.0 and 2.5 kW, respectively, at room temperature. The drain-drain load impedance of 1.5 ohms was not readjusted for higher power levels. The MRF154 MOSFETs were then replaced by MRF150 devices which have a quarter of the current and power capability. Actually, the MRF154 uses four MRF150 chips. In this case, a doubling of the output pulse power could be demonstrated by cooling as seen by the measurements of Figure 6 and 7. This despite the fact that the load impedance and the circuitry were again not optimized for maximum power or best linearity. Figure 6 shows the output power as a function of the input drive; Figure 7 and 8, as a function of the (average) bias current and supply voltage, respectively. Note that the long-term duty factor of many pulsed power amplifiers is relatively small (1 percent) so that the average power and therefore the coolant fluid boil-off is also low. An energy of 85 Watt-hours is required to boil off one liter of liquid nitrogen, which costs about 5 cents in large quantities. It is also possible to build high-efficiency RF power amplifiers (9-15). It has been demonstrated that the pulsed RF output power can at least be doubled by cooling.

An important MOSFET parameter is the drain-source ON-resistance. As shown by the measurements of Figure 9, the ON-resistance of the MRF154 (125 VDC, 60 A, 600 W, 100 MHz) decreases by about a factor of 4 if

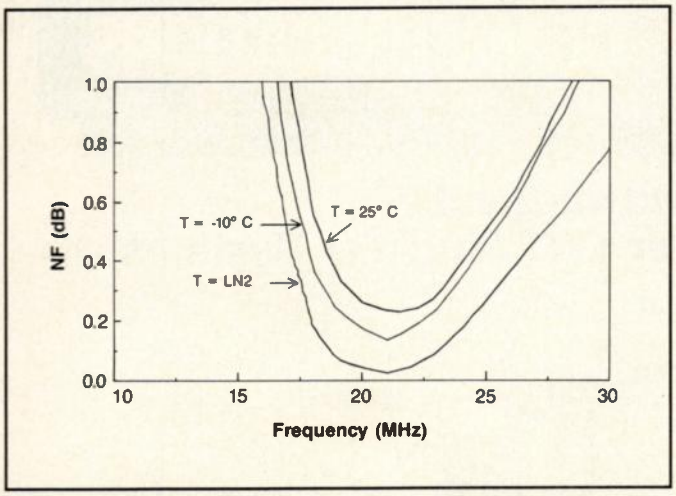

Figure 4. GAP-21 noise figure versus frequency.

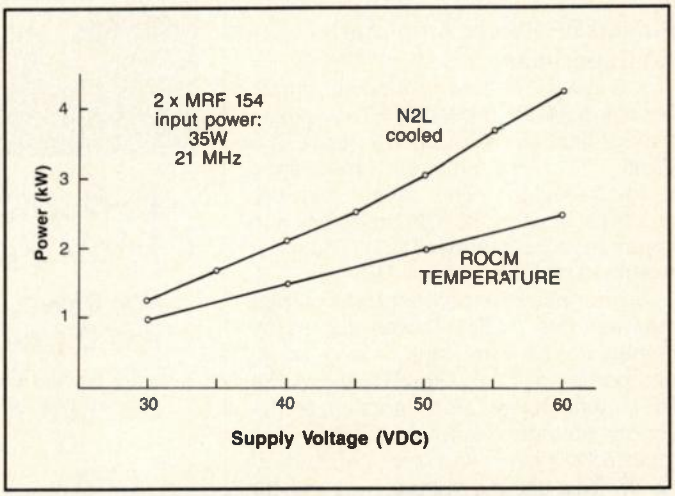

Figure 5. RF output power versus supply voltage.

cooled. This is interesting especially for designers of switch-mode power supplies. More measurements on a variety of power MOSFETs are summarized in Table 1. The last column shows the improvement factor F defined as the warm/cold ratio of the ON-resistance.

Conclusion

Even without superconductors low-temperature electronics may be useful in several applications. This is especially true in systems where cryogenics is already applied such as in magnetic resonance imaging machines which employ superconducting magnets. In addition to ultra-low-noise preamplification and high-speed supercomputers, LTE may be useful for electronic power generation in all applications where the long-term duty cycle is low and the overall efficiency high. It has been demonstrated that by cooling, the output power of a pulsed RF amplifier using MOSFETs can be at least doubled.

Acknowledgements

The author is grateful to Dr. R.W. Redington and GE Medical Systems (Milwaukee) for their support of this work. Hideaki Uno (YMS, Tokyo) made the measurements of Figure 4 at GE-CRD. C. Rossi, R. Argersinger and R. Giaquinto built and tested the circuits and helped produce the graphs. Thanks are also due to Dr. W.A. Edelstein for his constant encouragement.

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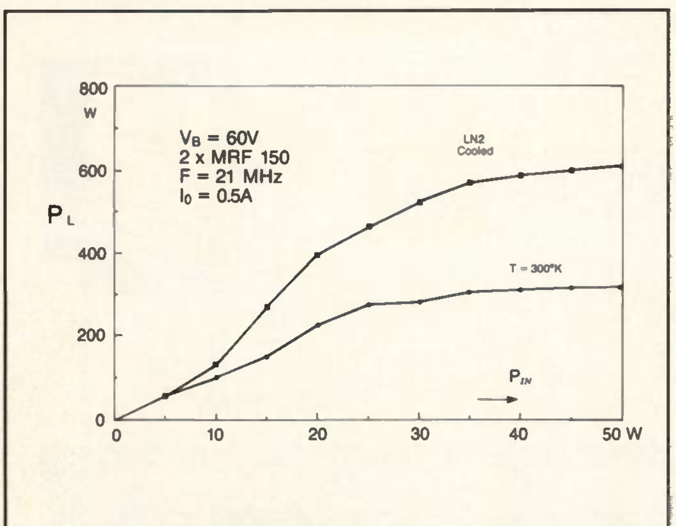

Figure 6. Output versus input power.

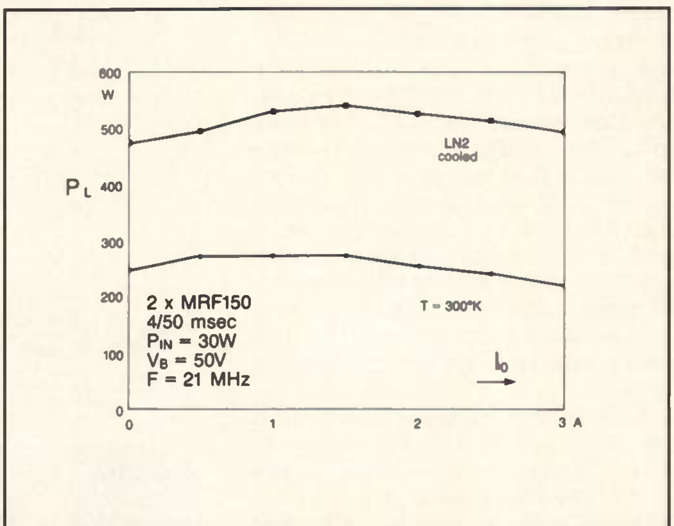

Figure 7. Output power versus average bias current.

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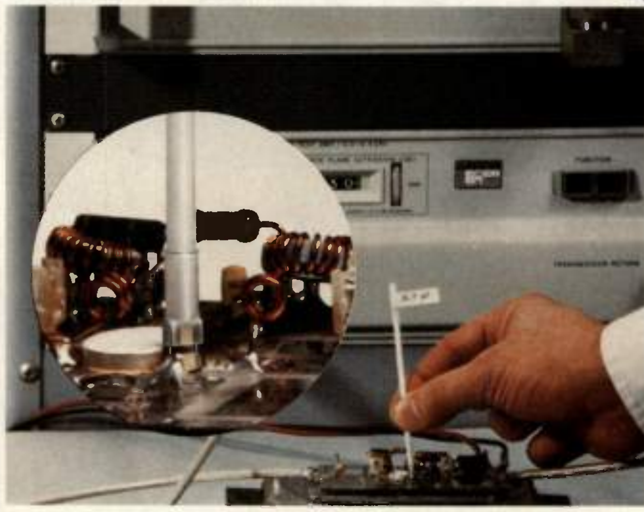

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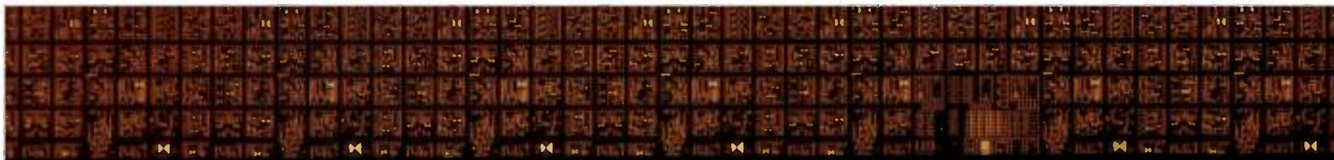

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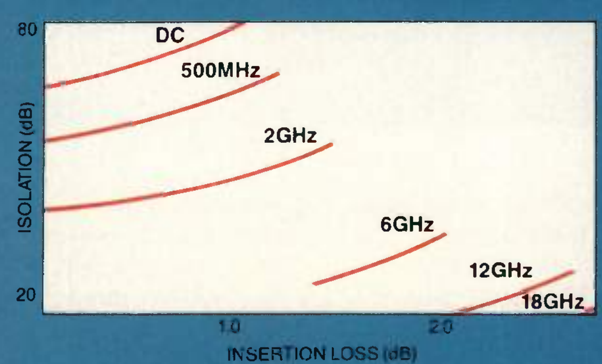

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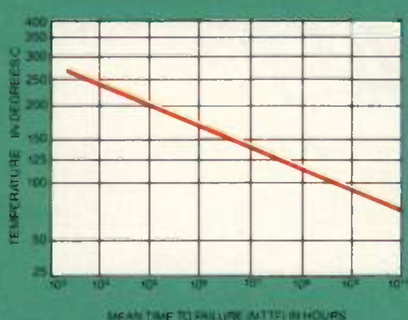

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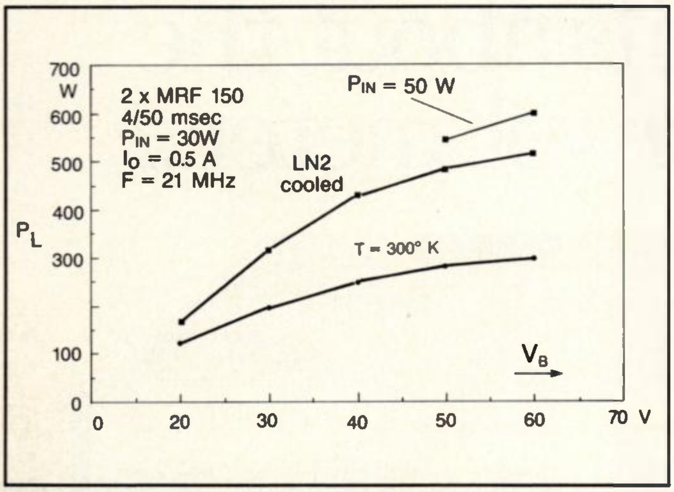

Figure 8. Ouput power versus supply voltage.

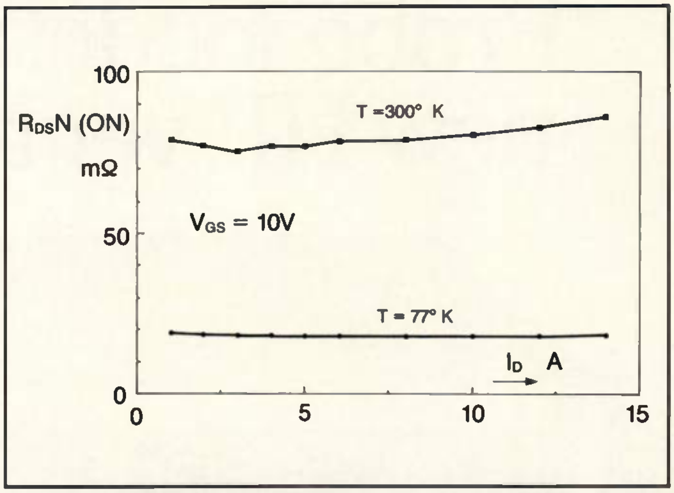

Figure 9. MRF154 ON-resistance versus drain current.

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Device	I_D A	V_{GS} V	R_{DS}(300K) Ω	R_{DS}(77K) Ω	$F = \frac{R_{DS}(300K)}{R_{DS}(77K)}$
MTM2N45	1	10	4.95	0.680	7.2
	1	20		0.637	
MTM7N45	1	10	0.66	0.224	2.95
	1	20	0.63	0.214	
MRF148	1	10	1.36	0.381	3.5
	1	20		0.351	
DVD150T	1	10	2.05	0.425	4.8
	1	20	1.96	0.384	5.1
MRF154	1	10	0.080	0.019	4.2
	1	20	0.076	0.018	4.2
BSM121	1	10	14.2mΩ	3.5mΩ	4.0
	1	20		3.3mΩ	

Table 1. MOSFET ON-resistance R_{DS} (ON).

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Operation of Linear Class AB Amplifiers

By Hakan Turkoz
Military Electronics Ind., Turkey

In general, linear amplifiers do not work as linear sources. They distort the input signal, causing harmonics at the output. To decrease the harmonic distortion, it is possible to use sharp bandpass filters at the outputs of narrowband amplifiers. But this solution is not applicable to broadband amplifiers, because the harmonics fall into the amplifier's band and filtering those harmonics means lowering the bandwidth.

A possible solution for this harmonic distortion problem is to enlarge the linear region of the system for bandwidth improvement. Push-pull amplifiers are used for this purpose. Figure 1 shows a block diagram for this type of amplifier. The input balun (BALance to UNbalance transformer) circuitry in Figure 1 divides the input power into two signals of equal magnitude, but 180 degrees out of phase. After an input matching circuitry, the signals are fed to the transistors' bases as shown in Figure 2.

With a proper bias voltage applied to the bases, both transistors are set to conduct in the positive cycles. So, the collector waveforms can be drawn as in Figure 3. The signals from the collectors of the transistors are also 180 degrees in phase and feed the combiner. This is a balun similar to the one used in the input circuitry. From here the output waveform becomes a full sinewave.

Analysis of the Waveforms

The collector waveform of the first branch can be written as:

$$I_{C1}(t) = \frac{I_P}{\pi} + \frac{I_P}{2}\,\text{Cos}\,\omega t + \frac{2I_P}{3\pi}\,\text{Cos}\,2\omega t - \frac{2I_P}{15\pi}\,\text{Cos}\,4\omega t + \ldots \quad (1)$$

Note that a cosine sinusoid applied to a nonlinear, non-memory device produces a periodic output which may be expanded in a Fourier cosine series with no sine terms (1). Since $I_{C2}(t)$ is a 180 degree phase-shifted form of $I_{C1}(t)$, it can be written as:

$$I_{C2}(t) = \frac{I_P}{\pi} + \frac{I_P}{2}\,\text{Cos}\,(\omega t + \pi) + \frac{2I_P}{3\pi}\,\text{Cos}\,(2\omega t + 2\pi) - \frac{2I_P}{15\pi}\,\text{Cos}\,(4\omega t + 4\pi)$$

$$= \frac{I_P}{\pi} - \frac{I_P}{2}\,\text{Cos}\,\omega t + \frac{2I_P}{3\pi}\,\text{Cos}\,2\omega t - \frac{2I_P}{15\pi}\,\text{Cos}\,4\omega t \quad (2)$$

As explained above, two signals having 180 degrees phase difference with respect to each other are added at the output of the balun, which causes the subtraction of one signal from the other. If these two transistors are properly matched, $I_{P1} = I_{P2}$ and:

$$I_{C1}(t) - I_{C2}(t) = I_P\,\text{Cos}\omega t \quad (3)$$

This can be shown in the frequency domain as illustrated in Figure 4. It is clear that all harmonics cancel out, resulting in a pure sinewave at the output of the balun. However, this happens in the ideal case; in reality some unwanted harmonics remain due to:

1) Amplitude mismatch — unidentical transistors which cause a beta mismatch and/or improper input and/or output matching circuitry.

2) Phase errors — these are caused by input and/or output balun and/or matching circuitries.

In the case of amplitudes being unequal, $I_{P1} \neq I_{P2}$, the peak values of collector currents of transistors 1 and 2, respectively. The output current of the balun can be written as (1):

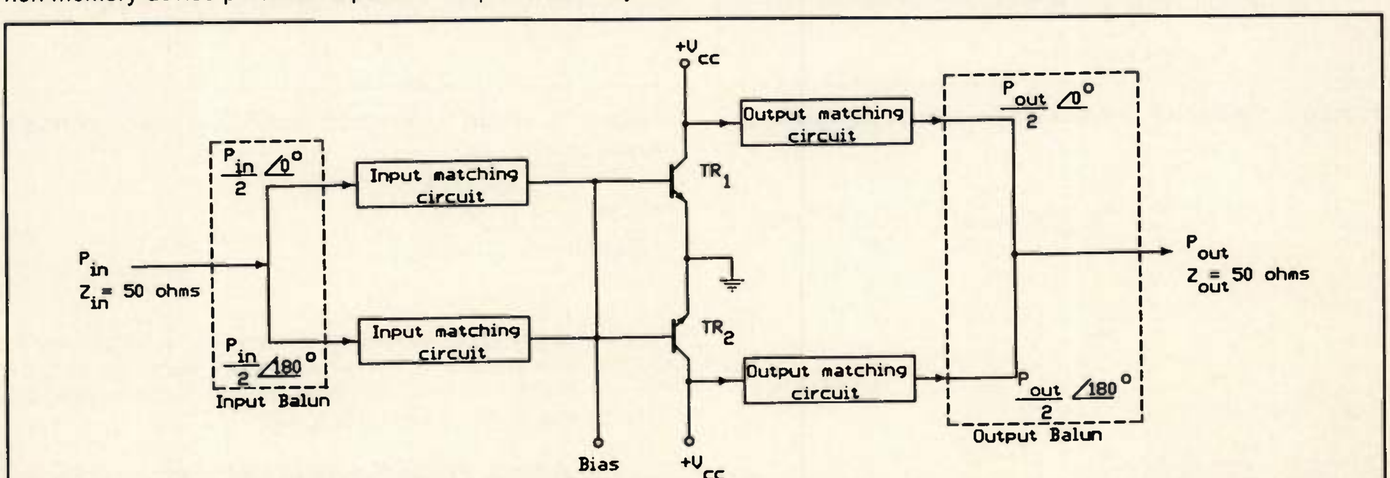

Figure 1. General block diagram of a linear push-pull amplifier.

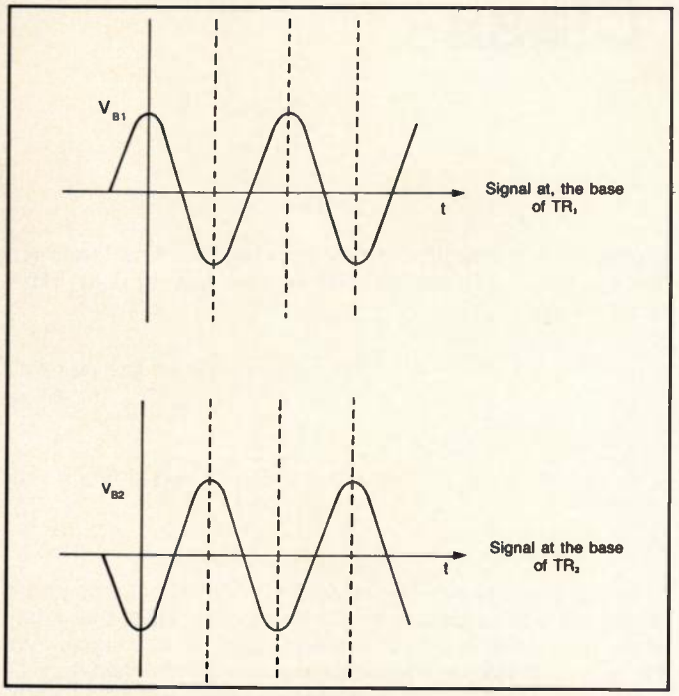

Figure 2. The phase shift property of the balun and feed of the transistors.

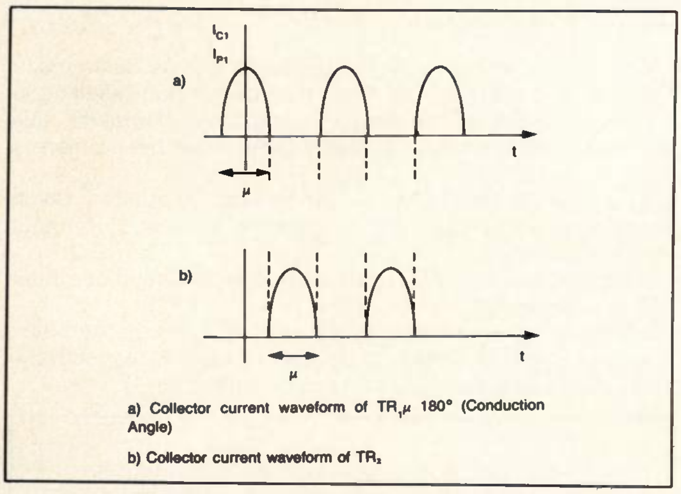

Figure 3. Collector current waveform of transistors.

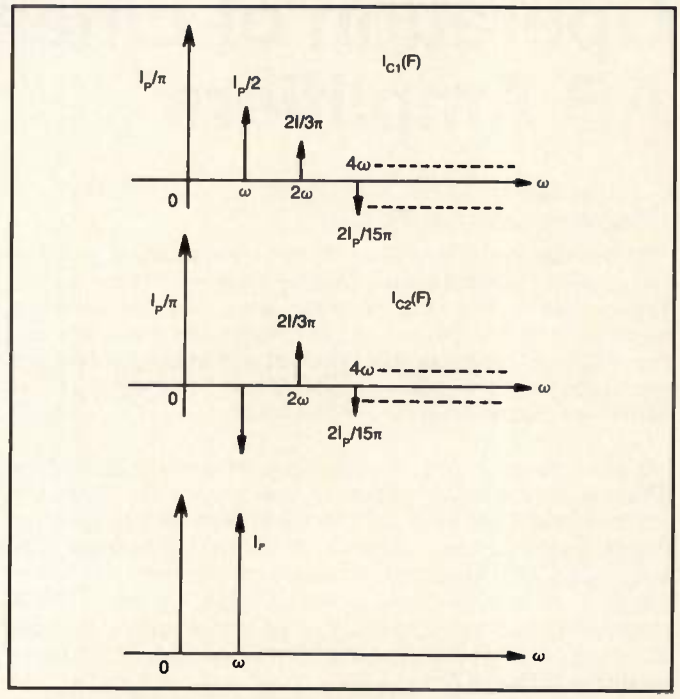

Figure 4. Frequency domain view of I_{C1} and I_{C2} and resultant signal at the output of balun.

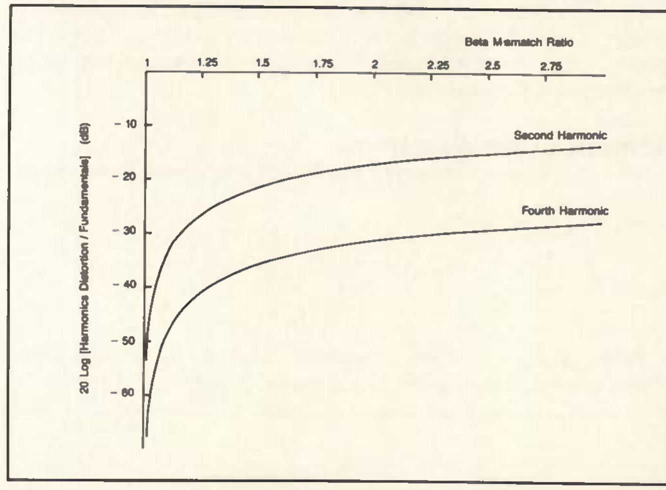

Figure 5. Beta mismatch ratio versus harmonic supression.

$$I_{C1}(t) - I_{C2}(t) = \frac{(I_{P1} - I_{P2})}{\pi} + \frac{(I_{P1} + I_{P2})}{2}\cos \omega t + \frac{2(I_{P1} - I_{P2})}{3\pi}\cos 2\omega t$$

$$- \frac{2\,(I_{P1} - I_{P2})}{15\pi}\cos 4\omega t + \ldots \qquad (4)$$

From the equation,

$$\frac{\text{Second Harmonic}}{\text{Fundamental}} = \frac{4\,(I_{P1} - I_{P2})}{3\pi(I_{P1} + I_{P2})} \qquad (5a)$$

$$\frac{\text{Fourth Harmonic}}{\text{Fundamental}} = \frac{4\,(I_{P1} - I_{P2})}{15\pi(I_{P1} + I_{P2})} \qquad (5b)$$

As an example, assume that transistors have a 1/2 mismatch of beta. This leads to a 14 percent second harmonic and 2.8 percent fourth harmonic distortion. Figure 5 shows how the beta mismatch affects harmonic levels.

Contribution of Phase Errors to Harmonic and Phase Distortion

Assuming a phase error term of ϕ_e in the $I_{C2}(t)$ expression:

$$I_{C2}(t) = \frac{I_P}{\pi} + \frac{I_P}{2}\cos(\omega t + \pi + \phi_e) + \frac{2I_P}{3\pi}\cos(2\omega t + 2\pi + 2\phi_e)$$

$$-\frac{2I_P}{15\pi}\cos(4\omega t + 4\pi + 4\phi_e) + \ldots \quad (6)$$

at the output of the balun,

$$I_{C1}(t) - I_{C2}(t) = \frac{I_P}{2}[(1 + \cos\phi_e)\cos\omega t - \sin\phi_e \cdot \sin\omega t]$$

$$+\frac{2I_P}{3\pi}[(1 - \cos 2\phi_e)\cos 2\omega t + \sin 2\phi_e \cdot \sin 2\omega t]$$

$$-\frac{2I_P}{15\pi}[(1 - \cos 4\phi_e)\cos 4\omega t + \sin 4\phi_e \cdot \sin 4\omega t] + \ldots \quad (7)$$

It can be noted from the above equation that both phase and harmonic distortion terms appear due to the phase error term. Phase distortion terms are Sinωt, Sin2ωt, Sin4ωt, etc. and harmonic distortion terms are Cos2ωt, Cos4ωt, etc.(2)

When ϕ_e is approaching 0 degrees, all harmonic terms disappear and the Cosωt term stays alone which means ideal working conditions for the amplifier. Figure 6 and 7 explain how harmonic and phase distortion terms vary with the phase error term ϕ_e).

Concluding from the above sections, note that both amplitude mismatch and phase error terms in the push-pull amplifier output create significant errors which are undesirable and must be minimized.

Analysis Using Exponential Nonlinear Model

In the previous sections a push-pull amplifier was realized assuming that the transistors were working linearly. But this assumption is not true since the transistors' base-emitter junctions show exponential characteristics. The following analysis is based on the nonlinear model of the transistors and Figure 8 shows the block diagram of the push-pull amplifier.

Considering the exponential characteristic, the input and output signals of the transistor can be represented as in Figure 9. $V_1(t)$ is the base signal of TR_1 with a biasing voltage V_b, so:

$$V_1(t) = V_b + V_1 \cos \omega t \quad (8)$$

Hence, emitter current can be written as:

$$i_1(t) = I_s e^{V_b/\gamma} e^{x\cos\omega t}$$

where:

$$X \approx \frac{V_1}{\gamma} \text{ and } \gamma \approx \frac{kT}{q} \quad (9)$$

Since maximum of $i_1(t)$ occurs when Cosωt=1,

$$I_P = I_s e^{V_b/\gamma} e^X \quad (9a)$$

Thus,

$$i_1(t) = \frac{I_P}{e^X} e^{X\cos\omega t} \quad (9b)$$

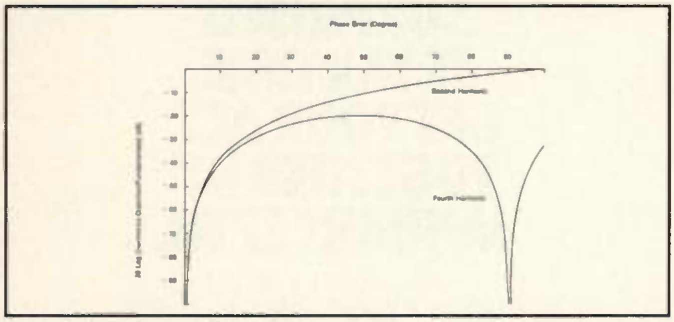

Figure 6. Phase error ϕ_e versus harmonic suppression.

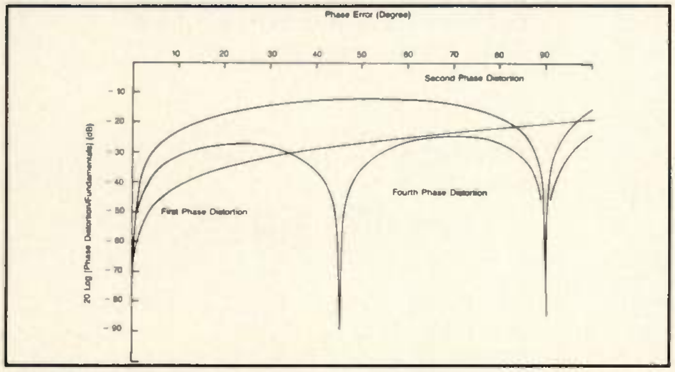

Figure 7. Phase error ϕ_e versus phase distortion suppression.

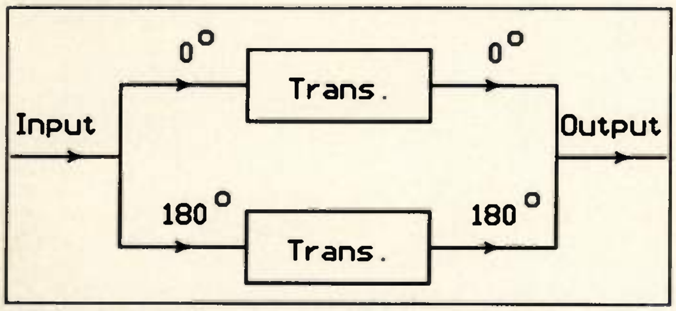

Figure 8. General block diagram of the push-pull amplifier.

For this signal, it is possible to write Fourier series expansion as:

$$i_1(t) = \sum_{n=0}^{\infty} C_n \bullet \text{Cos } n\omega t \qquad (10)$$

Where:

$$C_o = \frac{I_P}{e^X} \left(\frac{1}{2\pi} \int_{-\pi}^{\pi} e^{X\text{Cos}\Theta} d\Theta \right) = \frac{I_P}{e^X} I_o(x) \qquad (11)$$

$$C_n = \frac{2I_P}{e^X} \left(\frac{1}{2\pi} \int_{-\pi}^{\pi} e^{X\text{Cos}\Theta} \text{Cos} n\Theta d\Theta \right) = \frac{2I_P}{e^X} I_n(x) \qquad (11b)$$

Fourier series expansion terms become Bessel functions of order "i".

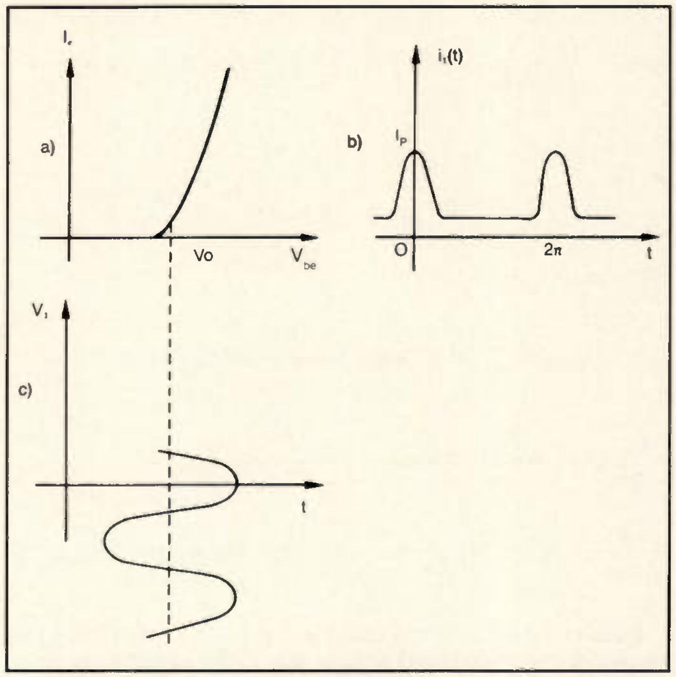

Figure 9. a) Emitter-base junction characteristic of the transistor; b) Collector signal for exponential non-linear characteristic; c) Base signal.

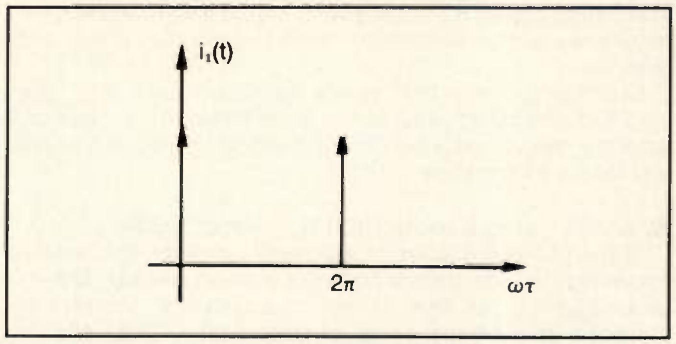

Figure 10. Collector waveform (X→∞).

$$i_1(t) = \frac{I_P}{e^X} I_0(x) \left[1 + 2 \sum_{n=0}^{\infty} \frac{I_n(x)}{I_0(x)} \text{Cos } n\omega t \right] \qquad (12)$$

For small X,

$$I_0(x) \approx 1, \qquad I_1(x) \approx \frac{x}{2}, \qquad I_n(x) \approx 0 \qquad (13a)$$

$$I_1(t) \approx \frac{I_P}{e^X} (1 + x\text{Cos}\omega t) \qquad (13b)$$

From this approximation in a small signal operation case, one can easily see that even if one transistor is operated, harmonic distortion is negligible.

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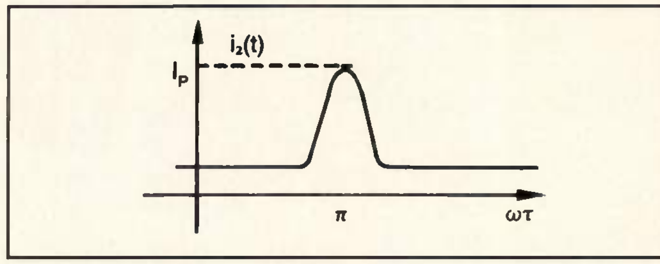

Figure 11. 180° Phase shifted waveform of $i_1(t)$.

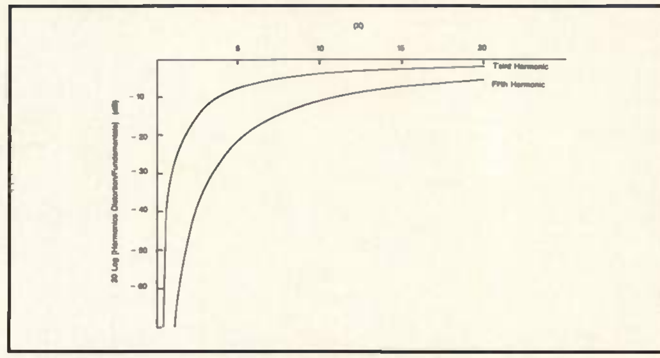

Figure 12. X versus harmonic supression.

However, when X approaches infinity, Figure 9 changes and takes the form shown in Figure 10. Since there is a 180 degree phase difference between two transistor outputs, $i_2(t)$ can be written as follows and can be represented as in Figure 11. At the output balun, $i_2(t)$ is shifted 180 degree again and it is added to $i_1(t)$.

$$i_2(t) = \frac{I_P}{e^X} I_0(x) \left[1 + 2 \sum_{n=0}^{\infty} \frac{(-1)^n I_n(x)}{I_0(x)} \text{Cos } n\omega t \right],$$

$$I_n(-x) = (-1)^n I_n(x) \qquad (14a)$$

$$i_1(t) - i_2(t) = \frac{4 I_P I_1(x)}{e^X} \text{Cos } \omega t + \frac{4 I_P I_3(x)}{e^X} \text{Cos } 3\omega t + \frac{4 I_P I_5(x)}{e^X} \text{Cos } 5\omega t + \ldots \qquad (14b)$$

Figure 12 shows how the harmonics change with varying X. According to that figure, harmonic suppression reaches 0 dB when X reaches infinity. However, in the linear model case, the push-pull amplifier does not create odd harmonics, even if some amplitude or phase error is introduced into the system. In the exponential model case, without considering the errors used in the linear model case, some harmonics exist. Note that these are odd harmonics. These cases are shown in Figure 5, 6, 7 and 12.

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About the Author

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Characterizing Resonators with S-Parameter Network Analyzers

By Tim Semones,
Innovative Measurement Solutions

Resonators, such as quartz crystals, surface acoustic wave (SAW) grooved reflectors and dielectric resonators, are widely used in frequency control, timing and filter applications. However, inadequate understanding of these devices usually results in designs that do not live up to expectations — they operate at unwanted frequencies, have an unexpected "Q", or are less reliable or manufacturable. What follows is a description of an accurate and repeatable technique for converting transmission and reflection measurements (in the form of S-parameters) of resonators into an equivalent electrical circuit. The equivalent electrical circuit parameters of a resonator are used to specify its characteristics. These parameters are also extremely useful in the design of filters and oscillators which use resonators.

Resonators can take several forms. Lower frequency resonators (typically less than 300 MHz) are usually mechanically resonant quartz vibrators. SAW devices are common at RF frequencies and dielectric resonators are finding applications at microwave frequencies. The electrical behavior of any of these devices, over a narrow range of frequencies near resonance, can be described by an equivalent one-port or two-port network. Figure 1 shows a one-port, two-terminal representation of a resonator. Figure 2 shows a two-port, three-terminal representation.

The motional parameters R1, L1 and C1 are common to both circuits. However the static capacitances differ slightly between the two models. The one-port static capacitance, C0 in Figure 1, is a combination of the effects of the two-port static capacitances C0, C13 and C23 shown in Figure 2. Static conductances G0, G13 and G23 could also be modeled. Static parameters can be calculated from measurements made at frequencies away from resonance. They are easily determined since they are relatively independent of frequency and are not affected by the resonance of the device.

Measurements near resonance allow computation of the motional parameters. The motional parameters can be calculated from the admittance or impedance behavior of the device near resonance. The transadmittance (admittance between pin 1 and 2) of the resonator can be shown to be of the form:

$$Y_{12} = \frac{R1}{R1^2 + \left(\omega L1 - \frac{1}{\omega C1}\right)^2} + j\omega C0 - \frac{\omega L1 - \frac{1}{\omega C1}}{R1^2 + \left(\omega L1 - \frac{1}{\omega C1}\right)^2}$$

When plotted in the admittance plane (Y-plane), Y_{12} maps the circular locus shown in Figure 3. The constants in the Y_{12} equation are the equivalent circuit parameters R1, L1, C1 and C0. From Figure 3, other frequencies of interest used to describe device behavior can be obtained.

All these frequencies depend to some degree upon the effective value of C0. Connection into any circuit will produce additional stray capacitance and therefore modify the effective C0 value. Thus, best correlation of measurements is obtained when the series resonance frequency, f_s, is referenced. One can conceptualize f_s as the frequency at which the device would resonate if no capacitance existed between pins or from the pins to the enclosure and use circuit.

Measurement and Data Reduction

Vector network analyzers can be used for measuring the S-parameters (scattering parameters) of a two-port network. These instruments are capable of measuring both the

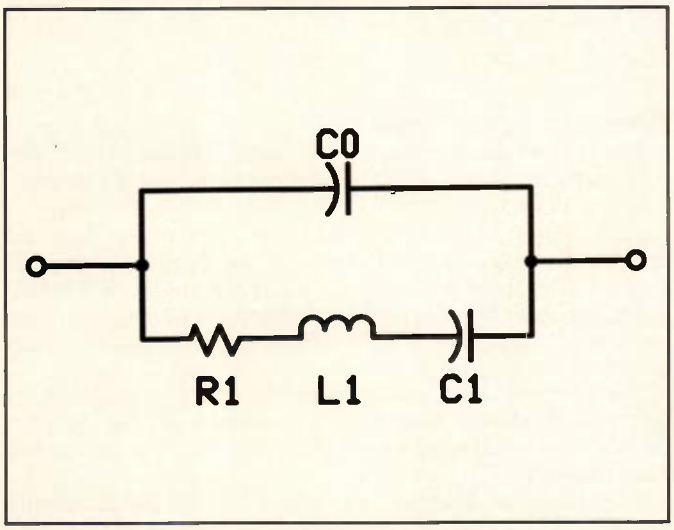


Figure 1. One-port equivalent circuit.

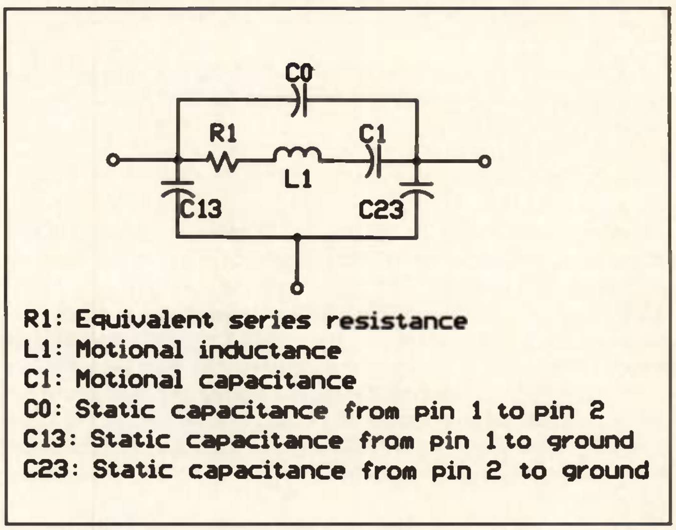


Figure 2. Two-port equivalent circuit.

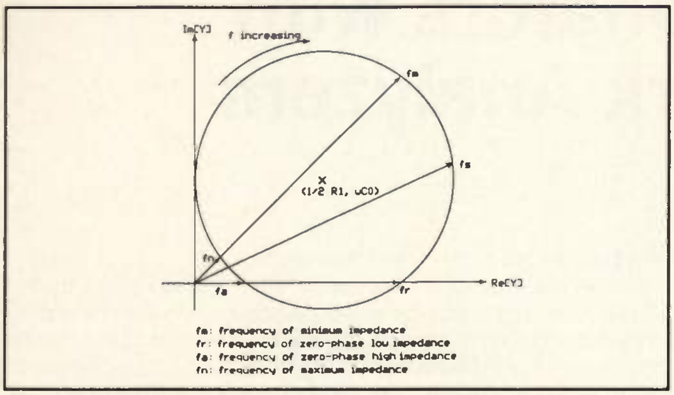


Figure 3. Admittance plane locus.

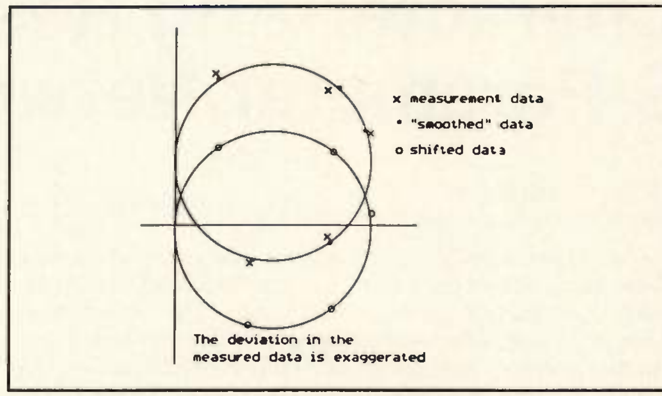


Figure 4. Admittance plane data reduction.

magnitude and phase response of a device under test. One distinct advantage of a vector analyzer over a scalar analyzer is the ability to measure "known calibration standards" such as shorts, opens, matched terminations, thrus and delays to construct an error model of the measurement system. Once this error model is constructed, the effects of imperfect isolations, mismatches and frequency response may be vectorially subtracted from an actual measurement to determine more precisely the S-parameters of the device under test.

In April 1985, the Electronic Industries Association (EIA) adopted a national test standard for the estimation of equivalent electrical circuit parameters for resonators. This test standard (EIA-512), available from the EIA, is based on a testing and data reduction methodology used at Bell Telephone Laboratories since the early 1970's. The standard specifies that S-parameter network analyzers be used to perform resonator characterization. The techniques for vector error correction of systematic measurement errors are detailed. So is the methodology for estimating the equivalent circuit parameters from error-corrected S-parameter measurements. What follows is a brief overview of the data reduction method prescribed in EIA-512.

Once error-corrected S-parameters are obtained for the device at several frequencies near resonance, the transadmittance at each frequency can be calculated as:

$$Y_{12} = \frac{-2S_{12}}{(1 + S_{11})(1 + S_{22}) - S_{12}S_{22}} \left(\frac{1}{Z0}\right)$$

If the resonator was measured as a one-port device then the admittance at each frequency can be calculated as:

$$Y = \frac{(1 - S_{11})}{(1 + S_{11})} \left(\frac{1}{Z0}\right)$$

If total equivalence to the model was obtained, the transadmittance (or admittance) would map a perfect circle in the Y-plane as shown in Figure 3. The center of the circle would be at ($1/2R1$, $\omega_s C0$). Due to random measurement error and any non equivalence to the model, the measured Y_{12} (or Y) data will not map a perfect circle. Some of the randomness may be removed by first calculating the best fit, least squares residual circle for the measured values. Once this circle is calculated, the data may be "smoothed" by translating the measured admittance points along the radii of this circle such that they now lie on the best fit circle.

Let Y_{12}' represent the "curve-fit-smoothed" values of admittance. Subtracting the imaginary component of the center of the circle from each admittance point would relocate the circle such that its center would lie on the real axis. Centering the circle on the real axis removes the parallel admittance of the static capacitance parameters. Mathematically, each admittance point would be shifted such that:

$$Y_{12}'' = Y_{12}' - j\omega_S C0$$

The circle now represents the admittance locus of the series resonant circuit only. The Y_{12}'' values can then be converted to impedance by:

$$Z = \frac{1}{Y_{12}''} = R'' + jX''$$

From here the values of X" can be fit to a polynomial function of frequency. For this function, f_S is the frequency of which X"=0. Motional inductance, L1, is calculated from the slope of the function as:

$$L1 = \frac{1}{4\pi} \frac{dx''}{df} \text{ evaluated at } f_s$$

Motional resistance is calculated from the diameter of the best fit circle in the admittance plane. The other parameters of interest are the motional capacitance C1 and the unloaded resonator Q. They can be calculated as:

$$C1 = \frac{1}{4\pi^2 f_S^2 L1} \qquad Q = \frac{1}{2\pi f_S C1 R1}$$

System Implementation

The mathematics involved in this type of measurement can only reasonably be handled by a computer-based test system. A system would consist of:

1. A vector network analyzer with S-parameter test set capable of making measurements in the frequency range of interest. The network analyzer must be HP-IB (IEEE-488) programmable. The source of the network analyzer should be synthesized and have at least 1 Hz resolution for testing high Q resonators.

2. A computer with HP-IB interface for controlling instrumentation. The computer must be able to perform complex number calculations quickly and be able to address a large amount of main memory.

3. A software program for calibrating the measurement system, setting up measurements, performing vector error correction, and estimating equivalent circuit parameters of the

resonator.

4. Text fixture and calibration standards.

Any commercially available test and computing equipment that meets the guidelines mentioned above could be used for this measurement. Measurement software in support of the EIA-512 measurement standard could then be developed. Application packages have been developed for the HP 8753 (300 kHz to 6 GHz), the HP 8720 (130 MHz to 20 GHz), and the HP 8510 (45 MHz to 40 GHz) network analyzers. The software runs on the HP Series 200 and 300 computers and is available directly through Hewlett-Packard as the HP 8516A Resonator Measurement Software.

One of the main functions of the software is to calibrate the measurement system. By measuring known terminations, the systematic errors can be characterized. Known terminations consist of short circuits, open circuits, 50-ohm terminations, and thru connections. The systematic errors accounted for in the calibration process include imperfect directivity and isolation in the test setup, frequency response in both the transmission and reflection paths, and impedance mismatches in the test setup. The test fixture shown in Figure 5 allows calibrations to be performed at the same plane as the measurement. The calibration standards are designed to have the same "footprint" as the packaged device. For transmission measurements, the full 12-term error model is used. For reflection measurements the one-port, three-term error model is used. These error models are well-established and are presented in detail in various references.

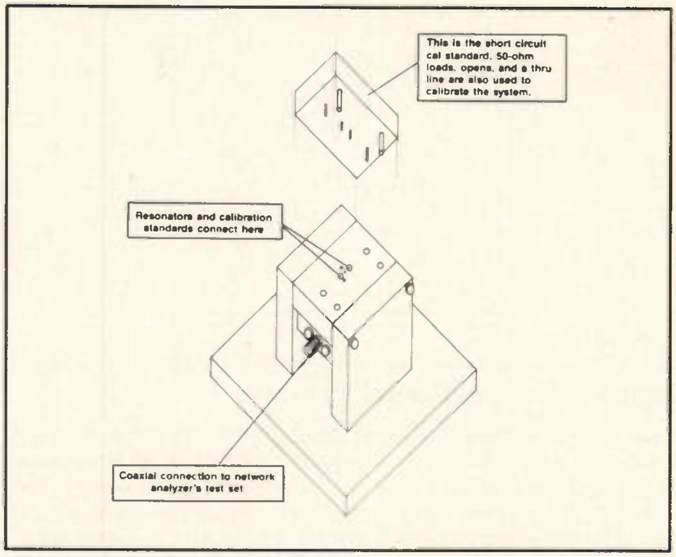
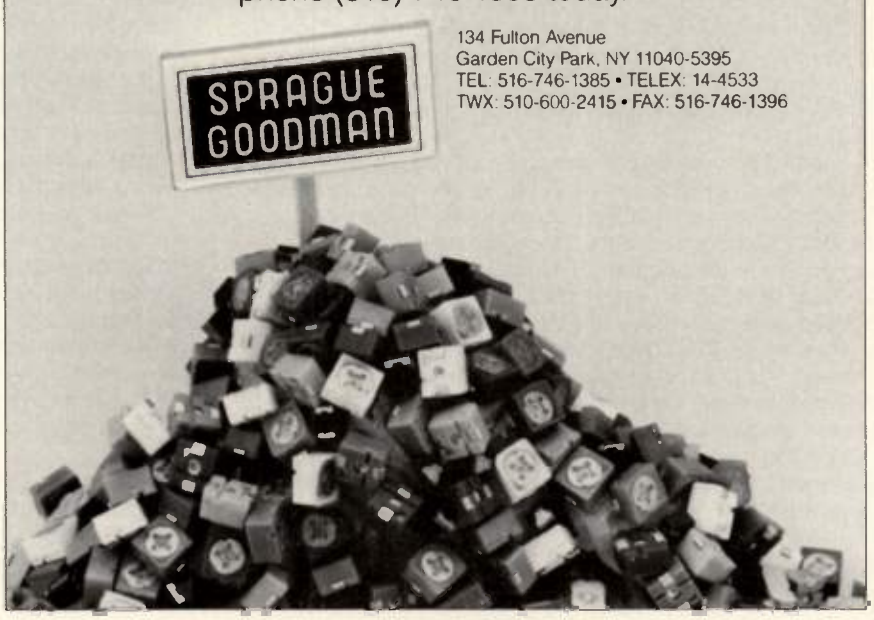


Figure 5. Calibration/test figure.

Typically, error-corrected measurements can only be made at the frequencies where the calibration was performed. This is very restrictive for the measurement of resonators. Resonators are typically very high Q devices and are best characterized by



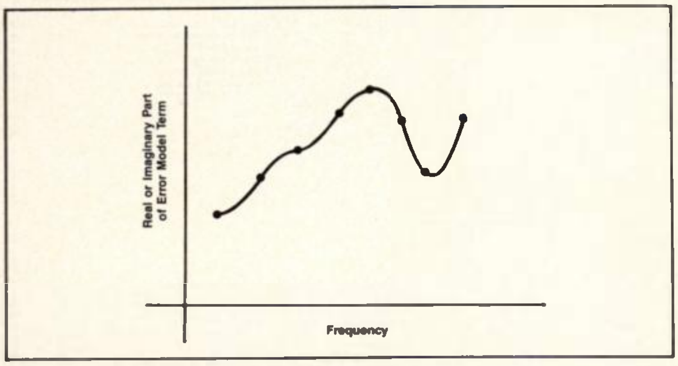


Figure 6. Cubic spline fitting of data.

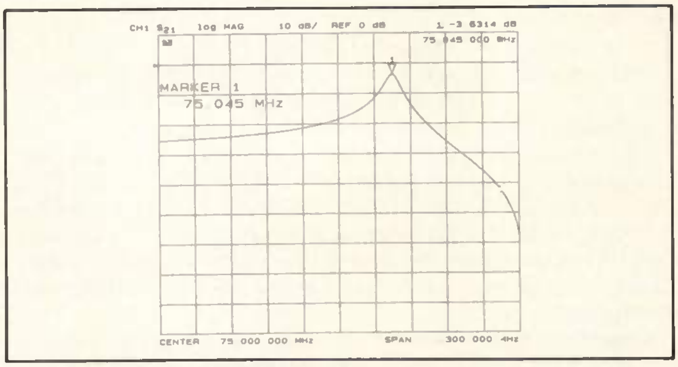


Figure 7. Resonance search window.

measurements centered about the resonant frequency in a tight frequency span. To avoid having to calibrate at an enormous number of frequencies, an interpolation scheme is used in the software. The system can be calibrated over any frequency span of the network analyzer. Note that 51 frequencies are used in the calibration. The interpolation technique used is the fitting of data to a cubic spline. The real and imaginary part of each error term is fit to a series of cubic splines. Each cubic represents the behavior between sample points. The splines are calculated by requiring that each cubic include the endpoints and that the slopes of each adjoining cubic are equal. This gives the mathematical equivalent of connecting the sample points with a french curve. This process is depicted graphically in Figure 6. This technique allows the system's error terms to be interpolated at any frequency inside the span used during calibration. Once a calibration is performed, error-corrected measurements can be made at any frequency inside the calibration span.

The first task of the measurement routine is to locate the resonance response of the device. Once the area of resonance has been identified, detailed measurements can be made to calculate the equivalent circuit parameters. The criteria for identifying the resonance area is a transmission maximum for two-port measurements and an impedance minimum for one-port measurements. A search window can be set manually on the analyzer or set automatically by the nominal f_s and nominal Q. Figure 7 shows a device with the search window of f_s ±50 QBW set by the program. Markers are shown on the maximum transmission of the two-port measurement. QBW is defined by:

$QBW=f_s/Q$ here the nominal f_s and Q are used.

It is important to note that maximum transmission (or minimum impedance) frequency is not equal to series resonance frequency f_s or zero phase frequency f_r. Series resonance frequency is obtained from the admittance and impedance behavior near resonance. However, very good results are obtained using the S-parameter measurement information obtained to decide where to go in frequency to make detailed measurements. The identification of maximum transmission (or minimum impedance) response is determined on a series of three successively narrow sweeps as the system zooms in on the area of resonance.

Once the approximate resonant frequency is determined, measurements in the area of the resonance response are taken. These are the measurements that will be used to calculate the resonator's equivalent circuit. The measurements will be centered on the maximum transmission (minimum impedance) point from the last sweep in the search for resonance. The frequency span will be ± QBW of the device. This gives data that covers ± 120 degrees on the admittance circle shown in Figure 3. The equivalent circuit parameters are then calculated from the error corrected S-parameters (or reflection coefficient) as detailed in EIA-512.

Other capabilities of the software are measuring resonant parameters as a function of drive level or temperature and characterizing spurious (anharmonic overtones) responses. These are all very critical considerations in the design of filters and oscillators. Any variation in the motional resistance R1 of a resonator will cause the insertion loss of the filter to vary with input power. Resonant frequency, f_s as a function of temperature is essential information in designing compensated oscillators. Spurious responses affect both filter and oscillator performance. Having the ability to define the resonator's equivalent circuit and its dependencies is invaluable in the design of filters and oscillators.

Presentation of Typical Measurement Data

Typical output for the software is the motional arm parameters. Static capacitance and conductance parameters may also be presented. S-parameter measurements such as minimum insertion loss and frequency, insertion phase and loaded Q can also be examined. Table 1 shows the measurement results of a 567.9 MHz SAW resonator.

The repeatability of the technique is quite good. Table 2 shows the computed statistical profile for ten consecutive measurements made on a filter crystal. The power dissipated in the crystal during the measurement was 100 nanowatts.

This shows the measurement technique to have a short term repeatability of mid-parts in 10^9 for frequency, and a few tenths of a percent for motional arm parameters. An experiment was conducted to determine the degree to which EIA-512 resonator measurements can be correlated from location to location. Ten different crystals were used for the experiment at six different locations. Each device was measured ten times during five different test sequences and the results showed the measurements to be repeatable roughly to within one part in 10^7 for frequency, and 2 percent for motional parameters for all sets of measurements. This indicates that a manufacturer and user of a 10 MHz crystal should expect to get series resonant frequencies within 1 Hz of each other using the EIA-512 methodology.

Conclusion

The vector network analyzer is a very powerful measurement tool. It allows precise characterization of one- and two-port networks. By measuring well-established calibration stan-

f_s	=	567 899 829.675	Hz
R1	=	189.609	Ohms
L1	=	.5136	mH
C1	=	.4589	pF
Q	=	9648	

Table 1. 567.9 MHz SAW resonator.

Mean f_s	32 515 925.905	Hz
σf_s	.159	Hz
σf_s	.005	ppm
Mean R1	11.759	ohms
σ R1	.014	ohms
σ R1	.12	%
Mean L1	14.712	mH
σ L1	.047	mH
σ L1	.33	%

Table 2. Statistical profile for a crystal filter.

dards, the systematic, repeatable errors in the test setup can be removed mathematically from the measurement. The ability to perform this vector error correction becomes even more important as higher frequency devices are tested. A methodology for converting the error-corrected transmission and reflection measurements of a resonator to its equivalent circuit parameters has been presented. The technique is based on the EIA-512 US National Test Standard for characterizing quartz crystal resonators. Measurement data shows the method to be outstanding in terms of both short term repeatability and correlation from site to site.

The author would like to acknowledge the contributions of David Lynch of Hewlett-Packard Network Measurements Division to this article.

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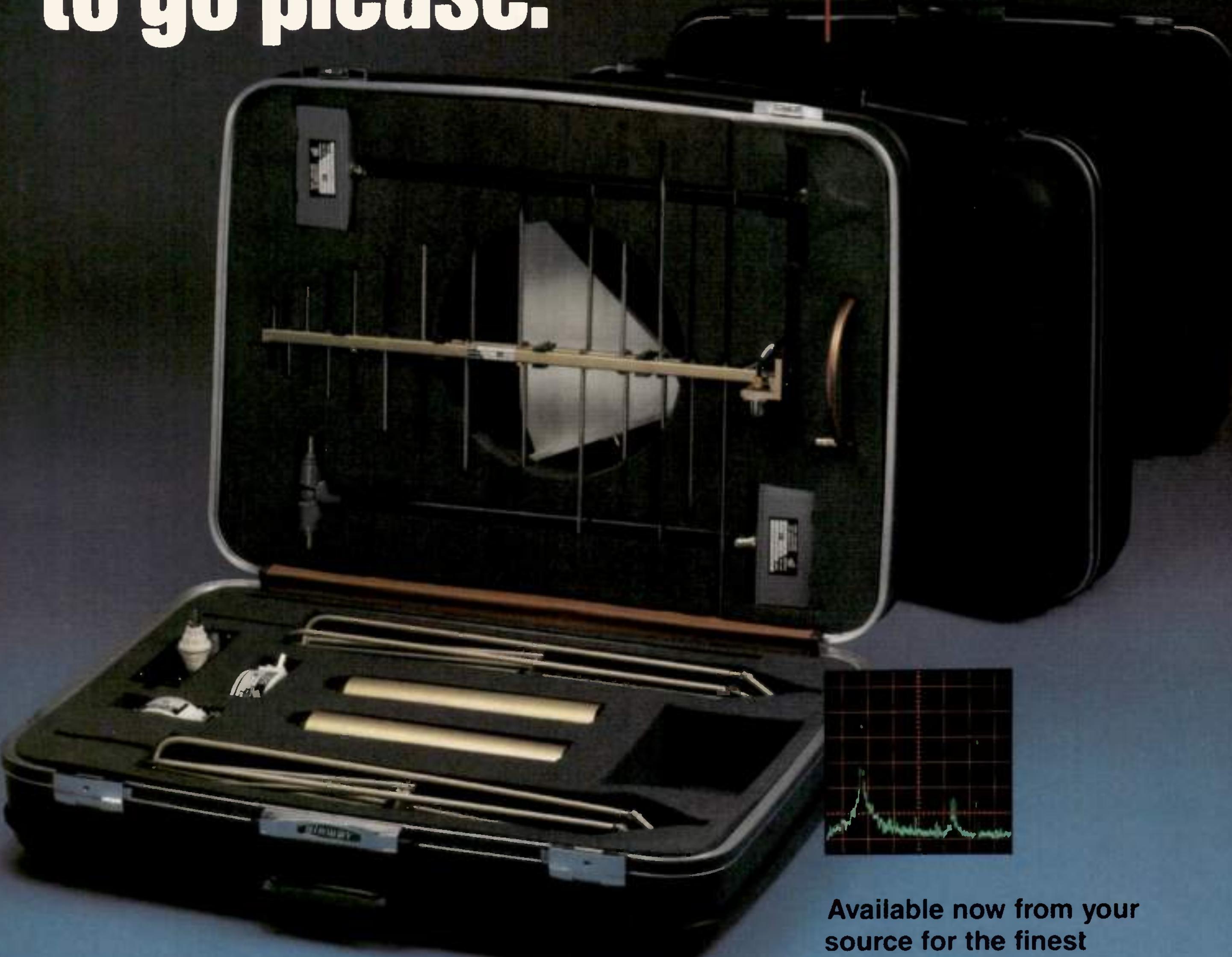

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SAS-200/530	150 - 550 MHz	Broadband Dipole
SAS-200/540	20 - 300 MHz	Biconical
SAS-200/541	20 - 300 MHz	Bicon'l Collapsible

MODEL #	FREQ. RESP.	DESCRIPTION
SAS-200/542	20 - 300 MHz	Biconical, Folding
SAS-200/550	001 - 60 MHz	Active Monopole
SAS-200/560	per MIL-STD-461	Loop - Emission
SAS-200/561	per MIL-STD-461	Loop - Radiating
BCP-200/510	20 Hz - 1 MHz	LF Current Probe
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EMI Signal Measurement Automation

By Roger Southwick
EMC Consulting

Over the past few years, the author has spent a considerable amount of thought and effort in developing and designing a more efficient approach to the measurement of EMI (electromagnetic interference) signals. The result of these efforts is a paper "A Theory to Optimize the Detection and Measurement of EMI Signals" (1), which explains the mathematical development of a method to optimize the detection of EMI signals. This optimization ensures a high probability of detection plus measurement accuracy. The results also show that a spectrum analyzer with a dual trace, MAX HOLD trace, and positive peak detection is the ideal receiver.

Through these efforts, a personal theory of EMI signal measurement has been developed, which states the following: 1. It is necessary to detect a signal prior to measuring the signal; and 2. Only signals that have been detected, and for which estimates of frequency and amplitude are available, can be accurately measured.

The second result of this work is the "EMI Measurement Program." This program is the practical application of the theory and is the subject of this article. The program, as presently written, specifically performs the FCC 15/J, VDE, VCCI or similar type measurements. A second version will apply to MIL-STD 461/462. Whether the reader intends to use the program or not, its description will explain the primary aspects of the author's EMI signal measurement theory.

To gain an overall understanding of the program a flow diagram is shown in Figure 1. The program is divided into two parts: Analysis and Measure. The Analysis part of the program deals with the analysis and manipulation of measured data that has been recorded on the data disk. There are three separate Analysis subprograms: Intermodulation, Statistical Analysis and Composite. The Measurement portion of the program, covered in this article, has three subprograms: E-Field, Conducted and H-Field. The E-Field and H-Field subprograms have two measurement bands while the Conducted subprogram has six measurement bands.

In the initial subprogram, EMC, the operator selects Measure followed by the measurement subprogram, the band, the antenna factor and the limit. The measurement subprogram chosen is then chained-in and a menu is presented from which the measurement is further defined. When a measurement is completed, additional measurements with the same band, limit, and antenna factors can be made as often as desired, or the operator may choose to return to the subprogram EMC to make another band selection.

Measurement Menu

The measurement main menu permits the operator to design the measurements to different requirements: to record and plot the data, and/or to choose the Selected Peak and the Q-P options. Ambient, align, search data, overload and sector options are also selected from this menu. At the end of each measurement, an auto mode option is available. This option will perform another measurement with the same options selected in the previous measurement. The operator need only add an identifying parameter; the rest is automatic.

Measurements

The measurements, the most important aspect of the program, are defined by the theory, which specifies a maximum number of sweeps during a finite time interval, called the delay interrupt. A flow diagram of the measurement process is shown in Figure 2. The actual measurements are performed in sequence in three parts: 1. Detection — it occurs during the sweep of the entire frequency band; 2. Selected Peak — an individual measurement of those signals selected by the operator from the trace made during Detection by means of a cutoff level; and 3. Q-P — a second measurement of the signals measured in the Selected Peak measurement. The spectrum analyzer parameters are set and the delay interrupt time interval calculated in the subprogram EMC.

Ambient

The EMI Measurement Program has a provision to deal with ambient signals, which involves measuring all the ambient signals above an operator-set limit. When the Selected Peak measurement option is selected along with the ambient option, the program reverts to a local control mode for the spectrum analyzer

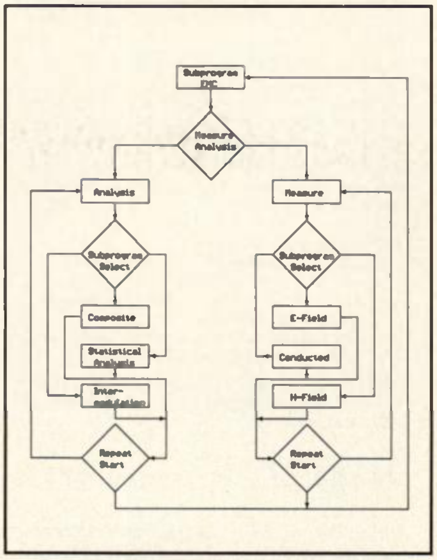

Figure 1. Program flow diagram.

whenever an ambient signal is within a specific frequency separation from the signal being measured. The operator must then set the spectrum analyzer marker on the signal to be measured. An option to reduce the resolution bandwidth is included so that the ambient signal and the desired signal can be resolved. When the operator has selected the correct signal, the program regains control of the spectrum analyzer to complete the measurement automatically.

Measurement Bands

Measurement bands are based on three factors: 1. the frequency range specified by the regulation; 2. the bandwidth of the available sensors; and 3. the need to minimize frequency measurement errors. The frequency range of the regulation must obviously be covered. In some instances this must be done in parts. The parts should be selected to ensure three things: that each part has a sensor with a corresponding bandwidth; that the band frequency range does not introduce unacceptable frequency errors; and that as few parts as possible are selected.

Frequency errors are the result of inexpensive spectrum analyzers which lack phase-lock LO circuits. Wide frequency ranges with a low start frequency will result in unacceptable errors. In the below-30 MHz measurement subprograms, the bands are separated at 1 MHz. It is important to remember that scans across the entire measurement bands are made only in the Detection part of the measurement process, where only an estimate of the signal amplitude and frequency is required. Numerous small bands will resolve this problem, but this is inefficient and redundant.

Detection

The first part of the measurement sequence is the signal detection. During this part the spectrum analyzer scans between the band-end-frequency points in the MAX HOLD mode during the delay interrupt period. The analyzer functions are decoupled and the scan rate set to the point at which about 3 dB of CW (continuous wave) desensitization occurs. The increased scan rate improves the probability of detection. The second trace is also turned on in the normal mode, and as the measurement progresses the traces will separate as a function of the randomness of the signals being measured. This provides the operator with a means to observe the randomness of individual signals.

Data Culling

After the Detection function is complete, the data of the MAX HOLD trace is transferred to the computer. The highest data points of each sequential set of five data points are transferred. This transfer process reduces the number of data points by a 5 to 1 ratio. The data is then converted to field strength and displayed with the limit on the computer. If the Selected Peak option has been selected the operator can set the cutoff level, an off-set value above or below the limit. The program then does a sort and displays the number of signals above the cutoff.

The operator can reset the cutoff until the desired number cf signals is selected. If for some reason the cutoff is set in the spectrum analyzer noise, an array in the Cull subroutine will overload and the operator has an option to raise the cutoff level. If the cutoff level is not raised, the video bandwidth will be reduced to reduce the noise level. The frequency estimate of the signals selected is used to set the spectrum analyzer controls for the next part of the measurement process — Selected Peaks.

Selected Peaks

In the Selected Peak measurement, signals that were measured during the Detection part and selected by the cutoff are remeasured. The measurement is now made with a narrow frequency span so that each signal is measured separately. The span is set as narrow as possible because the span width determines the frequency resolution of the measurement process. The width of the frequency span is determined by the error of the estimate of the signal's frequency. Only one signal is measured per span. The scan rate is coupled, but now with a narrower scan width there will be no CW desensitization and the probability of detection will not be reduced. Hence, an accurate frequency and amplitude measure is assured.

As part of this measurement, the program is stopped so the operator can either adjust the EUT (equipment under test) configuration for maximum radiation or turn the turntable to determine the azimuth of a signal's maximum radiation. This maximization is accomplished by use of the dual trace display. One trace is in MAX HOLD and the other is in the normal mode. The adjustment to the EUT or turntable is made over the complete possible adjustment range to set the MAX HOLD trace. The operator must then repeat the adjustment until the normal trace approximates the MAX HOLD trace, at which point the EUT or turntable has been set to a maximum configuration.

During the Selected Peak measurement, the spectrum analyzer resolution bandwidth is first reduced by one step from that used in the Detection part. The actual Selected Peak process is quite complex and depends on the nature of the signal being measured. The process consists of three parts, the first two of which have two phases. The first phase of the first two parts takes 10 sweeps. The second phase of the first two parts scans during the delay interrupt period, which is considerably longer than the 10 sweeps of the first phase. After the 10 sweeps of the first phase, the peak search function locates and measures the highest signal in the span. When the ambient option and an ambient signal is within the span the search is done by the operator. The amplitude of the highest signal is then compared to the amplitude of the same signal when it was measured in the Detection part of the measurement. This comparison ensures that the correct signal has been selected — it has approximately the same amplitude and frequency. If the comparison fails, the resolution bandwidth is increased by one step and the program moves onto the second phase of the first part. If the comparison is successful the program skips the second phase of the first part and moves to the first phase of the second part and the marker is centered on the display and the span width reduced. This process repeats in the second part, except that the span width is reduced only once in either part one or part two.

In the third and last part the final measurements of the signal's peak, log average and frequency are made. If the amplitude comparison is never successful, the measurement is made at the center of the display. This subroutine has demonstrated a consistent ability to find and measure the correct signal. Each signal selected by the Cull process is measured in this manner.

Quasi-Peak (Q-P)

When the Q-P option is selected in the measurement subprogram main menu, Q-P measurements are made on the same signals that were measured in the Selected Peak part of the measurement

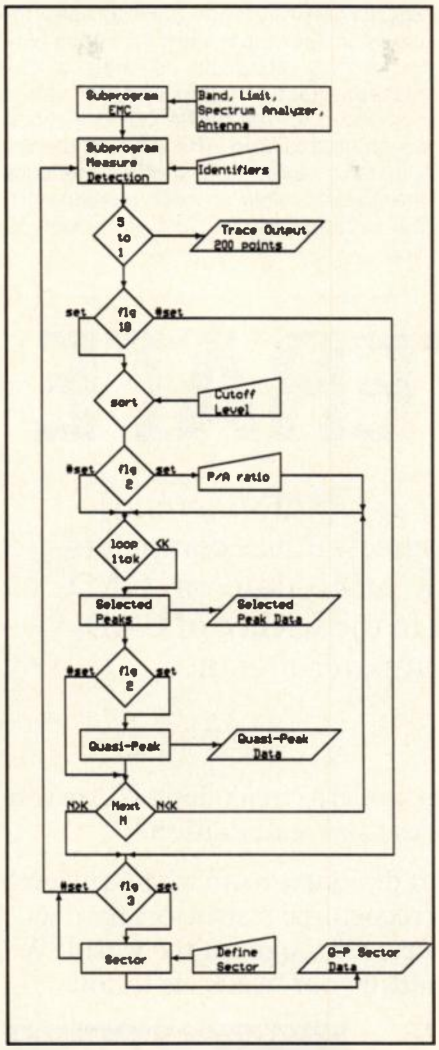

Figure 2. Measure flow diagram.

process, and they are made directly after the Selected Peak measurement so that the same EUT configuration can be left in place. The Q-P measurement option can be selected from the measurement main menu only when the Select Peak measurement is selected, because the Q-P measurement uses the data provided by the results of the Selected Peak measurement to set the spectrum analyzer center frequency and reference level.

For the actual measurement, the spectrum analyzer is set to the desired center frequency and to the zero scan mode. The signal level is set to the top of the spectrum analyzer display and the switch from the log to the linear mode is made. This totally automated Q-P measurement subroutine sets two conditions: 1. A feedback loop adjusts the signal level to the upper third of the display by changing the spectrum analyzer reference level; and 2. the Q-P detector post amplifier is set by the signals A/P (log average to peak) and S/N (signal to noise) ratios. If the S/N ratio is less than 18 dB or the A/P ratio exceeds 5 dB, the amplifier is turned on.

The duration of the measurement is controlled by the delay interrupt, during which time the feedback loop constantly adjusts the reference level to keep the signal in the upper third of the display. When this condition is met, a Q-P measurement is taken and the values compared to that of the last Q-P measurement are taken. The larger of the two values is saved and another measurement taken. This process continues for the duration of the delay interrupt period.

Sector

The measurement main menu offers an option to scan sectors of a band with the Q-P detector. This option is available at two points in the program. The first point is just prior to the Selected Peak measurement, and the second point is just after all the Q-P measurements are completed. When this option is selected, the operator can use a multi-step process to select any frequency sector of the band, which will then be scanned by the spectrum analyzer with the Q-P detector. The data will be displayed and plotted, but not saved. This option is very useful in locating steady-state signals buried in noise.

Data Storage and Content

An important consideration is the data, which will be measured and recorded on disk for future analysis. There are two types of data to consider: the defining parameters of the measurement, and the actual measured data. The defining parameters include the instrument parameters and information to identify a specific test. The program records this data in a string in coded form. A comment string to identify the data set is also recorded. The measured data is recorded in two arrays. One array contains 200 amplitude points, which are the continuous data trace from the Detection function. The other array has three parts that contain peak amplitude and frequency from the Selected Peak function, and Q-P amplitude data from the Q-P function. This data is recorded automatically when the record option is selected.

Limits

Each measurement band has four limits. Limits are selected by the operator from a menu in the subprogram EMC. When no data exists in a limit file, the operator is guided through the process of entering the limit data and title. This limit data is then recorded in a file and will be available until it is erased by the operator. Limit data can be either linear or log in the subprograms Conducted and H-Field and must be linear in the E-Field subprogram. Limit data for E- and H-Field, the two radiated subprograms, is entered at a distance selected by the operator. An option in the limit selection process permits the operator to select any measurement distance, and the program converts the limits to the selected distance.

Antenna Factors

Antenna factors work in a manner similar to the limits although the number of data points is greater. There is also a provision to measure the cable losses above 30 MHz, when a tracking generator is available. A subroutine leads the operator through the process, and the data is recorded with each antenna factor set. When the antenna factor is called, the cable losses are automatically added. The cable loss can also be entered when the values are known or measured by another method. The cable losses can be changed without affecting the antenna factors.

Graphics

Graphics is an important consideration for plotting as well as for the computer display. A subprogram GRID, is used to generate the graphic displays and plots. The graphic data is displayed on the computer display. When the plot option is selected from the measurement subprogram main menu, the data will also be plotted. The plot includes the data trace with identifying marks, to distinguish between Selected Peak and Q-P amplitudes. The limit and the cutoff are also included on the plot. All plotted and displayed data is converted to field strength or, in the case of the conducted data, the LISN factor is included.

Printouts

Data printout is selected by an option of the measurement subprogram main menu. This printout includes all the signals selected for individual measurement. For each signal the following data is provided: frequency, amplitude peak, amplitude Q-P, limit level, signal to limit both peak and Q-P, S/N, and A/P. The signals are also printed a second time ranked according to the limit-signal amplitude difference. A screen dump of the computer display can also be printed.

Conclusion

In conclusion, the theoretical basis for the measurement of EMI signals has been combined with the measurement technology in a user friendly program designed with all the options needed to meet the requirements of the FCC, VDE and VCCI type regulations. The result is both increased test efficiency and accuracy. Increased efficiency includes the assurance of signal detection and the ability of the operator to select the most appropriate options for the measurement situation. Accuracy of each measurement is assured since each signal is measured individually with optimum receiver settings. The EMI Measurement Program provides significant improvement over current technology in both the efficiency and accuracy.

Further information on this EMI measurement software can be obtained directly from the author. rf

About the Author

Roger Southwick is owner/president of EMC Consulting, 2716 N. Estrella, Tucson, AZ, and has been involved with EMC measurements and compliance testing for the past 28 years. He can be reached by telephone at (602) 792-9491.

A Test Oscillator for Overtone Crystals

By Clint Bowman
Prospect Heights, IL

Not too long ago, a fabricator of AT cut quartz crystals would have been out of his mind to accept a production order for a job requiring wafers of 20 MHz dimensions. However, at present, catalogs listing 9th overtone crystals to 225 MHz are common. (This equates to a fundamental dimension of considerably more than 20 MHz). At least one supplier now offers AT fundamentals of 500 MHz.

Figure 1 shows a reliable, easily duplicated circuit to exploit the newly available crystals. The first thing the experienced overtone oscillator expert will note about this schematic is its apparent lack of a feed back path to excite the crystal. There is feedback in this circuit in the form of a "gimmick" which will be explained later.

The circuit evolved from tuned plate-tuned grid (TPTG) oscillators of vacuum tube technology, where the grid tank acted as a passband filter to sustain oscillation, or not, depending upon its bandwidth and frequency relationship with the tuned plate circuit.

A properly processed quartz plate as a high Q resonator exhibits excellent filtering attributes at its fundamental as well as its odd overtones. Positioned in the base circuit of a common emitter transistor amplifier, it will perform in a manner similar to the TPTG concept. Further, the introduction of controlled feedback to this simple circuit assures reliable and repeatable operation to at least 200 MHz when suitable crystals are available.

The 20 pF ceramic disc capacitor connected between the emitter and the cold end of the collector tank serves as the feedback "gimmick." (The author suspects that the .01 disc ceramic tank bypass becomes progressively less effective as the frequency is increased and accordingly more tank energy is available to the emitter. Also, the 20 pF capacitor placed physically adjacent to the cold end of the tank adds additional energy by induction.) The single turn output inductor is positioned between that capacitor and the tank. For crystals of low activity and at higher overtones, this link may have to be pulled out of exact alignment with the tank (looser coupling) for oscillation to occur readily.

No particular attention was given to the Q or L/C ratio of the tank. The trimmer came from Radio Shack and the coil was 5T of 26 enamelled wire 3/16 in. ID. These values permitted testing of 5th overtone crystals cut for 65 to 72 MHz at higher order overtones, up to and including the 15th at 200 MHz. The poor adjustment resolution of the trimmer made selection of 13th and 15th overtones somewhat critical, but once selected, oscillation started and restarted at supply voltages of less than 5 volts. A nominal supply voltage of 9 volts was the target. At 9 volts, sufficient overtone output is available to drive active mixers and/or tripler multipliers.

The tank should be a closed loop, physically and electrically, while the .01 bypass should not be part of the tuned circuit. The 100 ohm resistor and .001 bypass is desirable for additional isolation from the power supply. This is especially true if a multiplier stage is driven.

Construction was done on G-10 board stock. The resistors and bypass capacitors were located conventionally on the non-copper face. The transistor, crystal, tank and 20 pF capacitor were soldered to the copper face with appropriate etched or routed connections.

The upper frequency of operation is limited by the shunt capacitance and/or activity of individual crystals. A shunt capacitance problem is usually indicated by a broad area of unwanted oscillation around the expected frequency of the overtone selected. Some crystals were found to exhibit this phenomenon as low as 150 MHz. As the tank trimmer is tuned through each overtone frequency, the system must avalanche into and out of oscillation as an indication of true crystal control. No detectable oscillation should be observed when tuning between overtone frequencies. Also, placing inductors across the crystal, in an attempt to null out unwanted shunt capacitance, has been found to be of doubtful benefit and may complicate matters.

About the Author
Clint Bowman is retired after a 50-year career in the electronics and radio industry. He can be reached at Box 282, Prospect Heights, IL 60070. Tel: (312) 255-1669.

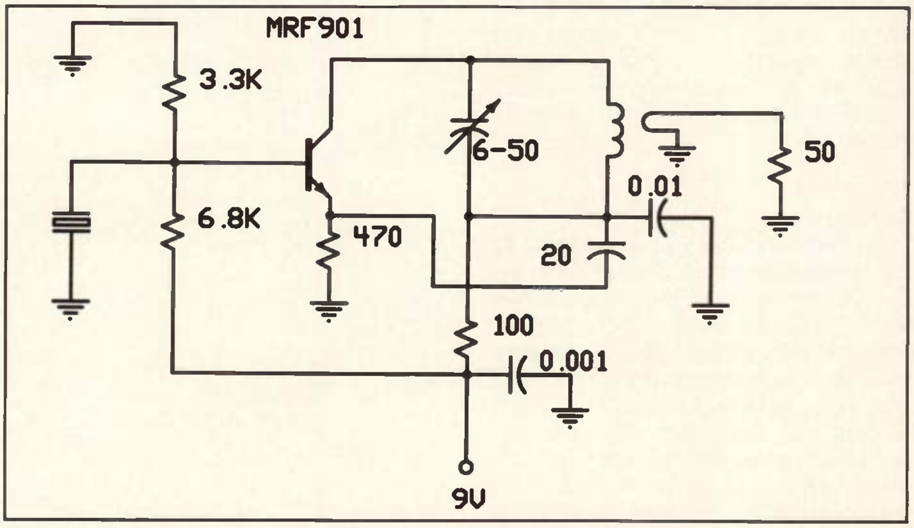

Figure 1. Overtone oscillator (65-200 MHz).

The RF Technology Expo 89 Technical Program

RF Technology Expo 89, February 14-16, promises to provide a unique opportunity for RF engineering professionals to gather to discuss ideas and problems, trends and techniques. Under the direction of Session Chairman Tim Healy of Santa Clara University, the technical program offers papers covering a wide range of important RF topics. Segments on receiver design, small-signal circuits and process technology are a few of the nearly 40 presentations scheduled. Tutorial sessions on mixer fundamentals, radiowave propagation and design topics complete the agenda for the diverse technical program being presented in Santa Clara.

Tuesday, February 14 — 8:30 to 11:30 a.m.

Session A-1: Design Seminar (3 hours)

Phase-Locked Loop (PLL) Frequency Synthesizer Building Blocks
- from Motorola Inc.'s "Imaginology"
This session covers Motorola's current product line of PLLs, the building blocks that comprise a frequency synthesizer application, design considerations and future product plans.

RF Discrete/RF Low Noise Amplifier Design
- from Motorola Inc.'s "Imaginology"
Examples and analysis of design approaches are presented in detail. Noise matching, stability analysis, CAE simulation, microstrip and lumped-element impedance matching networks will be considered. In addition, some basics on selecting the right low-noise transistor for the job, and how to interpret a low-noise transistor data sheet will also be covered.

Session A-2: Filter Design

Design of Wideband Transmission Line Filters for UHF and Microwaves
Robert W. Fitzgibbon, G.E. Aerospace
This tutorial on wide-band transmission line filter design includes a review of L-C filter design, extension of L-C theory to transmission line structures, design of high-pass structures using coupled-line elements, practical design considerations and more.

The Thin Film Resonator/Filter Integrated RF/Microwave Technology
K.M. Lakin, Richard S. Ketcham and G.R. Kline, Iowa State University
This paper presents a tutorial overview of a newly developed Thin Film Resonator (TFR) technology that has produced a class of passive frequency control devices integrated directly on Si and GaAs substrates along with transistor gain elements. Projected impact on RF/microwave subsystems integrated at the chip level is also discussed.

S-VAN: A Circuit Pole and Zero Extraction Program
Howard Russell, OPAL Engineering
Presented is the design of a PC-implemented analog circuit simulator based on the state-variable method of circuit analysis. With this method the extraction of circuit state matrices and circuit poles and zeros is made possible. Program features and applications for the evaluation of circuit system performance are discussed.

Session A-3: Process Technology

A Bipolar MMIC Active Mixer for Applications to 5 GHz
J. Wholey, I. Kipnis and Kim Fischer, Avantek
Double balanced active mixers have been fabricated using an RF/microwave silicon bipolar MMIC technology. A Gilbert cell-based circuit design is used to achieve the double balanced mixer type characteristics, with conversion gains for RF/LO bandwidths to 5 GHz and IF to 1 GHz bandwidth. The paper presents an overview of the IC technology used, discusses circuit design and summarizes the RF measurements on a typical mixer.

Computer-Aided Calibration of a Wafer Probe Station
Alan Sailer, EEsof Inc.
A description is presented of a practical method of performing a two-tier calibration on a Design Techniques Wafer Probe Station using the computer-aided test program ANACAT ™.

Analysis of Test Performance Data to Enhance Quality Control in the Manufacture of RF Components and Circuits
Steve Waite, Hewlett-Packard
This paper presents a data-driven test structure for automated measurements which allows the use of a common data base for various classes of measured data. Statistical tools allow rapid and convenient access to test performance data. Information derived from this data base is used to optimize production processes and refine product design.

Tuesday, February 14 — 1:30 to 4:30 p.m.

Session B-1: Design Seminar (3 hours)

RF Communications — Low-Cost RF Integrated Circuits for Short-Range Radio Systems (with hands-on workshop)
- from Motorola Inc.'s "Imaginology"
This seminar focuses on modulation types and methods, receiver design and partitioning, detection and RSSI. Techniques for measuring and testing transmitter or receiver performance will be explained and demonstrated. Hands-on displays and hardware will be used to show the latest in low-cost RF integrated circuit technology in the less than 1 GHz spectrum.

Session B-2: RF Power Topics

Specifying High-Power Diode Switches
Joseph C. Hill, Enon Microwave Inc.
Specifications unique to diode switches operating in a high power environment are discussed. Failure mechanisms, typical solutions and examples are presented. Topics covered include thermal runaway, voltage breakdown due to VSWR buildup, and in-band vs. out-of-band performance.

Microwave Power Transistors for "Mode S" Systems
Tony Harris, SGS-Thomson Microelectronics

RF Technology Expo 89 Offers Special Courses

RF Circuit Design Part I: Fundamentals
Les Besser, Besser Associates Inc.
Monday, February 13,
8:00 a.m. to 5:00 p.m.

This popular course in RF design fundamentals begins with an introduction to high frequencies. Lumped and distributed components, parasitic effects, and use of the Smith chart are discussed, as well as transmission lines. Small signal amplifier design is also reviewed, with the afternoon session covering unilateral and bilateral design using constant gain circles, computer-aided synthesis and optimization, stability consideration and more.

Computer-Aided Filter Design
Randy Rhea, Circuit Busters
Monday, February 13,
8:00 a.m. to 5:00 p.m.

This course covers L-C filter design and analysis, with emphasis on principles and solving practical problems using the personal computer. The course discusses the modern lowpass prototype, its transformation to highpass, bandpass and bandstop configurations, and the transfer function amplitude and delay characteristics of each. Additional topics include elliptical transfer function filters, determination of required filter order, effects of component Q and parasitics, filters as matching networks and distributed (transmission line) filters.

RF Circuit Design Part II: Advanced Topics
Les Besser, Besser Associates Inc.
Tuesday, February 14,
8:00 a.m. to 5:00 p.m.

Modern filter design, including computer-aided synthesis, is covered. Impedance transformations are extended to broadbands, using both lumped and distributed elements and complex terminations. The small signal amplifier design is also extended to broadband design. Large signal amplifiers of Class-B and -C types are evaluated through the latest CAD tools. Other nonlinear circuits, such as oscillators, mixers and frequency multipliers are introduced.

An additional fee of $185 is charged for each course, and advance registration is strictly required. Registration for a second course can be obtained for $135.

The mode select secondary surveillance radar system is discussed here. Requirements that the system places on a transmitter and ultimately on the microwave power transistor employed are derived.

Suboptimum Operation of Class-E Power Amplifiers
Frederick Raab, Green Mountain Radio Research Company

This paper examines the characteristics of the class-E power amplifier when optimum operation cannot be achieved. Operation below and above the critical frequency is examined.

Session B-3: Various RF Topics

Broadband Transmission Line Feasibility Study
D. Burnham, T.R. Lamp, Arthur E. Manoly and S.B. Cohn, Hughes Aircraft Co.

Introduction to AT- and SC-Cut Quartz Crystal Resonators
Bruce R. Long, Piezo Crystal Co.

This presentation examines the association between quartz resonator performance and the unique physical properties of crystalline quartz, with the goal of highlighting the properties that guide the design and specification of quartz resonators and oscillators.

A Method for the Design of Wide Tuning Range Voltage Controlled Crystal Oscillators
Edward S. Marrone, Appcom Inc.

This paper presents a method, for use in the design of VCXOs, based on a knowledge of the impedance behavior of the crystal with its external passive tuning elements over the frequency band of interest. Emphasis is on wide tuning range requirements where the frequency variation may exceed ±50 parts per million (PPM).

Wednesday, February 15 — 8:30 to 11:30 a.m.

Session C-1: Mixer Tutorial (3 hours)

Mixer Fundamentals
Donald Steinbrecher, Steinbrecher Corporation

Fundamentals of mixer design using various configurations are presented in this tutorial. Emphasis is placed on the effects that design parameters and external influences have on mixer performance.

Session C-2: Component Technology

Microwave and Millimeter Wave Packaging
Bertrand L. Berson and F. Rosenbaum, Berson Associates

An Inexpensive Silicon Monolithic IC Process for Microwave Low and Medium Power Circuits
Paul Sanders, Motorola Semiconductor Products Sector

Transistors fabricated with dielectric isolation technology have long been recognized for their advantages over conventional junction isolated ICs. However, fundamental disadvantages such as low density limitations and device tub (collector region) thickness tolerance still exist. This paper describes and evaluates patented modifications to the fundamental isolation process aimed at minimizing these factors.

A Silicon RF Amplifier Using a Dielectrically Isolated Monolithic Microwave Integrated Circuit (DIMMIC) Process
Peter Bachert, Michael McCombs and Paul Sanders, Motorola Semiconductor Products Sector

A three-stage silicon monolithic RF power amplifier is described. Performance characterization, including a comparison to a thin-film hybrid discrete prototype, is discussed.

Subnanosecond Switching With DMOS FETs
Ed Oxner, Siliconix Inc.

This presentation describes limitations once attributed to high-speed DMOS switching and offers a novel driver that makes subnanosecond switching possible with DMOS FETs.

Session C-3: Small-Signal Circuits I

Design and Use of a 2 to 6 GHz GaAs MMIC Gain Block for Commercial Markets
William Mueller, Avantek Microwave Semiconductor Division

The design of a two-stage GaAs FET feedback MMIC amplifier, intended to operate as a low-cost gain block across the 2 to 6 GHz frequency band, is described. A brief tutorial on resistive feedback amplifiers and a description of the MMIC structure are presented. Special features of the design, including a series biasing scheme and the incorporation of package parasitics into the RF matching structures, are discussed.

A New Design Technique for a Space Qualified 0.8 to 1.6 GHz GaAs MESFET Low Noise Amplifier
Mary A. Holly, FEI Microwave Inc.

GaAs MESFET manufacturers in the microwave industry rarely provide noise figure and S-parameter data below 2 GHz. This limitation is reviewed and a design method for a 0.8 to 1.6 GHz space qualified (S-level) low noise GaAs FET amplifier is discussed and demonstrated.

Audio Processing for Cellular Radio, or High Performance Transceivers
Ali Fotowat, Signetics Corp.

In an FM receiver the demodulated baseband signal has an f noise spectrum. To improve FM receiver sensitivity and maintain good signal-to-noise ratio (SNR) for higher tones, the baseband signal's high frequency components are amplified before transmission (emphasis), and the opposite is done after reception (de-emphasis). In addition, in the case of a noisy channel, the audio signal's dynamic range can be compressed before transmission and expanded back after reception.

Wednesday, February 15 — 1:30 to 4:30 p.m.

Session D-1: Instrumentation and Test Methods

Understanding Digitizing Oscilloscopes
Robert A. Witte, Hewlett-Packard

The principles of operation of digitizing oscilloscopes are presented. Although analog oscilloscopes are familiar instruments for time-domain measurements, digitizing models have performance characteristics that offer additional measurement capabilities, but which require an understanding of the digitizing process and how it affects the analog signals being examined.

Application of RF Techniques in the Design of a Digital Data Bus
Fred Studenberg, Rockwell International

INFO/CARD 50

Exhibit Hall Prize Drawings Are a Hit at RF Expo East

This past October, at RF Expo East in Philadelphia, five companies conducted prize drawings at their booths. One of the lucky winners was Donald Hoerr, a reliability engineer at Krautkramer Branson. He is shown here accepting his prize, a laptop computer, from Bob Murphy and Don Davis of American Technical Ceramics. Hoerr was one of many RF engineers who stopped by the ATC booth to look over their RF/microwave capacitors. At RF Technology Expo 89 in Santa Clara, ATC plans to give away a VCR .

Also reporting terrific interest in their prize drawings at RF Expo East were Amperex/Philips (a compact disc player), Circuit Busters (=Superstar= software package), Coaxial Dynamics (RF wattmeter and sampling element), and Complete Hybrid Parts Supply, C.H.P.S., (a videocassette recorder).

Engineers attending RF Technology Expo 89 should check the official show program as well as look carefully as they travel around the exhibit floor; there will be some nice prizes waiting for them.

The RF design of a 2 Megabaud digital data bus is described here. Included are a discussion of the RF techniques used in determining the basic architecture of the bus, a computer analysis of signaling waveforms, and the choice of modulation and detection methods. Also presented is a detailed description of the design and analysis, using CAD, of a wideband directional coupler for use with a balanced transmission line.

New Measurement Techniques for Testing Both Linear and Nonlinear Devices with the 8753B RF Network Analyzer
Barry Brown, Hewlett-Packard

This paper describes techniques for the measurement of harmonic distortion, gain compression, conversion loss and two-tone intermodulation distortion, as well as of linear parameters such as gain or insertion loss, bandwidth, group delay, reflection coefficient and reverse isolation, using the HP 8753B Vector Network Analyzer. Detailed measurement setups and proper techniques for best accuracy are discussed, along with many practical examples.

Session D-2: Frequency Synthesis

Complex Waveform Generation Using Direct Digital Synthesizer Techniques
Robert P. Gilmore, QUALCOMM

The Direct Digital Synthesizer (DDS) produces sine wave signals with fine frequency resolution, a broad bandwidth of operation, fast switching speed between output frequencies, good spurious and phase noise performance, and in VLSI form has small size and low power consumption. This paper provides a summary of DDS operation, describes the QUALCOMM Q2334 Dual DDS, and gives data on using the Q2334 to generate complex (quadrature I and Q) signals for various applications.

A Unified Approach to Understanding Oscillator Noise and Injection-Locking
Tim L. Hillstrom, Hewlett-Packard

A method of oscillator analysis is presented which allows a unified approach to examining both oscillator noise and injection-locking. The quasi-linear bandpass amplifier model used facilitates the solution of both PM and AM noise spectra in the free-running and centrally driven cases. Applications to low-noise systems and comparison to phase-locked loops (PLLs) are presented.

Quantified Prediction of DDS Spurs
Earl McCune, Digital RF Solutions

This presentation begins with a focus on system nonlinearities, and proceeds to a discussion of a mixer model and process waveform insensitivity. A method for determining spur amplitude is detailed and evaluated.

Session D-3: Receiver Design

Receiver Design — Simplified
Jerry Iseli, RF Monolithics Inc.

Through the use of low-loss surface acoustic wave (SAW) filter technology, single conversion VHF-UHF receivers can be easily implemented. The problem of image and spurious signal rejection when converting directly from VHF-UHF to low intermediate frequencies is solved by the high performance capabilities of SAW technology. A two-channel receiver is presented that illustrates this technology.

Alternatives to Zero-IF Demodulation
Richard Webb, Webb Laboratories

This discussion explores the non-zero-IF in general with emphasis on undersampling techniques. Presented are demodulation methods which retain many of the zero-IF advantages while solving its major difficulties.

A Low-Cost, High-Performance Noise Blanker for Long-, Medium- and Short-Wave Applications
Oliver L. Richards, Sprague Semiconductor

A system is presented which suppresses impulse noise to inaudibility. As a cost-effective monolithic integrated circuit, it will permit wice use even in cost-sensitive applications. The circuit is based on an improved understanding of RF blanking.

Thursday, February 16 — 8:30 to 11:30 a.m.

Session E-1: Propagation Tutorial (3 hours)

Radiowave Propagation
Daniel R. Dorsey, Jr., DocSoft Enterprises

This session presents an introduction to basic principles and characterizations involved in radiowave propagation. Discussion includes a study of VLF propagation, especially seawater propagation and submarine communications. This is followed by a look at HF propagation, with an examination of the structure and characteristics of the earth's atmosphere and ionosphere and an introduction to several "exotic" modes of propagation. The final section of this session covers propagation at VHF and above, with a consideration of atmospheric effects and satellite communications.

Session E-2: PLL Topics

Phase Lock Loop (PLL) Synthesizer Switching Speed Optimization and Measurement Techniques
Dan T. Gavin, RF Prototype Systems

This paper discusses theory of acquisition in a digital PLL, details of critical parameters required to design a fast switching PLL and methods to predict switching speed using computer models. Also presented are methods for measuring PLL switching speed and a technique to model the delay-like term that is due to the sampling process.

A Phase-Lock Loop in a Noncooperative Environment — A Pulse Input
Michael F. Black, Texas Instruments

In most PLL applications, the environment can be easily described in terms of input and output frequencies, bandwidths, and switching times, but some applications demand more of a loop. Here the environment is not "text book" and all the offsets and nonlinearities often buried in routine operations may surface. A pulsed input to a phase lock loop is such a non-cooperative environment.

Session E-3: Small-Signal Circuits II

An Integrated Chipset for Cellular Mobile Telephones
P.J. Hart and T.G.R. Hall, Philips Components Application Laboratory

Described here is a chipset developed for AMPS and TACS which substantially reduces the complexity and cost of a portable mobile unit. The architecture has been configured to minimize power consumption through the use of low current IC technologies and maximum use of standby modes. CMOS integrated filters are used extensively to reduce off-chip components and a single clock source drives all functions. Serial bus control is adopted throughout to minimize IC package size and PCB complexity, providing simple production testing and features expansion.

UHF, L-Band and S-Band Applications of Low-Noise GaAs FETs
Al Ward, Avantek Microwave Semiconductor Division

The design considerations of low-noise GaAs FET amplifiers for noise figure, stability and input match are reviewed. Microstrip amplifier results are reported in this paper for four designs over the 0.45-2.3 GHz range with noise figures of 0.4-0.6 dB in this frequency range.

Gilbert Type Mixers Vs. Diode Mixers
Ali Fotowat, Signetics Corp.

The characteristics of double balanced gilbert type mixers are compared with diode mixers, in the 50 to 1300 MHz frequency range. Conversion gain, LO power requirements, third order intercept, 1 dB compression points, LO and RF feed-throughs, and noise figures will be compared.

★ ★ ★ **The Fourth Annual** ★ ★ ★

Your idea may win this Grand Prize, provided by Webb Laboratories:

CommView
Receiver simulation software. Calculates pre- and post-detection SNRs, bit error probability and AGC voltage for user-entered system cascades. Graphics support Pagemaker and Ventura desktop publishing software.

FilSolv
Webb Labs' filter synthesis package. Creates practical, buildable lowpass, highpass and bandpass filters in Butterworth, Chebyshev, Bessel and Elliptic realizations. Incorporates losses found in "real" components. Files can be saved in formats compatible with major circuit analysis packages.

SYSCAD
RF/Microwave system engineering software. Performs link, terminal and RADAR characterization, receiver architecture analysis, transmit and receive spurious analysis through an order of 2000, plus phase noise calculations.

TRANSCAD
Powerful single and coupled transmission line and waveguide synthesis package. Analyzes and synthesizes over 40 structures, including nearly every microwave geometry of interest. Applies numerical methods to the best known algorithms to eliminate common synthesis errors.

Plus, a Zenith *SupersPort* laptop computer, with an 8088/8087 pair running at 8 MHz, 640 K RAM, a 3.5 in. 720 K floppy and an internal 20 MB hard disk! Includes CGA graphics, MS-DOS 3.21 and carrying case. Perfect for running all of Webb Labs' software!

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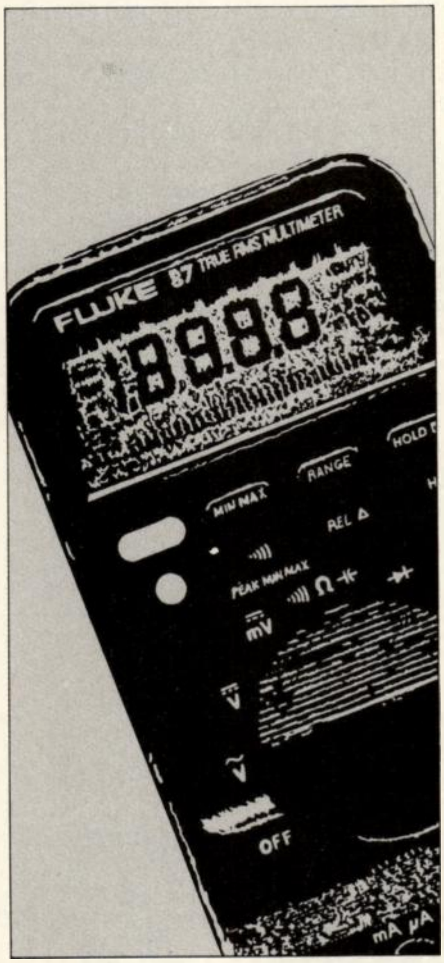
★ ★ RF Design Awards Contest ★ ★

or one of five runner-up prizes from Fluke.



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Factory Radio Communications

Noise and propagation measurements reveal limitations for UHF/microwave indoor radio communication systems

By Theodore S. Rappaport
Virginia Polytechnic Institute and State University

A glimpse into a typical factory reveals a high degree of automation has entered into the work place. Computer-driven automated test benches, wire-guided robots and PC-controlled drill presses are a few examples of the proliferation of computer technology and automation in manufacturing. The boom in automation has created a need for reliable real-time communications in factories. In 1985, the Manufacturing Automation Protocol (MAP) networking standard was established by manufacturing leaders to encourage commercialization of high data rate communications hardware for use in computer-controlled manufacturing. MAP is capable of supporting 10 megabit per second (Mbps) data rates for short periods. MAP networks (and TOP networks in office buildings) rely on coaxial cable or fiber optic cable to interconnect users. Twisted-pair interconnection of computer terminals is also commonly used. This article discusses the use of radio links for communication in modern factories.

The method for transporting parts-in-process in a futuristic, but realistic, just-in-time (JIT) manufacturing environment is one of the areas of research at the National Science Foundation (NSF) Engineering Research Center (ERC) for Intelligent Manufacturing Systems. Analysis has shown that an inexpensive, agile mobile robot fleet, capable of navigating without any type of pre-made track, could easily accommodate the type of material flow required for a JIT manufacturing system. A truly autonomous guided vehicle (AGV) that does not use any type of tether will require a radio system for control. Optical systems are viable, but become inoperative when obstructed. Furthermore, radio systems will be useful for quickly and cheaply connecting often moved manufacturing equipment and computer terminals. Radio will also accommodate reconfigurable voice/data communications for other facets of factory and office building operation and may eventually be used in homes and offices to provide universal digital portable communications (1).

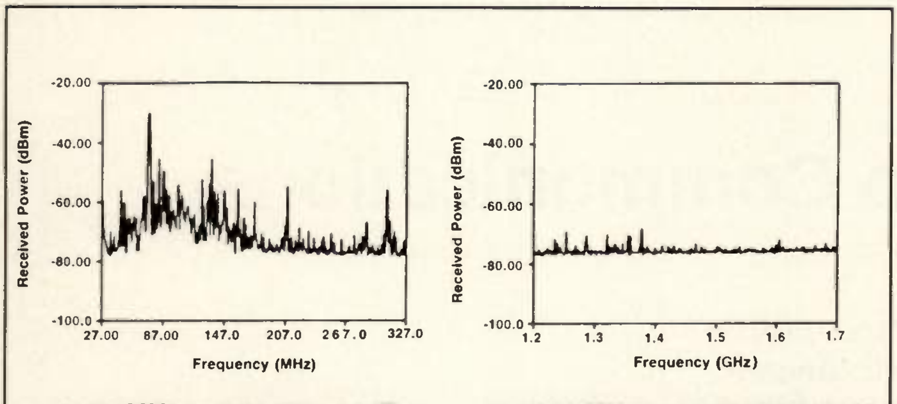
Presently, communications between computers and automated machines are conducted almost exclusively over cable. Narrowband radio systems (with data rates less than 10 kbps) are currently used in some factories for dedicated control of overhead cranes and wire-guided vehicles and for inventory control. While narrowband systems are well-suited for human operation and simple communications, it is anticipated that for a moderately sized AGV fleet (greater than 25 vehicles), data rates of several hundred kbps will be needed to accommodate real-time computer control and navigation of CIM-integrated AGV systems employing multiple-access radio networking.

In the United States, the FCC has allocated spectrum for narrowband industrial radio communications in VHF (450 MHz) and UHF (900 MHz) bands. More recently, the FCC has authorized the use of suitably designed spread-spectrum systems for 900 MHz, 2400 MHz and 5725 MHz (3). If transmitters meet with FCC approval, unlicensed 1 W transmitter power levels may be used over bandwidths greater than 25 MHz. In Japan, spectrum has been set aside for 300 mW, 4800 bps indoor radio systems operating in the 400 MHz and 2450 MHz bands (4).

Accurate characterization of the operating channel is a mandatory prerequisite for the development of reliable wideband indoor radio systems. Radio channel propagation data from factory buildings have been made available for the first time through a research program sponsored by NSF and Purdue University. As shown here, it is not environmental noise, but rather multipath propagation that limits the capacity of a radio link. The severity of multipath is largely dependent upon factory inventory, and building structure and age.

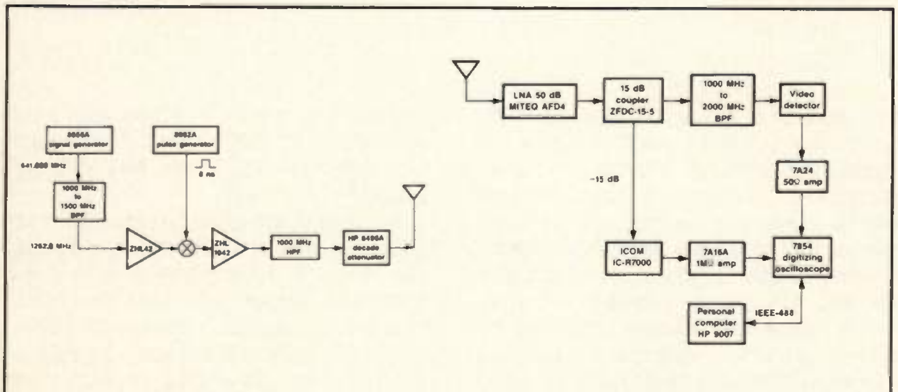
Factory Noise

Although much of the radio noise encountered in factories arises from weak emitting sources, measurements have revealed that some types of industrial equipment emit harmonic RF energy and can radiate substantial noise up to several hundred megahertz (8). Equipment such as RF-stabilized arc welders, induction heaters and plastic bonders are acute sources of noise. Although interference is significant at HF and VHF, noise signatures of such equipment fall off rapidly above 1 GHz (8). Recent empirical measurements have confirmed that typical machine-generated noise levels in operational factories are much less severe at higher frequencies (9). Figure 1 shows results of peak noise power spectrum measurements made along an engine manufacturing transfer line in full operation. Worst-case noise levels are seen to be



a) 27 MHz to 327 MHz (VHF) b) 1200 MHz to 1700 MHz (UHF)

Figure 1. Noise power spectrum measured 4 m from engine cylinder machining line (9).



a) Transmitter b) Receiver

Figure 2. Block diagram of factory multipath measurement system.

40 dB lower at UHF/microwave frequencies and are only 5 dB above the thermal noise floor. These results are encouraging and indicate that noise will not severely hamper most factory radio systems operating at UHF and above.

Multiple-Access Networking Considerations

Future factory radio communication systems will rely on multiple-access techniques to accommodate many fixed and portable/mobile terminals. Multiple-access techniques such as frequency division multiple-access (FDMA), time-division multiple access (TDMA), code division multiple-access (CDMA, also called spread-spectrum) and carrier-sense multiple-access (CSMA, also called packet radio) partition channel users into non-overlapping signal spaces. Because of non-ideal conditions, however, there is inevitable overlapping of signals and the resulting co-channel interference can appear as lengthy message delays or as degradation of the desired received signal.

Random access (CSMA, CDMA) radio local area networks are attractive because they have relatively few synchronization requirements. Unlike fixed assignment networks (FDMA, TDMA) which assume all users require their own channel, random access techniques rely on "bursty users" and assume that the likelihood of many users using the network at one time is small. For AGVs using reliable on-board dead-reckoning systems, infrequent position updates

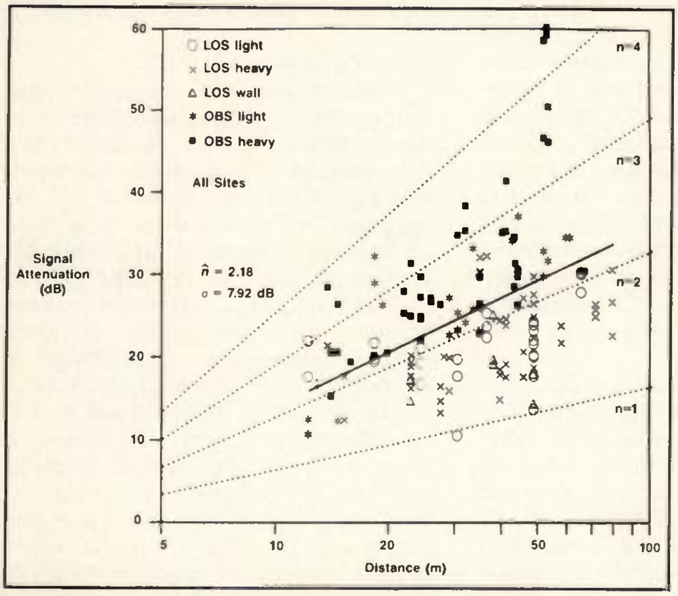


Figure 3. Large scale signal attenuation at all measurement sites.

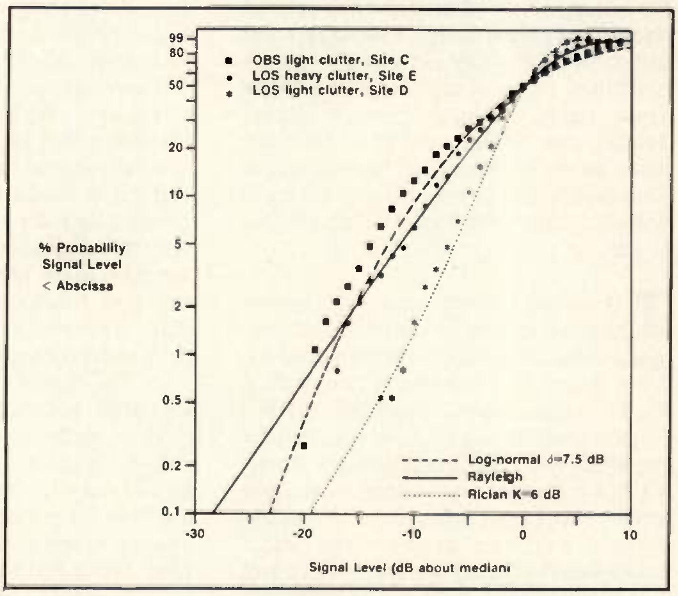


Figure 4. Cumulative distributions for three measurements and their fit to various distributions.

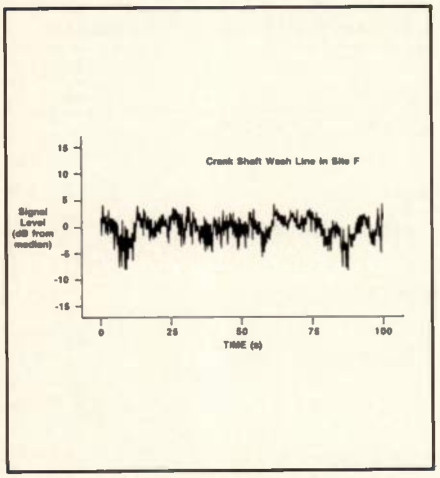


Figure 5. Temporal fading measurement in engine assembly area across crankshaft wash line (Site F). T-R separation is 25 m.

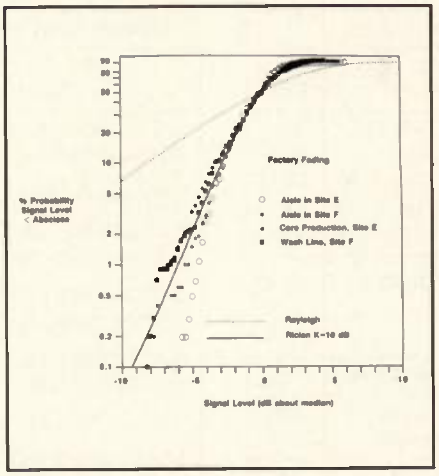


Figure 6. Cumulative signal level distributions for temporal fading data in various factory locations.

suggest the use of random access networks for AGV control. On the other hand, direct remote control of a fleet of vehicles by a central dispatching station (such as might be warranted for cleaning a contaminated nuclear reactor) would warrant a fixed assignment scheme.

At the ERC for Intelligent Manufacturing Systems at Purdue University, considerable progress has been made in determining realistic limitations on the delay characteristics of packet radio networks (10). Also, a powerful product form solution model for packet radio systems has been developed (11). CSMA and CDMA strategies can be merged to enhance multiple-access communication performance in a multipath environment while providing some ranging capability (12,13). In Reference 12, fundamental expressions that permit the calculation of bit error rates in packet spread-spectrum systems have been provided; these expressions permit system designers to analyze throughput and delay as functions of the number of simultaneous users.

As the number of users increases, the real-time communications capability of random access techniques diminishes, and a fixed assignment approach is required. Furthermore, if central computers using parallel processing architectures are required to simultaneously communicate, navigate and control many simultaneous users on a virtually continuous basis, TDMA or FDMA approaches will be desired. Portable/mobile users transmitting large blocks of data (i.e., MIS, video transmissions, high resolution graphics, maps) are accommodated best by a fixed assignment network. Selection of networking strategies of radio depends heavily upon the number of users, the duration of transmissions, the limit of sophistication at each terminal, and the importance of real-time control.

Multipath Propagation

Due to the large metal content of a factory, multipath interference is created by multiple reflections of the transmitted signal from the building structure and surrounding inventory. The resultant received waveform is a sum of time- and frequency-shifted versions of the original transmission and, depending on parameters of the signal and channel, the received signal may be greatly distorted.

Historically, multipath has been identified as the most limiting factor in portable radio communication systems. For narrowband factory radio systems, multipath causes large fluctuations (fading) in received signal levels due to temporal variations of the channel and the receiver. Additional signal loss will occur when an AGV is shadowed by inventory and equipment. In wideband systems, the scatterers create intersymbol interference and cause the channel to be frequency selective. Consequently, the maximum data rate supported by a multipath channel is limited. Typical fading channels require 30 dB more transmitter power to achieve low bit-error rates (10^{-4}) compared to non-fading systems.

Path Loss Exponents in Different Factories				
Factory Site	n	σ (dB)	No. of Points	Corr. Coef.
Site B	2.39	10.20	33	.94
Site C	1.89	5.55	41	.98
Site D	2.43	7.94	34	.96
Site E	2.12	8.03	18	.96
Site F	1.92	4.79	17	.98

Table 1. Path loss exponent as a function of factory site.

Path Loss Exponents in Different Factory Geographies				
Factory Geography	n	σ (dB)	No. of Points	Corr. Coef.
LOS light clutter	1.79	4.55	26	.98
LOS heavy clutter	1.79	4.42	43	.98
LOS along wall	1.49	3.9	8	.98
OBS light clutter	2.38	4.67	23	.99
OBS heavy clutter	2.81	8.09	43	.97
All Geographies*	2.18	7.92	135	.96

*LOS measurements along wall not included in computation.

Table 2. Path loss exponent as function of factory topography.

Shadowing Effects of Common Factory Equipment	
Obstacle Description	Attenuation (dB)
2.5 m storage rack with small metal parts (loosely packed)	4-6
4 m metal box storage	10-12
5 m storage rack with paper products (loosely packed)	2-4
5 m storage rack with paper products (tightly packed)	6
5 m storage rack with large metal parts (tightly packed)	20
Typical N/C machine	8-10
Semi-automated Assembly Line	5-7
0.6 m square reinforced concrete pillar	12-14
Stainless Steel Piping for Cook-Cool Process	15
Concrete wall	8-15
Concrete floor	10

Table 3. Shadowing effects of some common factory equipment.

To determine propagation characteristics inside factory buildings, radio wave propagation experiments at 1300 MHz were made in five fully operational factories (14). Over 30,000 narrowband fading measurements and 950 wideband impulse response measurements were made in a diverse collection of industries and building structures. Factories that participated in the research include leading engine and automobile parts manufacturers and dry-foods producers. An overview of the experiments and the measurement equipment are given in (15). Briefly, four distinct topographical settings were identified in each of the five factories. Topographies ranged from line-of-sight (LOS) transmission paths along lightly cluttered aisles to heavily cluttered, obstructed paths between adjacent aisles. In each topography, three measurement locations were selected, with graduated transmitter-receiver separations between 20 and 80 m. The transmitter was positioned in the clear in the center of the particular topography while the receiver was moved along 1 m tracks at each measurement location.

Wideband channel impulse responses were measured in the time domain by repeatedly transmitting a 10 ns pulse and receiving on a digital storage oscilloscope the attenuated, distorted and delayed versions of the pulse. The measurement apparatus consisted of a periodic pulse-modulated transmitter with a peak output power of 1 W. The receiver consisted of a low noise amplifier followed by a square law envelope detector and a 350 MHz digital storage oscilloscope. A directional coupler allowed CW envelope measurements to be made simultaneously by a modified communications receiver. The measurement system block diagram is shown in Figure 2. Wideband discone antennas (16) were used at both transmitter and receiver.

CW measurements revealed that path loss falls off exponentially with distance and is described by a log-normal distribution about a mean path loss law given by:

$$\text{Path loss}(d) \propto d^n \qquad (1)$$

where d is the distance between transmitter and receiver in meters and n is the mean path loss exponent found by using a linear least squares fit to a scatter plot of measured path loss against measured distance (17). This model has also been found to hold at UHF for channels inside and around houses (2). Figure 3 shows the received signal strengths relative to a reference measurement (made at 10 wavelength distance) over various topographies at all five factories. Tables 1 and 2 indicate that in all cases, received power and T-R separation are highly correlated, thus confirming that equation 1 is a valid model for factory radio systems. Furthermore, although signals attenuate more rapidly with distance in obstructed topographies, the worst case attenuation is not as severe as in partitioned homes and office buildings (18,19). This is due to large ceiling expanses, wide aisles, and metal ceiling truss work and inventory that readily facilitate multiple paths.

Because accurate descriptions of path obstacles were kept during the factory measurements, it is possible to extract from the data the RF signal loss caused by typical factory surroundings. By comparing the received signal levels for shadowed locations with the ensemble average of the factory measurements, shadowing losses have been computed. Table 3 indicates typical shadowing losses that can occur when a receiver is placed directly behind an obstruction (deep shadowing). The data reveal that knife-edge diffraction theory is pessimistic; deeply shadowed locations experience received signal levels consistently

5 to 20 dB larger than predicted by knife-edge diffraction. For long paths with obstructions located in the middle of the path, knife-edge diffraction is in better agreement with the empirical data.

Measurements made with a moving CW receiver over many local areas reveal that fading is usually Rayleigh in heavily cluttered LOS and lightly cluttered obstructed topographies, Rician for paths along perimeter walls and over lightly cluttered LOS paths, and log-normal for paths that traverse heavily cluttered obstructed topographies. Figure 4 illustrates some of these typical fading distributions and their fit to some of the observed fading data.

Additional CW measurements were made to determine the temporal variation of factory channels caused by motion of personnel and work in progress. The transmitter and receiver were positioned to traverse busy assembly lines and main aisles. Figure 5 shows a typical measurement and the corresponding changes in signal strength over several seconds. Figure 6 illustrates that temporal fading between fixed radio terminals is well described by a Rician distribution having K 10 dB.

Measurements made over identical paths with different receiver antenna heights reveal that received signal strengths are often highly correlated (not independent) for separations of 2 wavelengths (0.5 m). As seen in Figure 7, however, close-spaced antenna diversity may be useful when antennas are located in a horizontal plane in line with the LOS path. Energy density antennas that couple both electric and magnetic fields may also be useful in combatting multipath fading (20).

Factory channel impulse response measurements (also called power delay profiles) reveal that for LOS paths there typically exist only a few specular multipath components, with the direct path having a larger signal level than the latter components. Over obstructed paths, however, when either the transmitter or receiver is shadowed by large equipment or by stacks of inventory, the predominant energy arrives 50 to 150 ns after the first observable signal (2,14). To determine how individual signal components change with receiver motion, 19 equally spaced power impulse response measurements were made along 1 m tracks throughout five factories. Figure 8 illustrates how specular reflections from perimeter walls, etc. are easily distinguishable. In Figure 9, typi-

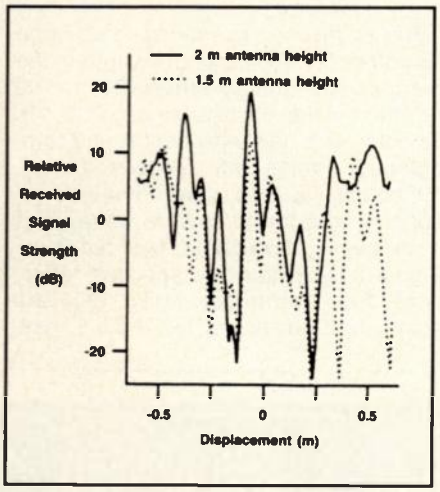


Figure 7. Received signal envelope using height diversity (1.5 m and 2.0 m antenna heights at receiver).

cal multipath power delay profiles are presented.

One measure of multipath conditions is the RMS delay spread σ which is inversely proportional to the maximum usable data rate of a channel. RMS delay spread is computed as the square root of the second central moment of the power delay profile. A food processing factory that manufactures dry goods and has considerably less metal than the other factories had multipath delay spreads consistently half of those observed in metalworking factories. The worst case RMS delay spread was 300 ns in a modern engine plant; typical values are between 100 ns to 200 ns. Unlike in office buildings (19), delay spread values in factories do not depend on whether or not there exists an LOS path.

In Reference 21, it was shown that the coherence (flat fading) bandwidth over Rayleigh fading channels using DPSK modulation is approximately 1/50th of the reciprocal of RMS delay spread. For factory radio channels, this suggests worst-case maximum data rates of 33 kbps using simple receivers, with higher capacity coming about from distributed antennas, adaptive equalizers and diversity techniques. Recently, rapid changes in channel group delay have been found to cause burst error in digital communications systems due to shifts in eye pattern timing (22,23). This phenomenon, known as jitter, becomes increasingly important as operating bandwidths are increased while the fading rate of the channel remains small. Such a situation arises in an indoor radio communication system. In Reference 6, empirical measurements were presented that indicate that channel delay spread can change by as much as 180 ns over a few centimeters of receiver movement.

Conclusion

Extensive measurement, characterization and modeling of indoor factory radio channels have been carried out. The work here reveals that manmade noise is not a serious problem at frequencies greater than 1 GHz, and that fading characteristics are highly dependent upon local topography in the workplace. Shadowing data and large scale path loss models have been developed and form the basis for designing reliable narrowband indoor radio systems for portable communications and AGV control. Wideband measurements reveal that current technology limits data rates to about 50 to 100 kbps. While this accommodates current needs, it is anticipated that greater capacity will be required for the highly automated and flexible factories of the future. Ongoing work at Virginia Tech is aimed at developing robust wideband communication system designs for indoor radio communications. rf

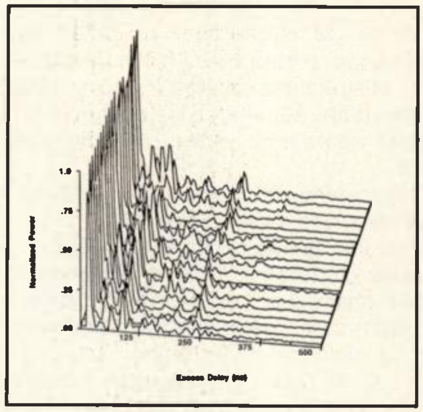


Figure 8. Closely spaced power impulse response measurements in a factory building. Note the specular components due to wall reflections are easily identifiable (14).

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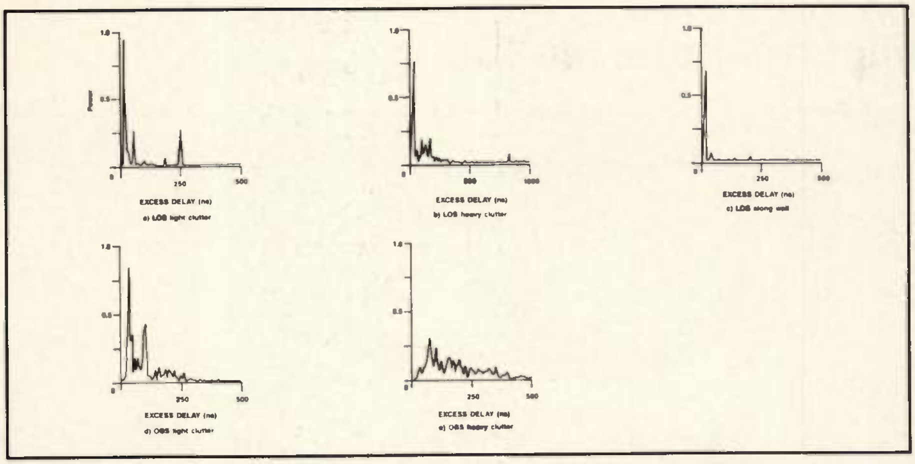

Figure 9. Typical multipath power impulse responses computed as a spatial average of 19 measurements over a 1 m track.

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About the Author

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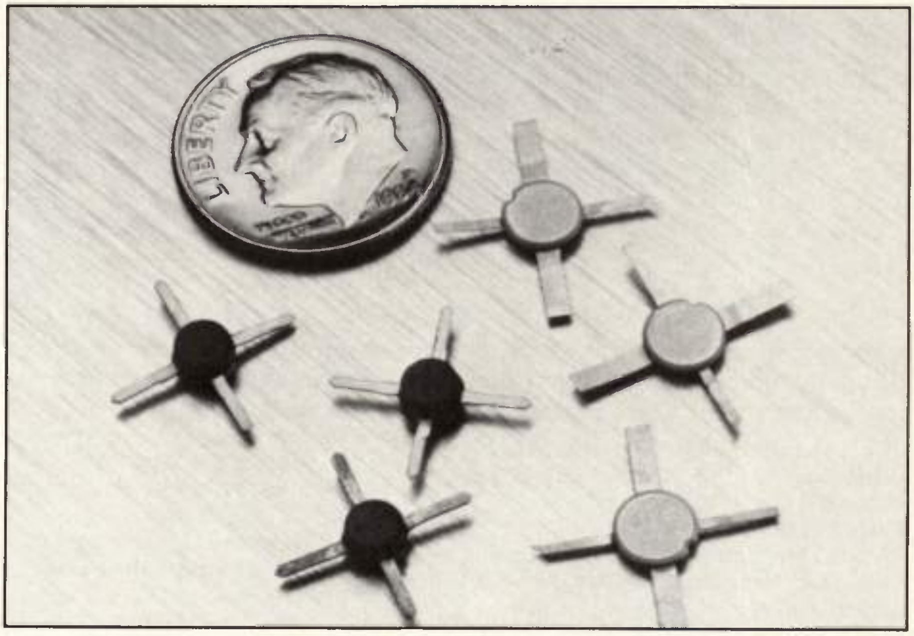
Avantek Introduces Silicon Bipolar MMICs



These additions to the MODAMP™ series silicon bipolar monolithic microwave integrated circuit amplifiers feature a combination of high third-order intercept point and low noise figure. The MMICs are 50 ohm gain blocks for use in IF and RF amplifier design.

At 500 MHz, Models MSA-1120 and MSA-1104 feature gain of 12 dB, third-order intercept point of 30 dBm and noise figure of 3.6 dB. The MSA-1120 is housed in a 200-mil diameter BeO disk package while the MSA-1104 is packaged in a low-cost 145-mil plastic package.

The Avantek 1104 has a gain flatness of ±1 dB typical and 3 dB bandwidth of 1.3 GHz. Input VSWR is 1.5:1 and ouput VSWR is 1.7:1. The 1120 features a maximum gain flatness of ±1 dB, and has an input VSWR of 1.7:1 and output VSWR of 1.9:1.

The MODAMP MSA series of silicon bipolar amplifiers is fabricated using a 10 GHz f_T, 25 GHz f_{max} silicon bipolar process which utilizes nitride self-alignment, ion implantation and gold metallization to achieve good uniformity, performance and reliability. When purchased in 100-piece quantity, the 1120 is $25 and the 1104 is $3.25. **Avantek, Inc., Santa Clara, CA. Please Circle INFO/CARD #220.**

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The XL Series of PTFE/woven-glass substrate materials from Tachonic Plastics are available in sizes up to 36 inches wide and 12 feet long. It is designed to reduce processing costs and enhance system reliability for large antenna arrays.

The large substrate sheets eliminate the need to construct the antennas in sections, which means improved structural integrity and better electrical performance. The improvements are of particular benefit in aircraft and aerospace applications where high stress and extreme temperature cycling are concerns.

The XL Series offers various combinations of electrical and mechanical properties, with dielectric constants from 2.15 to 2.6 ± 0.002, dissipation factor as low as 0.00075 at 10 GHz and good dimensional stability. The XL products meet MIL-P-13949G. **Tachonic Plastics, Limited, Petersburg, NY. Please circle INFO/CARD #219.**

Isotropic Probe System

The Model 7100 system for susceptibility testing, radiation hazard measurement and field mapping applications combines probes, metering units, processors and software. The elements of the probe are based on a design developed at the National Bureau of Standards. Each element is a tapered dipole measuring 8 mm from tip to tip. Three elements are placed in a mutually orthogonal arrangement in each probe. The size of the probe offers minimal field perturbance, detection of frequencies up to 10 GHz and a dynamic range of 1 to 1000 V/m.

Between the probe(s) and the system's data processing and interface units is the Model 7120 probe metering unit. It functions as a signal perprocessor that does signal amplification, analog-to-digital conversion, digital filtering and computing of field strength. The metering unit also self-calibrates each of the probes' three detection channels, automatically computing correction factors at timed intervals. The unit has been designed to provide maximum isolation of the metering circuitry from the field being measured and the display unit. Signal output is through a fiber optic cable.

The Model 7110 data processing/interface unit is the system's data acquisition and processing module. The unit permits up to eight probes to be connected for multiple samplings. An option, Model 7140, may be substituted for the data processing/interface unit. It permits a PC to be used for the data acquisition and processing functions. An RS-232 port is required for each probe input. **EMCO, Austin, TX. Please circle INFO/CARD #218.**

Air Core Inductors

Renco Electronics introduces air core inductors that can be wound in any length clockwise, counter clockwise or with variable pitch for operation up to 1000 MHz. The inductors can be wound with wire gauges from 8 to 32 and current handling capability up to 50 amps, depending on wire gauge. When purchased in 1000-piece quantity, the inductor costs 40 cents. **Renco Electronics, Inc., Deer Park, NY. Please circle INFO/CARD #217.**

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RT/duroid^R 6002 microwave circuit laminate from Rogers Corp. is a ceramic PTFE composition with a dielectric constant of 2.94 ±0.04 at 10 GHz (73 degrees F) and a dissipation factor of 0.0012. In conventional glass-reinforced PTFE substrates, a rise in temperature will cause a drop in dielectric constant. Because of the combination of PTFE and ceramic filler in RT duroid 6002, the change in dielectric constant is small and the device will stay within tolerance in most cases. **Rogers Corp., Rogers, CT. INFO/CARD #216.**

Compandor IC

The TK-10650M is composed of a compressor circuit, to raise the average modulation level of the audio input above system noise before it is transmitted, and an expander circuit to restore the original audio dynamic range characteristics for receiving. Features include remote switchable dual inputs and outputs, input limiting to prevent overmodulation, two independent mute circuits, an internal microphone amplifier to accommodate low-level inputs and low harmonic distortion. The device only requires coupling capacitors as external components. In production quantities, it costs $1. **Toko America, Inc., Mt. Prospect, IL. INFO/CARD #215.**

Shielding Integrity Monitor System

Lindgren R. F. Enclosures introduces the IM Series shielding integrity monitor system, Model 27100-, designed for TEMPEST applications. The system provides an immediate automatic indication of the RF shielding effectiveness by means of a user-initiated test sequence. It includes a transmitter and receiver unit which is designed for either ceiling or wall mounting. The 902 to 928 MHz corner reflector antennas mount on swivel bases which allow for optimum RF illumination and detection of shielding leakage. A built-in alarm will indicate if RF leakage levels exceed a user preset level. An optional search loop antenna, which attaches to the receiver module, can be added to pinpoint sources of RF leakage such as around the door in a shielded room. **Lindgren R. F. Enclosures, Addison, IL. Please circle INFO/CARD #214.**

MMIC GaAs Converter

Pacific Monolithics introduces the PM-CV0302 double-balanced, wideband up- and downconverter, with LO buffer, RF and IF amplifier. It achieves 10 dB of gain while providing a minimum of 30 dB isolation between ports. The ports are matched to 50 ohms and are DC isolated. **Pacific Monolithics, Sunnyvale, CA. INFO/CARD #213.**

Scalar Network Analyzers

The HP 8757E is a scalar network analyzer that features three detector inputs with choice of AC or DC detection. Other features include 76 dB dynamic range with AC detection, two display channels, internal plotter/printer buffer and fully annotated display. The 8757C has all the features of the 8757E including color display with four display channels, optional fourth detector input, limit-line test capability, disk interface, adaptive normalization, and up to 1,601 measurement points each sweep. When combined with a swept-frequency signal source, directional bridge and detectors, the systems can be configured to measure transmission and return loss from 10 MHz to 40 or 50 GHz in coax, or to 100 GHz in waveguide. The 8757E costs $7,500 and the 8757C costs $9,000. **Hewlett-Packard Company, Palo Alto, CA. INFO/CARD #212.**

Transimpedance Amplifier

Sipex introduces the SP9610 fast settling DC-coupled transimpedance amplifier with 100 MHz bandwidth at unity gain. The -3 dB bandwidth at a gain of -1 is 100 MHz and drops to 75 MHz at a gain of -20. The amplifier settles to 0.1 percent in 20 ns with overshoot amplitude of less than 1 percent. Pricing varies from $50 to $120 each depending on temperature grade. **Sipex Corp., Billerica, MA. INFO/CARD #211.**

Function Generator

The Model 288 is a programmable function generator with synthesized frequency accuracy from 2 mHz to 20 MHz. The instrument has selectable output impedances at 50, 75, 135 or 600 ohms which provides flexibility for telecommunications, laboratory, CATV and high frequency audio applications. Operation modes include continuous triggered, frequency modulation, amplitude modulation, sweep internal and phase lock from 20 Hz to 20 MHz. Waveform symmetry is fully programmable from five to 95 percent in one percent steps for all waveforms. Synthesizer accuracy is 0.01 percent and distortion is 0.5 percent at 100 kHz. Model 288 is priced at $3,295. **Wavetek San Diego, Inc., San Diego, CA. Please circle INFO/CARD #210.**

Digital Oscilloscopes

The LeCroy 9420 is a digital oscilloscope that samples repetitive waveforms up to 10 gigasamples/sec (transients up to 100 megasamples/sec). The screen has a resolution of 4096 by 4096 points and the instrument has a dynamic range up to 72 dB with 500 uV/div sensitivity. The non-volatile 50k memory allows high time resolution recording and high single shot bandwidth on all time-base settings. This 350 MHz oscilloscope costs $14,900. **LeCroy, Chestnut Ridge, NY. Please circle INFO/CARD #209.**

Quartz Crystals

M-tron's ATS-49 crystals are available from 3.579545 to 20 MHz and feature either radial lead configurations or surface mount lead configurations. Series resistance is frequency dependent from 120 ohms maximum below 4.1 MHz to 40 ohms maximum at 20 MHz. The crystals are available for load capacitances of 10, 18 or 20 pF or as series resonant units. **M-tron Industries, Inc., Yankton, SD. INFO/CARD #208.**

rf technology expo 89

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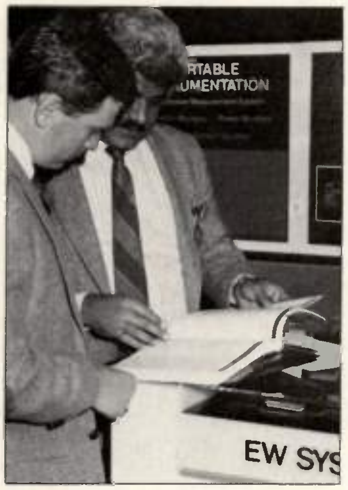

RF Technology Expo 89 will help you improve your on-the-job performance by bringing you the latest in design techniques.

Engineers will have a hard time deciding which technical sessions to attend. Program chairman Tim Healy, Santa Clara University and *RF Design* editor Gary Breed have included tutorials on mixers and radio propagation, design seminars and workshops, plus outstanding papers covering all important areas of rf design techniques and component applications. The complete schedule is on the next page.

We are again presenting Fundamentals Part I, plus have added Fundamentals Part II, Advanced Topics, both taught by Les Besser. Another special course offered is Computer-Aided Filter Design, taught by Randy Rhea of Circuit Busters. These courses are dedicated to bringing you up-to-speed on rf design techniques.

You'll want to set aside plenty of time to spend on the exhibit hall floor visiting over 150 manufacturers, eager to give you hands-on demonstrations and offer solutions to your design problems.

All this and more will be waiting for you in Santa Clara in February. The registration form is on page 35 — fill it out and get it in the mail today!

SESSION SCHEDULE (as of Dec. 15)

TUESDAY, EXHIBITS OPEN — 11:00 a.m. - 6:00 p.m.

February 14, 1989

Design Seminar

8:30 a.m. - PLL Frequency Synthesizer Building Blocks — from Motorola's Imaginology

10:00 a.m. - RF Low Noise Amplifier Design — from Motorola's Imaginology

Filter Design

8:30 a.m. - Design of Wideband Transmission Line Filters for UHF and Microwaves — Robert Fitzgibbon, G.E. Aerospace

9:30 a.m. - The Thin Film Resonator/Filter Integrated RF/Microwave Technology — K.M. Lakin, et. al., Iowa State Univ.

10:30 a.m. - S-VAN: A Circuit Pole and Zero Extraction Program — Howard Russell, OPAL Engineering

Process Technology

8:30 p.m. - A Biopolar MMIC Active Mixer for Applications to 5 GHz — J. Wholey, I. Kipnis, Avantek

9:30 a.m. - Computer-Aided Calibration of a Wafer Probe Station — Alan Sailer, EEsof

10:30 a.m. - Analysis of Test performance Data to Enhance Quality Control in the Manufacture of RF Components & Circuits — Steve Waite, Hewlett-Packard

Design Seminar (3 hours)

1:30 p.m. - 4:30 p.m. - Low-Cost RF Integrated Circuits for Short-Range Radio Systems (with hands-on workshop) — from Motorola's "Imaginology"

RF Power Topics

1:30 p.m. - Specifying High Power Diode Switches — Joseph Hill, Enon Microwave

2:30 p.m. - Microwave Power Transistors for Mode S" Systems — Tony Harris, SGS-Thomson Microelectronics

3:30 p.m. - Suboptimum Operation of Class- E Power Amplifiers — Frederick Raab, Green Mountain Radio Research

Various RF Topics

1:30 p.m. - Broadband Transmission Line Feasibility Study — D. Burnham, et. al, Hughes Aircraft

2:30 p.m. - Introduction to AT and SC-Cut Quartz Crystal Resonators — Bruce Long, Piezo Crystal Company

3:30 p.m. - A Method for the Design of Wide Tuning Range Crystal VCOs — Edward Marrone, APPCOM, Inc.

WEDNESDAY, EXHIBITS OPEN — 11:00 a.m. - 6:00 p.m.

February 15, 1989

Tutorial Session (3 hours)

8:30 a.m. - 11:30 a.m. - Mixer Fundamentals — Dr. Donald Steinbrecher, Steinbrecher Corp.

Component Technology

8:30 a.m. - Microwave and Millimeter Wave Packaging — B. Berson & F. Rosenbaum, Berson Associates

9:30 a.m. - An Inexpensive Silicon Monolithic IC Process for Microwave Low and Medium Power Circuits — Paul Sanders, Motorola

10:00 a.m. - A Silicon RF Amplifier Using a Dielectrically Isolated Monolithic Integrated Circuit (DIMMIC) Process — Peter Bachert, Motorola

10:30 a.m. - Subnanosecond Switching with DMOS FETs-Ed Oxner, Siliconix

Small-Signal Circuits I

8:30 a.m. - Design and Use of a 2 to 6 GHz GaAs MMIC Gain Block for Commercial Markets — William Mueller, Avantek

9:30 a.m. - A New Design Technique for a Space-Qualified 0.8-1.6 GHz GaAs MESFET LNA — Mary Holly, FEI Microwave

10:30 a.m. - Audio Processing for Cellular Radio, or High Performance Transceivers — Ali Fotowat, Signetics Corp.

Instrumentation & Test Methods

1:30 p.m. - Understanding Digitizing Oscilloscopes — Robert A. Witte, Hewlett-Packard

2:30 p.m. - Application of RF Techniques in the Design of a Digital Data Bus — Fred Studenberg, Rockwell Intl.

3:30 p.m. - New Measurement Techniques for Testing Both Linear and Nonlinear Devices with the 8753B RF Network Analyzer — Barry Brown, Hewlett-Packard

Frequency Synthesis

1:30 p.m. - Complex Waveform Generation Using Direct Digital Synthesizer Techniques — Rob Gilmore, Qualcomm

2:30 p.m. - A Unified Approach to Understanding Oscillator Noise and Injection-Locking — Tim Hillstrom, Hewlett-Packard

3:30 p.m. - Quantified Prediciton of DDS Spurs — Earl McCune, Digital RF Solutions

Receiver Design

1:30 p.m. - Receiver Design - Simplified — Jerry Iseli, RF Monolithics

2:30 p.m. - Alternatives to Zero-IF Demodulation — Richard Webb, Webb Laboratories

3:30 p.m. - A Low-Cost, High Performance Noise Blanker for Long-,Medium-, and Short-Wave Applications — Oliver Richards, Sprague Semiconductor Group

THURSDAY, EXHIBITS OPEN — 10:00 a.m. - 2:00 p.m.

February 16, 1989

Tutorial Session (3 hours)

8:30 a.m. - 11:30 a.m. - Radiowave Propagation — D.R. Dorsey, DocSoft Enterprises

PLL Topics

8:30 a.m. - PLL Synthesizer Switching Speed Optimization and Measurement Techniques — Dan Gavin, RF Prototype Systems

9:30 a.m. - A Phase-Lock Loop in a Non-cooperative Environment — A Pulsed Input — Michael Black, Texas Instruments

10:30 a.m. -

Small Signal Circuits II

8:30 a.m. - An Integrated Chip Set for Cellular Mobile Telephones — P.J. Hart, T.G.R. Hall, Philips Components Applications Laboratory

9:30 a.m. - UHF, L-Band and S-Band Applications of Low Noise GaAs Fets — Al Ward, Avantek

10:30 a.m. - Gilbert Type Mixers Versus Diode Mixers — Ali Fotowat, Signetics Corp.

Microwave Cable Assembly

"UTiFLEX" has the benefits of a semi-rigid coaxial cable while providing a low-density PTFE dielectric and flexible shielding. It provides shielding up to 26.5 GHz over a temperature range of -55 degrees C to +165 degrees C. The cable assemblies are available with SMA, PN, PC3.5, PC7 and TNC connectors. **Micro-Coax Components, Inc., Collegeville, PA. INFO/CARD #207.**

PIN Diode Switch Driver

Raytheon introduces a monolithic quad PIN diode switch driver. The RC4447 has four independent driver circuits with turn-on and turn-off times of 35 ns. Each channel can provide both true and complementary outputs that can be used to drive series and series/shunt PIN diode configurations. Typical pulse repetition rate at 50 percent duty cycle and 25 degrees C is 14 MHz. Packaging options, over the military range, include a 20-lead, 0.3 inch wide ceramic DIP and DICE for hybrid applications. The commercial version is available in a 20-lead plastic DIP. Pricing for the military grade, RM4447, in 100-piece quantities starts at $45 each. **Raytheon Company, Mountain View, CA. Please circle INFO/CARD #206.**

Hyperabrupt Varactor Tuned Oscillator

The 2 to 4 GHz hyperabrupt varactor tuned TO-8 oscillator (HV87T- 1) has a minimum power output (50 ohm) of 10 dBm with a maximum 1 dB power pulling at 12 dBm return loss. Frequency pulling is 6 MHz max (12 dB return loss) while frequency pushing is 10 MHz/volt. Typical harmonics are at -17 dBc and phase noise at 100 kHz offset is -100 dBc/Hz. **Magnum Microwave Corp., Fremont, CA. INFO/CARD #205.**

PIN Driver

These inverting PIN drivers provide steady-state output current with current spikes for fast PIN and NIP switching. Low input capacitance and logic current make these drivers TTL, LSTTL, high-speed CMOS and NMOS compatible. The device has 0.01 uF bypass capacitors. **Impellimax, Nashua, NH. Please circle INFO/CARD #204.**

Power Meter Retrofit Kit

The Bird Electronic Corp.'s Model 43 THRULINE[R] wattmeter can now be upgraded to read true peak RF power. The Model 4300-400 retrofit kit enables users to measure peak power of single sideband, AM modulated RF and limited rectangular pulse signals. The kit includes a PC board which mounts inside the 43 housing. **Bird Electronic Corp., Solon, OH. INFO/CARD #203.**

Polynomial Waveform Synthesizer

Models 2040 and 2045 polynomial waveform synthesizers offer a data rate of 800 megapoints/sec and waveform entry through computer downloads, drawing on graphic tablets and oscilloscopes, point and line segment entry and real world capture from the Analogic Model 6100. The 2040 offers two output levels, each 1 volt p-p, in phase opposition to provide both single-ended and differential outputs at a bandwidth greater than 700 MHz. The settling time is less than 1 ns to 2 percent of final value and less than 5 ns to within 1 percent of final value. The 2045 provides one low-level output at the full 700 MHz bandwidth and another 5 volts p-p output at 200 MHz bandwidth and 8-bits resolution over the full dynamic range. The 2040 costs $13,500 and the 2045 costs $14,500. **Analogic Corp., Peabody, MA. INFO/CARD #202.**

EMI/RFI Shielding

Equipto Electronics introduces a line of RFI/EMI shielded cabinets, consoles and work stations. The enclosures, tested to MIL Spec 285, have 140 dB of attenuation. **Equipto Electronics Corp., Aurora, IL. INFO/CARD #201.**

Fixed Attenuators

Alan Industries has added a Type N connector, per MIL-C-39012, to its MHP line of fixed attenuators. The devices cover from DC to 18 GHz at 5 watts average and 5 kW peak. Attenuation values of 1, 3, 10, 20 and 30 dB are standard with other values available upon request. Specifications over the DC to 18 GHz range include 50 ohm impedance, 1.35:1 maximum VSWR and accuracy of ±3 dB from 1 to 6 dB and ±5 dB from 7 to 40 dB. Price ranges from $105 to $210 each in quantities of 1 to 24. **Alan Industries, Inc., Columbus, IN. INFO/CARD #200.**

rf software

Layout and Schematic Software

EEsof introduces ACADEMY — a software tool that integrates the task of design entry, simulation (including linear and nonlinear analysis, optimization and tuning), mask layout and documentation. Its graphical design environment features layout-driven simulation ™. The program creates and simulates the design from the layout and schematic. By placing layout elements directly, without having to first create a schematic, the engineer is able to more easily visualize and size the physical layout of the circuit as design entry and simulation are being performed. Also, the user can change elements or topology, sweep, tune, optimize, or perform any other simulation function at any point in the design cycle. ACADEMY's design environment integrates Touchstone®, Libra™ and Mi-CAD ™. The program is priced between $6,000 and $14,000, depending upon platform, configuration and options. **EEsof, Inc., Westlake Village, CA. Please circle INFO/CARD #196.**

Analog Workbench for the IBM AIX/RT

Analog Design Tools announces the availability of Analog Workbench ™ for the IBM AIX/RT™. The Workbench software uses the X-Windows available for the AIX/RT. This CAE tool performs the design and simulation of integrated circuits and printed circuit boards. The IBM AIX/RT operating system is designed to be compatible with UNIX System V.2™, and features many functions of Berkeley 4.3. The AIX/RT is a RISC-based (reduced instruction set computer) using X-windows, the emerging industry standard for windowing techniques. **Analog Design Tools, Inc., Sunnyvale, CA. INFO/CARD #195.**

FET Model Parameter Extraction Software

RoMPE ™ (Robust Model Parameter Extractor) is a program for extraction of FET model parameters from measurement data. It accepts measurement data in the form of small-signal S-parameter and or DC bias measurements. Depending on available data, RoMPE can be used to extract DC model parameters, small-signal model parameters or both simultaneously. It offers the combined power of novel techniques in device modeling and the gradient-based 11 or 12 optimizers through a user interface. The software supports FET models including the Materka and Kacprzak, Harmonica and Curtice. **Compact Software, Inc., Paterson, NJ. Please circle INFO/CARD #194.**

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rf literature

SAW Information Sheet

This information sheet gives a brief overview of SAW devices. It highlights products available from Tadiran and features SAW bandpass filters, SAW delay lines, SAW resonators, CHIRP and RAC pulse compressors, correlators and convolvers, and SAW custom subassemblies. The products cover from 10 to 1500 MHz. **Tadiran Ltd., Micro Technology Div., Holon, Israel. INFO/CARD #193.**

Power Amplifier Catalog

Kalmus introduces a catalog on its line of amplifiers for EMC, EMP, EMI, RFI, NMR, MRI, spectroscopy, telecommunications, and laboratory. Application and tutorial-type information is included. **Kalmus Engineering International, Ltd., Woodinville, WA. INFO/CARD #192.**

Microwave Products Catalog

This catalog covers attenuators and accessories for RF and microwave applications. Catalog 89-20 contains new products and updates mechanical and electrical specifications for existing products. Among the accessories included are DC blocks, RF fuses, circuit protectors, directional couplings, impedance matching pads, terminations, precision loads, detectors, return loss bridges and resistive dividers. **Alan Industries, Columbus, OH. INFO/CARD #191.**

Catalog Describes Surface Mountable Inductors

Featured in this catalog is a line of surface mountable inductors including shielded and compact units. The inductors range from 0.01 uH to 1000 uH and the shielded units range from 0.10 uH to 560 uH. Surface mount filter beads are also described. **Delevan, SMD Division, East Aurora, NY. Please circle INFO/CARD #190.**

SAW Frequency Control Brochure

Sawtek announces the release of its Frequency Control Components brochure. It is designed to help the user in selecting and specifying appropriate SAW components for respective applications. Included is information concerning the theory of SAW resonator operation and typical performance parameters for resonators and delay lines. The brochure covers frequency tolerances, including temperature and long term stability. It discusses Q, phase noise, loss, spurious suppression, packaging, radiation performance and power handling. For clarification of terms, a list of definitions is included. **Sawtek, Inc., Orlando, FL. INFO/CARD #189.**

Antenna Measurements Application Note

This application note, AN360-10, discusses antenna measurement techniques using the Wiltron 360 vector network analyzer. AN360-10 concentrates on far-field measurements, but also mentions other antenna measurements such as monopulse and near field. Several configurations are presented for both compact and long range antenna ranges. **Wiltron, Morgan Hill, CA. INFO/CARD #188.**

Brochure Describes Microwave Substrates

This brochure gives information on Trans-Tech's family of substrates for microwave device applications. It provides electrical and mechanical specifications for various types of substrates plus intended applications including microwave and high speed digital circuits, millimeter wave devices and microwave integrated circuits. **Trans-Tech, Inc., Adamstown, MD. INFO/CARD #187.**

PIN Diode Product Bulletin

M/A-COM announces the availability of bulletin 4325 which covers their packaged silicon PIN diodo product line. Included is a comprehensive combination of PIN diode electrical characteristics and package outlines in 17 case styles. Products are available for fast switching circuits to 3 ns and for high voltage, high power switches to 2000 volts. **M/A-COM, Inc., Burlington, MA. INFO/CARD #186.**

Parametric Divider Application Note

Application note 1, "Phase Noise and the Parametric Frequency Divider for Phase Locked Source Applications," from Telemus describes the phase locking principle, residual phase noise and noise floor, loop stability and phase margin, two practical examples, and suggestions for other practical PLL circuits using parametric dividers. A list of references, technical notes and application notes is included. **Telemus Electronic Systems Inc., Nepean, Ontario, Canada. Please circle INFO/CARD #185.**

Satellite and Military Microwave Integrated Assemblies Brochure

Described in this brochure is the company's capability to design and produce integrated assemblies. Included are discussions of component building blocks, MIC components, EW receiver subsystems, communications receivers, frequency conversion products, switching subsystems and frequency generation products. In each category, typical examples of production assemblies are presented with specifications. **FEI Microwave, Inc., Sunnyvale, CA. Please circle INFO/CARD #184.**

Catalog Highlights Receiving Multicouplers

This catalog describes equipment for military and commercial customers for surveillance and signal distribution applications. Covered are specifications and features on HF receiving multicouplers, receiving multicouplers and telemetry receiving multicouplers. They cover the 2 to 2400 MHz range and are available in either rack mount or compact configurations. **Advanced Milliwave Laboratories, Inc., Westlake Village, CA. INFO/CARD #183.**

Products and Capabilities Brochure

I.T.S. Electronics introduces its products and capabilities brochure. The company designs and manufactures microwave and millimeter wave components and subsystems to customer specifications and interface requirements in the 900 MHz to 40 GHz range for OEM applications. The main specialization is dielectric resonator oscillators and up/down converters. The brochure also mentions the consulting services offered by the company which include design services, product planning and support, and technical marketing support. **I.T.S. Electronics Inc., Concord, Ontario, Canada. INFO/CARD #182.**

Application Note Describes Wideband Pulsed Component Tests

HP application note 343-2, "Dynamic Component Testing Using Vector Modulation Analysis," describes how the HP8981A vector modulation analyzer can characterize various components (in gain and pulse) under pulsed conditions. It describes modern phased-array radar and other coherent-signal systems. **Hewlett-Packard Company, Palo Alto, CA. Please circle INFO/CARD #181.**

Advertiser Index

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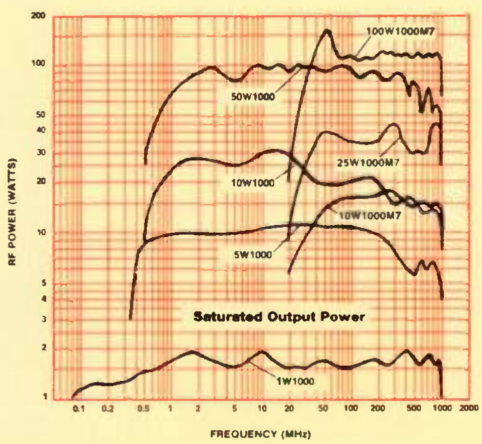

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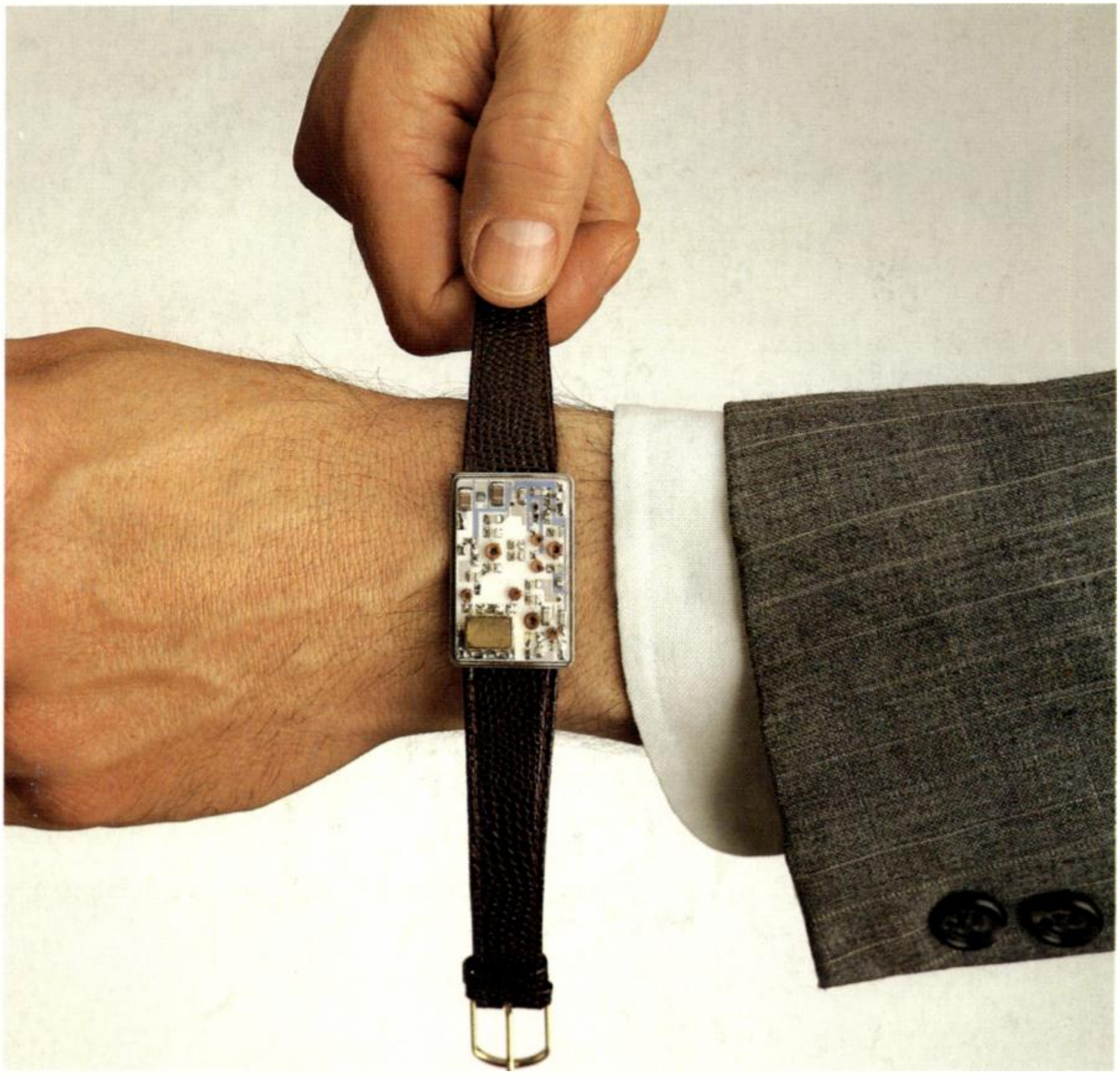

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For More Info. on Oscillators, Circle #71.