rf design

high frequency and analog engineering

December 1987

New Instrument Combines Digital and Analog Synthesis

Featured Technology – S-Parameters of Wideband Op Amps

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INFO/CARD 2

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NE345L-10B	**40 dbm**	**9 db**	**40% @ 2.3 GHz**
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NEC®

INFO/CARD 3

California Eastern Laboratories

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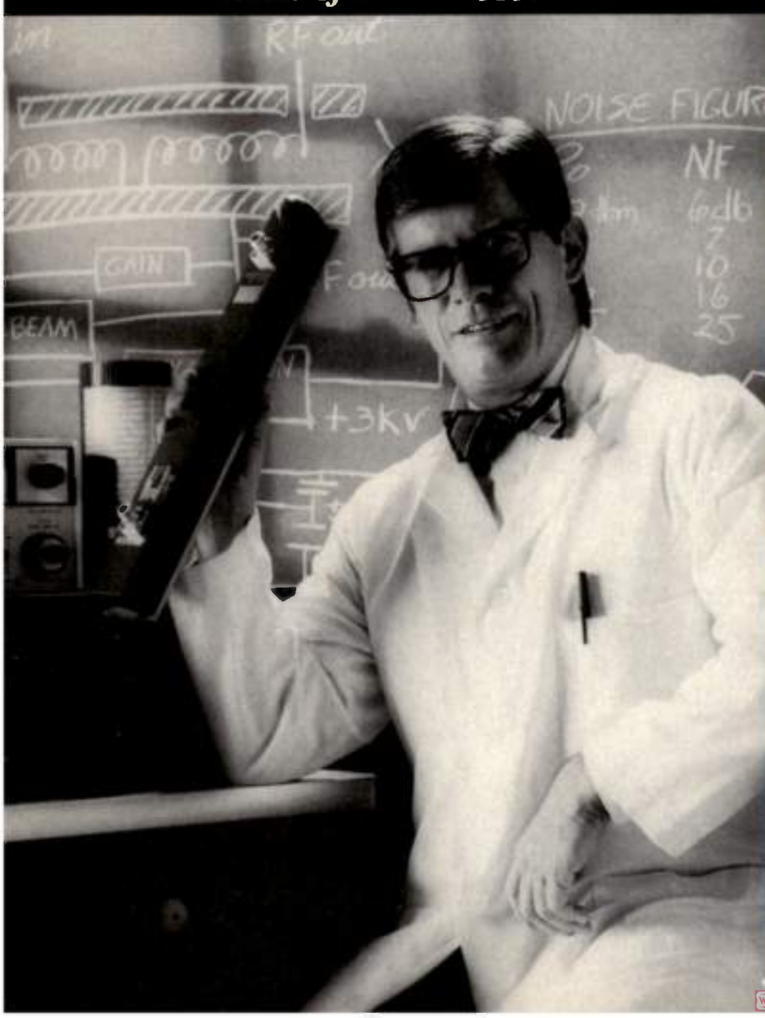
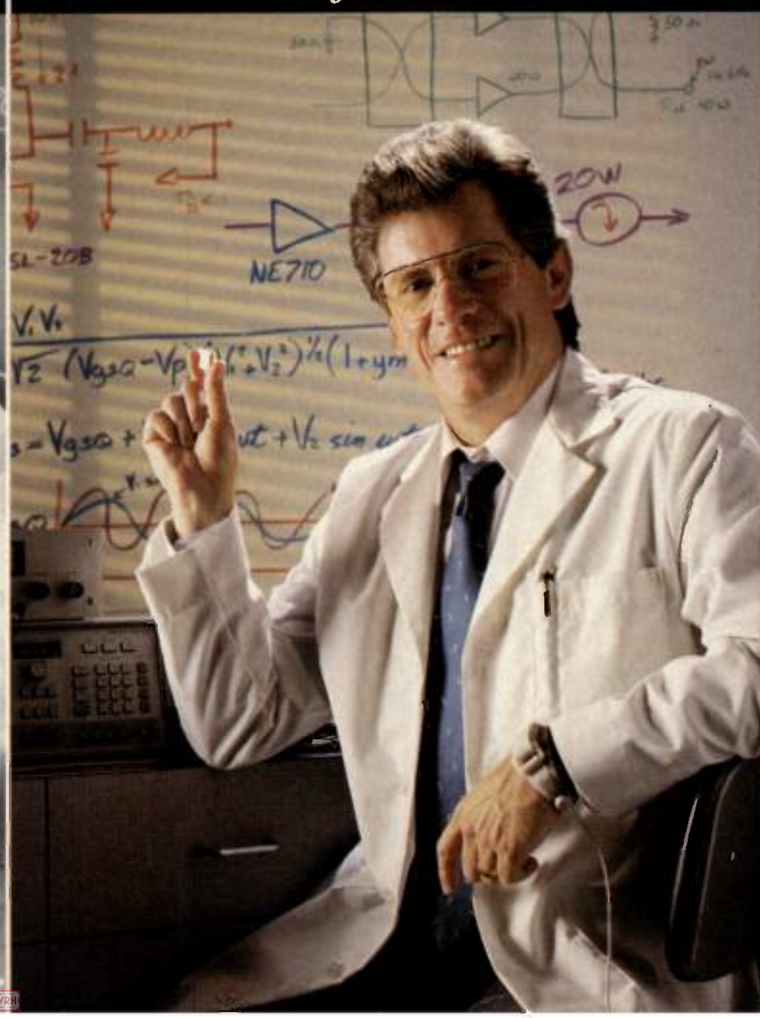
Western (408) 988-3500 **Eastern** (301) 667-1310
Canada (613) 726-0626
Europe NEC Electronics GmbH 0211/650301

State of the art 1959.



State of the art 1987.



rf design

December 1987

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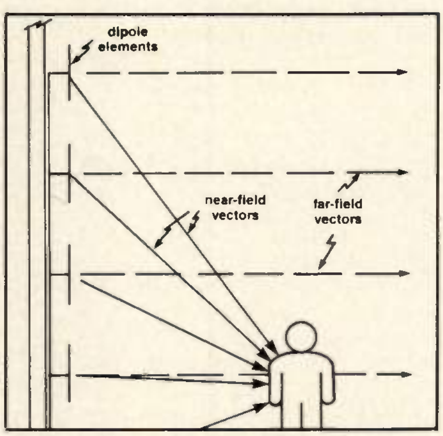

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Departments

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rf editorial

Join the Celebration

By Gary A. Breed
Editor

It's December, when we usually look back and reflect on the year that is ending. I am not a big fan of "end of the year" editorial retrospectives, so you won't see that in this column. Significant events of the past 12 months are relatively fresh in our minds, and my further commentary isn't going to add a whole lot.

However, a *ten-year* retrospective is quite another matter. That is what we are going to be doing in 1988 to celebrate the 10th anniversary of *RF Design*! I am a big fan of history — it's important to know something about the events and achievements that got us where we are today, whether they happened in 1987 or 1978. *RF Design* will be entering 1988 with excitement and enthusiasm, along with a sense of humility and thanks that we have been able to grow from a germ of an idea to an established part of the engineering scene.

The year-long celebration culminates with two very special issues in October and December. October is our official Anniversary Issue, and will feature the recollections and analysis of some of our long-time supporters: readers, authors and advertisers. Their perspectives on the last 10 years of RF history will undoubtedly be fascinating reading.

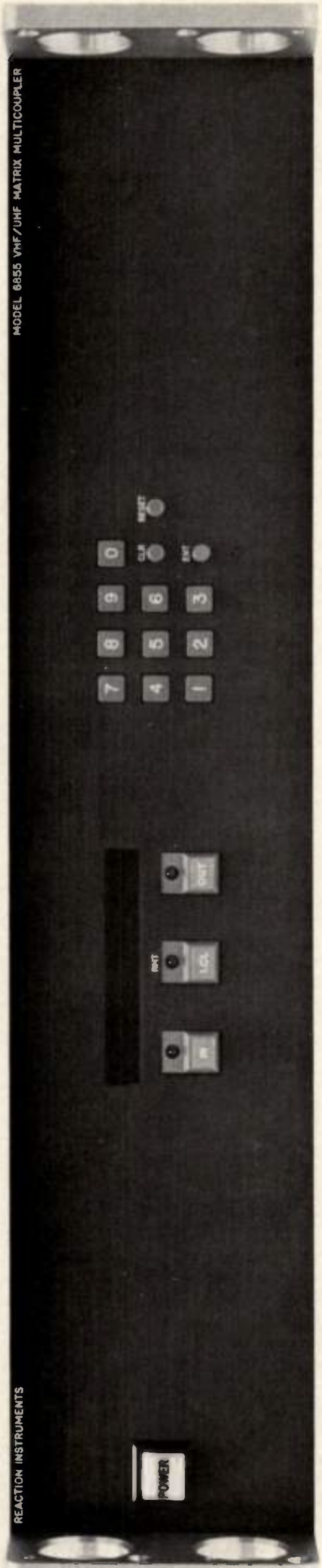
In December we will change the direction of our focus by asking another group of engineers to make their best predictions for the next 10 years. We all know there is no magic "crystal ball" to see the future, but the views of thoughtful, experienced members of our industry will surely be able to get us thinking about the future of RF.

Where Were You 10 Years Ago?

We want to know *your* views on the past 10 years, too! Send us a short note telling us what you remember best, or what things you think were important in the world of RF since 1978. In our "Letters" column, we will publish as many of our readers' comments as possible. It doesn't matter whether you point out the good, the bad, or the ugly — every viewpoint is a valuable contribution.

In the course of history, very few of us get to make much of an impact. At *RF Design*, we are happy to be passing a milestone that indicates our impact has been significant. Join the celebration by sharing your personal view of the past 10 years with your fellow readers.

Gary A. Breed



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INFO/CARD 5

Do RF Engineers Need Certification?

By Mark Gomez
Assistant Editor

With new mandatory and voluntary regulations being imposed in the RF industry there is a need assure the competence of personnel responsible for complying to these standards. Particular areas of importance to the RF engineer are regulations imposed by Military standards and compliance to FCC and foreign regulations and voluntary standards.

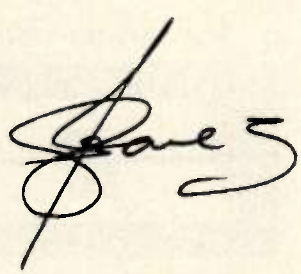
Many RF companies are responsible for supplying government departments and military services with specifically certified components and subsystems. The certification is normally obtained by having the facilities inspected and devices concerned tested and pass a high standard of evaluation. In order to ensure continued compliance the engineers should be tested on their theoretical and practical understanding of manufacturing and performance requirements. This ensures that the human element is taken into consideration as well as the facility and finished product.

Another sector of the industry of concern is EMC personnel at test facilities. EMC engineers and technicians play a very important role in the certification of a product. Companies that build systems and sub-systems generally farm out their compliance testing (eg. MIL-STD 461C) to EMC test facilities. Engineers responsible for this kind of work should be tested to verify their competence in understanding the standard and carrying out the required tests.

When a product is passed by an EMC test facility, the company that makes the product is generally ready to market it. If a product was not properly tested, and if there is a hidden problem with non-compliance, the product may be seized by the FCC. This usually results in fines and lost revenue for the client company. The fines caused by non compliance can be expensive. In 1982, the FCC issued $11,350 worth of fines while in 1986 this figure rose to $878,750. During this period the number of citations rose from 33 to 959.

From this we can surmise that the number of EMC test facilities will be increasing at a fairly rapid rate, creating a number of jobs in the industry. With the in-flux of newcomers, the quality of testing is going to drop unless measures are taken to ensure that engineers understand what is expected of them. Certification for these engineers can be achieved by creating a structured program for training followed by an apprenticeship where the engineer is supervised by a senior member who has a thorough understanding of the system. After a certain length of time the new engineer should be required to take a written as well as a practical examination where upon successful completion she or he will be allowed to perform tests individually.

Certification such as P.E. (professional engineer) registration is not sufficient since it does not necessarily take into account specific regulations. However, P.E. registration together with the NBS NVLAP lab accreditation program would be one way to tailor a proper certification program for RF engineers. With the proper certification of engineers in such crucial positions, the level of compliance can be maintained or increased within the growing RF industry. Once a proper trend is achieved we can be sure the quality of RF engineering will be maintained.



rf design

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Publisher
Keith Aldrich

Editor
Gary A. Breed

Assistant Editor
Mark Gomez

Consulting Editors
Andy Przedpelski
Robert Zavrel

National Sales Manager
Kate Walsh

Advertising:
West Coast District Manager
Mary Bandfield
1341 Ocean Ave., Ste. 58
Santa Monica, CA 90401
(213) 458-6683

Midwestern States
Kate Walsh
Main Office

Eastern Sales Manager
Joseph Palmer
36 Belmont Rd. S.W. 3
West Harwich, MA 02671
(617) 394-2311

Advertising Services
Jenny Thompson

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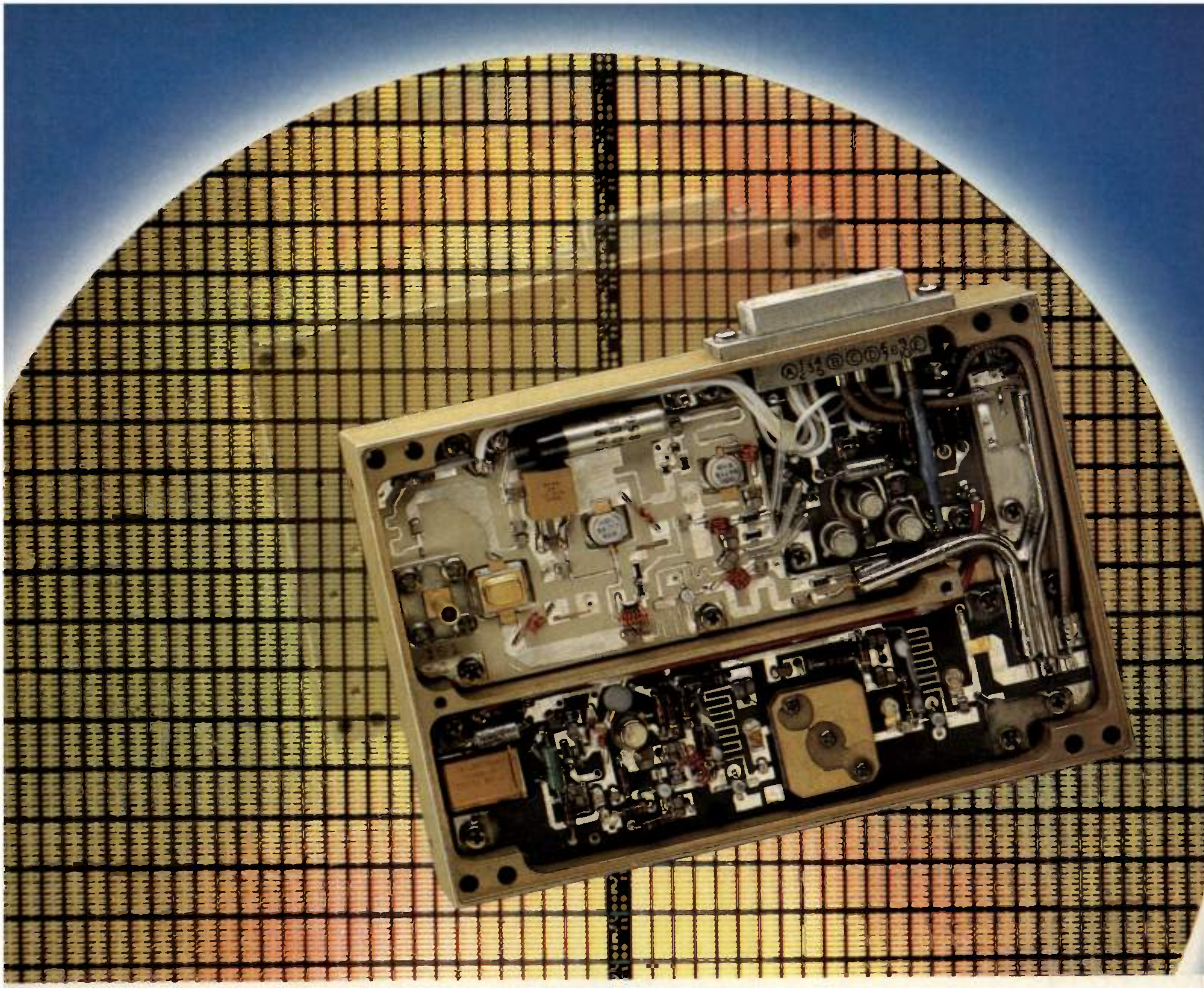


rf letters

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

International Comments

Editor:

Suggestion — Articles on technical aspects of NMR spectroscopy/spectrometry, also MRI (medical, industrial, geological).

D.M. Bussell
University of Aberdeen, NMR Section
Aberdeen, Scotland

Editor:

I would like to see the working principle of cellular radio, frequency hopping radios, SSB transceivers, satellite communications equipment and antennas.

Suheyla Guven
PTT Genel Müdürlüğü
Ankara, Turkey

Man vs. Machine

Editor:

I truly admire your understanding of the computer's proper role in engineering, as expressed in your September editorial. But, having been an editor myself, I know that the real power in a magazine lies with the advertising manager. This is clearly evidenced by ads which promote the mindless computer you warned of. One shows a bundle of goodies to be discarded. There are three roach clips (pardon me — I mean hemostats) and a perfectly good calculator. Perhaps the lights never go out in California. But the strangest artifact is a module marked "N.F.G." this probably means "noise figure: good," but a more cynical person might read it as "not functioning good" or something equally professional.

Most engineers want to spend *more* time in the lab, not less. And, contrary to the ads, "tweaking trash" is not necessarily a waste of time — it can be a worthwhile learning experience. Seeing a circuit come to life in the laboratory is the real thing. Doing it with "just a few keystrokes" just isn't the same.

George Woodward
Teleco Oilfield Services
Meriden, CT

Help celebrate the 10th Anniversary of *RF Design* during 1988 — send us your observations, recollections, or philosophical musings about the past ten years of RF technology. We will print as many letters as we can.

Technical Presentations Highlight RF Expo East

Although Mother Nature did her best to slow things down, over 1000 RF engineers made their way to the World Trade Center in Boston to attend RF Expo East 87. Overwhelmingly, their purpose in attending was to learn — about the products and services offered by the exhibitors; what fellow engineers in RF and related industries are doing; but most of all, about the art and science of RF engineering.

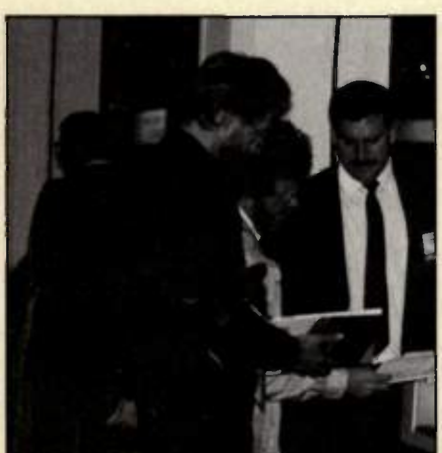
Many took advantage of the formal classroom instruction in Les Besser's "Fundamentals of RF Circuit Design" one-day course. Approximately 230 (50 per cent more than last year) attended this course, which has been revised and refined to more precisely meet the educational needs of RF engineers. Evidence of the changing nature of RF engineering was seen in an impromptu survey made at the beginning of the two sessions: about one-fifth of the course attendees identified themselves as being involved in digital design, data acquisition or transmission, industrial electronics or medical applications.

Exhibiting companies offered the first public showing of many products. Test instruments, components, modules and system subassemblies were viewed by interested attendees. Despite a slump in total attendance caused by a major snowstorm on the second day the Expo, many exhibitors noted that those engineers able to attend represented the most important RF manufacturers.

Products introduced at RF Expo East that had not been announced in advance included the S-Series of microwave sweep generators from Integra Microwave. The S-0210 model covers 2-10 GHz with a leveled power output of +13 dBm and harmonics at −55 dBc. Optimax introduced a 240-270 MHz low noise bipolar amplifier, the AH-5780, with 14.4 dB gain and 1.7 dB NF. Another announcement came from AVCOM of Virginia, showing low-cost YIG signal sources to demonstrate their increasing capabilities.

Seven of the 15 technical sessions had standing-room-only crowds (in rooms seating 160), including the three special tutorial sessions on power amplifiers, CAD filter design, and phase-locked loops. In addition, sessions on oscillators and multipliers, RF components, and RF test systems had more engineers than available seats. Other technical sessions drawing substantial interest involved digital applications, high power RF, and principles of analog design. The high interest in these engineering sessions demonstrates the need for a continuing effort in education and information for the RF community. This was underscored by the attendees repeated references to the sessions as "courses," rather than "papers."

Engineers at RF Expo East got a look at the future in a session on superconducting technologies. Beginning with an introductory tutorial by Professor Michael Tinkham of Harvard, seven engineers and scientists offered practical and theoretical applications for superconducting materials in filters, low-noise amplifiers, oscillators and delay line applications. This emerging technology will undoubtedly have an impact on future RF components and design techniques. Those attending were able to get a preview of its impact on their work, as well as techniques being used to achieve superconductivity.



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These new symmetrical slotted shielding strips of beryllium copper permit continuous spring contact throughout their length, providing the perfect answer for a variety of shielding requirements.

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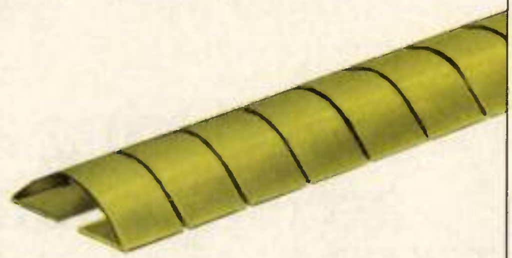
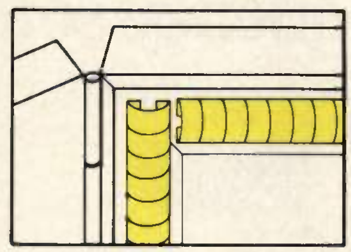
The rivet-mount design incorporates the addition of an integral track, pierced for mounting with nylon push rivets. This configuration allows bi-directional engagement, and is specially designed for slide applications, PC board connections, etc.

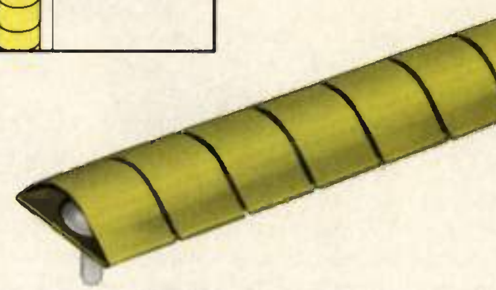
The third design also incorporates an integral track-mount design, but employs a double-faced adhesive tape instead of push rivets. This provides for fast, easy field replacement in military applications, especially where high frequencies do not permit the use of mounting holes.

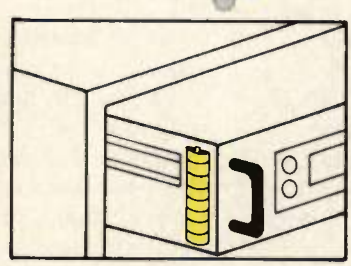
For complete information, including exact specifications, dimensional drawings, etc., on these and other Instrument Specialties shielding strips, use this publication's Reader Service Card. Or write to us directly at Dept. RFD-36.



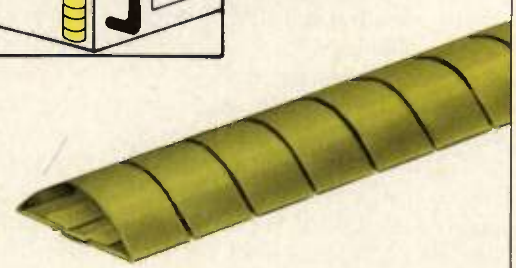


Adhesive-mounted strips for typical electronic enclosures.





Strips with integral mounting track* and nylon push rivets, for sliding drawer applications.



Strips with integral mounting track* and self-adhesive strip for fast field replacement.

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NBS Expands Electromagnetics Lab Program

The electromagnetics laboratory accreditation program managed by NBS under the National Voluntary Laboratory Accreditation Program (NVLAP) has been expanded to meet requests from participating labs, manufacturers, and the U.S. Naval Air Systems Command. Test methods have been added to help labs improve the quality of testing on products that must meet Federal Communications Commission (FCC) approval and to assure the performance of electronic devices for weapons systems. The expanded program includes test methods for radio frequency devices including receivers (FCC Part 15); industrial, scientific and medical devices (FCC Part 18); radio transmitters (FCC Part 90); and a military standard (MIL STD-462) to measure electromagnetic interference characteristics.

MMD, AMT Announce Merger

In a joint announcement, Microwave Modules and Devices (MMD) and American Microwave Technology (AMT) confirmed their intention to merge by acquisition, leaving AMT as a wholly owned subsidiary of MMD. Since they plan to share technologies, the two microwave and RF amplifier companies are expecting new products, capabilities and applications to emerge. MMD's products are used in defense radar, communications and broadcast applications. AMT's products are used in medical, instrument and electronic warfare markets. MMD, headquartered in Mountain View, Calif., is expecting to maintain AMT's operations in Fullerton, California.

New FCC Rules Publication

Pike & Fischer, Inc. announces the availability of *Private Radio Rules Service,* a new publication for public safety and business communications professionals who have to keep up with changes in the Federal Communications Commission's rules and regulations.

Private Radio Rules Service consists of a looseleaf reference volume containing the full text of *Part 90,* "Private Land Mobile Radio Services," *Part 94,* "Private Operational-Fixed Microwave Service," *Part 95,* "Personal Radio Services," *Part 99,* "Disaster Communications Service," and *Part 17,* "Construction, Marketing and Lighting of Antenna Structures" of the FCC's rules. All the FCC materials are updated on a regular bimonthly schedule, and each update includes a "Washington" newsletter that discusses Commission rule makings and summarizes significant recent court decisions and government actions affecting the allocation of spectrum for two-way radio and private paging.

A one-year subscription to *Private Radio Rules Service* is $175, plus a one-time charge of $85 for the 1300-page reference volume. Write Pike & Fischer, Inc., Suite 433N, 4550 Montgomery Ave., Bethesda, MD 20814; or call (301) 654-6262.

Tachonics and Gigabit Logic In Second Sourcing Agreement

Tachonics Corporation, an affiliate of Grumman Corporation's Electronics Systems division, and Gigabit Logic, Inc. have announced a second sourcing agreement whereby both companies will manufacture and distribute the same lines of gallium arsenide digital integrated circuits. This second sourcing agreement will include both standard and application specific gallium arsenide integrated cir-

cuits. The second sourcing agreement calls for design, manufacturing and test data of Gigabit Logic's standard cells and of its Picologic product family to be transferred to Tachonics. The standard cell "SCI" family includes a library of 25 fully characterized macros, and the Picologic family consists of over 30 standard logic functions. Cell libraries will be co-developed for future gallium arsenide processes.

MSC Joins Westinghouse MIMIC Team

Microwave Semiconductor Corporation (MSC) today announced that they have been added to the Westinghouse "Phase 1" MIMIC program team. MSC's role as a team member will be to develop power technology and provide "Power MMIC" foundry services. The company's team responsibilities will also include serving as a merchant supplier of MMIC sets. Along with team members Avantek and Rockwell, MSC will contribute technical support to the Westinghouse team. MSC was selected for its technology including: sub .5 micron E-beam gates; small area via-holes; high voltage power MMIC process; large signal non-linear modeling. MSC has recently completed a 100,000-square-foot wafer fabrication facility with 7,500 square feet of Class 10 clean area.

Airtron Acquires Hyletronics

Airtron, division of Litton Industries, Inc., has acquired Hyletronics of Littleton, MA. Hyletronics specializes in microwave stripline components and subassemblies including: solid state switch-driver assemblies, linear attenuators, variable attenuators, digital attenuators and directional couplers. Airtron has its divisional headquarters in Morris Plains, NJ. They serve the aerospace, avionics, communications, marine and military marketplaces.

Ford and Vitesse Sign GaAs IC Second Source Agreement

Ford Microelectronics, Inc. and Vitesse Semiconductor Corporation announced an agreement to provide alternate sourcing for foundry production of custom large-scale integrated (LSI) gallium arsenide (GaAs) integrated circuits. This agreement is the first of its kind among commercial gallium arsenide manufacturers. Compatible design rules for custom E/D gallium arsenide products can be furnished immediately. Ford and Vitesse share similar company charters of designing, manufacturing, and marketing digital LSI Enhancement/Depletion (E/D) gallium arsenide circuits for the commercial and military markets. To date, other gallium arsenide IC manufacturers have focused on producing small- to medium-scale integrated devices using the current industry standard Depletion Mode process.

EPSCO Receives $1.3M Contract

EPSCO, Incorporated of Westwood, MA, announced that its RF Division located at Westlake Village, CA, received a $1,255,000 contract from the U.S. Navy. The contract is for the design and production of a quantity of Command Transmitter Systems to be used at the Pacific Missile Test Center. The current contract has options extending into 1988 to purchase additional systems. The Division is also under contract to deliver a quantity of command transmitters to Hill Air Force base. EPSCO, Incorporated designs and manufactures RF/Microwave transmitter components and subsystems for defense and commercial markets.

rf calendar

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

January 20-21, 1988
San Diego Electronics Show
Del Mar Fairgrounds, San Diego, CA
Information: Epic Enterprises, Show Management, 3838 Camino Del Rio North-Suite 164, San Diego, CA 92108; Tel: (619) 284-9268

February 7-9, 1988
ADEE 88
Rivergate Exhibition Center, New Orleans, LA
Information: Show Manager, ADEE West, Cahners Exposition Group, 1350 East Touhy Ave., P.O. Box 5060, Des Plaines, IL 60017-5060. Tel: (312) 299-9311

February 10-12, 1988
RF Technology Expo '88
Disneyland Hotel, Anaheim, CA
Information: Linda Fortunato, Cardiff Publishing Company, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111; Tel: (303) 220-0600; (800) 525-9154

February 23-25, 1988
NEPCON West '88
Anaheim Convention Center, Anaheim, CA
Information: Jerry Carter, Cahners Exposition Group, 1350 East Touhy Ave., P.O. Box 5060, Des Plaines, IL 60017-5060; Tel: (312) 299-9311

March 7-10, 1988
33rd International SAMPE Symposium & Exhibition
Anaheim Convention Center, Anaheim, CA
Information: Marge Smith, P.O. Box 2459, Covina, CA 91722; Tel: (818) 331-0616

March 8-10, 1988
Southcon '88
Orange County Convention Center, Orlando, FL
Information: Electronic Conventions Management, 8110 Airport Boulevard, Los Angeles, CA; Tel: (213) 772-2965

April 19-22, 1988
IEEE Instrumentation/Measurement Technology Conference
San Diego Princess Hotel, San Diego, CA
Information: Bob Myers, IMTC, 1700 Westwood Blvd., Los Angeles, CA 90024; Tel: (213) 457-4571

May 9-11, 1988
38th Electronic Components Conference
Biltmore Hotel, Los Angeles, CA
Information: EIA, 2001 Eye St. N.W., Washington, DC 20006

rf courses

The George Washington University

SAW Devices and their Signal Processing Applications
February 22-25, 1988, Washington, DC
Electromagnetic Interference and Control
February 22-26, 1988, Washington, DC
Fiber-Optics System Design
February 29-March 2, 1988, Washington, DC
Electronic Countermeasures
February 29-March 4, 1988, Washington, DC
Solid-State Radar Transmitters
February 29-March 1, March 8, 1988, Washington, DC
Microwave Radio Systems
March 7-8, 1988, Washington, DC
Hazardous RF Electromagnetic Radiation
March 16-18, 1988, Washington, DC
Frequency-Hopping Signals and Systems
March 21-23, 1988, Washington, DC
Elements of Optical Warfare
March 30-April 1, 1988, Washington, DC
Spread-Spectrum Communications Systems
April 4-8, 1988, Washington, DC
Grounding, Bonding, and Shielding
April 7-8, 1988, Washington, DC
Modern Communications and Signal Processing
April 18-22, 1988, Washington, DC
Introduction to Receivers
April 18-19, 1988, Washington, DC
Modern Receiver Design
April 20-22, 1988, Washington, DC

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

Besser Associates

Microwave Circuit Design I: Linear Circuits
Feb 1-5, 1988, Los Angeles, CA
June 20-24, 1988, Los Angeles, CA
Microwave Circuit Design II: Non-linear Circuits
Feb 8-12, 1988, Los Angeles, CA

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

UCLA Extension

Superconductive Electronics
January 26-28, 1988, Los Angeles, CA
Microwave Circuit Design I
February 1-5, 1988, Los Angeles, CA
Microwave Circuit Design II
February 8-11, 1988, Los Angeles, CA
Modern Microwave Techniques
April 25-28, 1988, Los Angeles, CA

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

Test Systems, Inc.

MIL-STD-1553
February 24-25, 1988, Phoenix, AZ
May 10-11, 1988, Phoenix, AZ

Information: Leroy Earhart, Test Systems, Inc., 217 W. Palmaire, Phoenix, AZ 85021; Tel: (602) 861-1010

Interference Control Technologies, Inc.

Grounding and Shielding
February 8-12, 1988, Phoenix, AZ
February 22-26, 1988, Atlanta, GA
March 7-11, 1988, Palo Alto, CA
March 21-25, 1988, Hilton Head, SC
Tempest Facilities
February 1-5, 1988, Palo Alto, CA
Intro to EMI/RFI/EMC
March 15-17, 1988, Orlando, FL

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

Integrated Computer Systems

Digital Signal Processing
March 1-4, 1988, Ottawa, Canada
March 8-11, 1988, San Diego, CA
March 22-25, 1988, Washington, DC
April 26-29, 1988, Toronto, Canada
May 10-13, 1988, Washington, DC
Image Processing and Machine Vision
February 23-26, 1988, Ottawa, Canada
February 23-26, 1988, San Diego, CA
April 12-15, 1988, Washington, DC
April 26-29, 1988, Palo Alto, CA
Hands-On Programming in C
February 2-5, 1988, Washington, DC
February 16-19, 1988, Montreal, Canada
Hands-On Advanced Programming in C
February 23-26, 1988, San Diego, CA
March 8-11, 1988, Ottawa, Canada
April 5-8, 1988, Washington, DC
April 19-22, 1988, Los Angeles, CA
May 10-13, 1988, Toronto, Canada
May 24-27, 1988, Palo Alto, CA
Fiber Optic Communication
February 9-12, 1988, Los Angeles, CA
February 23-26, 1988, Washington, DC
March 15-18, 1988, Palo Alto, CA

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

Compliance Engineering

Compliance Seminars: EMI, Safety, ESD, Telecom
February 9-12, 1988, San Francisco, CA
April 19-22, 1988, Chicago, IL
June 7-10, 1988, Boston, MA

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

EMC Services, Inc.

EMI Control in Switched Mode Power Supplies
February 17-19, 1988, San Diego, CA
June 27-30, 1988, Boston, MA
Filter Design for Switching Supplies
February 22-23, 1988, San Diego, CA
July 1-2, 1988, Boston, MA

Information: Mark Nave, EMC Services, 11833 93rd Avenue North, Seminole, FL 33542. Tel: (813) 397-5854

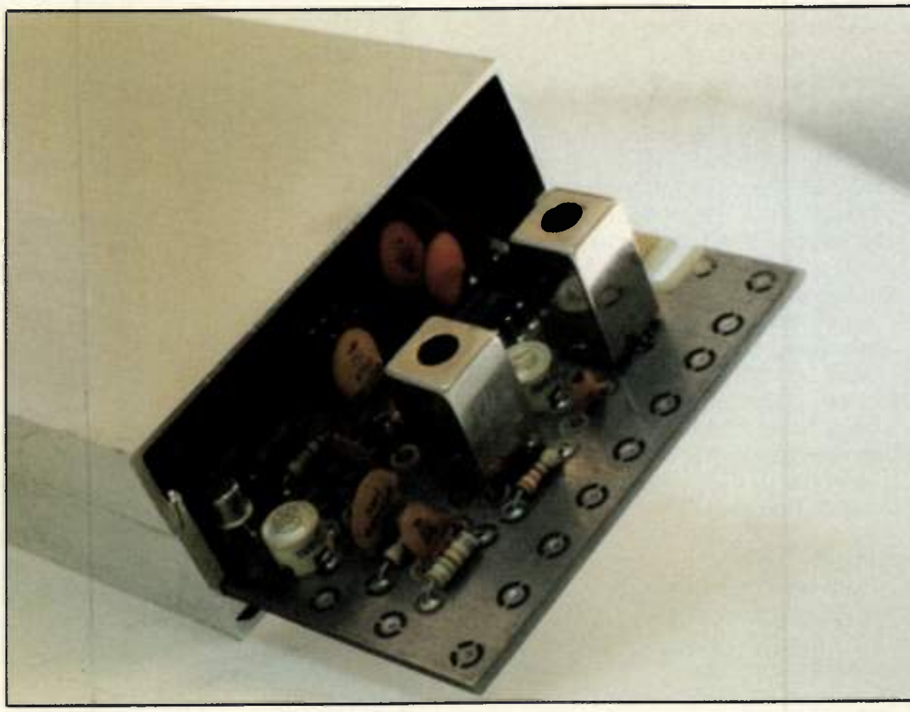
Georgia Institute of Technology

Principles of Pulse Doppler Radar:
High, Medium and Low PRF
February 23-25, 1988, Atlanta, GA
Infrared Technology and Systems Applications
February 24-26, 1988, Atlanta, GA

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

Development of a New Direct VHF Synthesizer

Engineering Staff
Programmed Test Sources



This story about the new PTS 300 synthesizer is an excellent case history describing development of a new product. By sharing functional and performance goals, and the engineering choices necessary to meet them, PTS' engineers not only describe their new instrument, they let us in on their design philosophy and engineering techniques.

Frequency synthesizers for producing a range precision frequencies came into widespread use during the 1960s and '70s. They vary in form from simple digitally tuned radio receiver-oscillators to complex microwave instruments costing $50,000 or more. Synthesizers sold as separate entities may be divided into two broad groups: "pure" synthesizers and synthesized signal generators. This distinction is mainly one of the intended use.

The PTS 300 is a "pure" frequency synthesizer. Instruments in this category incorporate only frequency generating synthesis circuits, and are usually designed to serve as systems components. Synthesized signal generators, primarily designed for laboratory use, are typically equipped with modulation capabilities, calibrated output attenuators and shielding to permit sub-microvolt sensitivity measurements.

The ability of frequency synthesizers to perform a particular job is determined largely by the users requirements for four parameters:

1. Frequency range, resolution and accuracy.
2. Purity of output signal in terms of the suppression of unwanted discrete outputs and spurious (angle) modulation.
3. Frequency switching speed.
4. Price.

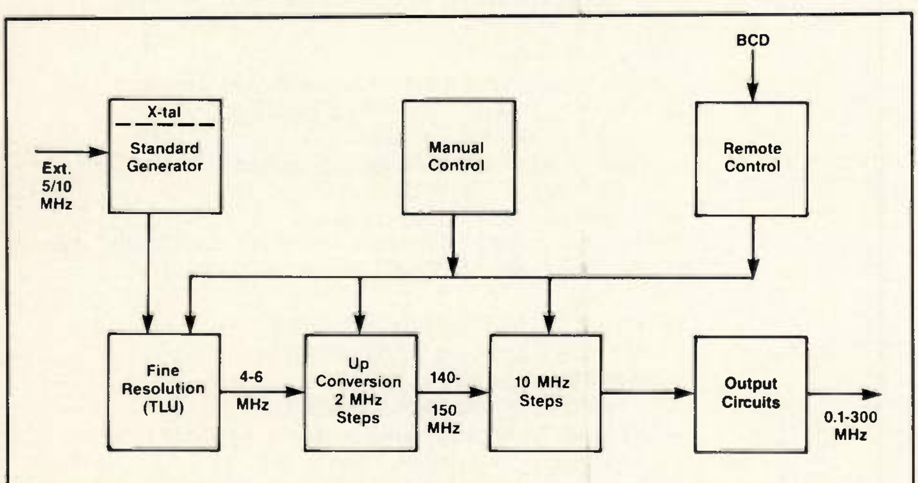


Figure 1. Block diagram PTS 300.

Design Goals and Engineering Philosophy

PTS' present line of synthesizers consists of five units with maximum frequencies of 40, 120, 160, 250 and 500 MHz. All have similar specifications, allowing the customer to select an instrument closely tailored to his frequency coverage needs without paying for excess performance. Although instruments have actually decreased in inflation-adjusted prices over the last few years, contemporary synthesizer design is not a mature technology, and properly directed R & D can enhance performance and still reduce cost.

To this end, PTS set the following target for a comletely new instrument: frequency coverage of more than 250 MHz with 1 Hz resolution, 20 μs frequency switching speed, −60 dB spurious outputs and broadband phase noise (0.5 Hz-15 kHz) below 1 milliradian, plus an architecture which would allow the simple integration of a fine resolution section offering phase continuous frequency switching and optional phase rotation. MTBF of 25 to

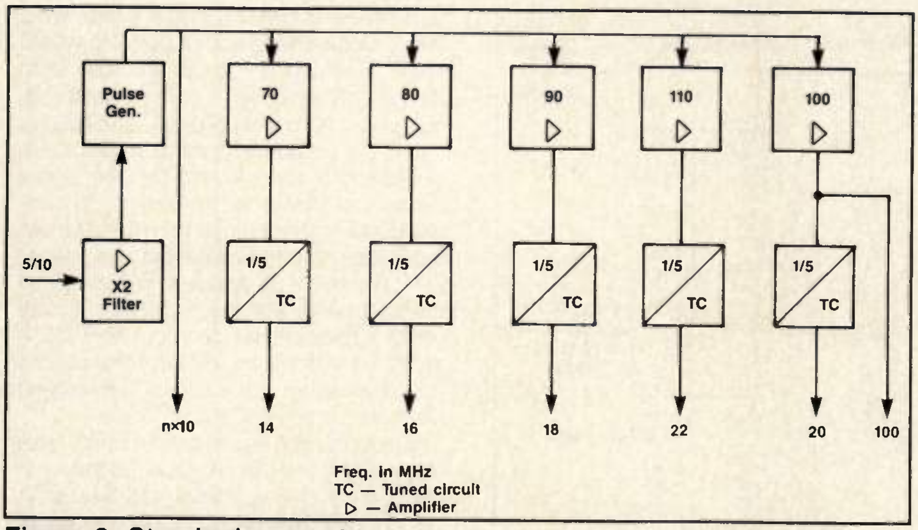


Figure 2. Standard generator.

30,000 hours, 3½-inch cabinet size, and a cost reduction of 20 percent from the present 250 MHz unit were further goals.

To reach these goals, a review of current technology was conducted. The need for cost-effective fine resolution, phase-continuous frequency switching and phase rotation all pointed to table-look-up direct-digital synthesis (TLU-DDS). This technology is offered in present PTS units as an option covering a 3 MHz bandwidth. It was determined that this bandwidth could be increased a factor 10 at the expense of considerably higher power consumption, higher manufacturing cost and a spurious level of only 40-45 dB. This technology alone is not suitable for a unit covering 250 MHz.

This situation is not new for the synthesizer designer. It is usually possible to produce a moderately narrow band of frequencies with fine resolution at a reasonable complexity and cost. However, whether the technology used is divide-by-n, repetitive mix-and-divide or TLU-DDS, it proves disproportionately difficult and expensive to increase the band coverage to even 100 MHz. More significant digits of the output signal must be produced by a different approach, and as a result, most modern synthesizers use a hybrid configuration.

Faced with this problem earlier in the design of the 160 unit, PTS engineers had developed a simple, effective solution: auxiliary frequency economy. The reduction in auxiliary frequencies and their use and re-use in both the fine resolution and more significant digit sections in the PTS 160 allowed the direct analog synthesizer to remain moderately priced. The HP 5100, the first direct synthesizer, used 27 auxiliary frequencies, while the PTS 160 makes do with only eight and a pulse. It was only natural, then, that the PTS design team further pursue simplification by reducing again the number of auxiliary frequencies needed and increasing the commonality in their generation.

Figure 1 is a block diagram of the PTS 300. Note that all auxiliary frequencies are produced in one module. This standard generator takes either 5 or 10 MHz form an internal or external source and in a pulse generator produces a "picket fence" of equal-amplitude frequencies from 10 to 150 MHz spaced at 10 MHz intervals. The 70 through 110 MHz frequencies are divided by 5 to produce 14, 16, 18, 20 and 22 MHz frequencies. It is evident that the filtering required to produce these frequencies with a suppression of spurious frequencies to 60 dB is minimal, because 2 MHz sidebands are at least 9 percent removed, while 10 MHz sidebands are divided and are even further removed from the carriers. The 14 through 22 MHz and the 100 MHz frequency form the set of auxiliary frequencies used in conjunction with the "picket-fence" pulse. The outputs and functions of this module are diagrammed in Figure 2.

TLU-DDS Fine Resolution Generation

Table-look-up direct digital synthesis was chosen to provide PTS 300's fine resolution. TLU-DDS, also called simply DDS, derives its name from the digital "table-look-up" process that is used to generate a sine wave frequency output. The technique uses a four-stage process, to cover a bandwidth with arbitrarily fine resolution. Block one is a phase accumulator driven by a system clock which increments phase from 0 to 2 π linearly in steps which are proportional to the selected frequency. The next block, a PROM look-up table, uses the output of the phase accumulator (or more specifically, the MSBs of the output) as an address into the PROM for the stored value of the sine wave amplitude. Block three, a DAC, receives the digital sine wave values from PROM and converts them to an analog output. A low-pass filter cutting off just above the desired bandwidth is used to suppress the clock frequency, the

Range:	0.1-300 MHz
Resolution:	1 Hz
Switching Time:	3-20 u sec.
Spurious:	−60 dB
Phase Noise:	63 dB (0.5 Hz-15 kHz); −115 dBc/Hz at 1 kHz offset
Price:	$5,050.00; Manual, remote incl. TCXO-standard
Phase Rotation:	Optional Resolution <0.5°

Table 1. PTS 300 Major Specs.

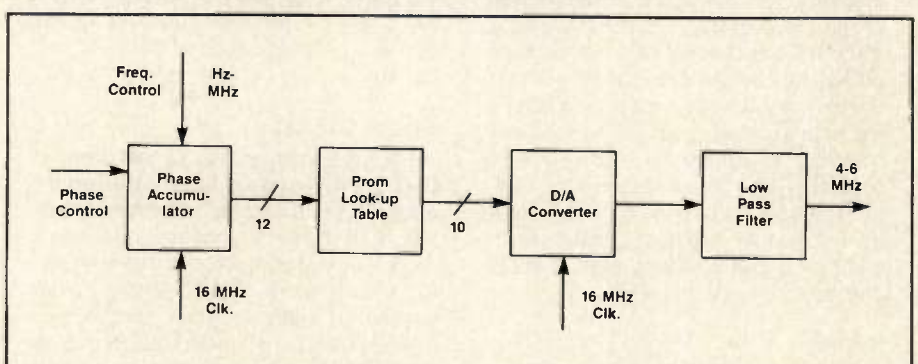


Figure 3. TLU-DDS section.

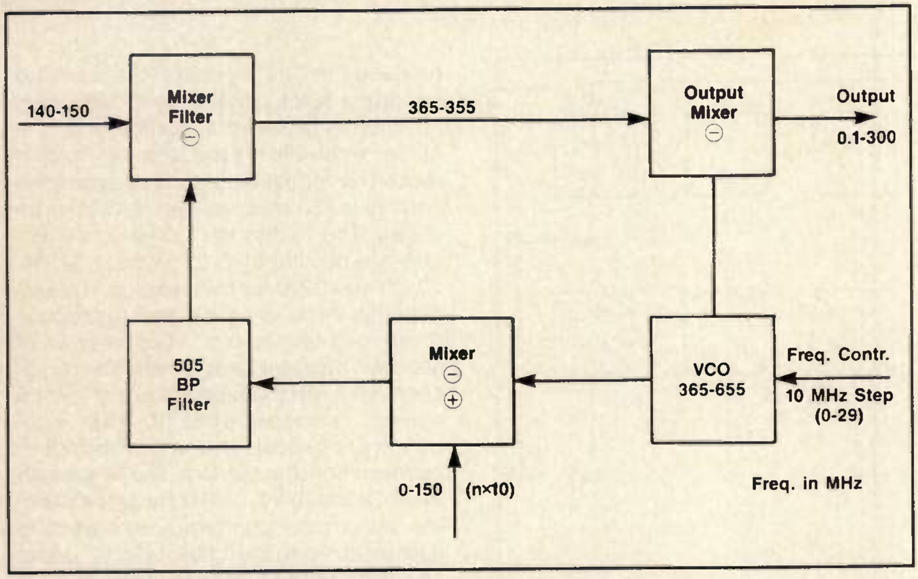


Figure 4. Wideband output 10 MHz step section.

output alias and higher harmonics.

Phase continuous frequency switching in this type of synthesizer results from the fact that within one clock cycle the phase increments output by the phase accumulator will assume the value proportional to the new frequency. Phase rotation can also be peformed by including a second accumulator which adds an increment proportional to the desired phase rotation to the output of the phase accumulator, and using the new sum as the address into the PROM of the stored sine wave values. Finally, another interesting property is the capability to arbitrarily set the phase of the output signal to zero by asynchronously resetting the phase accumulator to zero.

The key design decision for this section was the choice of the clock frequency, because it determines directly (via the Nyquist Theorem) the output bandwidth of the DDS, and the required speed (and power consumption) of the logic family employed. Further key components affected by the clock frequency are the PROMs and the DAC. All of the above also have a direct impact on the spurious output suppression performance.

An architecture allowing for the output of exact decimal frequencies and for BCD programming was selected rather than a binary architecture, to avoid code conversion in a BCD and decimal oriented market. With at least 7 decades of resolution required, internal propagation delays mandated F-type or faster logic. However, ECL logic was ruled out as too power intensive. Furthermore, it was established that a clock speed above 20 MHz would make reaching a −60 dB spurious level difficult. Resolution in the phase accumulator (or more precisely, the resolution of the portion of the accumulator output used to address the PROM) is the determining factor in the level of spurious frequencies which arise from finite phase quantization. In theory it is only necessary to increase this resolution to reduce angle modulation sidebands, but this is a first-order approach not considering PROM and DAC effects, and overall degradation with increasing clock speed is the usual practical result.

Unfortunately, F-type logic components required by a BCD-oriented DDS do not support reliable operation at 20 MHz. A novel hybrid binary-BCD DDS was therefore developed. This DDS operates at 16 MHz, generates exact decimal output steps with a resolution of 1 Hz, and provides an output bandwidth of 6 MHz. In addition, this architecture allows for a more efficient utilization of PROM storage, resulting in an improvement in the spurious output level over that provided by available pure-BCD DDS synthesizers. The final TLU-DDS fine resolution section is outlined in Figure 3.

MHz Step Up-Conversion

Up-conversion of the TLU output, containing all steps from 1 Hz to 1 MHz, is accomplished conventionally in the block following the TLU and takes the form of two mixes interspersed with selectivity of conventional double tuned filters and gain. The auxiliary frequencies from the standards-generator described are 100 MHz and 14-22 MHz (n × 2). The latter five frequencies are switched with transistors and together with the 2 MHz coverage from the TLU an output band of 10 MHz from 140-150 MHz is covered and constitutes the input to the 10 MHz step section.

10 MHz Step Generation

A wideband output generation scheme presently favored by many designers is a three-band approach, with an octave covering the top half of the desired output frequencies, a mid-band derived by one or two divisions by 2, and a low-band generated by a heterodyne system. Massive RF switching, discontinuities and three different specifications for spurs and noise are some of the detracting properties of this system.

PTS's approach is a simple one-band beat-frequency system. The same 10 MHz picket fence used to produce the auxiliary

Synthesizer Systems in Brief

Direct

With the aid of a limited number of auxiliary or standard frequencies, which are derived from the frequency standard, the output band is produced solely by arithmetic operations on these frequencies, using generally fixed-tuned filters and RF switches in addition to mixers, multipliers and dividers. The "mix-and-match" approach permits the use of many *identical* modules producing resolution-steps of widely differing significance, and arbitrarily small steps.

Indirect

Using phase-lock loops which may take various forms: Divide by n, fractional n and mix and divide governed by a derivative of the frequency standard. Mix-and-divide synthesis again can use many identical modules as above.

Direct Digital

Phase, accumulated at a rate dependent on frequency selected, is used to address a PROM which stores discrete values of the sine function. A D/A converts the digital output of the PROM to a sine wave which is low pass filtered to remove clock frequency, aliases and D/A glitches. Maximum frequency is one-half of clock.

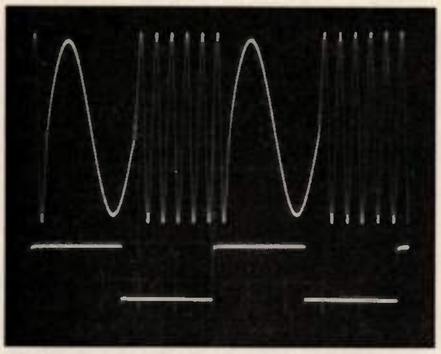


Figure 5. Switching sequence 100.080 to 100.480 MHz (−100 MHz) rate 40 kHz.

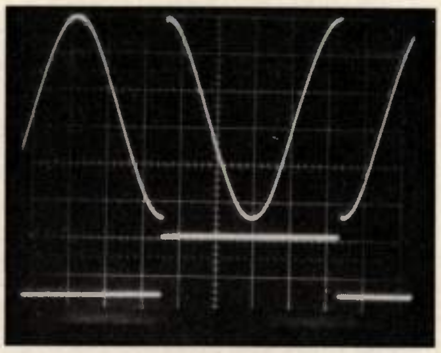


Figure 6. 180° phase step, 2 kHz rate.

frequencies is also fed to the 10 MHz step generator. Here, a drift-cancelled oscillator produces the 10 MHz steps from 0 to 290 MHz. Figure 4 shows the essentials of this arrangement. The technique employed is similar to the superheterodyne in principle, with tunable selectivity replaced with a stable fixed-tuned filter. At the same time this accomplishes up-conversion to final mix-frequencies which are high enough to produce the full wide-band output with an acceptable final mix ratio.

Packaging and Shielding

To achieve suppression of spurious outputs it is necessary to shield the various functional blocks. Depending on the degree of suppression required, packaging methods range from mechanical castings with gaskets and screws at 1-inch intervals to simple drawn shield cases. Regardless of the spurious specification, packaging accounts for a substantial portion of the cost of synthesizers. For this reason, and to allow the PTS 300 to be presented in a 3½ inch package, a new modular system was developed and tooled. (For manufacturability and ease of service all PTS products are of modular construction.) This new system uses a horizontal deck to support and interconnect vertical modules of varying length, all containing conventional circuit boards. The aluminum housing for these boards consists of two asymmetric half-shell extrusions that hold the board when assembled into their rectangular module form (see photo).

The more critical modules are outfitted with coax connectors and feed-through-filtered power and data lines, while the remaining modules use board-edge connectors reaching through the module bottom. Finally, only one shell is used to house boards that can remain open. All modules are readily removable.

Reliability Features

The PTS 300 must give our customers the same reliability that they have come to expect from the present line. Based on statistically meaningful quantities of equipment in the field with time frames of years, PTS in 1984 increased its warranty to two years and simultaneously covered years two through ten with a flat $300 repair charge. A failure rate of 3 to 5 percent per year is typical. This, dependent on duty rate, translates into a MTBF of approximately 25,000 hours. The same

PTS 300

Other

Figure 7. Carrier ±5 MHz, BW 95 Hz, Ref. −2 dBV.

basic concepts in design and engineering employed in earlier instruments were applied to this new design to maintain the track record.

From the outside in, a substantial frame-cabinet and the modules themselves lend rigidity to the complete structure, and provide the mechanical integrity required for protection of the electrical circuitry during transport, handling and installation.

Next and perhaps most important is the thermal management of the instrument. Since chemical processes (destructive or other) double in speed with every 10°C increase in temperature, significant benefits are derived from moderate reduction in internal power dissipation. A general heat-rise of 15°C or less is considered mandatory for PTS designs.

Surface mount devices were considered for this instrument, since a reduction in size was needed. They were ruled out for several reasons: sufficient component density, in light of power density, could be achieved with conventional components; assembly time savings for projected quantities would not permit early payback of special equipment costs; finally, reservations about reliability of a thermally stressed sandwich of substantially unequal materials (fiberglass and ceramic) persist, and industry experience to date does not dispell these concerns.

An aspect of considerable benefit to the reliability of PTS equipment is a disinclination to be found at the cutting edge of technology. The watchword is proven concepts of simplicity and economy.

Performance

The design described meets all targets established at the outset: Table 1 summarizes the salient specifications, Figure 5 shows a phase continuous switching sequence and Figure 6 depicts a 180° phase step.

With 1 GHz signal generators costing roughly $4,000 to $6,000 available from at least four major manufacturers, it is reasonable to ask why the PTS 300 should command $5,000 when it does not have the range or the additional signal generator capabilities of these devices. Two performance parameters account for the difference. The first is switching speed. It is readily understood and usually specified unambiguously so that the user can judge whether the speed offered by the much slower signal generators is adequate for his use. 3-20 μs for the PTS 300 contrasts with times several orders of magnitude longer.

Signal purity in terms of close-in phase noise is the other area in which very significant differences exist and where several methods are used to characterize performance of synthesized sources. Figure 7 depicts identical spectrum analyzer scans of 10 kHz for a PTS 300 and a $6,000, 1 GHz signal generator. Note the noise pedestal which is very typical for this type of generator. For "off-channel" tests of receivers noise one channel width offset from the carrier needs to be some 130-140 dBc/Hz, which is a demanding specification.

For many high-Q resonance applications, however, phase noise closer than 1 kHz to the carrier is becoming more important. Spectral density figures are quoted to 10 Hz offsets and are sometimes demanded for 1 Hz and 0.1 Hz offsets. In this area the phase noise of the PTS 300 is distinctly superior. For more information on the PTS 300, please circle INFO/CARD #152. rf

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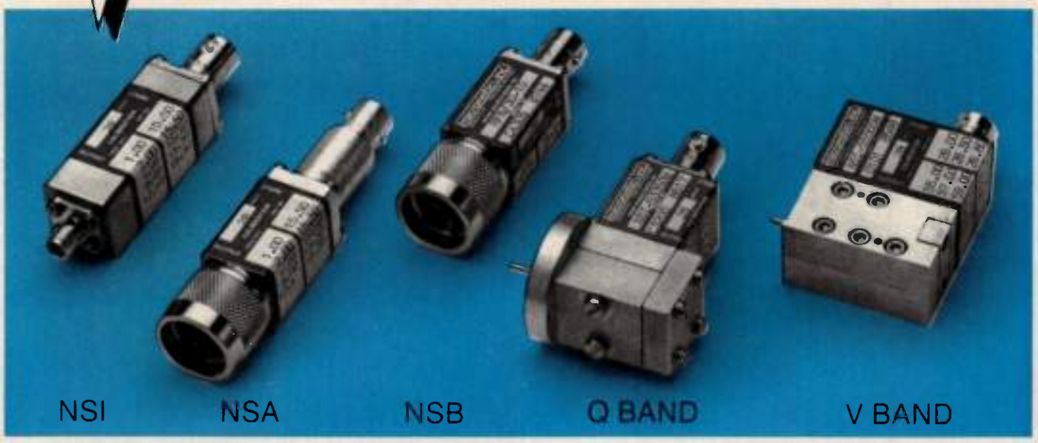

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RFN/30-10	.010- 1.0	30 Min	±1	N	.010,.500,1.00
RFN/25L	1.0 - 2.0	30 Min	±1		1.0,1.5,2.0
RFN/25S	2.0 - 4.0	30 Min	±1	S	1.0
RFN/25C	4.0 - 8.0	30 Min	±1		
RFN/25X	8.0 -12.0	25 Min	±1	B	GHz
RFN/25Kμ	12.0 -18.0	25 Min	±1	NSA	STEPS

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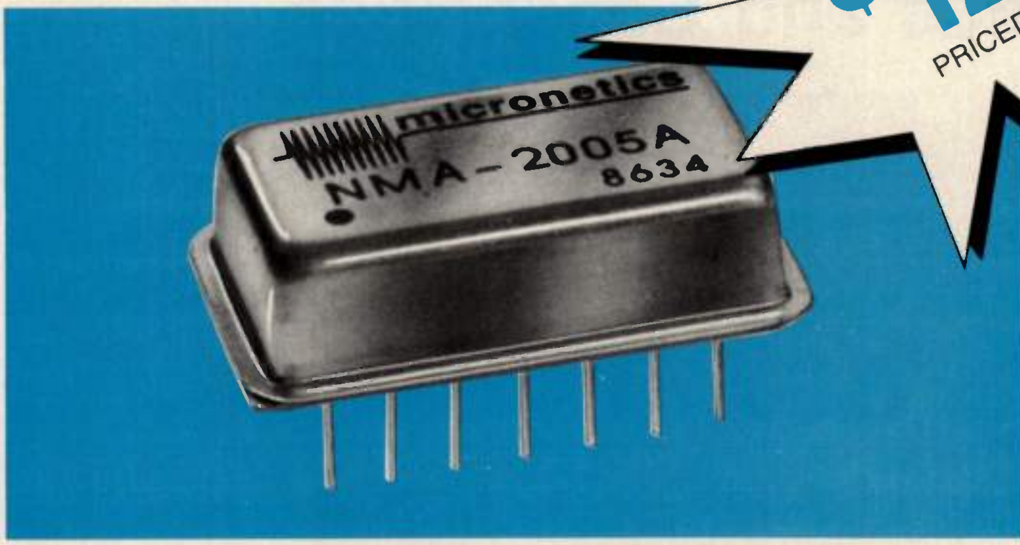

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		Flatness	mV/band	$\mu V/\sqrt{Hz}$	dBm/band	dBm/Hz	ENR(dB)
NMA-2001	100Hz-100kHz	± .5 dB	5	15.8	−32	−82	91.0
NMA-2002	100Hz-300kHz	± .5 dB	10	18.2	−27	−82	92.2
NMA-2003	100Hz-1MHz	± .5 dB	10	10.0	−27	−87	87.0
NMA-2004	100Hz-3MHz	± .5 dB	10	5.8	−27	−92	82.2
NMA-2005	100Hz-10MHz	± .5 dB	10	3.2	−27	−97	77.0
NMA-2006	100Hz-30MHz	± .5 dB	5	.91	−33	−108	66.2
NMA-2007	500Hz-100MHz	± .75dB	2.5	.25	−39	−119	55.0
NMA-2008	500Hz-300MHz	±1.0 dB	4.4	.25	−34	−119	55.0
NMA-2009	500Hz-500MHz	±1.5 dB	5.6	.25	−32	−119	55.0

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INFO/CARD 19

Test Equipment — New Features and Capabilities

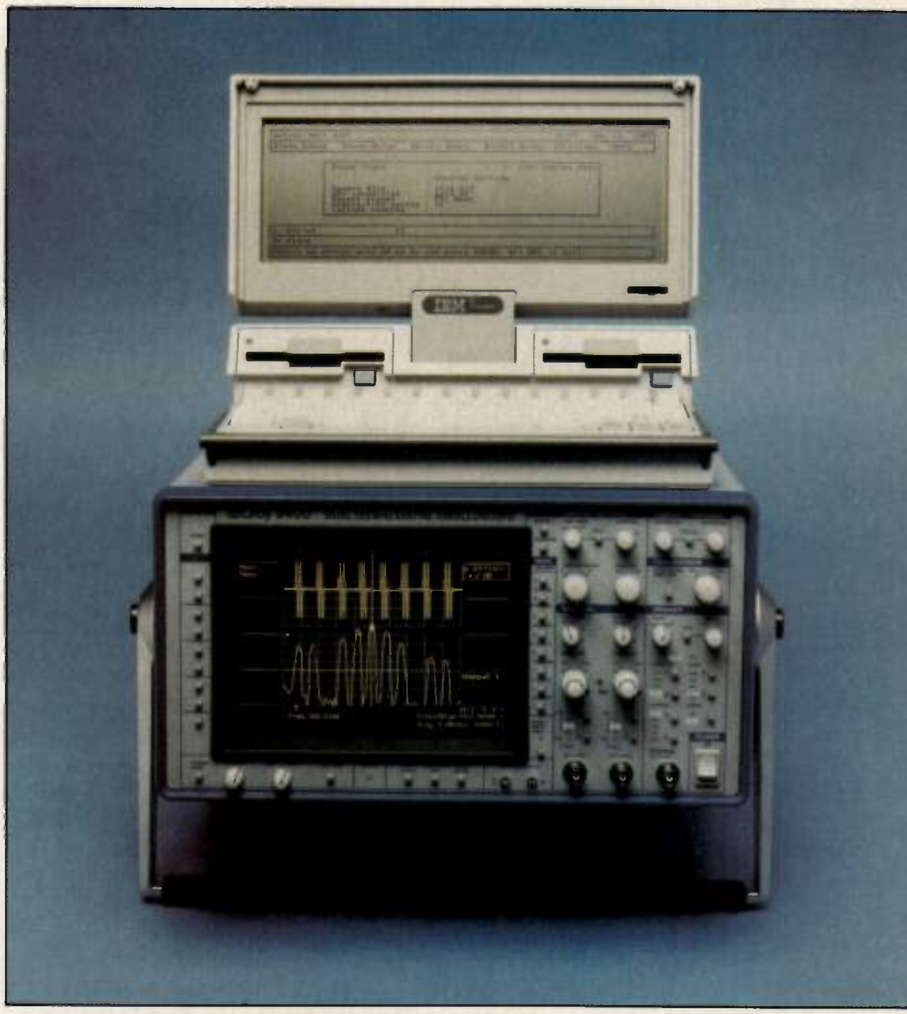
By Mark Gomez
Assistant Editor

The new era of test equipment has added powerful features to otherwise conventional test equipment. Options like floppy disk drives, high resolution displays, and automatic screen dumping to printers are commonly seen. Spectrum analyzers incorporated with built-in demodulators and audio monitors are also now available. IEEE-488, GPIB and RS232 links are universally available options. Interface and control software together with laptop controllers are available from the instrument giants as well as smaller instrument firms. With an abundance of companies in this market, the RF test instrument consumer can choose from a large assortment of instrument/option combinations at competitive prices.

Oscilloscopes are very versatile and important instruments to the RF engineer. Two packages for LeCroy's 9400 digital storage oscilloscope offers mass storage and remote control. The user can store and retrieve full, partial, or segmented waveforms. Partial waveform storage allows recording only that section of the waveform that is of interest, ensuring efficient storage of hundreds of waveforms on a floppy disk. Front panel setups together with date and time stamps can also be stored. The MS01 package includes an IBM laptop computer with full keyboard, screen and dual floppy disk drives. A GPIB for communication and data transfer up to 220 kbytes/sec is included.

A writing speed of 3000 cm/us is featured in the Iwatsu Instruments Model TS-8123 100 MHz oscilloscope. A digitizing speed of 1200 cm/us (equivalent to a 25 GHz clock) can be obtained when waveforms are converted from analog to digital format after analog storage.

A feature that allows the user to observe waveforms, setting conditions and measured values on a single display is incorporated in a 60 MHz CRT readout oscilloscope from Leader Instruments. The LBO-2060 reduces set-up time by displaying the salient setting conditions such as channel sensitivity, main and delayed sweep time and triggering controls. A cursor provides direct readout of voltage differences in volts and percentage, time difference, frequency in Hz and phase difference in degrees.



This LeCroy oscilloscope features mass storage.

Rapid Systems has a 2-channel 20 MHz digital storage oscilloscope that uses a PC for display and storage. The features include 2-channel simultaneous acquisition, 20 MHz sampling rate per channel, switch selectable 1 M ohm or 50 ohm BNC input, programmable gain and sample rate, menu driven operation and screen dumps to the printer. It is tailored for IBM and compatible computers.

Power Meters

IEEE-488 interface has been incorporated into the Rohde & Schwarz Model NAP power meter. The meter measures incident and reflected power directly from an integral directional coupler. Four 50 ohm power sensors with a frequency coverage of 25 MHz to 1 GHz is available with a power range from 20 mW to 1100 W. This instrument also calculates VSWR, reflection coefficient and return loss. Another feature provided is DC analog outputs proportional to incident and reflected power for plotting purposes.

A single channel microwave power meter which is complemented by a broad family of sensors including thermocouple and diode sensors for low and high power measurements is available from Wavetek. The Model 8531 features GPIB and one button calibration.

Spectrum Analyzers

The current trend in spectrum analyzers is portability, storage devices for stor-

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Solartron Instruments, Elmsford, NY. INFO/CARD #154.
Noise Com, Inc., Hackensack, NJ. INFO/CARD #153.

ing waveforms and control settings, pop-up menus, GPIB and low cost. The new generation of these instruments feature versatility even though the price and size are headed downwards. Tektronix recently introduced the 2756P which has an operating range from 10 kHz to 325 GHz. This particular instrument has an average noise level of −134 dBm and a resolution of 3 MHz to 10 Hz. The portable version of the above instrument is designated the 494AP.

A surface acoustic wave spectrum analyzer that features a 10 MHz bandwidth with 16 kHz resolution and designated the 160-10-100(C)MC is available from Phonon. Its dynamic range is 70 dB. This instrument has applications in general high speed signal processing, doppler processor for laser radar, goniometry and electronic counter measures.

A single unit that is capable of vector network and spectrum measurements is available from Hewlett-Packard (HP 4195A). It has a frequency range of 10 Hz to 500 MHz, a flexible disk drive, color graphics CRT and provides rectangular, tabular, Smith and polar display formats for viewing measured data.

Vertical raster scan CRT display is included in the A-8000 from IFR Systems. Other interesting features of this instrument include a frequency range of 10 Hz to 500 MHz, single function keyboard entry, menu driven display modes and automatic amplitude calibration.

Laboratory Amplifiers

Amplifiers are no exception to the trend of size and price reduction. Certain companies are even producing modular amplifiers for OEM applications. Modular units also make servicing and repairing easier.

Class A linear performance with Class B efficiency is a key feature of Analogic's AN80 Series amplifier. This is accomplished with high speed bias gating of high power FETs. It provides single chassis pulsed power from 100 W to 1000 W and is field expandable from 2 kW to 4 kW with additional chassis.

Instruments for Industry has introduced the Model M5580 amplifier that has 75 W of output with its frequency range broken down into two bands: 10 kHz to 500 MHz and 500 MHz to 1.0 GHz.

Instantaneous bandwidth can be obtained with the Models 25W1000M7 and 10W1000M7 broadband amplifiers from Amplifier Research. The outputs are 25 W and 10 W respectively.

Function Generators

In order to evaluate how a system performs, the engineer has to be able to simulate a condition related to its field application. Function generators are the one key instrument that almost every RF engineer must have access to in order to ensure that his analog system works the way it is supposed to.

Custom and standard waveforms can be generated with the LeCroy Model 9100 arbitrary function generator (AFG). It features custom waveforms in a dual output generator at up to 200 mega points per second. The AFG generates square waves or pulses up to 100 MHz and sine waves up to 25 MHz.

The Rohde & Schwarz function generator AFGU has a frequency range from 1 uHz to 20 MHz and produces sinewave, triangle, square, trapeze and pulse signals. User specific waveforms can be generated using the arbitrary functions. A 4K parameter memory with a resolution of 10 bits is available and start/stop addresses can be set to produce curve segments or individual curves. The XY coordinates can be entered via the keyboard or IEC/IEEE bus. Other features include internal or external FSK and pulse modulation, external AM, FM and VCO.

Other Instruments of Interest

Receivers are definitely a major part of RF testing. Since the dawn of RF, engineers created the need to be able to measure the signal being transmitted in terms of intensity and phase. Some of the new features in receivers include wide dynamic and frequency ranges. The Weinschel VM-7 for example is a 30 MHz receiver designed for applications where precise measurements of RF power ratio are required over a wide dynamic range. The 7516-1 from Interad Ltd. is a VHF/UHF receiver with a frequency range of 20 to 1000 MHz and noise figure of 10.5 dB.

A frequency counter with nine digits of resolution is available with Racal-Dana's Model 1999. This 2.6 GHz counter has external arming that provides different portions of the burst to be synchronized for frequency profiling. Optional GPIB provides full programmability of front panel function keys and signal conditioning controls.

A frequency response analyzer from Solartron features two channels operating in parallel and offers basic gain and phase accuracy of 0.02 dB and 0.2 degrees respectively. The analyzer uses a single sine correlation analysis technique to provide fast and precise measurement of amplitude and phase.

A noise source that provides 50 W of white Gaussian noise from 10 to 175 MHz is available from Noise Com. The NC 9800 has a VSWR of 2:1.

The amount of new and interesting instruments is too large to be mentioned in an article of this size. The instruments mentioned are the ones that RF engineers most commonly use. The integration of digital techniques and processing has brought about some high precision, fast and relatively cheap instrumentation. The list of options being offered with the new family of instrumentation is not only long but it also provides a wealth of information and control that can be obtained with a single instrument.

The ability to interface and remotely control instruments has eased the burden of the test engineer. Also, the convenience of being able to process and store and recall data and control setting has reduced the setup time for specific pieces of equipment.

For additional information on the products listed please circle the appropriate reader service number. rf

S-Parameters of Wideband Op Amps and Buffers

By Brian Mathews
Harris Corporation

All electrical engineers study two-port parameters. Typically covered are y, h, and perhaps Z-parameters. Measuring these parameters becomes increasingly difficult as higher frequencies are attained. It is possible to transform the total voltages and currents in the standard two-port equations into terms of travelling waves or transmission lines. In this way, parameters are derived in terms of signal power transmission and reflection coefficients. Characterizing wideband op amp and buffer components in the frequency range from 100 kHz to 200 MHz using S-parameters would allow RF designers to work with these devices in terms they are familiar with. This report describes the test methods used and will provide test results in a graphical form.

S parameters are reflection and transmission coefficients that can be used to describe a linear two-port network, much the same way as y, Z, or h-parameters. "S" or scattering parameters differ from the others because they define the network in terms of its characteristics due to incident travelling waves. The S-parameter equations are as follows:

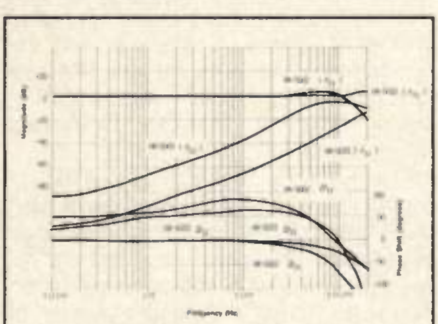

Figure 1A. A plot of S_{21} and S_{12} versus frequency for HA-5002 and HA-5033.

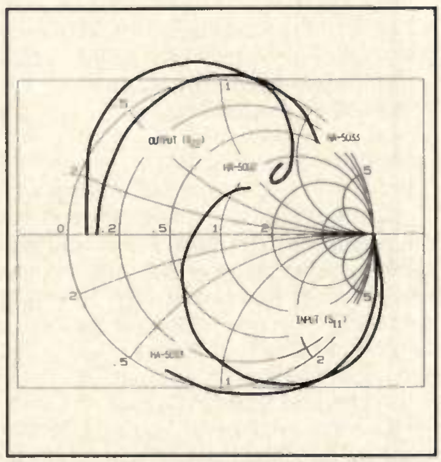

Figure 1B. Complex impedance (normalized to 50 ohms) from 100 kHz to 200 MHz for HA-5002 and HA-5033.

$$b_1 = S_{11}a_1 + S_{12}a_2$$

$$b_2 = S_{21}a_1 + S_{22}a_2$$

where:

$$a_1 = \frac{E_{i1}}{\sqrt{Z_o}} \qquad a_2 = \frac{E_{i2}}{\sqrt{Z_o}}$$

$$b_1 = \frac{E_{r1}}{\sqrt{Z_o}} \qquad b_2 = \frac{E_{r2}}{\sqrt{Z_o}}$$

E_{in} represents the voltage wave incident on port n, while E_{rn} is the wave reflected from port n and Z_o is the characteristic impedance of the transmission line. Since a_1, a_2, b_1 and b_2 are composed of a voltage divided by the square root of an impedance, the magnitude of variables a_n and b_n squared are the power incident or reflected at port n.

In general S-parameters have the advantage of being easier to measure at high frequencies than other two-port parameters. The standard parameters require the shorting and/or opening of the network's terminals, which cannot be done easily at high frequencies. To achieve an *open* or *short* termination, a *short* is used and the line length is varied until a *short* or *open* is reflected to the circuit under test. The line length would have to be varied as the frequency changed to get a swept frequency measurement. Also, many active devices are not stable with a *short* termination. S-parameters require only that the network terminals be terminated in the system characteristic impedance. They describe the network completely, including magnitude and phase information. In particular, S_{11} and S_{22}, in polar form with a Smith chart overlay, provide a direct measure of complex input and output impedance versus frequency.

Although S-parameters are usually used to describe discrete transistors for RF and microwave design purposes, they can provide valuable information about any linear two-port network, including op-

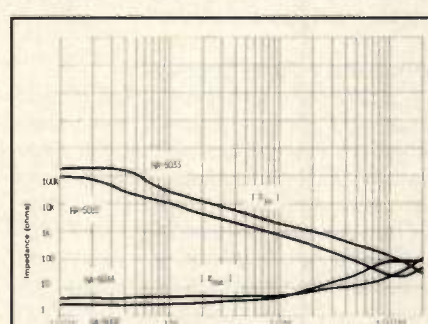

Figure 1C. A graph of impedance versus frequency for the HA-5033 and HA-5002.

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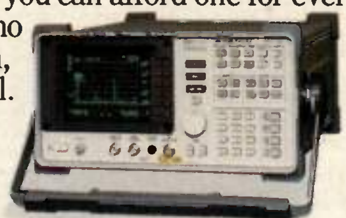

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Newton refracts light through a glass prism, circa 1672. "The Bettmann Archive."

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A short review of S-parameters

S or scattering parameters, are a method of describing an n-port linear network, similar to the well known h, y and Z parameters. The difference with S-parameters is that where h, y, and Z are defined in terms of total voltage and current, S-parameters are defined in terms of the incident and reflected power at a port of the network, referred to the characteristic impedance of the transmission lines involved.

Transmission line theory tells us that unless the line is perfectly terminated in its characteristic impedance there will be a reflection from the end of the line of an applied or incident signal and that this reflection property will set up a standing wave. Utilizing these facts, the S-parameters can be derived. The convention of using "a" as the incident parameter and "b" as the reflected parameter will be used in this discussion.

Given that E_{i1} and E_{r1} are the incident and reflected voltages at port one, and likewise for E_{i2} and E_{r2}, then the expressions for total voltage and current are:

$$V_1 = E_{i1} + E_{r1} \qquad V_2 = E_{i2} + E_{r2}$$

$$I_1 = \frac{E_{i1} - E_{i2}}{Z_o} \qquad I_1 = \frac{E_{i2} - E_{r2}}{Z_o}$$

V_n is the voltage at port n, and I_n is the current into port n, and Z_o is the characteristic impedance. Substituting into the h-parameter equations:

$$V_1 = h_{11}I_1 + h_{12}V_2$$

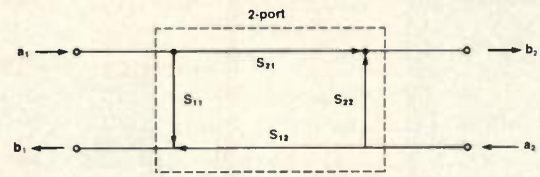
$$I_2 = h_{21}I_1 + h_{22}V_2$$

Rearranging terms so that incident waves are the independent variables and reflected waves are the dependent variables yields:

$$E_{r1} = f_{11}E_{i1} + f_{12}E_{i2}$$

$$E_{r2} = f_{21}E_{i1} + f_{22}E_{i2}$$

Where f_{11}, f_{12}, f_{21}, and f_{22} are functions of the h-parameter set that now relates travelling voltage waves rather that total voltage and current. Note that h-parameters were chosen arbitrarily and any parameter set could have been used. Defining new variables a_1,



S-parameter description of a 2-port network.

S-parameter description of a 2-port network.

b_1, a_2, and b_2 (also known as incident parameters and reflected parameters-as follows:

$$a_1 = \frac{E_{i1}}{\sqrt{Z_o}} \qquad a_2 = \frac{E_{i2}}{\sqrt{Z_o}}$$

$$b_1 = \frac{E_{r1}}{\sqrt{Z_o}} \qquad b_2 = \frac{E_{r2}}{\sqrt{Z_o}}$$

This yields the S-parameter equations:

$$b_1 = S_{11}a_1 + S_{12}a_2$$
$$b_2 = S_{21}a + S_{22}a_2$$

Figure 4 shows a conceptual model for a two-port network described by S-parameters. The magnitude of a_n or b_n squared is the power incident or reflected at the respective port. As the diagram indicates, S_{11}, the input reflection coefficient, is a measure of the fraction of incident signal at port 1 that is reflected back to the source and thus is directly related to input impedance. S_{21} is the forward transmission coefficient and is the fraction of incident signal at port two which is transmitted back through the network to the input port one, while S_{22}, the output reflection coefficient, is the fraction which is reflected back to the load.

An attractive feature of this arrangement is that by terminating either port in the characteristic impedance the reflection term is reduced to zero. Thus when port two is terminated properly no signal is reflected, $a_2 = 0$, and:

$$S_{11} = \frac{b_1}{a_1}$$

$$S_{21} = \frac{b_2}{a_1}$$

Likewise, port two can be driven and port one can be terminated which sets $a_1 = 0$ and then:

$$S_{12} = \frac{b_1}{a_2}$$

$$S_{22} = \frac{b_2}{a_2}$$

Although S-parameters are thought of as signal power relationships, if the signal source has a source impedance equal to the characteristic impedance and the opposite port is terminated properly, the forward and reverse transmission coefficients, S_{21} and S_{12}, are simply voltage transfer ratios, V_{in}/V_{out}, either in the forward or reverse direction. It can be shown that for a lossless transmission line terminated in its characteristic impedance:

$$S_{11} = S_{22} = 0$$

This means that zero energy is reflected which is consistent with transmission line theory. Considering S_{11} or S_{22} as just the single S of a one-port, it can be shown that for an open circuit, S = 1, and for a short circuit S = −1. To conclude this discussion a list of conversion from "S" to h, v, and Z-parameters is provided in Table 1.

References

1. Roy Hejhall, RF Small Signal Design using Two-Port Parameters, Motorola Semiconductor Products, Inc., Application Note AN-215A

2. Franklin Kuo, *Network Analysis and Synthesis*, John Wiley and Sons, 1966

3. S-Parameters. . .circuit analysis and design, Hewlett-Packard Company, Palo Alto, California, Application Note 95

4. Parameter Design, Hewlett-Packard Company, Palo Alto, California, Application Note 154

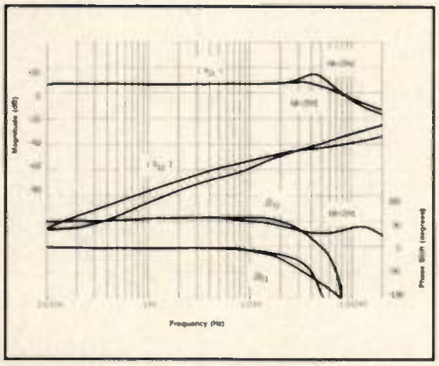


Figure 2A. S_{21} and S_{12} plots.

amps and buffers. Usually op-amps are only characterized for input and output impedance at low frequencies. By examining swept-frequency polar plots of S_{11} and S_{22}, the exact values of input and output impedance in the frequency range of interest can be determined. In fact, the proper instrument will be capable of displaying impedance versus frequency directly. The other parameters can be used to evaluate the transfer characteristics of the amplifier. S_{21} is the ratio of voltage incident at the load to the voltage incident at the input port, a plot of gain and phase over frequency (Bode plot). S_{12} is a measure of reverse isolation or the ratio of voltage incident on a termination placed at the input terminals to the applied incident voltage at the output terminals.

General Considerations

To ensure the integrity of the test results great care has been taken to minimize test

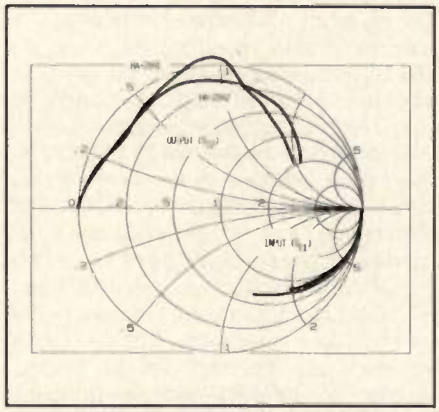


Figure 2B. Complex impedance.

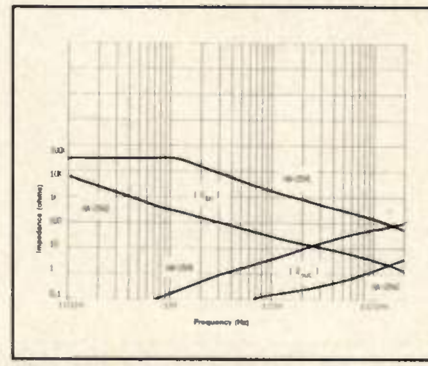


Figure 2C. Impedance plot.

circuit parasitics. All test fixtures are built either on PC boards with ground planes or in metal boxes with the case grounded. Component lead lengths have been kept as short as possible although it was necessary to socket the test devices rather than solder them into the boards. Probe cable lengths were kept to a minimum and precision matching loads were used as necessary.

The op-amps were tested in various feedback conditions, typically in a non-inverting configuration (see test results

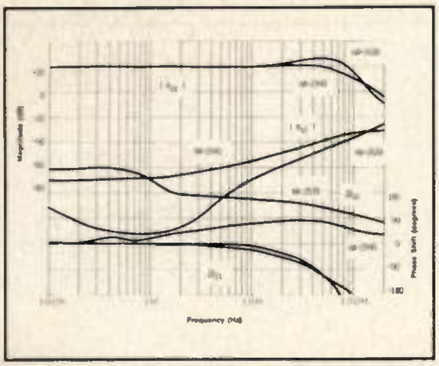


Figure 3A. S_{21} and S_{12} for the HA-2539 and HA-2540.

section for exact configuration). Also, some devices were not designed to drive RF loads directly so their output stage is buffered. These different test configurations are indicated in the results section.

The primary test instrument for this evaluation is the Model 3577A network analyzer from Hewlett-Packard. An associated instrument, the 35677A S-parameter test set allows direct measurement of S-parameters over the 100 kHz to 200 MHz frequency range. Signal power, sweep time, display scale, display format, and many other factors are selectable from a series of menus and associated front-panel function keys. The network analyzer performs calibration routines to compensate for test fixture and cable impedances. This evaluation is based on a 50 ohm characteristic impedance.

Some of the device characteristics can be predicted based on what is know about the circuits. A fundamental difference between the devices is that some are op-amps while others are unity-gain buffers. The op-amps all have two differential inputs and provide complex amplification. The buffers are single-ended with a single input terminal and a fixed unity open-loop gain over a specified bandwidth. The two input terminals on the HA-2539 and HA-2540 each connect to the bases of two transistors. The HA-2541 and HA-2542 have simpler input stages and each input terminal connects to only one base of a transistor. The buffers (HA-5033 and HA-5002) input terminals connect to the bases of four transistors. The base of a transistor can be modelled as a large resistor in parallel with a parasitic capacitor so the devices with fewer base

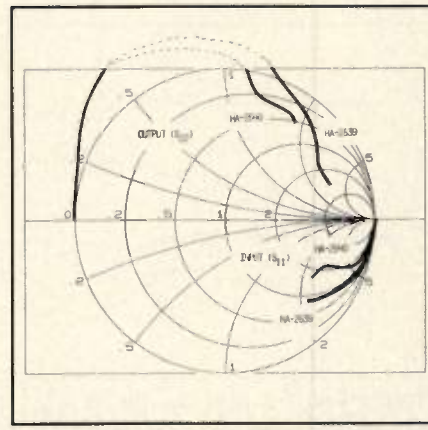


Figure 3B. Complex impedance for the HA-2539 and HA-2540.

connections at the input terminals should have higher input impedance at high frequencies. The output model is a very small resistance in series with an inductor due to the nature of a transistor's emitter, and all these devices have emitter connections at the output. Some devices have emitter degeneration resistors between the output device emitter and the output terminal so these devices will exhibit higher open-loop output impedance.

Since the input and open-loop output impedances of these devices are usually not equal to the characteristic impedance of a standard RF transmission line, the general nature of the S-parameter curves can be anticipated. Owing to the high input impedance, most of the incident signal is reflected so S_{11} is near unity and it's real component decreases as frequency increases while the imaginary part traverses the capacitive half of the plane with steadily decreasing negative values. Due to the low, inductive output impedance, S_{22} starts with a small real component which stays small through a large frequency range but eventually veers inward toward the center of the Smith chart while the imaginary part remains in the inductive half of the plane with steadily increasing positive values. In addition to Smith chart plots of S_{11} and S_{22}, the network analyzer provides plots of input and output impedance which is included in the results section.

The graphical results of the testing are shown in the accompanying figures. The S_{21} plots of those devices that cannot drive a 50 ohm line are actually plots of the device with a buffer between the device's output and the instrument's test port. All other plots are directly from the device itself with no buffering. Note that in most cases the signal level is approximately −10 dBm at the output of the device under test.

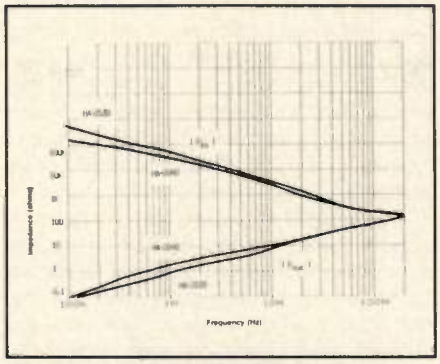


Figure 3C. Impedance versus frequency for the HA-2539 and HA-2540.

Interpretation of Results

As the S_{21} curves indicate, these devices operate over varying bandwidths with the HA-5033 having the widest effective bandwidth. Figure 2A shows the response of the HA-5033 to be flat to 100 MHz and then slight peaking to 200 MHz. Next in bandwidth is the HA-5002 buffer with an effective bandwidth of approximately 100 MHz (Figure 1A). Note that the buffers do not provide the amount of reverse isolation (S_{12}) that the op-amps do, but they are still adequate for most purposes. The widest band op-amp is the HA-2539 which provides 20 dB of gain out to 60 MHz with less than 180 degrees phase shift (see Figure 3A). Also, the HA-2539 isolates the input from the output by at least 40 dB over it's entire useful frequency range (Figure 3A). This isolation characteristic is common to all the op-amps. Remember that the op-amps are general purpose and their response is strongly dependent on feedback and load conditions. A different gain configuration, with different load and feedback conditions may produce a significantly different response, so any particular application situation should be evaluated on a breadboard before committing it to production. As the S_{21} plots show, all these devices are useful well into the tens of MHz, especially the HA-2542 which can drive the 50 ohm line directly. The HA-2542 has a frequency compensation pin which can be used to tailor the frequency response. It could be used to eliminate the gain peak evident in the S_{21} curve in Figure 2A.

The simple assumptions made previously regarding the number of bases connected to the input terminal is shown to be wrong by the plots of input impedance. Based on that assumption, the buffers would have lowest input impedance then HA-2539/2540 and HA-2541/2542. As the Z_{in}/Z_{out} curves indicate, the highest input impedance devices are the buffers HA-5002/5033, followed by the op-amps HA-2539/2540, and HA2541/2542. Thus, it is obvious that other circuit design factors must be considered to predict the nature of the S-parameter curves. The most significant characteristic of these devices' input impedance is that it is constantly changing with frequency. This implies that a properly tuned conjugate network in series with the input terminal would yield a constant input impedance.

The S_{22} and Z_{out} plots show that all these devices have very low output impedance over their operating frequency ranges, none higher than 100 ohms magnitude. Of note are the S_{22} plots in Figure 3B indicating that the HA-2539/2540 have negative real components of output normalized impedance, which is common in active devices.

Conclusion

Although S-parameters are most commonly used to describe discrete transistors, they can indicate a great deal about op-amp and buffer products as well. This report has shown many of the advantages of using S-parameters, as well as describing what information they can provide about linear devices. rf

About the Author

Brian Mathews is a marketing engineer at Harris Semiconductor, Palm Bay Road, M/S 58-68, Palm Bay, FL 32905. His phone number is (305) 729-4644

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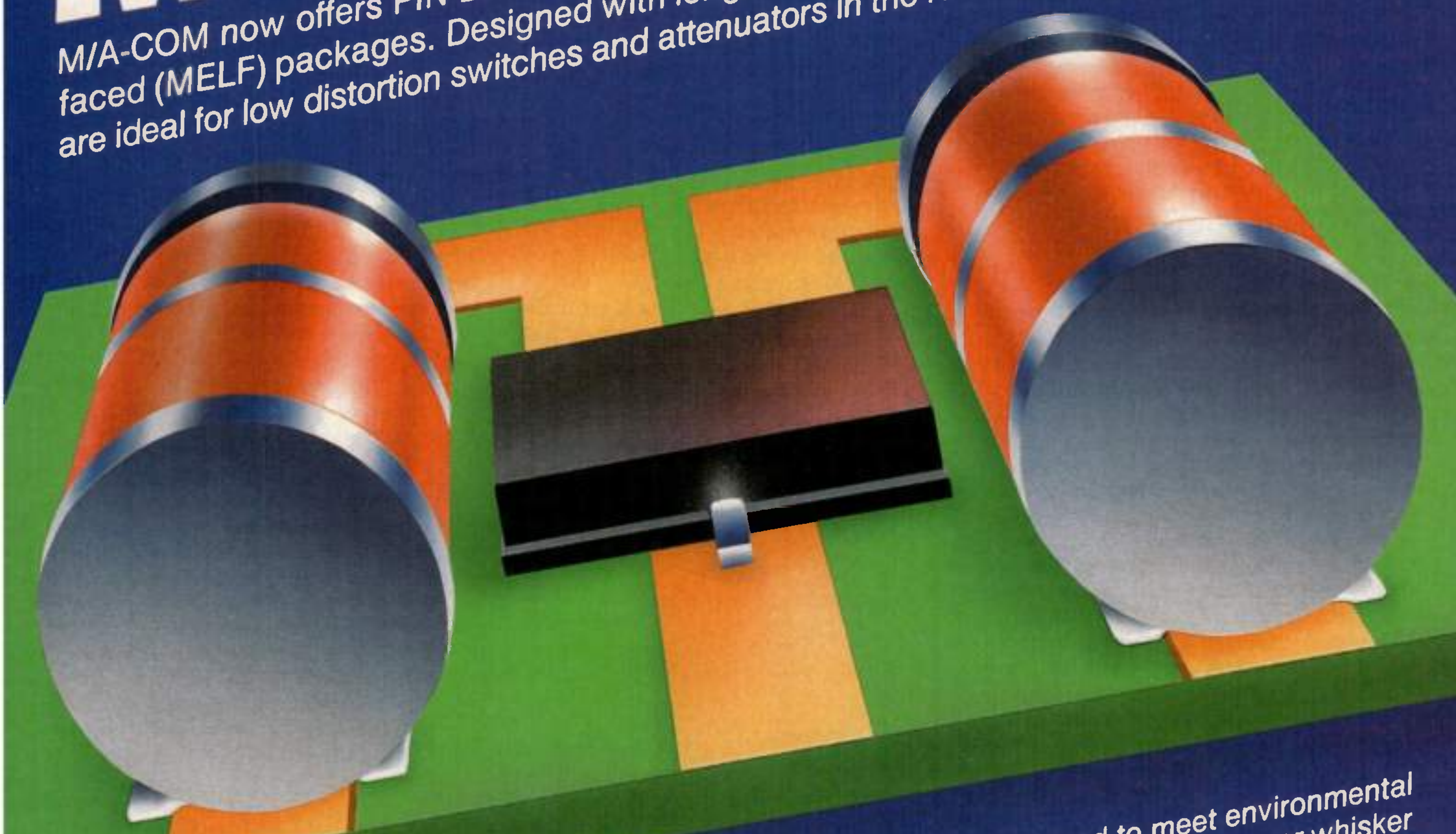

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RF Radiation Hazards: Power Density Prediction for Communications Systems

Gary A. Breed
Editor

Public awareness of the potential hazards of non-ionizing (electromagnetic) radiation is growing rapidly. Unfortunately, until that awareness grows to the point where there is proper understanding of the phenomena involved, mis-statements, unfounded claims, and other such incomplete information will be tossed about as being "the truth." This note covers the fundamentals of power density prediction, using the simplest antenna radiation models, providing an introduction to the methods required for evaluating public safety concerns.

The standard most commonly referred to for the limits of human exposure to RF is ANSI C95.1-1982. Figure 1 shows the limits contained in C95.1-1982 is both graphical and tabular form. The nature of the standard, its development and possible future modification has been discussed previously (1, 2). This article's examples are based on this standard.

To begin an understanding of power density, we first must look at the fundamental radiation model: the isotropic radiator (Figure 2). By definition, an isotropic radiator is a point source radiating equally in all directions (in three dimensions). The power density resulting from an isotropic source is the projection of the source power onto an element of a spherical surface, given by:

$$P = P_t/4\pi R^2 \text{ [Units in mW, cm — } P \text{ (mW/cm}^2\text{)]} \qquad (1)$$

where, P is the power density, P_t is the transmitted power, and R is the distance from the source.

From this basic model, all other far-field models can be derived. Figure 3 shows a hemispherical model cross-section, which is a point source radiating in half-space (not penetrating below a planar ground surface). The relationship of the hemispherical to isotropic power density is a factor of two, since the same power illuminates half the area, compared to isotropic, therefore:

$$P = 2\, P_t/4\, \pi R^2 \qquad (2)$$

One more common model is the half wavelength dipole (Figure 4). Because the radiation from the dipole exhibits directivity, the radiation in favored directions is increased by a factor of 1.64 (2.15 dB) over an isotropic radiator:

$$P = 1.64\, P_t/4\, R^2 \qquad (3)$$

Real World Applications

Radiation from most antenna systems can be referenced to one of the above models. For example, a one-quarter wavelength vertical monopole fed against ground is a combination of the hemispherical and dipole models; or, a commercial communications antenna may be specified as having a gain of 6 dB relative to a dipole. As long as we are in the far field (usually considered to be a distance 10 times the longest dimension of the antenna), the simple models can be used.

The first example is a 100-watt mobile radio operating at 150 MHz, using a one-quarter wavelength monopole antenna mounted on an automobile body. The antenna is a combination of a dipole (including the monopole's ground image) and hemispherical radiator (making the assumption that a metal car body represents an "infinite" ground plane), hence the power density at the point of maximum radiation is:

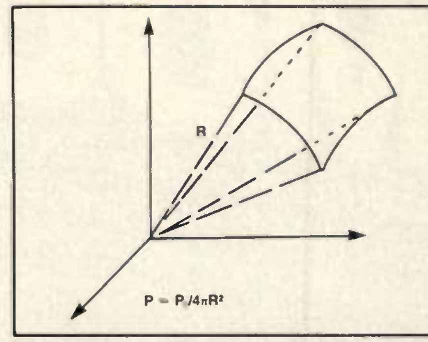

Figure 2. Isotropic radiator model.

Radio Frequency Protection Guide (RFPG)

Frequency Range (MHz)	E^2 (V^2/m^2)	H^2 (A^2/m^2)	Power Density (mW/cm^2)
0.3-3	400,000	2.5	100
3-30	4,000 ($900/f^2$)	0.025 ($900/f^2$)	$900/f^2$
30-300	4,000	0.025	1.0
300-1500	4,000 (f/300)	0.025 (f/300)	f/300
1500-100,000	20,000	0.125	5.0

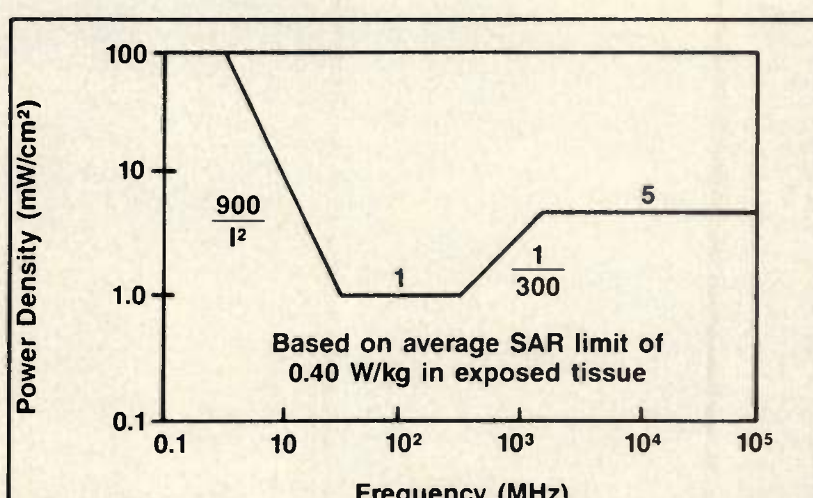

Figure 1. ANSI C95.1-1982 Standard.

New Product Helps Maintain Test Site Integrity

Generator Provides Reference Standard

How do you know if the integrity of your test site is being compromised? Leaky gaskets, loose cable connections, and stray RF signals are only a few of the things that can cause test site characteristics to change. Sometimes the changes are so gradual, they may go unnoticed for an extended period of time. Until these flaws are corrected, the validity of your test results are in question.

What is the best way to assure accuracy and repeatability of your test site? Perform periodic maintenance and calibration of your test equipment, then make attenuation measurements of the site itself. However, for maximum confidence, you'll probably need to do this more often than is practical.

Now EMCO solves this problem with the introduction of the Model 4610 Royce Field Site Source. Site verification is now so simple it can be performed in just a few minutes at the start of each day.

The Model 4610 is a portable self contained emissions generator that produces a short output pulse with harmonics in the 10 to 600 MHz range—levels near FCC Class A & B limits. To verify your site, you would use a signal analyzing device and an antenna to measure some or all of the emitted signals produced by the Model 4610. By comparing the amplitude of the received frequencies with references you established earlier, you can easily spot variations that indicate areas to investigate.

The Royce Field Site Source from EMCO—another way to "Test With Confidence!"

Call or write for a reprint of an IEEE Symposium paper describing theory and usage.

New Catalog and Calendar Available

EMCO's new 80 page catalog is packed with helpful product info on more than 50 different antennas and accessories for EMI/RFI compliance testing. Send for your free catalog today and we'll also send you our 1988 calendar—it's a big 20" x 30" that includes helpful formulas and a product selection guide.

Call or write for your copy today.

Metal Topped Turntables Preferred by New FCC Standard

Nine Metal Turntable Models Available

The proposed FCC MP 4 (July 1987) regulation suggests the use of metal topped turntables for compliance testing of floor standing equipment. While not yet required, metal topped turntables are nevertheless gaining popularity. And EMCO is the popular choice! It's easy to see why. We offer nine models to choose from, with diameters ranging from four to sixteen feet and load capacities of up to 5000 lbs. (custom sizes and special load ratings are available).

Our standard features include; digital readout controller with an IEEE-488 bus, 10 meters of cable, 370 degree rotation, choice of 100 or 220 VAC on export models, two year parts and labor warranty. Options include; grounding system, variable speed motor, continuous rotation, shielded room kit, on-site installation.

Call or write for a complete description of both our metal topped and standard turntables.

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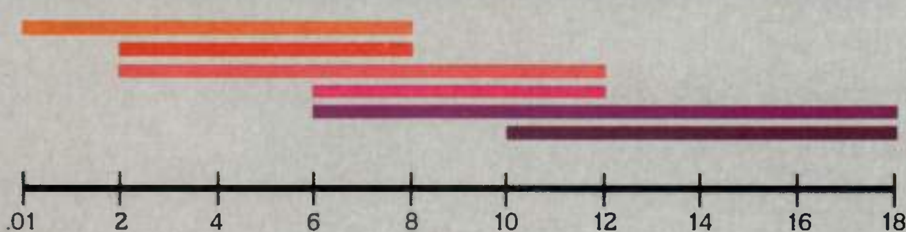
The Microwave Sweeper with Auto-Lock



Ranges and features that set the new standard

Giga-tronics Series 610 Microwave Sweepers are all you expect from a sweeper, and a lot more.

- Sweep speeds to 600MHz/msec for fast, real-time testing
- Five (8 via the bus) frequency identifying markers
- F1/F2, marker to marker and ΔCF sweep modes with direct BW readout
- Ten milliwatts of leveled output power and 119dB of attenuation
- Excellent CW phase noise characteristics
- Wide range AM and FM
- Save/recall of complete panel settings and IEEE bus control

Only the Series 610 has them all.

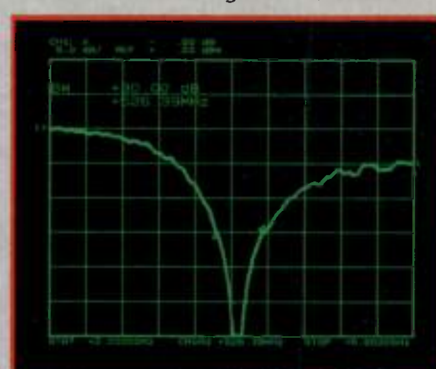
Plus Auto-Lock

Auto-Lock means CW accuracy and stability. Accuracy is 1 part per million; a few kilohertz vs the old standard of tens of megahertz. Stability is equally good, over time, temperature and line or load variation. It also provides digital lock at the start of each sweep. Like adding a $6,000 lock-box or source synchronizer, but Giga-Sweeper has it built-in at no extra cost; the perfect match for your network analyzer.

And More

More Giga-Sweeper extras: pulse modulation, spectral purity and step and lock mode. Pulse modulate a Giga-Sweeper with 100nsec pulses, you'll get on/off ratios >80dB and rise/fall times <25nsec. Harmonics (>40dB down) are 15 to 20dB better than your old sweeper. Spurs are >55dB down, CW SSB phase noise typically <-75dBc/Hz at 10kHz offset. Step and lock stops at precise frequencies, giving you time to record, or make adjustment, before stepping on.

A Giga-Sweeper is a sweeper, a lock-box and a signal generator for the price of the sweeper. Prices start at about $15,000 and don't go over $22,000.



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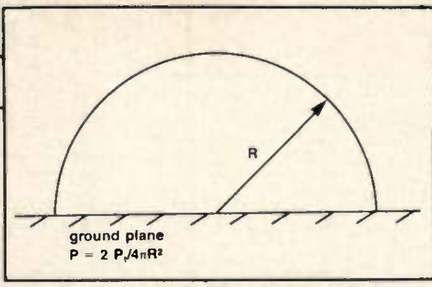

Figure 3. Hemispherical model.

$$P = 3.28\ P_t/4\ R^2 \quad (4)$$

The maximum radiation will be normal to the antenna element, or horizontal. With 100 watts power, this is:

$$P = 3.28\ (100000\ \text{mW})/4\ R^2 = 26101/R^2 \quad (5)$$

At this frequency, the RFPG limit is at its lowest, 1 mW/cm². The distance at which the limit is equalled is then:

$$1 = 26101/R^2 \text{ or,} \quad (6)$$

$$R = 161.6\ \text{cm} \quad (7)$$

From this we see that within 162 cm the radiation from this system exceeds the 1 mW/cm² ANSI guideline. However, it must be noted that the RFPG includes six minute time averaging. To be exposed to RF in excess of the limits, a person must be within 162 cm of the antenna for six minutes, during which the transmitter is operated continuously. This would be an unusual, but possible, situation. This corn-putation demonstrates the hazard poten-

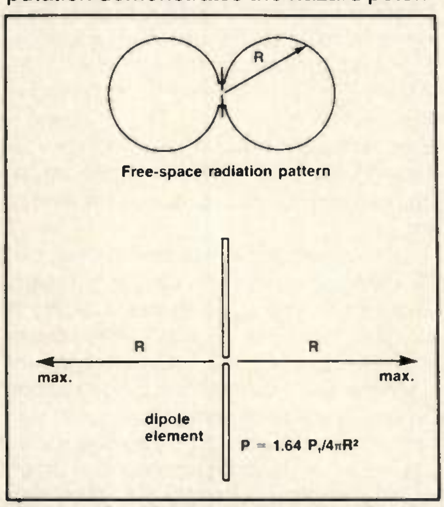

Figure 4. Half-wavelength dipole model.

tial of high-power VHF mobile transmitters. Fortunately, the general trend in land mobile communications is toward lower power mobiles, using repeaters to achieve the desired range.

The next example of a situation that might be encountered by the public is an amateur radio installation with a Yagi-Uda antenna array operating at 29 MHz. The following parameters are assumed:

Antenna height = 30 feet (9.1 m) above ground

Power output = 1500 W (amateur legal limit)

Antenna gain = 11 dBi

Distance from antenna to nearest accessible point (neighbor's home) = 40 feet (12.2 m).

The power and height were chosen to make this a "worst case" example, allowing maximum radiation figures to be used.

The isotropic model is first multiplied by the gain (11 dB = 12.6 numerical gain), then the information is substituted into the power density formula to get:

$$P = 12.6\ (1500 \times 10^3\ \text{mW})/4\pi\ (1220)^2 = 1.01\ \text{mW/cm}^2 \quad (8)$$

At 29 MHz, the RFPG guideline is 900/f² mW/cm², or 1.07 mW/cm². The situation described creates a power density approximately equal to the limit, but again, only if the conditions are continuous. In this case, such continuity is possible, since amateurs are authorized to use FM and FSK modes which have a continuous power output, and a person can certainly remain stationary in their own home.

While these are definitely "worst case" examples, they should point out the need for attention to RF power density levels when planning any communications facility. Although the land mobile and amateur radio services are not currently regulated with regard to hazardous radiation by the Federal Communications Commission, such regulation could be introduced at any time.

Figure 5 illustrates the inability of the above simple models to predict actual radiation in near-field situations.

The example is that of a multiple-dipole array, a configuration that might be used in land mobile communications, and related to the types of antennas used for FM and television broadcasting (3). In the near field, where a worker might be located, or other persons might be present if the array is rooftop mounted, the far-field model breaks down. The power and phase relationships among the elements create different power densities, although the resulting level will always be less than that predicted by a point source/far field models such as those used earlier.

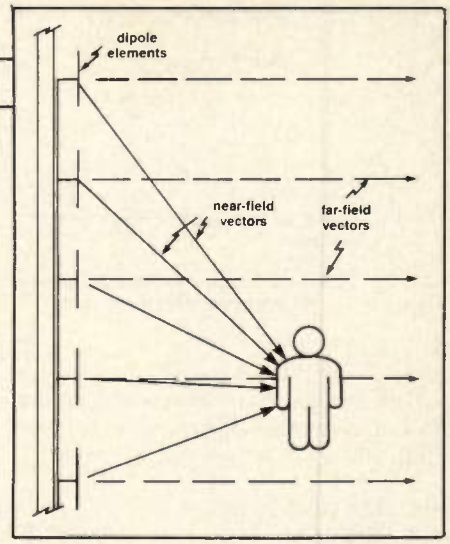

Figure 5. Example of near-field exposure to multi-element dipole array, demonstrating need for separate near-field analysis.

The topic of near-field antenna modeling is too large to be addressed in this paper, which was intended to provide a basic understanding of the situation. However, to predict compliance with the ANSI RFPG in all situations, such modeling will be necessary. The Numerical Electromagnetic Code (NEC) or its PC-based subset MININEC3 (4) are logical choices for more complex antenna modeling.

Of course, actual measurements can be made on an existing facility, but many times data is required before a facility is constructed. With governmental bodies and the public very interested in environmental concerns, including radiation hazards, advance planning dictates that modeling and prediction replace measurements as the primary means of determining whether a facility complies with the ANSI guidelines. rf

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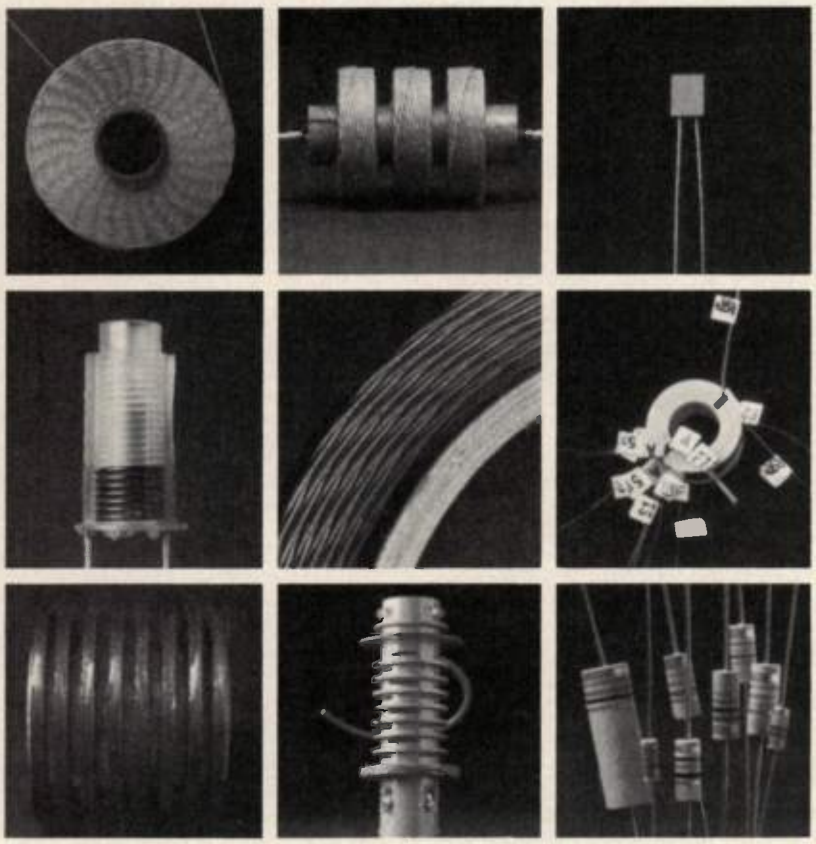
2. M. Gomez and G. Breed, "RF Radiation Hazards: An Update on Standards and Regulations," *RF Design*, Vol. 10, No. 10, October 1987, p. 33-37.
3. "Near-Field Radiation Properties of Simple Linear Antennas with Applications to Radiofrequency Hazards and Broadcasting," Electromagnetics Branch, Office of Radiation Programs, U.S. Environmental Protection Agency, June 1978.
4. J.C. Logan and J.W. Rockway, "The New MININEC (Version 3): A Mini-Numerical Electromagnetic Code," Naval Ocean Systems Center, Technical Document 938, September 1986.



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Reduce synthesizer spurs by incorporating Paramixer technology into critical frequency translator stages. Paramixer frequency converters have been designed having M × N products (M>3, N>2) at more than −100 dBc with 0 dBm input.

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Noise figure	<6.5 dB
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INFO/CARD 34

Marconi Introduces A Scalar Analysis System

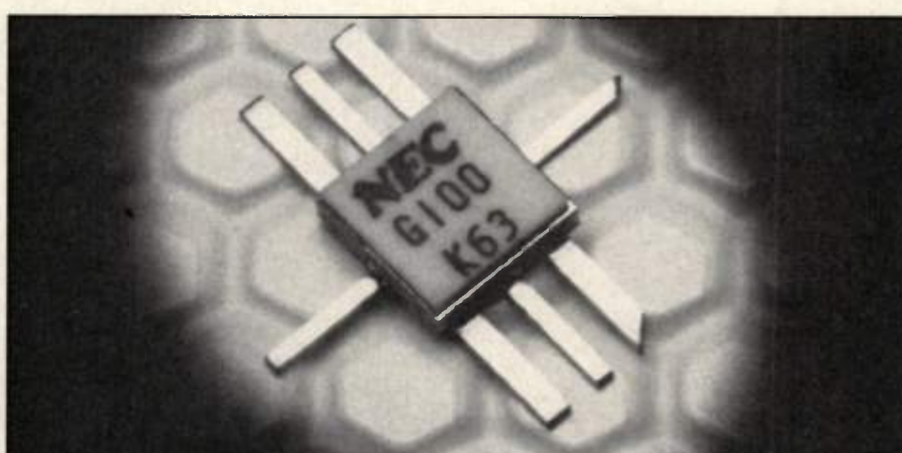
The Model 6311 programmable sweep generator is designed for scalar network analysis, active device measurement and ATE testing. It was developed to complement the existing Model 6310 and offers an extended frequency range of 10 MHz to 20 GHz. Its features include a frequency accuracy of ±3 MHz typically in CW mode and ±20 MHz over any sweep width is provided for precision swept measurements by digital control.

When used in conjunction with Marconi's 6500 Automatic Amplitude Analyzer and an autotester, the 6311 forms part of a complete scalar network analyzer system. Major applications for the system include testing cables, connectors, amplifiers, PIN switches and test applications in radar, telecoms, and satellites.

The high purity signal coverage required for scalar analysis has been incorporated in the design of the 6311 to guard against serious errors in filter measurement caused by harmonics and subharmonics. Between 2 and 20 GHz, harmonics and sub-harmonics are −40 dBc and −60 dBc respectively. Coverage of .01 to 2 GHz is provided with low harmonics of −30 dBc and low spurious of −40 dBc.

The device has a power level accuracy of ±.5 dB over .01 to 2 GHz and ±4 dB over 2 to 20 GHz. For ATE testing, where speed of switching signals is important, a sweep of 15 ms from .01 to 20 GHz is provided. This meets ATE requirements such as TWT testing, radar system performance and military sub-system test racks. **Marconi Instruments, Allendale, NJ. INFO/CARD #220.**

GaAs MMIC Wideband Amplifiers from CEL



Two wideband amplifiers, the low noise UPG 100 and medium power UPG 101 have been added to the NEC family of GaAs MMIC amplifiers. Both devices have a frequency range of 0.5 to 3 GHz.

The UPG 100 has a minimum gain of 14 dB and a typical gain of 16 dB. The gain flatness is measured at ±1.5 dB maximum. NF in decibels is measured at 2.7 (typ) and 3.5 (max). The minimum 1 dB compression point is at 3 dBm while the maximum is at 6 dBm.

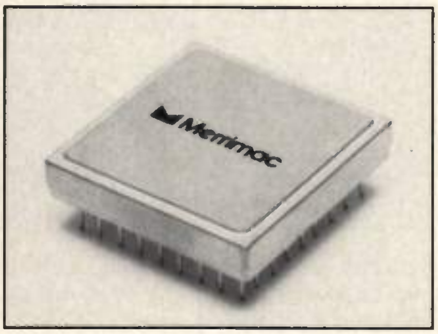
The UPG 101 has a gain of 12 dB minimum and 14 dB typical while maintaining the same gain flatness as the UPG 100. Typical NF is 5.0 dB and maximum NF is 7.0 dB. This device has a 1 dB compression point at 16 dBm (min) and the typical value is 18 dBm. Both devices are input and output matched to 50 ohms.

Applications for the devices include IF/RF amplifier to S-band for military and commercial communications systems, instrumentation, military EW and radar, GPS receiver LNAs, and satellite communications systems.

The devices come in chip form as well as in an 8 lead ceramic flat package suitable for surface mount, microstrip, and stripline applications. The UPG 100 is also available in a 4-pin can package (UPG 100A). In quantities of 100, the UPG 100P is $34.50 and the UPG 101P is $41. **California Eastern Laboratories, Inc, Santa Clara, CA. INFO/CARD #219.**

12-Way Power Divider

Merrimac introduces a 20 to 500 MHz 12-way power divider (PDP-12S-260) that has an isolation of 25 dB between channels with a maximum VSWR of 1.30:1.



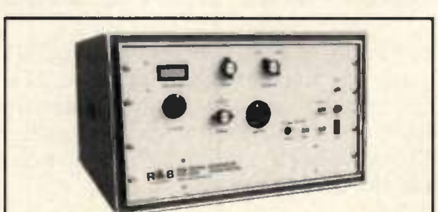
Amplitude balance has been controlled to 0.6 dB, and coupling including insertion loss is better than 13.8 dB. **Merrimac Industries, Inc., West Caldwell, NJ. INFO/CARD #218.**

High Power PIN Diode

A high power PIN diode VHF or UHF transmit-receive switch with a built-in high speed driver is available from Contronix. The switch can handle 1500 W CW into a 2:1 load VSWR. The operating range is either 20 MHz to 100 MHz or 220 MHz to 400 MHz. The typical VHF or UHF turn on time is 50 ns while the typical turn off time is 0.5 us. **Contronix, Centereach, NY. INFO/CARD #217.**

EMP Signal Generator

The PGF-5001 EMP signal generator is a self contained damped sinusoid pulse generator designed to produce damped sinusoid waves at frequencies from 10 kHz to 100 kHz. Single event and variable



repetition triggering mechanisms allow the operator to pulse the waveform up to 60 pulses per minute with the first half cycle set for positive or negative feedback. The instrument is priced at $12,100. **R & B Enterprises, West Conshohocken, PA. INFO/CARD #216.**

Receiver/Transmitter Modules

Lunar unveils a line of receiver and transmitter RF modules for high speed data communications in the VHF and UHF ranges. The features include dual synthesizers providing independent frequency agility for both transmit and receive; half or full duplex operation; compatibility with FSK, QPSK, and QAM modulation techniques; and micro-packaging for circuit card mounting. Applications for the modules include telemetry, remotely piloted vehicles and robotics. **Lunar Industries, Inc., San Diego, CA. INFO/CARD #215.**

Hybrid ECL Clocks

ECL clocks for graphics applications with frequency ranges of 10 kHz to 115 MHz, 10 kHz to 150 MHz, and 100 kHz to 200 MHz are available in 4-pin DIPs. **Reeves-Hoffman Division, Carlisle, PA. INFO/CARD #214.**

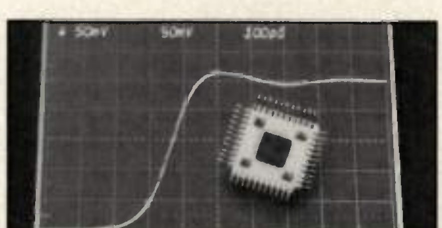
RF Amplifier

The VHP-06 has a bandwidth of 40 to 400 MHz, with 1 W continuous output and 44 dB nominal gain. The amplifier comes with a 75 ohm input and output imped-

ance and measures 2"× 5". **TIW Systems, Inc., Sunnyvale, CA. Please circle INFO/CARD #213.**

PIN Driver and Line Receiver

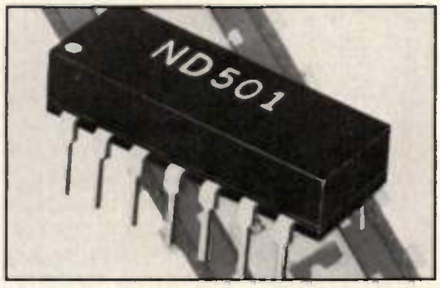
TriQuint introduces a PIN driver (TQ6330) and line receiver (TQ6331) pair that achieves 100 ps rise and fall times and support data rates of 3.0 Gbits/s. The inputs are ECL compatible and the output voltage levels can be controlled to in-



terface with ECL, TTL, and CMOS. The TQ6330-D is $98, TQ6330-M is $159, TQ6331-D is $98 and TQ6331-M is $159. **TriQuint Semiconductor, Beaverton, OR. INFO/CARD #212.**

Hybrid VCO

The ND-501 is a wideband voltage controlled oscillator fabricated using hybrid techniques and sealed in a fourteen lead dual in-line package. Applications for the ND-501 include FM modulators and demodulators, sub-carrier oscillators, phase-locked loops and voltage to frequency conversions. **Novadyne, Inc., Huntington Beach, CA. INFO/CARD #211.**

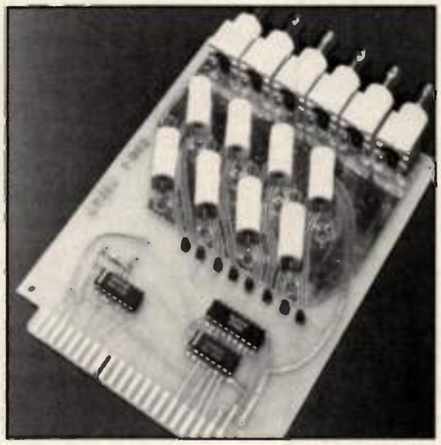


Fixed Delay Line

LV-611 Series bulk acoustic wave delay lines operate from 4 to 8 GHz with a bandwidth of 200 MHz. The components provide delays from 1 to 10 us with insertion loss as low as 35 dB. The LV-611 delay lines are hermetically sealed. **Phonon Corp., Simsbury, CT., INFO/CARD #210.**

Coaxial Switching Systems

Cytek introduces the CXA Series of coaxial switching systems. The systems are modular and each module has 8 relays with BNC receptacles for inputs and outputs and a 50 ohm characteristic impedance through the signal path. This gives the modules a bandpass which is flat from DC to 100 MHz with minimum distortion, attenuation and crosstalk. **Cytek Corp., Penfield, NY. Please circle INFO/CARD #209.**



Continuously Variable Attenuators

A line of continuously variable attenuators from DC to 800 MHz (Model LAV) is available from RLC Electronics. A choice of 50 or 75 ohm impedance is available. Prices start at $90 in unit quantities. **RLC Electronics, Inc., Mt. Kisco, NY. INFO/CARD #208.**

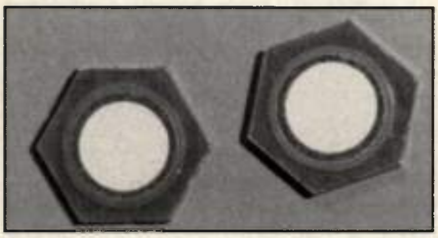
6-Way Power Divider

Norsal introduces an equal amplitude 6 way power divider covering the .75 to

3.0 GHz frequency range. The insertion loss is 1.2 dB max and the isolation is 20 dB minimum. VSWR is 1.35 (max) at all ports. **Norsal Industries, Inc., Central Islip, NY. INFO/CARD #207.**

PIN Chips

The Model CSB3779 high voltage PIN chip from Alpha features 1500 V minimum at 10 uA. The maximum power dissipa-



tion is 35 W while the maximum junction capacitance is 2.5 pF. **Alpha Industries, Inc., Woburn, MA. INFO/CARD #206.**

Right Angle Connector Assemblies

Penstock introduces swept right angle connector assemblies in SMA male-male or male-female with VSWR of 1.2:1 at 18 GHz (min). The assemblies come either fully gold plated or connectors gold plated

only. They are priced from $15.25 to $26.45 depending on style and quantity. **Penstock, Inc., Los Altos, CA. Please circle INFO/CARD #205.**

Single Crystal Oscillators

Series-PXS contains a single crystal oscillator that is phase locked by digital synthesis techniques to an external reference. Spurious outputs are better than 90 dBc and typical phase noise for a

101.1234 MHz output frequency is 136 dBc/Hz at 1 kHz and 152 dBc/Hz at 10 kHz. The unit measures 3"× 4"× 1". **Communication Techniques, Inc., Whippany, NJ. INFO/CARD #204.**

DC to 6 GHz Switch

Mini-Circuits' KSW-2-46 is a GaAs switch that operates from DC to 6 GHz with a control voltage as low as −5 V at 20 ns switching speeds. It provides 50 dB isolation and insertion loss of 1 dB. VSWR is measured 1.3:1 and the price is $32.95 in single quantities. **Mini-Circuits, Brooklyn, NY. INFO/CARD #203.**

5 V Pulse Generator

The Model AVMM-2-C pulse generator features a 0.3 to 2.0 ns variable rise time option and an output amplitude that is

INFO/CARD 37

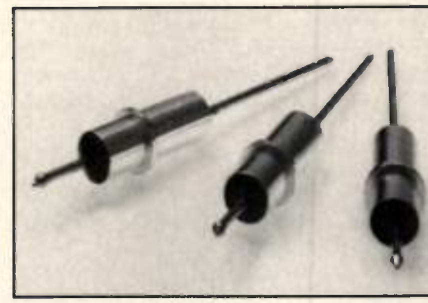
variable to 5 V. The output pulse width is variable from 0.5 to 10 ns and the pulse repetition rate is variable from 0 to 25 MHz. A delay control and synch output is provided for scope triggering purposes. The price ranges from $2,238 to $3,148. **Avtech Electrosystems Ltd., Ottawa, Ontario, Canada. INFO/CARD #202.**

GaAs Amplifier

The P35-4111 offers a small signal gain of 16 dB flat to ±1 dB over the 1 to 6 GHz range with output power of 18 dBm at the 1 dB compression point. The device has a noise figure of 6.0 dB with input and output VSWR less than 2.5. It is priced at $134.40 each when purchased in 100s. **Plessey Three-Five Group, San Diego, CA. INFO/CARD #200.**

EMI PI Filters

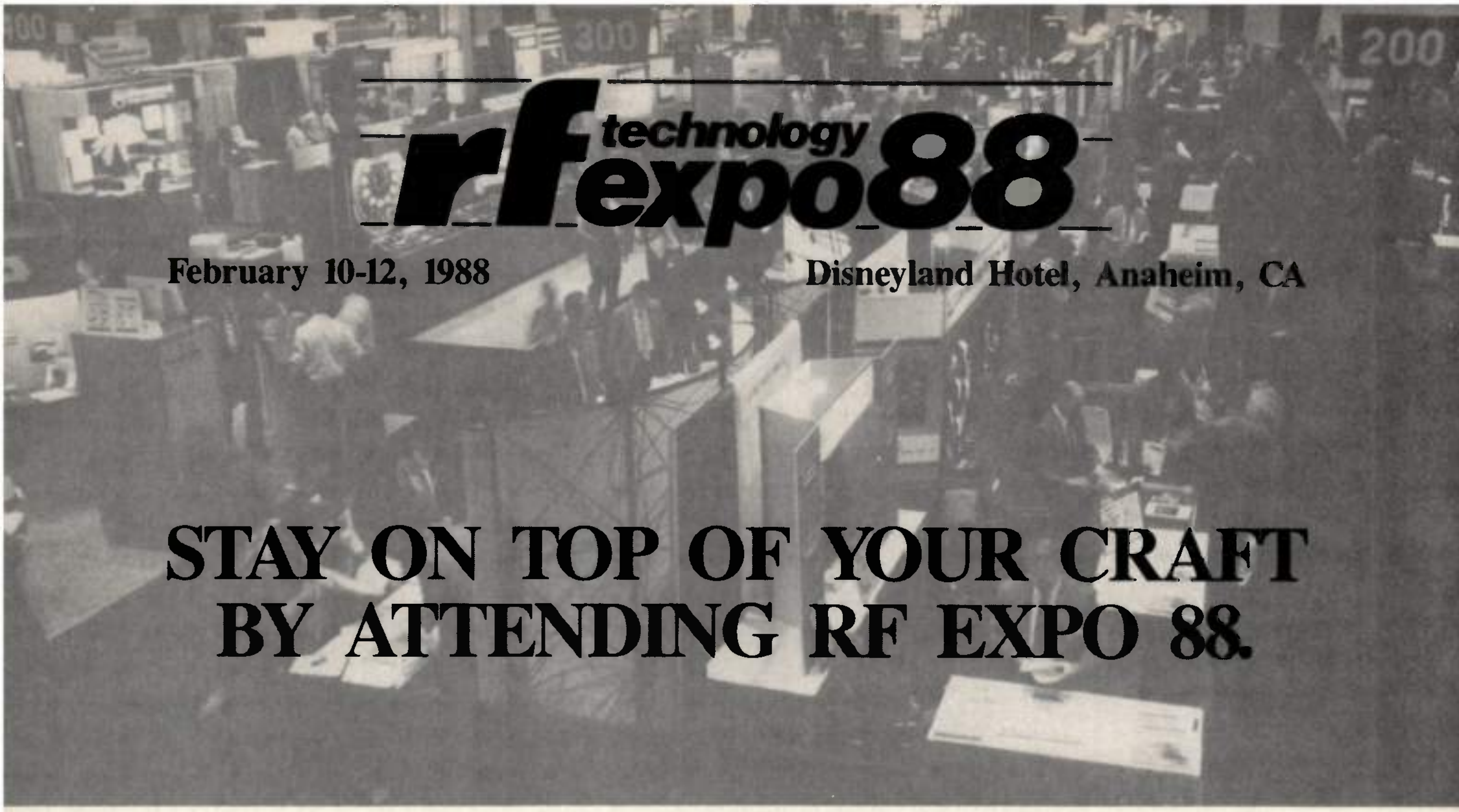
The Oxley dBZ4/P filters feature nominal capacitance values of 5,000 pF, 22,000 pF, and 44,000 pF with a working voltage of 200 V DC. Typical insertion loss



in a 50 ohm system at 77°F ranges from 14 dB at 1 MHz to 75 dB at 10 GHz. **Oxley, Inc., Branford, CT. Please circle INFO/CARD #201.**

1/2 W Transistor with 12 dB Gain

The Philips/Amperex BFG195 has a minimum h_{FE} of 40 and an f_T of 7.5 GHz at 50 mA collector current. Noise figure is typically 1.8 dB at 800 MHz. Pricing at



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RF 12-87

1000-piece quantities is $1.65 each. **Amperex Electronic Corp., Slatersville, RI. INFO/CARD #199.**

Compressive Receiver

The Model ER-7400 compressive receiver has a frequency range of 20 to 1025 MHz with a scan rate of 2000 MHz per ms and sensitivity of −118 dBm. The maximum output data rate is 8 MHz and the resolution is 20 kHz. The scan width for this device ranges from 100 MHz to 1000 MHz. **Interad Ltd., Gaithersburg, MD. INFO/CARD #198.**

Linear IF Amplifiers

Two linear amplifiers that have center frequencies from 20 to 160 MHz and bandwidths from 4 to 40 MHz are available from RHG. Model ICE2104 has a single IF output while Model ICEVT provides both IF and video outputs. The amplifiers feature typical IF gains of 70 dB and noise figure of less than 4 dB. **RHG Electronics, Inc, Deer Park, NY. Please circle INFO/CARD #197.**

Portable Spectrum Analyzer

The HP 8592A has a frequency range of 50 kHz to 22 GHz and an amplitude range of −109 dBm to +30 dBm. An internal preselector reduces multiple and image responses and a built-in comb generator enhances frequency accuracy to ±2.7 MHz at 22 GHz. HP-IB, HP-IL (HP interface loop) and RS-232 options are available. **Hewlett-Packard Company, Palo Alto, CA. INFO/CARD #196.**

Data Acquisition Shift Register

A 4/8-bit shift register, the SDA 8020, was designed as an interface between high speed A/D or D/A converters and the memories in data acquisition or waveform generating systems. It has ECL compatible inputs capable of demultiplexing an 8-bit data stream with a clock speed of up to 100 MHz into four parallel 8-bit TTL data channels with a clock speed of 1/4 of the serial clock. The device comes in a 68-pin plastic leadless chip carrier and is priced at $70 each in 100 unit lots. **Siemens, Iselin, NJ. INFO/CARD #195.**

Video Speed Sample/Hold

The SHM-360 and SHM-361 are high speed sample and hold devices featuring separate wideband input amplifiers, and reference voltage and clock outputs. The acquisition times are 8 and 12 ns with sampling frequencies at 18 and 35 MHz. The input amplifier has a −3 dB bandwidth at 25 MHz or 55 MHz depending on the device used and both have offset adjustment controls. **Datel, Mansfield, MA. INFO/CARD #194.**

Resonator Measurement Software

The HP 85165A resonator measurement software is used with a system that includes the HP 8753A or HP 8510 vector network analyzer and an HP 9000 Series 200 or 300 computer. It directs the measurement process and calculates the key resonator parameters in accordance with EIA standard 512. The program determines such values as series and parallel resonant frequencies, device "Q," zero phase crossing of impedance minima and maxima, and spurious responses. It uses the gathered S-parameter data to derive the device's equivalent circuit. The resonator measurement software is $5000. **Hewlett-Packard Company, Palo Alto, CA. INFO/CARD #193.**

Program Performs Harmonic Balance Simulation

Libra™, EEsof's harmonic balance simulation software program combines linear analysis in the frequency domain with time-domain analysis of nonlinear elements to model nonlinear circuits. Touchstone is completely integrated within Libra and existing Touchstone files can be run unchanged by Libra in its linear simulation mode. The software's capabilities include the ability to design large-signal circuits such as limiters amplifiers, attenuators, and mixers. Harmonic balance supports many different types of excitation, including frequency and power sweep. Inputs can include two frequency tones which is critical to analysis of intermodulation distortion and mixer performance. For nonlinear circuit simulations where the steady-state response to sinusoidal waveforms is desired, the program allows users to obtain solutions that include Touchstone's library of microwave elements. **EEsof, Inc., Westlake Village, CA. INFO/CARD #192.**

Rectifier Circuit Analysis Program

RectSim provides predictions for capacitor-input rectifier circuits. Applicable circuits are single-phase half-wave, full-wave bridge, and symmetrical doubler circuits. The program can make a series of analyses, sweeping specified parameters over desired ranges. It is available for IBM or compatible machines running under DOS 2.1 or later. It is priced at $99. **Design Automation, Inc., Lexington, MA. INFO/CARD #191.**

Systems Controller Software

Tektronix introduces a systems controller (PEP 301) that is designed for GPIB systems and the MS-DOS™ software environment. The package includes a high resolution graphics card, a color monitor, a dual voltage system unit, a GPIB interface and application software. **Tektronix, Inc., Beaverton, OR. INFO/CARD #190.**

C-Tools

C-Tools:1, a package for microcomputer C programmers using IBM PC, XT and AT or compatible systems, is available from Timberline Software. The 27 C function and demonstration program in this package are provided in C source code, allowing for easy study and modification to fit almost any application. These functions provide single command control over cursor movement, video page selection, color attribute assignments, window and window border formation, centering of text and positioning of left or right justified blocks of text anywhere on the screen. **Timberline Software, Leadville, CO. INFO/CARD #175.**

rf literature

Capacitor/Resistor Catalog

A high voltage/high power ceramic capacitors and high voltage resistors catalog (#62-09) is available from Murata Erie. It contains technical data on ceramic capacitors for high power and high voltage applications to 60 kV, custom capacitors, and high voltage resistors. Also included are applications, electrical and environmental characteristics and specific features for each product. **Murata Erie North America, Inc., Smyrna, GA. INFO/CARD #189.**

RF Power Amplifier Bulletin

Bulletin #RFA-4001 describes Antenna Specialists' line of RF power amplifiers. Complete performance specifications and typical output versus input power graphs are presented. The line comprises of three VHF models covering from 144-174 MHz; four models covering the 432-512 MHz UHF band; and three additional export models operating in the midband frequency range. Microstrip matching and filtering, relay T/R switch, protection against DC polarity reversal and high VSWR are characteristics of the complete line. **The Antenna Specialists Co., Cleveland, OH. INFO/CARD #188.**

Distributor Catalog Highlights Products

A distributor catalog featuring reference for over 1000 electronic components is available from TDK. It highlights ceramic capacitors, ferrite and chip beads, DC to DC converters, inductors, EMI/RFI filters, and active delay lines. Sub-categories for ceramic disc capacitors and multilayer ceramic capacitors are also included. Leading into each category is a "Features" section that highlights product capabilities and applications. The catalog also reviews electrical specifications, leads, packaging availability, part number configurations and operating specifications. In addition, photos and schematics are provided. **TDK Corporation of America, Skokie, IL. Please circle INFO/CARD #187.**

Capabilities Prospectus on Signal Generator

Application note 314-4, *Exceptionally Complex Signal Simulation for Multi-Signal Environments in Radar/EW Test* serves as a brief capabilities prospectus which describes the setup of the HP 8780A vector signal generator that is modulated by two HP 8770S signal simulator systems to replicate complex signal environments such as multiple signals, antenna scans, multiple lobing and staggered pulse trains. The combination provides complete programmable control of the carrier's pulse plane. **Hewlett-Packard Company, Palo Alto, CA. INFO/CARD #186.**

Product Selection Guide

Penstock introduces a product selection guide covering RF and microwave passive components from DC to 50 GHz and active components from DC to 18 GHz. **Penstock, Inc., Los Altos, CA. INFO/CARD #185.**

Signal Switching in ATS

Keithley has introduced a handbook called *A Guide to Signal Switching in Automated Test Systems*. It is designed to reduce the apparent confusion about switching systems and configurations to personnel working on personal computers in automated test systems for the first time to the more experienced ATE system designers with questions about specific switching configurations. **Keithley Instruments, Inc., Cleveland, OH. Please circle INFO/CARD #184.**

EMI Test Instrumentation and Accessories Catalog

The products featured in this catalog range from electromagnetic (EMI) test instruments and systems to accessories. Three microprocessor controlled EMI analyzers/receivers are featured followed by a listing of Electro-Metrics' computer controlled EMC systems, plus a synopsis of how the systems can be used for emissions and susceptibility measurements. This is followed by is a product review section on test equipment and accessories. **Electro-Metrics, Amsterdam, NY. INFO/CARD #1834.**

RF Switch Data Sheet

A data sheet on RF mechanical switches is available from Narda. It contains specifications, schematics, and outline drawings. The switches cover from DC to 18 GHz. **Narda Microwave Corp., Hauppauge, NY. INFO/CARD #182.**

Note Describes Linear Signal Processing

Application note LSP1 describes linear signal processing. Some of the topics covered include supply voltages for linear circuits, video op-amps, recommended design practices, advantages of using ± 5 V supply and application information. Descriptions of unity gain followers, composite amplifier applications, operational transconductance amplifiers, amplitude modulators, an 8 MHz VCO utilizing dual

OTAs, a 100 MHz high speed receiver, and various other topics are included. **VTC, Inc., Bloomington, MN. Please circle INFO/CARD #176.**

Quality Assurance Procedures Report

A report describing quality assurance procedures used by the Micro Crystal division of ETA for SMT and thru-hole miniature tuning fork crystals designed for medical and military applications is available. QA tests include screening, stabilization bake, electrical parameters, and high frequency vibration. All steps from production through delivery are charted in the report. **ETA Industries, Inc., New York, NY. INFO/CARD #181.**

RF Adapter Catalog

The catalog contains information on SMA, N, BNC, TNC, and 7 mm RF adapters. The adapters are available in bulkhead mount, panel mount, right angle, hermetic, between series and in series. All SMA, N, and TNC adapters have passivated stainless steel bodies, gold plated BeCu contacts and precision interfaces. **Coaxial Connectors, Inc., Braintree, MA. INFO/CARD #180.**

EMC Services Bulletin

This bulletin from Spectrum Control covers electrical EMC testing with services for testing to the requirements of FCC part 15. Coverage on military EMC testing with evaluation services to requirements contained in MIL-STD 285 shielding effectiveness and MIL-STD 461 conducted in radiated susceptibility emissions is included. **Spectrum Control Services, Inc., Erie, PA. INFO/CARD #179.**

Amplifier Handbook

This handbook contains data sheets on power op-amps, wideband amplifiers, and application notes. The devices featured include high current models with outputs up to 30 A, high voltage models, and wideband amplifiers with slew rates up to 4000 V/us. Some of the notes included in the handbook discuss general techniques such as current limiting, stability concerns, and safe prototype practices. Other notes place emphasis on specific application circuits. **Apex Microtechnology Corp., Tucson, AZ. Please circle INFO/CARD #178.**

Brochure Describes Scalar Analysis Systems

This brochure describes Marconi Instruments Series 6500-500 scalar analysis systems. It details the performance of the system. Included is a specification summary using private GPIB, detectors and autotesters. **Marconi Instruments, Allendale, NJ. INFO/CARD #177.**

Software Catalog

This catalog from EEsof describes computer aided engineering (CAE), computer aided design (CAD), and computer aided test (CAT). The CAE section describes both linear and non-linear simulators, network synthesis, and foundry libraries. The capabilities of Touchstone, LineCalc, Touchstone/RF, Microwave SPICE, Libra, E-Syn, Filter I, and Filter II are reviewed. Under CAD, MiCAD II and MICmask are described. The last section, CAT, features ANACAT which works in real time with vector network analyzer data from active and passive devices. **EEsof, Inc., Westlake Village, CA. INFO/CARD #174.**

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TRW's Communication Laboratory is a major contributor in the design and development of high technology analog and microwave hardware for space communication systems. The lab is involved in GaAs MMIC, solid state power amplifiers, low phase noise VCOs; receiver/transmitter components and subsystems, spread spectrum and command receivers; high-rate modulators, demodulators, bit synchronizers. We currently need experienced engineers in the areas of microwave design and hardware subsystem engineering to work on recently awarded programs such as the Tracking and Data Relay Satellite (F7/8) (TDRSS) and the Direct Detection Laser Transceiver System (DDLT). Qualified applicants should have a minimum of a BSEE/Physics and 4 years of relevant industry experience.

RF Electronics Laboratory

This laboratory is responsible for developing state-of- the-art microwave, millimeter wave, and electro-optics space communication hardware. In addition, we are at the forefront of technology insertion. Recent awards and a substantial business backlog translates into opportunities for growth and diversity within the Lab. This work involves the application of state-of-the-art devices, GaAs MMICs, HEMTs, HBTs, power FETS, Bragg Cells, Laser Diodes, and advanced design techniques to a broad range of payload hardware. Current openings include:

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- **Section Heads**-Oversee the work of several developing engineers working on communication hardware. Provide technical direction and guidance to section personnel. Lead R&D activities, functional management, and proposals. BSEE/Physics, minimum 7 years experience.
- **Microwave & Millimeter Wave Circuit Designers**-Perform hands-on hardware development of innovative circuits and subsystems using GaAs MMICs and other III-V devices such as HEMTs and HBTs. Design and develop mixers, low noise and power amplifiers, VCOs, switches, modulators, and other communication circuits. 3+ years experience.
- **Subcontracts Managers**-Responsible for requirements definition, vendor survey and selection, and technical management of subcontractors. Positions require communication systems, circuit design, and subcontract management experience.

Digital Electronics Laboratory

This laboratory is the design and development center for the application of analog/digital signal and data processing technology in space. The lab provides hardware for advanced spacecraft payloads and technology projects. Design activities range from system definition to detailed hardware design, including the development of custom LSI/VLSI and hybrid circuits for state-of-the-art applications.

We are seeking the senior and intermediates level professionals for the following positions. Detailed design, leadership, and management roles are available for most positions.

- **Frequency Synthesizer Engineers**-Develop spaceborne frequency synthesizers. Positions require strong hardware and analytical skills, plus experience in indirect frequency synthesis, phase locked loop theory, and filter design. Experience with design/use of advanced custom LSI and hybrid components desired. BSEE, 3-15 years experience.
- **Demodulator Designers**-Positions require experience in communication systems demodulators and spread spectrum design. Experience at data rates beyond 50Mbps desired. BS/MSEE, 4-15 years experience.
- **Signal Processor Engineers**-Positions require experience in Spaceborne or avionics signal processors, including FFT's and digital filter designs, plus the ability to provide creative engineering to low power, high speed applications of commercial and custom integrated circuits. BS/MSEE, 4-15 years experience.

Please send your resume to **Brenda Anderson** at **TRW ESG, Dept. RFD/1287, R10/1757, One Space Park, Redondo Beach, CA 90278.**

TRW Millimeter Wave and Microwave Technology Center (MMTC)

A key resource for TRW, MMTC is responsible for research, analysis, design and development of millimeter wave and microwave semiconductor materials, processing, devices, circuits, components, and subsystems. This vertically-integrated organization is responsible for providing microwave electronics technology leadership within the Electronics Systems Group, as well as technology transfer and insertion into TRW product lines.

We are currently searching for scientists and engineers who are interested in advancing the state-of-the-art and enhancing out capabilities in the design, fabrication, and test of reliable and cost-effective millimeter wave and microwave technology products:

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- **GaAs MMIC Design Engineers**—Energetic, experienced circuit designers in millimeter wave frequencies.
- **SAW Device Engineers/Technologists**—Experienced in surface-acoustic-wave device design and development.
- **GaAs MMIC Circuit Modellers**—PhDEE with academic or industrial experience in GaAs CAD modelling.
- **GaAs Device Test and Packaging Engineers**—BS/MSEE with experience in high-speed GaAs device test and packaging.

Should you have an interest in these or any other possible openings within MMTC, please give **John DePolo** a call at **(213) 297-8599.** If it is not convenient to call, please forward a copy of your resume to him at the following address: **John DePolo, TRW MMTC, Dept. RFD/1287, R10/1757, One Space Park, Redondo Beach, CA 90278.**

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Northrop Corporation's Defense Systems Division, located in sprawling Rolling Meadows, IL just northwest of Chicago, continues to provide innovation and leadership in its role as a major force in the electronic countermeasures industry. Our professionals contribute to the state-of-the-art within a creative, well-managed environment in which individuals are encouraged to develop their capabilities to the fullest, and work in concert as part of a winning team. **Positions below require a BSEE, Physics or equivalent, MS preferred.**

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We seek a seasoned professional to spearhead our EW Antenna Design activities. Will be responsible for the design, development and transition into production of Airborne Antenna Systems for ECM applications, and the supervision of a growing unit of design engineers and technicians. Position will have interface with manufacturing and program management. Requirements include a minimum of 12 years' experience in airborne antenna design with at least 4 years of project level experience involving budgetary/scheduling responsibilities. Strong management and interpersonal skills are also essential.

Antenna Design Engineers

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But you'll have to hurry, deadline for entries is March 31, 1988. . .so mail your entry to Gary Breed, Editor, today!

Entry Rules

1. Entries shall be RF circuits containing no more than 6 single active devices (tubes or transistors), or 4 integrated circuits, or be passive circuits or comparable complexity.
2. The circuit must have an obvious RF function (as defined on page 6 of November 1987, *RF DESIGN*) and operate in the below-3 GHz frequency range.
3. Circuits must be the original work of the entrant.
4. If developed as part of the entrant's employment, entries must have the employer's approval for submission.
5. Components used must be generally available, not obsolete or proprietary.
6. Submission of an entry implies permission for *RF DESIGN* to publish the material. All prize winning designs will be published, plus additional entries of merit.
7. Winners shall assume responsibility for any taxes, duties or other assessments which result from the receipt of their prizes.
8. Deadline for entries: **March 31, 1988.**

rf design

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A. Total No. Copies (Net Press Run)	37,026	36,520
B. Paid and/or requested circulation		
1. Sales through dealers and carriers, street vendors and counter sales	None	None
2. Mail subscription (Paid and/or requested)	34,444	34,462
C. Total paid and/or requested circulation (Sum of 10B1 and 10B2)	34,444	34,462
D. Free distribution by mail, carrier or other means (samples, complimentary and other free copies)	1,318	1,459
E. Total distribution (Sum of C and D)	35,762	35,921
F. Copies not distributed		
1. Office use, left over, unaccounted, spoiled after printing	1,264	599
2. Return from News Agents	None	None
G. TOTAL (Sum of E, F1 and 2 — should equal net press run shown in A)	37,026	36,520

10. I certify that the statements made by me above are correct and complete. (Signed) Robert A. Searle, President

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