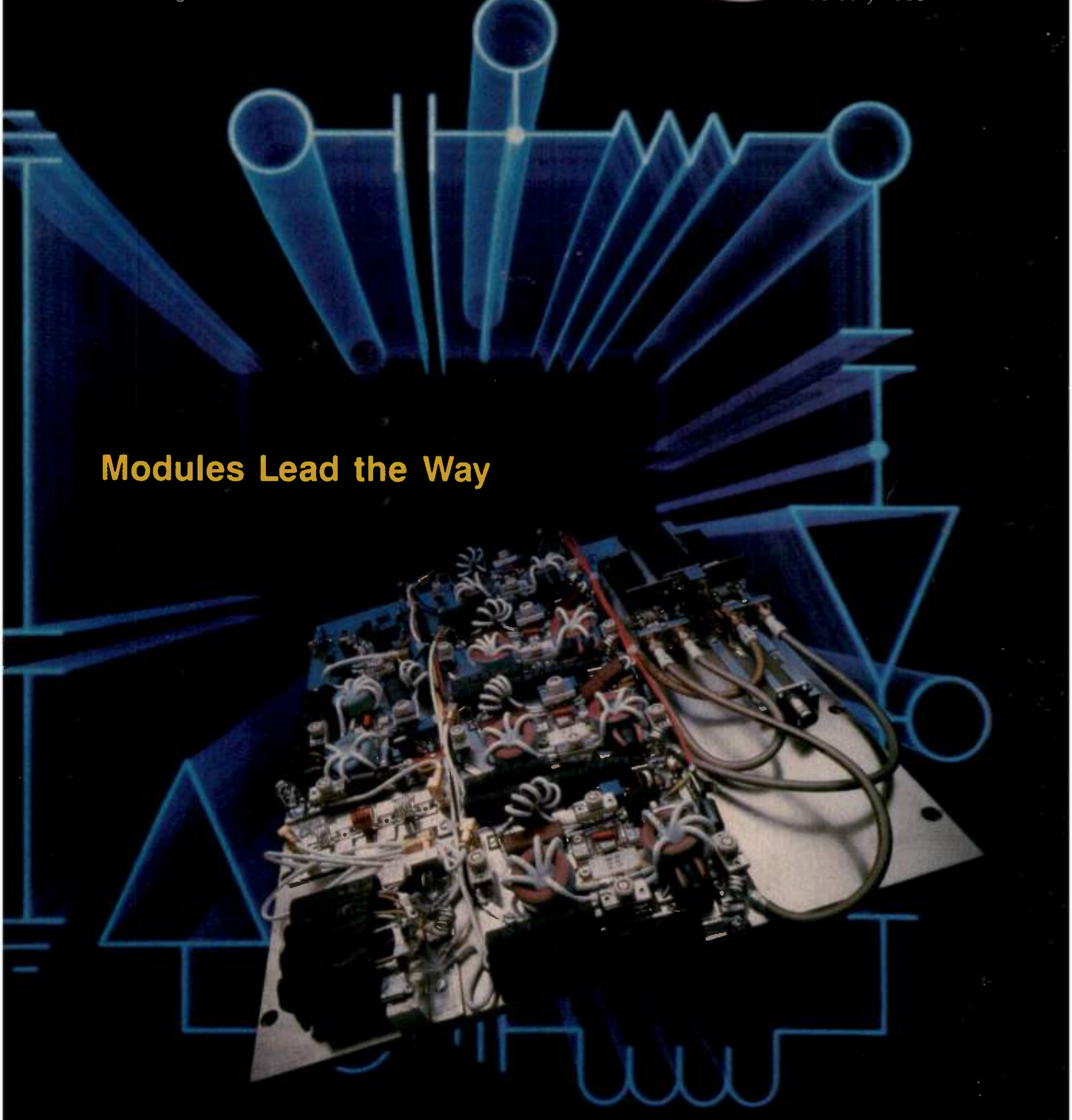
rf design

ideas for engineers

February 1985



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RF Technology Expo '85 Issue

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INFO/CARD 1

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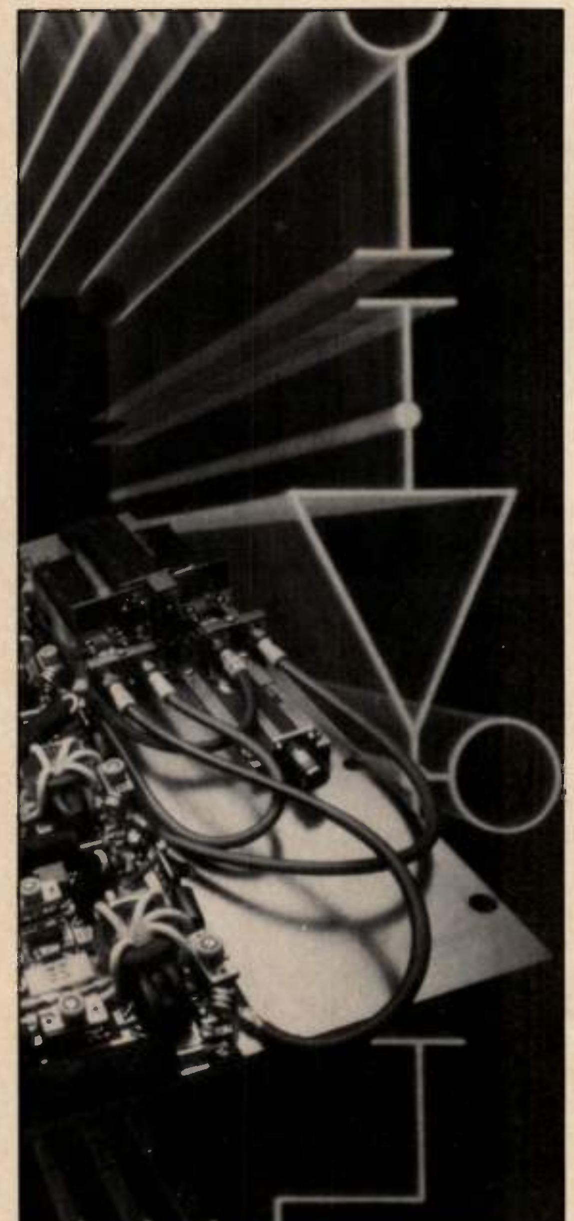
INFO/CARD 3

rf contents

February 1985



Special Report p. 26

Cover

February Cover —

The PB-2022 one-kilowatt amplifier provides 50 dB of gain in one modular "supercomponent." The PB-2022, and many other products, will be exhibited at RF TECHNOLOGY EXPO 85. Cover photograph courtesy of Acrian.

Features

Departments

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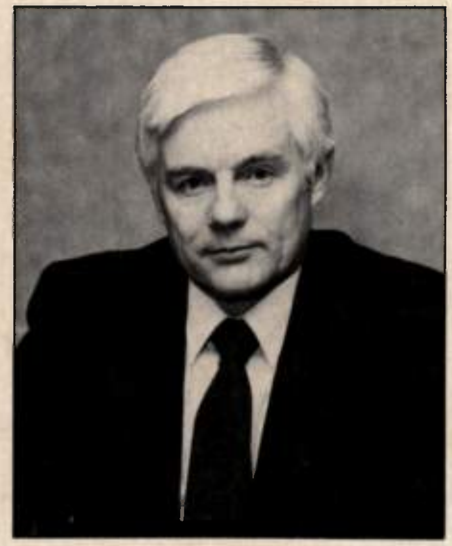
rf editorial

The Boom in RF Communications



Jim MacDonald
Editor

A news item in last month's issue told about the sales a new California company anticipates in communication systems operating below 2 GHz. Many companies are expecting a growing market for RF communications equipment, especially overseas.

Much of the world depends on the RF spectrum for local communications. The Europeans have been using cellular radio for years, getting their components from American firms. *RF Design* has learned that one African nation has contracted with an American firm for a nationwide Rf telephone system.

We at *RF Design* expect to see an RF communications boom in the next few years to rival the computer phenomenon of the last 20 years. People in ordinary occupations are finding they need to communicate faster. Stock brokers in New York, for example, can no longer rely on the telephone or the "tape" for the kind of minute-by-minute stock and bond quotations they need in a volatile market. They are turning to radio as highly selective narrowband antennas make radio communication spossible in the canyon-like streets.

Even the military, the largest user of satellite communications, is a large-volume buyer of RF equipment. Tactical battlefield communications and control systems still use VHF to a large extent, partly because short-range, line-of-sight communications are more secure.

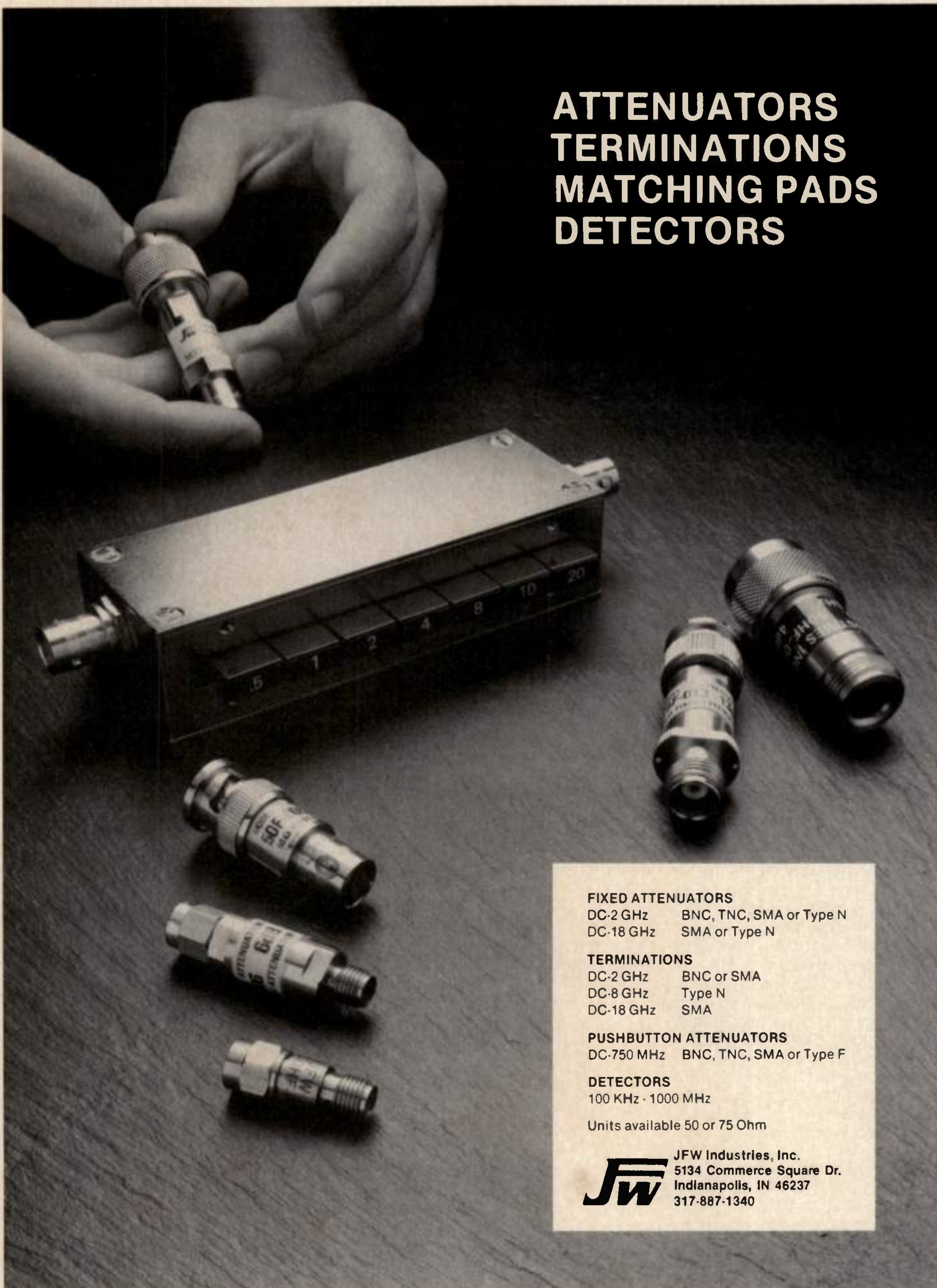
Information exchange in the civilian sector is becoming increasingly time-sensitive. The speed at which we can access information and perform calculations with digital equipment is mind-boggling, but how valuable is the information unless it can be communicated to the right people when they need it? America, with the best telephone system in the world, will probably continue to develop and improve satellite communications, but other nations may not have this capability for years.

Futurists talk about the decentralized workplace. They predict people will work at home on computers tied to a central office mainframe. If this does come about, think how important short-range radio and telephone communication may become. Electronic mail is no substitute for person-to-person conversation, either for conveying complex ideas or for that contact with other people we all need.

We are flooded with information about the world, but we have little communication with each other. Most of us probably know more about the health of the latest Russian leader than we do about the health of our next door neighbor. Sociologists may know why we isolate ourselves — maybe it is necessary. The recent growth in amateur radio, however, and the tenacity with which CB radio has held on in spite of its problems indicate a deep desire to communicate with our fellow human beings, even when we have nothing important to say.

As this issue goes to press the *RF Design* staff is preparing for the RF Technology Expo, January 23-25, bringing together engineers, physicists and manufacturers in the RF field. We hope thi exposition and symposium will provide the foundation for a continuing exchange of information. *RF Design* will provide a forum for this ongoing exchange.

Jim MacDonald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INFO/CARD 5

Giving Birth to a Community

Keith Aldrich
Publisher

As I write, the first RF TECHNOLOGY EXPO is still three weeks off . . . too early for a final count of attendees or exhibits or for a final assessment of its success. One thing is already clear, however, from the comments and attitudes of the people who have signed up in advance to be there. When closing time comes at noon on Friday, January 25, RF TECHNOLOGY EXPO 85 will have given birth to an RF engineering community.

A community is defined as a group of people who have been drawn together by some common interest. It is the "together" that has been missing. Heaven knows, from the enthusiasm that has greeted every step of the development of RF TECHNOLOGY EXPO, that the common interest was already there. But RF engineers have never been able to congregate before and they have missed it. They have *needed* it. They have had to work in near isolation, even as their technology boomed.

We expect well over a thousand RF engineers at the Disneyland Hotel for the first RF TECHNOLOGY EXPO. That's no multitude, but it is a very good start of an influential and coherent community. We expect those engineers to go back to work renewed in their skills and rekindled in their zeal because of the association with their peers and counterparts from around the world. We expect their work to profit and a fresh infusion of design ideas and solutions. We expect new relationships to develop between people and companies that ought to know each other and will profit because they do.

A lot to ask? It's only the sort of thing that occurs in every strong community. And this one is just bursting to be born.

A word about my simile: "giving birth" to a community. Birth is generally accompanied by a lot of hard, even painful, labor. This one has been no exception, and I'd like to give credit to the main coordinators.

Kathy Kriner, manager of Cardiff Publishing's Trade Show Division, has brought a high degree of professionalism to the task of convention manager. I didn't realize (it's hard to imagine) how many details there are to be tended to in that chore and she hasn't missed any.

Andrzej Przedpelski, VP of Development for ARF Products, Inc., has given the event its essential character through his selection of the more than sixty papers that make up the technical conference. He has been tireless in what amounted to a second full-time job during a peak-load period in his main one. *RF Design* will always be grateful.

Keith Aldrich

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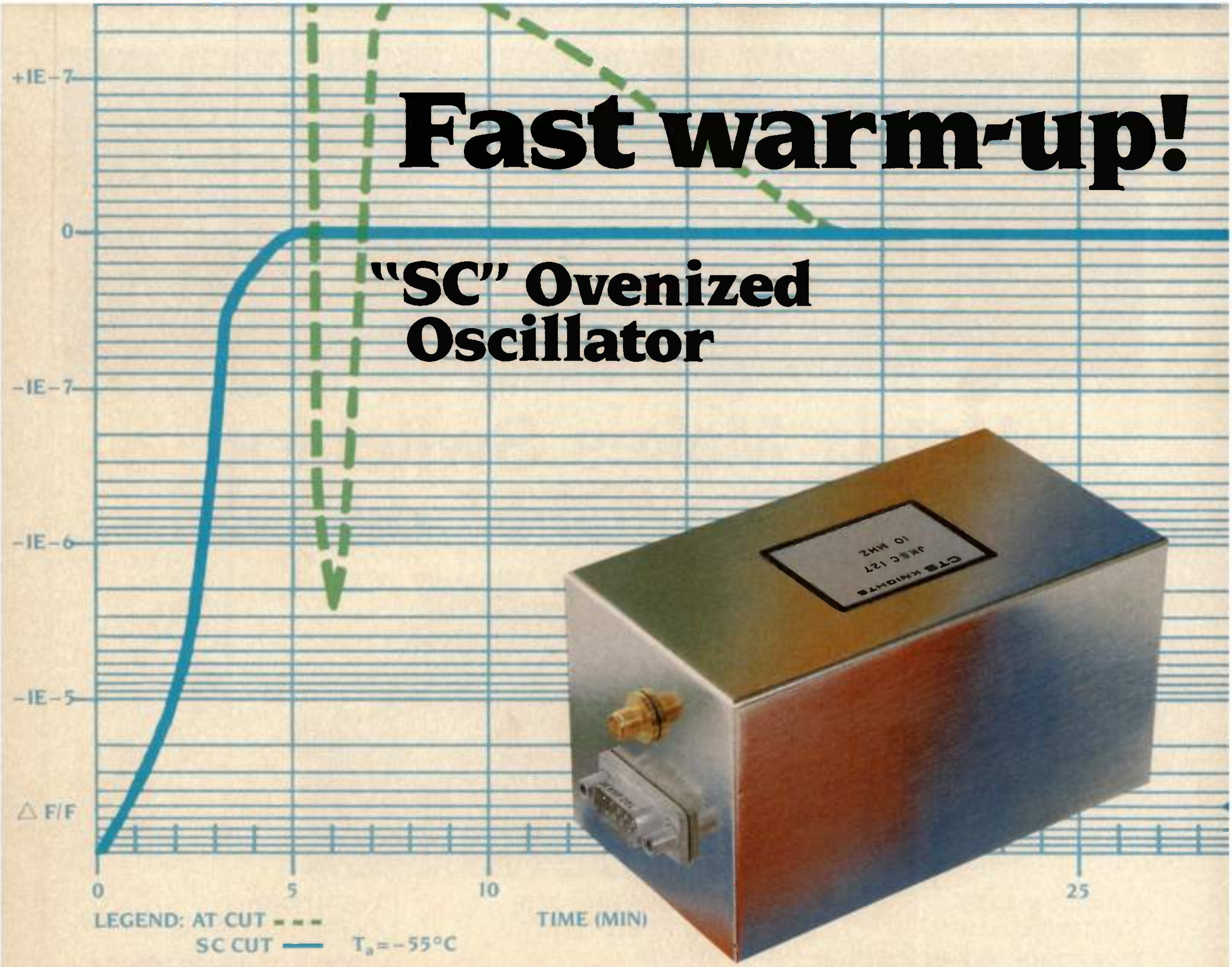

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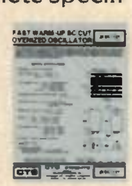

INFO/CARD 6

General Specifications
JKSC-127 Ovenized Oscillator (Stress Compensated)

Center Frequency	10.0 MHz and 10.230 MHz
Warm-Up	@ −55°C $\pm 5 \times 10^{-9}$ in 7 minutes @ −32°C $\pm 5 \times 10^{-9}$ in 5 minutes @ +25°C $\pm 5 \times 10^{-9}$ in 3 minutes
Input Power	Oven @ turn-on 1.2 A maximum @ +28 V Oven @ 25°C 125 mA typical @ +28 V Oven @ −55°C 240 mA typical @ +28 V Oscillator 20 mA maximum @ +15 V
Frequency Stability Vs. Temperature	$\pm 5 \times 10^{-9}$ from −55°C to +71°C
Phase Noise	(1 Hz BW) @ 10 Hz offset −120 dbc @ 100 Hz offset −140 dbc @ 1 KHz offset −150 dbc @ 100 KHz offset −150 dbc

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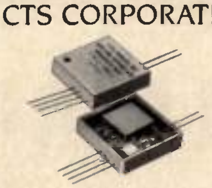

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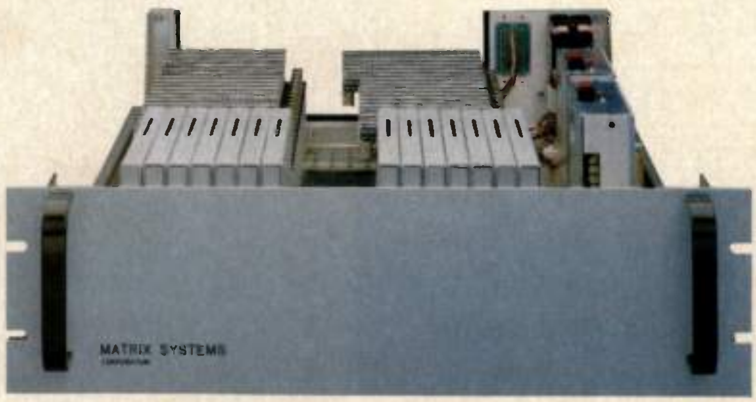

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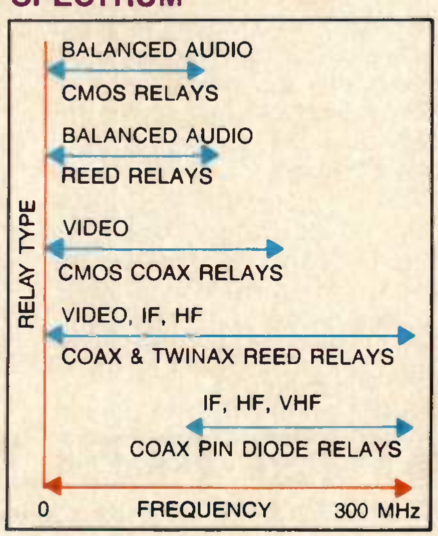

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INFO/CARD 11

the mobile communications industry. These proposals call for channel spacings of as low as 7.5 KHz using various forms of single sideband modulation. (Channel spacing of 12.5 KHz are already common in Europe in the VHF bands.) With most signal generators only just having acceptable performance at 20 KHz carrier offset (the current channel spacing), it is debatable that these generators will be able to perform off-channel tests or be useful for development work on the proposed new systems. Synthesized signal generators such as the Racal-Dana Model 9087 or Hewlett Packard 8662 feature similar phase noise at 3 or 5 KHz carrier offset as at 20 or even 100 KHz from carrier.

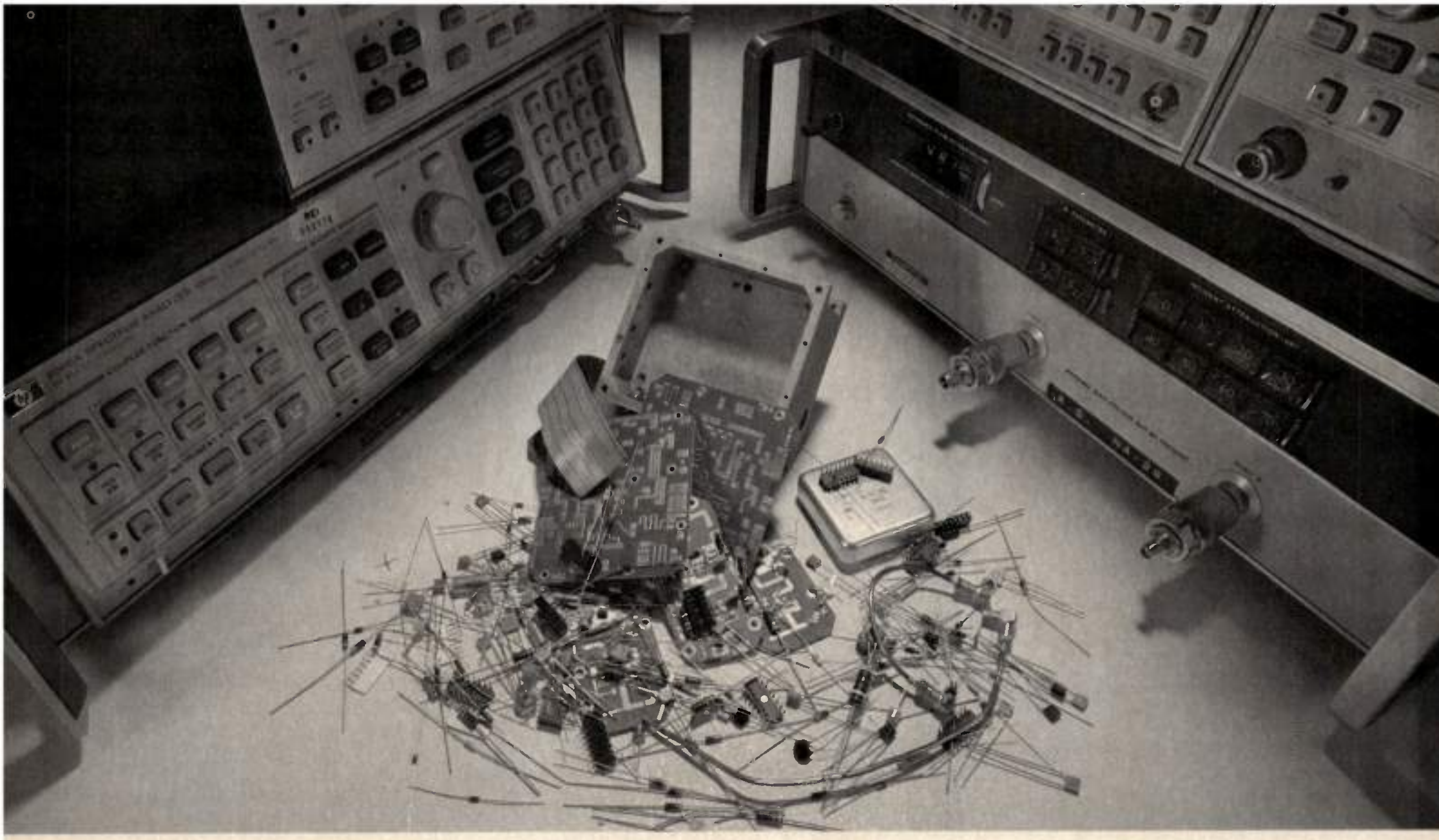
Very close to carrier, offsets of less than 1 KHz, the phase noise becomes important when working with low deviation phase modulation and/or when multiplying to microwave frequencies. Again, it is only the multi-loop sophisticated signal generators that can meet these demanding requirements.

Most modern FM communications systems feature either digital data transmission modes or selective calling with digital coding. To evaluate these systems under all operating conditions requires the ability to frequency modulate the carrier with very low rates, or in some cases even DC. The lower cost synthesized signal generators often only use a single phase locked loop which requires closed loop DC operation to maintain frequency stability. These systems usually can only FM at rates above 20 or 50 Hz. The more sophisticated multi-loop systems available from some manufacturers allow true DC coupled frequency modulation.

Switching speed/setting time is perhaps the third important area that may demand the consideration of a higher cost signal generator. For general purpose applications, a faster switching speed means that more tests may be made in a shorter period of time which can be important when, for example, fully characterizing a filter or checking a receiver for spurious responses. There are other applications particularly in the electronic warfare area that necessitate using a fast switching signal generator. Radio jammers often use a commercial synthesizer as the local oscillator. The response time of the jammer to track frequency agile systems often depends solely on the switching speed of the synthesizer. Switching speed is also important when checking the new generation of anti-jamming (ECCM) communication systems such as SINCGARS. To test an ECCM receiver dynamically, and with both traceability and repeatability requires that the signal generator can respond faster to a message to change frequency than the receiver. Currently, frequency switching speeds of less than 1 millisecond are required, which again precludes the use of the new economy signal sources.

I look forward to reading a further article on signal generators when the technology breakthroughs that influence performance rather than price/performance will be reviewed and discussed.

Sincerely,
Malcolm Levy
RF Products Manager
Racal-Dana instruments, Inc.
Irvine, CA 92714



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INFO/CARD 16

RF Design Launches First RF Technology Expo

Engineers from the United States and 10 foreign countries were among the more than 1,000 registrants expected at the first RF TECHNOLOGY EXPO '85, Jan. 23-25, at the Disneyland Hotel, Anaheim, California. Sponsored by *RF Design* magazine, this was the first expo held specifically for RF design engineers.

As this issue went to press, nearly the entire RF design engineering staff from several companies were planning to attend RF TECHNOLOGY EXPO '85 (Motorola Semiconductor, Phoenix, Ariz., was planning to bring 30 engineers). An *RF Design* reader survey early last year showed many engineers lacked basic RF design knowledge or had forgotten what they once knew. Electrical engineers were being pressed into service in this rapidly growing field with little or no training. Reponse to the expo has verified the reader survey.

Manufacturers of RF devices and tools rented more than 75 booths to display their new and established products, and discuss them with design engineers. Survey respondents had expressed a need to learn about available design components and tools.

Most engineers registered for the expo design communications equipment, many for government, military, aerospace and EMC/EMI applications. Many others design instrumentation and test equipment for military and commercial use.

More than 60 Papers Presented

In addition to the display booths, these interests were reflected in more than 60 papers scheduled in 16 sessions during the three-day event.

To accommodate as many specific interests as possible, three sessions were scheduled to run simultaneously each morning and afternoon. Each session featured several papers related to a general topic, i.e., components, circuits or techniques. Attendees could learn about several aspects of each topic without changing rooms. *RF Design* will publish a Proceedings of papers presented in all sessions that may be purchased by attendees forced to choose between equally

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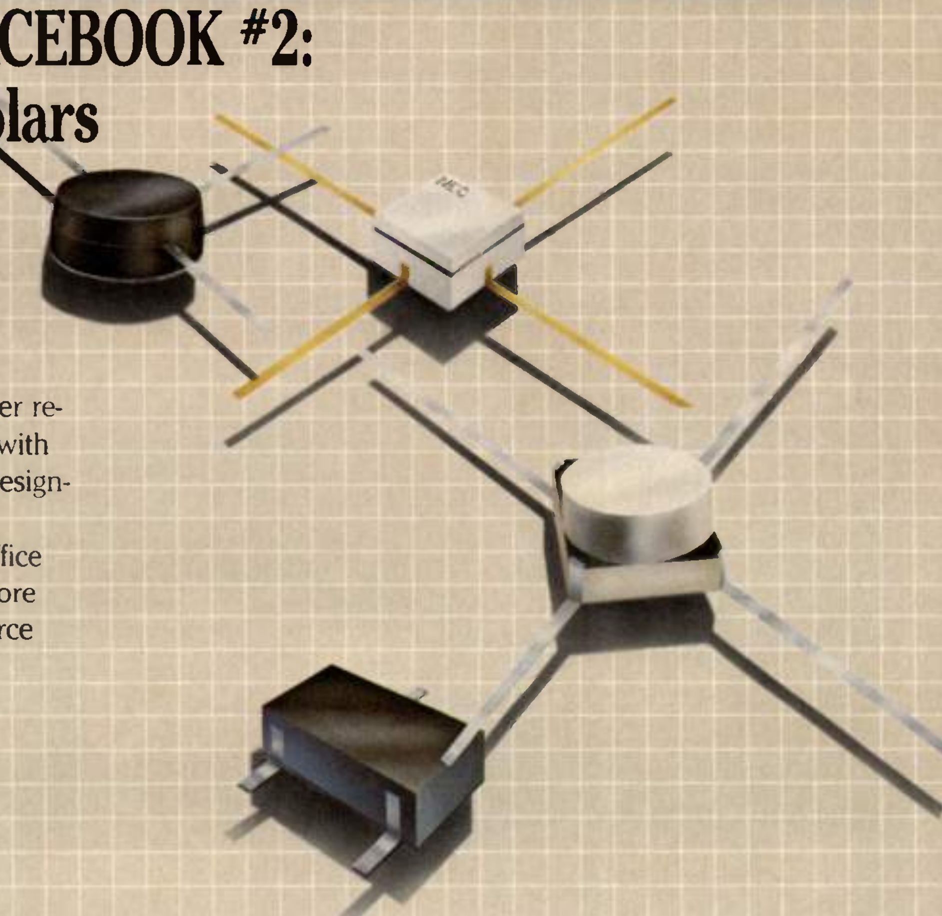

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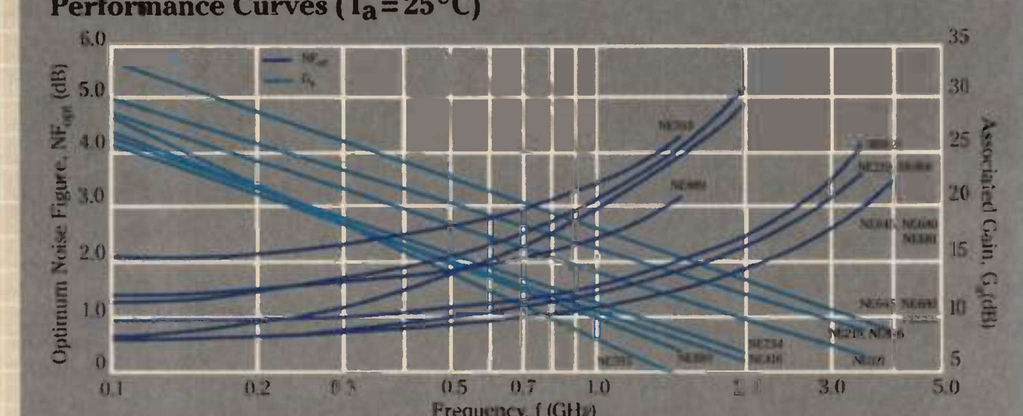

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INFO/CARD 17

attractive sessions and readers who could not attend RF TECHNOLOGY EXPO '85.

An all-day course, Fundamentals of RF Design, was scheduled for each of the first two days. Course instructors included Les Besser, president, Microwave Education Programs, Los Altos, Calif.; Professor K.C. Gupta, University of Colorado, Boulder; J. M. Johnson, president, Microwave Modules and Devices, Mountain View, Calif.; John Morton, engineering manager, Microsonics, Inc., Weymouth, Mass.; and Carl A. Erikson, Jr., director of processing operations, Anderson Laboratories, Bloomfield, Conn. *RF Design* is planning to include a transcript of this course in the Proceedings.

Encouraged by the response to RF TECHNOLOGY EXPO '85, *RF Design* is already planning next year's show. It, too, will be held at the Disneyland Hotel in January.

RF Technology Expo '85 Exhibitors

A.H. Systems, Chatsworth, Calif., EMI test equipment and antennas

Acrion, Inc., San Jose, Calif., Power transistors, products and assemblies

American Microwave Technology, Fullerton, Calif., OEM RF power amplifiers and sources

American Technical Ceramics, Huntington, New York, Porcelain and ceramic RF capacitors

Amperex Electronic Corp., Slatersville, Rhode Island, Wideband RF semiconductors and linear hybrids

Amplifier Research, Souderton, Penn., Amplifiers and accessories for RF and RFI susceptibility testing

Andersen Laboratories, Bloomfield, Conn., SAW oscillators and filters, frequency synthesizers and filter banks

ANZAC (Division of Adams-Russell), Dividers and log amplifiers

Applied Engineering Products, New Haven, Conn., Subminiature coaxial connectors and coaxial cable assemblies

Austron, Inc., Austin, Texas, Ovenized crystal oscillators and time frequency management equipment

Avantek, Inc., Santa Clara, Calif., Monolithic amplifiers, oscillators and mixer modules

Bird Electronic Corporation, Cleveland, Ohio, RF power measurement instruments, wattmeters and field-strength meter

Chomerics, Inc., Gardena, Calif., EMI shielding materials and components

Cirtech Corp., Stanley, Kansas, Frequency control products, crystal filters, etc. from DC to 200 MHz

Cohan-Epner Co., Booklyn, New York, Plated coatings for laser cavities and metal optics

Coil Craft, Cary, Illinois, RF fixed and tunable inductors and transformers

Communications Consulting Corp., Upper Saddle River, New Jersey, RF and microwave design and analysis software

Compact Software, Palo Alto, Calif., Software for design, analysis and optimization of MICs

Crystal Technology, Inc., Palo Alto, Calif., SAW bandpass filters, resonators, delay lines, convolvers and VCOs

Dow-Key, Santa Barbara, Calif., Electromechanical coaxial RF/microwave switches

EEsof, Inc., Westlake Village, Calif., RF/microwave software for design and analysis: Touchstone and MICAD

Electronic Surveillance Components, Inc., YIG Tuned transistor oscillators and solid state HP-8551 BWO replacement

EMC Technology, Inc., Cherry Hill, New Jersey, SMA connectors, terminations, loads, attenuators and MICs

ERBTEC Engineering, Inc., Boulder, Colo., Computer-enhanced HF CODAR radar system, amplifiers and time systems

Frequency Sources, Inc., Chelsmasford, Mass., Semiconductor products, varactors, diodes and capacitors

Greenray Industries, Crystal oscillators, VCOs, temperature compensated oscillators

Hewlett-Packard, Spokane, Wash., Signal generators and phase noise measurement equipment.

Holaday Industries, Inc., Eden Prairie, Minn., Isotropic broadband field strength meters with self-zeroing fields.

Intech, Inc., Santa Clara, Calif., Communications and satellite navigation equipment

JFW Industries, Inc., Indianapolis, Indiana, Fixed and programmable attenuators, divider and detectors

Johnson Manufacturing Corp., Boonton, New Jersey, Variable capacitors and microwave tuning elements

K & L Microwave, Inc., LC and cavity filters, phase meters and distoritionanalyzers

K & L Quartztek, Phoenix, Ariz., Quartz crystal filters and oscillators

Kay Elemetrics Corp., Pine Brook, New Jersey, RF attenuators

Keene Corp./Ray Proof Div., Norwalk, Conn., RF shielded rooms, anechoic chambers, absorbers and filters

L & M Engineering South, Inglewood, Calif., RF and microwave components and subsystems

Logimetrics, Inc., TWT amplifiers and RF signal generators

Marconi Instruments, Allendale, New Jersey, RF power meters, microwave scalar analyzer and signal generators

Matrix Systems Corp., Calabasas, Calif., Coaxial and audio switching systems and modules

Microwave Research Corp., RT/duroid microwave materials

Microwave Modules and Devices, Mountain View, Calif., High-power, solid state microwave modules, including amplifiers

Microwave Semiconductor Corp., Somerset, New Jersey, A full line of RF/microwave semiconductor products and components

Motorola, Inc., Franklin Park, Illinois, Quartz crystals, filters, oscillators and resonators

Motorola Semiconductor, Tempe, Ariz., RF transistors — module and discrete, linear products, logic functions

P & H Laboratories, Inc., Ferrite isolators and circulators, isoadapters and wave guide assemblies

Pacific Research and Development, Phase locked oscillators and frequency multipliers

Polarad Electronics, Inc., Lake Success, New York, RF test and measurement equipment.

Proto Stamping Corp., Redwood City, Calif., RF/EMI shielding and metal fabrication

Racal-Dana Instruments, Inc., Irvine, Calif., RF test and measurement equipment

Rogers Corp., Rogers, Conn., RT/duroid microwave materials

SAWTEK, Orlando, Florida, SAW devices

Soladyne, Inc., San Diego, Calif., Stripline and microstrip circuits

Swift and Associates, Van Nuys, Calif., Swift wrench and other products

The Program in Brief

Wednesday, Jan. 23, 8:30 a.m.-noon

Fundamentals of RF Design — Part 1

Computer-Aided Design
"Use of personal computers as a tool in prediction and control of EMI"
"CAD methodology for microwave oscillators"
"Small computers in RF design"
"CIAO and design: circuit optimization and synthesis programs for personal computers"

Components — Transistors
"Hybrid varactor-tuned oscillator modules: their practical applications in RF communications"
"Surface mounted components"
"Integrated circuits for IF amplifiers and demodulators"
"Motorola advanced amplifier concepts"

Transmitters
"A 4kW broadband (40 kHz to 40 MHz) pulsed power amplifier"
"RF operation of 450 volts vertical power MOS transistors in an ultra-lightweight HF transmitter"
"Low noise UHF transmitter design"

Wednesday, Jan. 23, 1:30 p.m.-5:00 p.m.

Fundamentals of RF Design — Part 2

Circuits
"Design compromise in single loop frequency synthesizers"
"A temperature stabilized RF power detector"
"An ultra-fast UHF voltage controlled attenuator with 35 dB linear dynamic range"
"Design of GaAs power FETs module"

Techniques
"Mounting considerations for RF low power plastic packages"
"Using Avantek MODAMP MMICs in broad and narrow-band filter design"
"Computer-aided design of phaseback loop circuits"

Antennas
"Helical antenna design"
"Snyder antenna"

Thursday, Jan. 24, 8:30 a.m.-noon

Fundamentals of RF Design — Part 1

Components
"The hybrid amplifier module for cellular telephone design"
"High frequency blind mating connectors for efficient microwave packaging"
"High voltage UHF power static induction transistors"

Circuits
"Aspects of discriminator design"
"A precision glitch-free RF step attenuator"
"A 900 MHz super amplifier"
"Precise bandwidth combline filter realization"

Techniques
"Amateur satellite communication uplink"
"Testing digital data systems"
"Precision phase noise measurements of oscillators and other devices from 1 MHz to 20 GHz"
"Adaptive HF radio systems"

Thursday, Jan. 24, 1:30 p.m.-5:00 p.m.

Fundamentals of RF Design — Part 2

Computer-Aided Design
"Matching network design using HP-41, HP-71 and HP-75 computers"
"Computer and calculator aided design tools for the RF engineer"
"RF computer aided engineering — mainframe performance on microcomputers"

Transmitters
"Large signal power amplifiers"
"A 2 GHz amplifier provides telemetry capability"
"An integrated Ka-band power amplifier"
"Class-D power amplifier load impedance for maximum efficiency"

Techniques
"Application of digital signal processing"
"ACSB — an overview of amplitude companded sideband technology"
"Electrical characterization of quartz crystal resonators through high performance vector network analysis"
"Application of coherent digital memories of communications jamming"

Synergy Microwave, Patterson, New Jersey, Mixers, power dividers modulators, quadrature hybrids and transformers

Tektronix, Inc., Woodland Hills, Calif., Spectrum analyzer, tracking generator and accessories

Tele-Tech Corp., Bozeman, Montana, Signal processing components and RF/microwave subassemblies

Telonic Berkeley, Inc., Laguna Beach, Calif., RF and microwave filters, RF attenuators and DSWR systems

Texscan Corp., Phoenix, Ariz., Spectrum analyzers, sweep generators, synthesized signal generators

Trilectric, Inc., Las Vegas, Nevada,

TRW RF Devices Division, Lawndale, Calif., Low noise small signal transistors, other transistors and RF amplifiers

Vari-L Co., Denver, Colo., Wideband signal processing components, mixers, transformers and hybrids

Varian-Eimac, San Carlos, Calif.,

Varitech Electronics, Inc., Lynbrook, New York, Fixed RF capacitors, dialectric and variable capacitors

Vectron Laboratories, Inc., Norwalk, Conn., Crystal oscillators, including TCXOs, VCXOs, VCOs, OCXOs and hybrids

Voltronics Corp., East Hanover, New Jersey, Precision trimmer capacitors

Wavetek, San Diego, Calif., Microwave and RF miniature components, RF signal sources

"Micro-Coax" Gives Its Name to New Company

A new company, Micro-Coax Components, Inc., has been formed by UTI Corp., Collegeville, Penn., out of its former Micro Delay Division in Collegeville, effective January.

Growing along with the booming RF market, the Micro Delay Division of UTI has had to expand its facilities four times in the past decade. The continuing growth has "dictated incorporation as a separate subsidiary," said Dr. Robert H. Schafer, president of the new Micro-Coax Components.

The Micro Delay Division was established in 1962 by Uniform Tubes (also a division of UTI) to produce miniature semi-rigid coaxial cable. The division developed several advanced techniques for producing a high quality, reliable semi-rigid coaxial cable and gave it the name Micro-Coax.

The Micro-Coax brand name's reputation was a major factor in selecting the name Micro-Coax Components, Inc., for the new operating company. Micro-Coax is the holder of patents for several other

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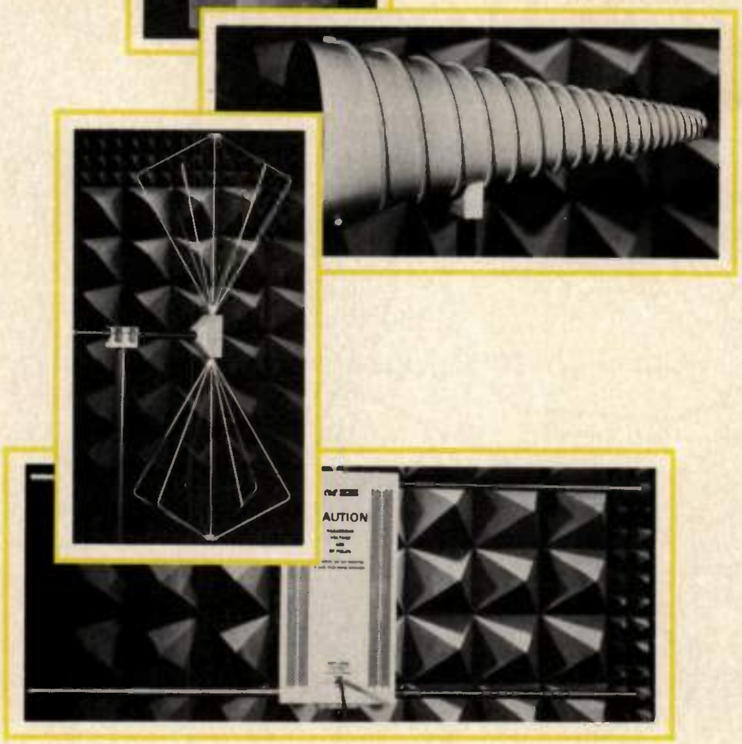

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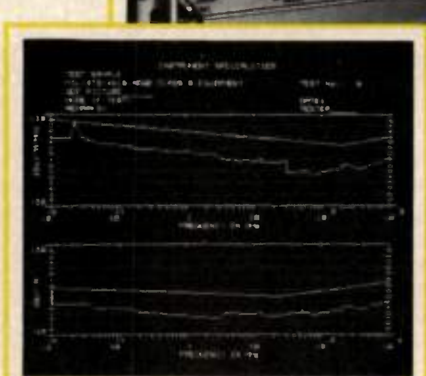


INFO/CARD 23

products, such as impedance transformer cable and assemblies, and low-pass, bandpass and high pass filters implanted within the cable assemblies. The "In-A-Cable" filters are being widely used for the suppression of undesired signals in transmitting sources and suppression of unwanted frequency bands in receiving systems. The company also offers a line of coaxial connectors, and coaxial and waveguide delay lines.

Micro-Coax Components, Inc., is planning to introduce several new products during 1985, according to Dr. Schafer.

EG&G/Cinox Pact Gives New Depth in Oscillators

Cinox Corp., a Cincinnati, Ohio firm familiar to *RF Design* readers as a maker of quartz crystals and crystal-based oscillators used for frequency control and stabilization, has been acquired by EG&G Inc. of Wellesley, Mass., for an undisclosed amount of cash.

Cinox has been since 1930 a privately-held company and now employs more than 200 people. Commercial and military applications of its components are primarily in the areas of communications, navigation, guidance, tracking and telemetry.

Cinox President W. Kirk Dance said the Cinox expertise in the design and manufacturer of high-performance oscillators would complement that of EG&G's Salem, Mass.-based Electronic Components Division in the development of atomic frequency standards for future military and commercial voice and data communication systems; space and global navigation systems; and military command, control and intelligence systems.

"The acquisition makes sense," Dance said. "Their technology matches our technology." He said the acquisition provides Cinox with the capital backing to increase an already impressive rate of growth. "We have grown so rapidly in the past four years that it attracted EG&G's attention," Dance said. "They have more capital than we do so we can grow faster."

In a private interview with *RF Design* (the phone is now answered "EG&G Cinox"), VP of Marketing Ron Stephens alleged that new product developments traceable to the new connection would be announced "shortly." For more information contact Ron at (513) 542-5555.

Cells Multiply In Chicago Carphone Market

Cellular Service coverage for the Chicago/Gary area.

Ameritech Mobile Communications, Inc., operator of the nation's first commercial cellular carphone service — launched in Chicago in October 1983 — recently announced plans to double the size of the Chicago system by mid-1985. The initial service area covered 2,500 square miles in the greater Chicago metropolitan area, ranging from Lake Forest on the north to Geneva on the west to Beecher on the south. In the announced expansion plan the coverage area will increase to 5,000 square miles, and range from Waukegan on the north to Gary, Ind., on the south (see map illustration).

Ameritech Mobile, which introduced its service with just 17 "cells," has since increased the number of cell sites to 29 and with the new expansion will boost that number to 56, including seven new cells specifically designed to improve service in downtown Chicago. The expansion will double customer capacity as well as system size. The company currently has about 12,000 customers. Capital investment to date has totalled $45 million. The expansion is expected to require another $21 million, according to Ameritech.

Most of the capital invested goes toward the purchase of RF equipment. Each cell site in the 56-cell system requires a transmitting/receiving tower and remote switching gear. Car telephone radios, receivers and antennas represent additional investment on the part of individual subscribers.

Ameritech Mobile, a subsidiary of Bell's Ameritech, also announced the availability of new custom calling features to enhance the carphone service. Call waiting, call forwarding, three-way calling and busy/no answer transfer are being introduced now to current customers. A revised tariff schedule filed with the Illinois Commerce Commission last October 24 reflects generally falling prices for standard services (e.g., $20 one-time charge to establish service).

Modules Lead the Way at RF TECHNOLOGY EXPO

By Kiyoshi Akima
RF Design

Many of the exhibitors at RF TECHNOLOGY EXPO are displaying modular devices that can be used as "supercomponents." Very few engineers will take the time to design a component, for example a resistor, needed in a system. One simply specifies the desired performance, and purchases a resistor. In the same way, a designer can specify a device such as a power combiner or an amplifier, and purchase a module which can then be used as if it were a component.

Both active and passive devices are available as modules, and they are available as monolithics or hybrids. They may be constructed using either thin or thick film technology, or both. While the remainder of this article focuses on one of the most widely available types of modular devices, the power amplifier, most of the discussion is also applicable to other types such as attenuators and frequency mixers.

Each type of construction has its advantages and disadvantages. Monolithics are formed on a semiconductor substrate by deposition and photolithography, as a printed circuit. As a result, they are generally smaller physically and less expensive than the hybrid modules. They can require less than a square inch of board space, and cost under $2 in production quantities.

Hybrids are constructed with discrete components on substrates. At the expense of size and cost, they provide better performance and higher power levels than can be achieved with monolithics. RF power amplifiers producing over 100 W are available, but they can cost as much as $200 or more.

Being standard 50 ohm in/50 ohm out devices, modules can be used without the need for additional mixers and shunts. If a single module won't do the trick, more can be cascaded, within the limits of each unit's power rating. Most modules do not allow external adjustments and tuning.

Modules provide many advantages. Among them are repeatability, size, time, and cost. The variations in component values have been taken into account, and the modules come "pre-tweaked" to meet tight tolerances. This can reduce the amount of adjusting and tuning required for each circuit.

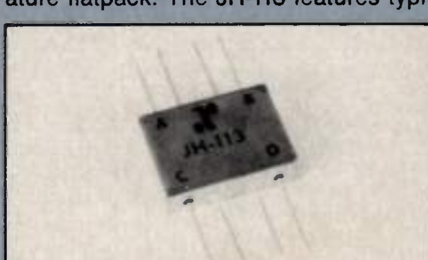
By using modules instead of discrete components, the resulting circuit can usually be made much smaller and simpler. Fewer components mean fewer interconnections. Fewer connections mean more leeway in the layout. Often the heat dissipation of a module is less than that of an equivalent discrete circuit. This can eliminate additional heat sinks or cooling systems.

The use of modules also considerably reduces the time required to produce a product. Once the requirements for an amplifier have been determined, the amplifier does not have to be designed and developed. The module manufacturer has already done this for you. The module, by being one component instead of a collection of elements reduces the time required to assemble the circuit. By not needing to tune each circuit the assembly time is reduced further.

Cost is another item that can be reduced by using modules. The time savings in the design and manufacturing phases translate directly into cost savings. Smaller circuits require less materials, and can be housed in smaller enclosures. Sometimes, the modules themselves also costs less than the discrete components required to build the equivalent circuit.

Supercomponents

The Anzac Division of Adams-Russell has developed a new quadrature hybrid to cover the 7 to 14 MHz band in a miniature flatpack. The JH-113 features typically 27 dB isolation and a low loss of 0.5 dB over the entire octave. Other features include 1.2:1 VSWR and 0.75 dB amplitude balance. The JH-113 is a hermetically sealed unit for military environments. **Adams-Russell Co., Anzac Div., Burlington, MA 01803. Booth #321, 323, 325; Info/Card #112.**



Adams-Russell

The Avantek MTO-8040 varactor-tuned oscillator covers 400 to 600 MHz with +10 dBm power output into a 50 ohm load. It

Avantek

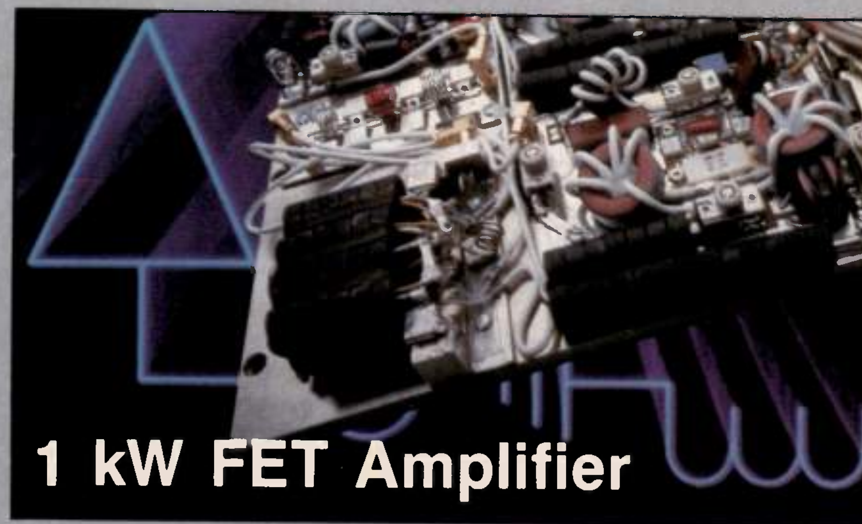
is packaged in TO-8V transistor cans and is fully tested and guaranteed over the full −54 to 85 C military temperature range. **Avantek, Inc., Santa Clara, CA 95051. Booth #516, 518; Info/Card #111.**

The BT500 active bias thermal tracking device from TRW provides excellent thermal tracking and requires only limited external circuitry for operation. It is available in a variety of packages, including the standard hermetic TO-60. **TRW Electronics Components Group, RF Devices Div., Lawndale, CA 90260. Booth #217, 219; Info/Card #110.**

The Watkins-Johnson WJ-EA54 Economy Amplifier provides 27 dB typical gain from 10 to 250 MHz. The unit's noise figure is 3.8 dB and its output power the

(Continued on page 29.)

Watkins-Johnson



1 kW FET Amplifier

A 1000 watt (1 kilowatt) solid state amplifier, the Acrian PB-2022, is designed for military and industrial communications, and research equipment. It is characteristic of a family of standard wideband high power amplifiers available from Acrian, Inc.

As the industry has grown in size and made advances in technology, competition has increased dramatically. Combined with a shortage of RF and microwave design engineers, it has become essential for systems manufacturers to shorten design time for customers. This has resulted in more and more component suppliers offering modules and sub-assemblies to systems houses. It saves customers substantial time and money in a rapidly moving market.

Custom sub-assemblies, like the PB-2022, are designed to meet these needs. Because they are familiar with advances in device technology, engineers at companies such as Acrian can select current state-of-the-art devices for wideband power amplifiers and therefore provide a technology edge for customers. Well-designed amplifiers can then be easily adapted to a standard product line, allowing systems companies faster access to markets.

The PB-2022

Designed to meet military specifications — like all Acrian sub-assemblies — the PB-2022 has wide instantaneous bandwidth (30-150 MHz), high power gain (+50 dB), ALC gain flatness, plus wide dynamic range (60 dB). It is unconditionally rugged and stable at 3:1 VSWR and has a wide temperature range (ambient to +50 C, with heat sink to +70 C). Offering superior performance, the PB-2022 uses Acrian's proprietary ISO-FET device technology.

As with all other Acrian sub-assemblies, the PB-2022 can be repaired in the field. It can be easily removed and replaced to minimize down time should a failure occur. The input splitter and the output combiner have excellent port-to-port isolation. This is important in the event of a failure in the output stage. If this happens, the amplifier will continue to operate at a reduced power level.

Because the PB-2022 is so efficient, a simple heat exchenger can be used. The amplifier can be easily cooled with only conventional heatsinks and forced air. When mounted into a 19 inch by 7 inch high rack, the unit can be cooled by using a 300 CFM of air with a back pressure of 1 inch of water with the proper selection of heatsinks and mechanical layout.

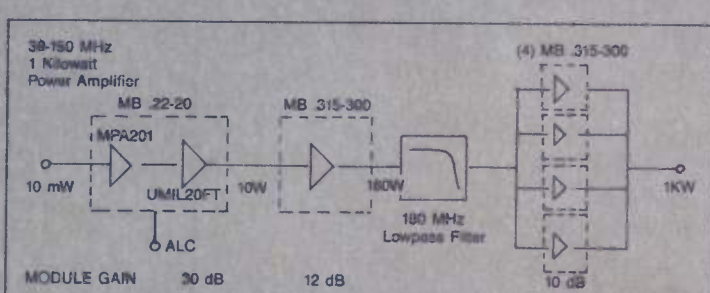
Design Features

The PB-2022 is made from two basic 50 ohm power block modules. The first is a 20 watt pre-amplifier, similar to the Acrian MB22-20. Two stages of amplification are employed: the first is a 50 ohm hybrid followed by a power FET. An ISO-FET was used at this point in the line-up due to its superior gain versus controlled voltage characteristic as well as its 4 dB noise figure and 15 dB of gain. More than 60 dB dynamic range is achieved in this single power block.

A common 300 watt module is used for the driver and in the combined output stage. Extensive use of ferrite-loaded coaxial transformers assure multi-octave bandwidths. The input has a 4:1 ratio, while the output has a 9:1 ratio. The quiescent current of each module may be individually set with an on-board potentiometer, thereby allowing module swapping. Typical module efficiency is greater than 60 percent.

The transistor is composed of 2 matched pills mounted on a common flange and is operated in the push-pull mode. This is called the "Gemini configuration." Both even and odd mode terminating resistors assure stable operation.

A conventional 50 ohm, 4-way in-phase splitter and combiner is used in the PB-2022. Unique combinations of 2-way, 6-way, and 2 x 4-way configurations have been demonstrated — all using the basic 300 watt power block module. **Acrian, Inc., San Jose, CA 95126. Booth #301, 303; Please circle INFO/CARD #189.**



Specifications

Operating Frequency	30 to 150 MHz Instantaneous
Power Output	1 KW into 50 ohm Load
Power Output into 2:1 VSWR	500 Watts Minimum
Power Input	+10 dBm
Power Gain	50 dB Minimum
ALC Control	Output Level Control Provision
Input Impedance	50 ohms 2.0:1 VSWR Maximum
Operating Voltage	28 Volts
Efficiency Overall	40% Min.
Harmonics	2nd <-25 dBc/3rd <-15 dBc
Stability	Unconditionally Stable in 3:1 VSWR

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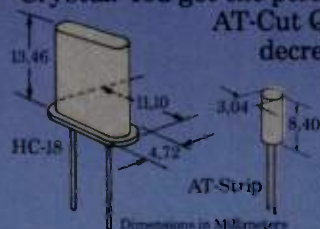
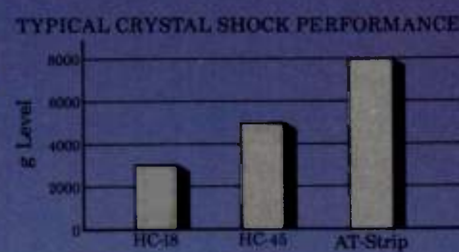


Both new and existing applications benefit from this development – pocket pagers, disk drives, modems, commercial communications devices, and driving microprocessor-based systems.

WITHSTANDS 8,000 g SHOCK FORCE

The new Motorola AT-Strip Crystals offer a shock survival level two and three times higher than traditional crystals.

These and other environmental characteristics are documented in tests performed in accordance with MIL STD 202.



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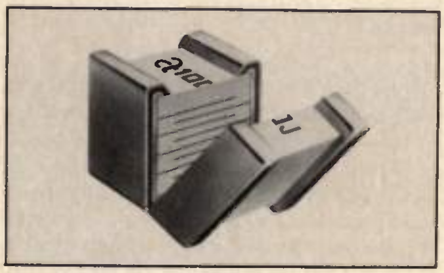
MOTOROLA INC.

Components Division

1-dB compression point is +5 dBm. Typical output VSWR is 1.2:1 and DC current required at 5 v is 30 mA. **Watkins-Johnson Co., Components Applications Eng., Palo Alto, CA 94304. Booth #500, Info/Card #109.**

Components

A new termination metallization called UNI-TERM has been developed by American Technical Ceramics. The process uses silver or silver palladium thick film as the primary layer. A proprietary nickel layer is then applied to the thick file material. A final application of a fugitive layer of pure gold completes the process. Some of the advantages of UNI-TERM are: compatibility with all standard circuit



American Technical Ceramics

attachment techniques including wire bonding, soldering, and epoxy bonding; excellent solderability; and reduced termination material migration. UNI-TERM is available at no extra cost on any ATC chip, and will be standard on new products. **American Technical Ceramics, Huntington Station, NY 11746. Booth #611; INFO/CARD #176.**

Surface acoustic wave hybrid oscillators from Andersen Laboratories are available in a standard design package for a wide range of applications. Compact,

Andersen Laboratories

low phase noise devices requiring no alignment, they are available with operating frequencies from 100 MHz to greater than 1 GHz. Both fixed frequency and VCO devices are available. **Andersen Laboratories, Inc., Bloomfield, CT 06002. Booth #211; INFO/CARD #175.**

A family of 21.4 MHz IF filters packaged in less than ½ cubic inch (1.75"L x 0.6"W x 0.44"H) will be exhibited by Cirtech. The family is available in 3 dB bandwidths from 2 kHz to 10 MHz and features spurious responses of better than 60 dB, attenuation better than 70 dB, and ripple below 1 dB. The size uniformity is ideal for applications offering optional bandwidths. The 0.44" height allows half-inch board spacings. These filters conform to MIL-STD-202, Method 204, Condition B. **Cirtech Corp., Stanley, KS 66223. Booth #511; INFO/CARD #174.**

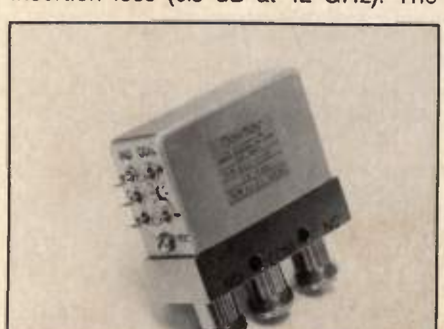
Coilcraft is exhibiting their line of surface mount inductors and transformers.

Coilcraft

Coilcraft, Cary, IL 60013. Booth #416; INFO/CARD #173.

Crystal Technology's surface acoustic wave filters can be used for IF filtering, timing extraction, and general spectral shaping in a wide variety of applications, including TV and CATV, satellite receiver, telecommunications, radar, and telemetry systems. They provide greater selectivity, reproducibility, and stability than either LC or helical filters, especially at UHF or L-band frequencies. Out-of-band rejection of 70 dB can be realized with a single filter, and over 100 dB can be achieved by cascading two units. **Crystal Technology, Inc., Palo Alto, CA 94303. Booth #412; INFO/CARD #172.**

The Dow-Key 402 series SPDT "Smart Switches" use the latest MIC detector and solid-state CMOS driver technology internally to detect power and VSWR changes and switch automatically when preset conditions are met. They feature high power handling (350 W at 1 GHz) and low insertion loss (0.5 dB at 12 GHz). The



Dow-Key Microwave

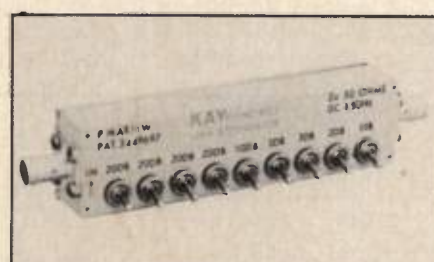
"Smart Switches" are designed for redundant transmitter applications where automatic switching is required if the power decreases in one channel (amplifier failure) or the antenna pattern is disturbed (disconnected or damaged). **Dow-Key Microwave Corp., Carpinterla, CA 93013. Booth #105; INFO/CARD #171.**

The TSO500 miniature thin film chip attenuators are available from EMC Technology in 1 to 20 dB values, for the frequency range from DC to 18 GHz. At-

EMC Technology

tenuation accuracy is ±0.25 dB. Impedance is 50 ohms and power dissipation is 0.1 W. The attenuators operate from –55° to 150°C. Measuring only 0.075" x 0.060" with 0.025" terminals, these automatically trimmed attenuators are suitable for circuits of all types where packaging density and improved high frequency performance are important considerations. **EMC Technology, Inc., Cherry Hill, NJ 08034. Booth #309; INFO/CARD #170.**

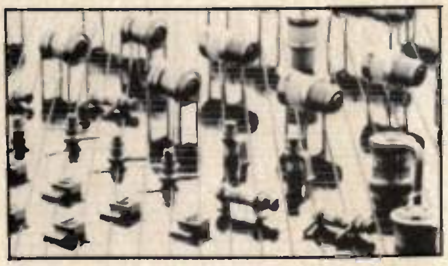
The Model 439 from Kay Elemetrics is a miniature bench attenuator designed to provide a frequency range of DC to 1500 MHz. Attenuation range is 0 to 101 dB in



Kay Elemetrics

1 dB steps. VSWR is 1.2 below 500 MHz and 1.4 above 500 MHz. Insertion loss is 0.2 dB below 500 MHz, 0.5 dB between 500 and 1000 MHz, and 0.8 dB above 1000 MHz. The 439 is available with BNC connectors, with SMA or TNC available as options. **Kay Elemetrics Corp., Pine Brook, NJ 07058. Booth #423; please circle INFO/CARD #169.**

The "A" and "E" line of internally sealed air trimmers offer ten full turns of adjustment, long life, Qs over 5000, internal stops, extended shaft options, and tuning ranges of either 0.8 to 10 pF or 0.8

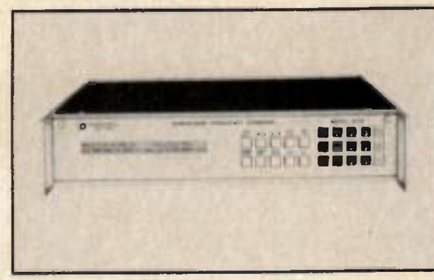


Voltronics

to 14 pF. Their non-rotating piston glass trimmers offer much higher capacitance values, exceeding 250 pF. The non-rotating design provides excellent linearity, high current capacity, low RF loss, high Q, and long life. The "M" series of sapphire trimmers are usable to 3 GHz while the "CP" series of surface-mounted trimmers are usable up to 5 GHz. **Voltronics Corp., East Hanover, NJ 07936. Booth #613; INFO/CARD #168.**

Systems

The Austron Model 2110 is a microprocessor-controlled disciplined frequency standard that automatically locks the frequency of its precision ovenized crystal oscillator to that of an externally applied reference having superior long-term stability. Using a third-order servo technique, the instrument is able to correct the frequency offset and aging of the internal oscillator. If the external reference is removed or fails, the 2110 will continue to apply corrections to the oscillator to hold it on frequency. Typically the unit can limit the frequency offset to a few parts in 10^{12} for several days following the loss of the reference. **Austron Inc., Austin, TX 78761. Booth #602; INFO/CARD #167.**



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Designed to be part of a larger multi-kilowatt RF power amplifier system, the Erbtec RF Amplifier Controller incorporates the intelligence and all the necessary electronics to monitor, control, and properly drive external high power vacuum tube amplifiers. Its modular architecture includes a RS-232 interface enabling all functions to be completely controlled and monitored by a remote computer. The instrument has very few manual adjustments, and no special tools are required for maintenance. **Erbtec, Inc., Boulder, CO 80301. Booth #316; INFO/CARD #166.**

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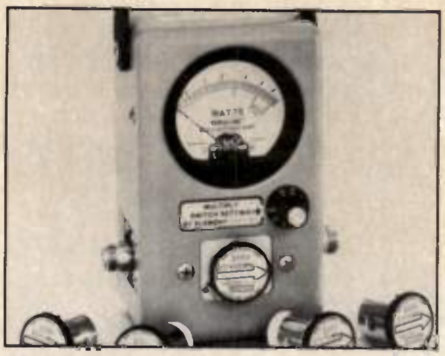
Test Equipment

A solid-state, cavity-tuned, RF power signal source, the RPS 3000 from American Microwave Technology produces 10 watts of CW output from 3.0 to 3.5 GHz. The output is isolated to safely provide maximum power operation into any VSWR. Actual power output can be monitored on the front panel. **American Microwave Technology, Inc., Fullerton, CA 92631. Booth #520; please circle INFO/CARD #164.**

A new series of five plug-in elements from Bird Electronic converts the company's THRULINE wattmeter into an extraordinarily sensitive instrument. The elements offer bi-directional RF power measurement from 20 mW to 100 W at



Bird Electronics

±5% accuracy of reading, in frequency bands from 25 to 1000 MHz. Full rated accuracy is maintained over the 5000 to 1 power range with temperature extremes between 0° and 50°C. The entire complement of elements enable the THRULINE to cover frequencies from 200 kHz to 1000 MHz and power from 20 mW to 10 kW. **Bird Electronic Corp., Solon, OH 44139. Booth #307; INFO/CARD #163.**

Four surface acoustic wave resonator oscillators form the heart of the Hewlett-Packard 8642A/B signal generators. These extremely high-Q devices operating near 800 MHz provide low SSB phase noise at offsets beyond 10 kHz. The 8642A covers the range of 100 kHz to 1057.5 MHz while the 8642B doubles the upper limit to 2115 MHz. Both models offer underrange to 10 kHz and a resolution of 1 Hz, 0.1 Hz with a special function. The

Hewlett Packard

output ranges from +20 to –140 dBm with a resolution of 0.1 dB. AM, FM, ϕM, and PM allow the 8642A/B to accurately simulate signals used for most types of RF communication systems. On demand, the generators can switch in a separate heterodyne output section to provide improved modulation performance for carrier frequencies below 132.2 MHz. **Hewlett-Packard, Palo Alto, CA 94303. Booth #522; INFO/CARD #161.**

Weighing in at 7.5 kg, the Marconi 2022 signal generator has a frequency range of 10 kHz to 1000 MHz, with a resolution of 10 Hz below 100 MHz and 100 Hz above 100 MHz. Output amplitude is +6 to –127 dBm with a resolution of 0.1 dB. Amplitude, frequency, and phase can be modulated externally or internally. Two elapsed time indicators — usage since last resetting and usage since manufacture — aid in analyzing reliability and cost-of-ownership. **Marconi Instruments, Allendale, NJ 07401. Booth #507; please circle INFO/CARD #160.**

For testing of communications systems, one of the most important parameters for a singal generator is its phase noise performance. The new FCC proposals to reduce channel spacings to as low as 7.5 kHz place stringent requirements on instruments used to test the new systems. The Racal-Dana 9087 generates signals with noise as low as –142 dBc/Hz at only 3 kHz offset from the carrier. With a frequency range of 10 kHz to 1300 MHz with a resolution of 1 Hz, the 9087 covers all HF, VHF, and UHF telecommunications bands as well as the LF and MF bands often used for radio navigation. The signal may be swept. The output is variable from +19 to –140 dBm (2 V to 0.0224 μV rms into 50 ohm) with a resolution of 0.1 dB. A GPIB interface provides for full programmability. In addition, its fast switching speed of 500 μs makes the 9087 suitable for FSK (frequency shift keying) simulation and the testing of electronic warfare systems. The 9087 offers total modulation

Racal-Dana

versatility, including AM, FM, ϕM, and PM from a combination of internal and external sources. Simultaneous AM+FM, AM+ϕM, FM+PM, and ϕM+PM allows accurate simulation of ECM/ECCM and "chirp" signals. **Racal-Dana, Irvine, CA 92713. Booth #405; INFO/CARD #158.**

The Polarad SMPD synthesized signal generator covers the frequency range of 5 kHz to 1 GHz with a resolution of 1 Hz.

Polarad Electronics

The output level range is +13 to –143 dBm with a resolution of 0.1 dB. Amplitude, Frequency, phase, and pulse may be modulated. Linear and logarithmic frequency sweeps are available, with both the sweep width and sweep time being freely selectable. THe SSB phase noise is <–143 dBc/Hz at 20 kHz from the carrier (at 100 MHz). **Polarad Electronics, Lake Success, NY 11042. Booth #311; Info/card #177.**

Option 07 gives the Tektronic 496 and 496P portable spectrum analyzers 75

Tektronics

ohm measurement capability in addition to the standard 50 ohm measurement. Calibration is provided so that it is no longer necessary for the user to convert the units or account for external losses when changing from 50 ohm to 75 ohm. Option 07's frequency range of 5 MHz to 1 GHz, and 300 kHz resolution provide measurement capability for all cable and broadcast systems. The 496/496P offer spectrum analysis and measurements in the 1 kHz to 1.8 GHz range with 80 dB dynamic range. **Tektronix Inc., Beaverton, OR 97077. Booth #504; please circle INFO/CARD #157.**

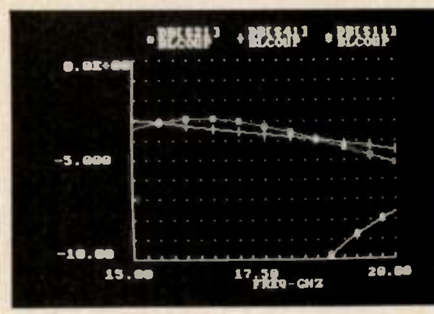
The HPIL (Hewlett-Packard Interface Loop) available as an option on the Texscan SSG-1000 and SSG-2000 signal generators enable a low-cost hand-held computer, such as the HP-41C, to control the instrument. The SSG-1000 covers the frequency range of 100 kHz to 1000 MHz with a resolution of 10 Hz. The SSG-2000 extends the range to 2000 MHz, with a resolution of 20 Hz above 1000 MHz. Spurious noise is below –60 dBc (–54 dBc above 100 MHz), and harmonics are below –30 dBc. AM, FM, and PM are available. **Texscan Instruments Corp., Indianapolis, IN 46226. Booth #417; please circle INFO/CARD #156.**

RF Software

The growing popularity of the IBM PC led Compact Software to develop a version of SUPER-COMPACT for the PC. SUPER-COMPACT PC models circuits as a series of two-ports. Up to fifteen variables may be optimized simultaneously. An important capability is the easy interface to the mainframe versions of the program. The initial analysis can be performed on the PC, and then uploaded to a faster mainframe for the "number-crunching." **Compact Software. Booth #100, 101; INFO/CARD #155.**

CADEC from Communications Consulting allows circuit analysis and optimization in the linear frequency domain. The circuit, described using the nodal method, is converted internally to a series of two-ports. The program includes a fast Fourier transformation of calculated frequency points to a large variety of user defined waveforms. CADEC is available for IBM PCs and compatibles and the Hewlett-Packard Series 200. **Communications Consulting Corp., Upper Saddle River, NJ 07458. Booth #515; please circle INFO/CARD #154.**

Touchstone/RF is a version of EEsof's Touchstone program that has been specially tailored for RF work. The costly microwave circuit models such as microstrips and striplines have been eliminated, reducing the cost by about a half. Touchstone/RF is available for the HP Series 200 computers and the IBM PCs and



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compatibles. The program is compatible with their MICAD circuit layout program. **EEsof, Inc., Westlake Village, CA 91362. Booth #610; INFO/CARD #153.**

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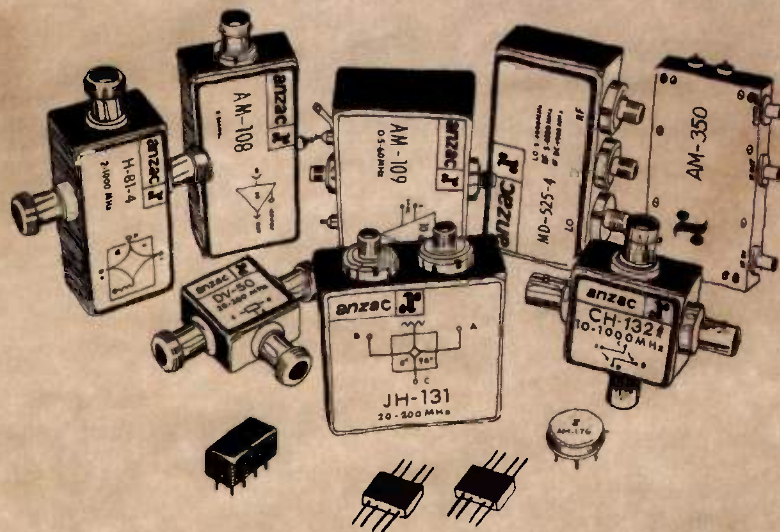

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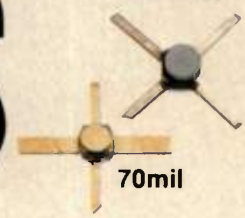

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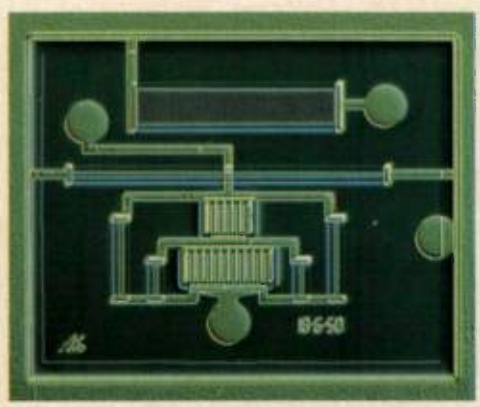

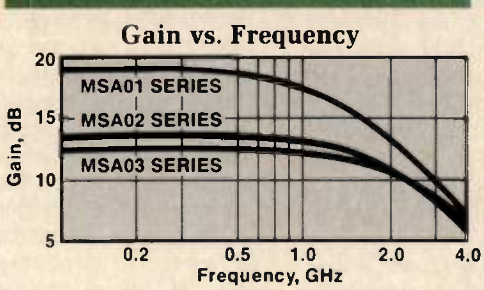

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The SAW Resonator: How It Works

Part I gives an introduction to the Surface Acoustic Wave resonator and a TI-59 program to model device responses.

By Jeff Schoenwald
Contributing Editor

Long-time readers of *RF Design* have encountered the Surface Acoustic Wave (SAW) resonator before[1,2]. The original concept belongs to Eric Ash, of the Imperial College in London, who made the first attempt to produce a high Q resonant acoustic device that is planar in its fabrication (like all semiconductor circuits today), uses SAW, and can scale the frequency spectrum well beyond the practical limits achievable, then or now, by bulk quartz crystal filters. The first truly successful devices were demonstrated by Texas Instruments, followed soon after by scores of industrial, government and university laboratories in the United States, Europe and Japan. The theory, fabrication and performance of the SAW resonator is well chronicled in some detail and variation in the proceedings of the IEEE Ultrasonics Symposium going to back to 1974.

In this article I have tried to provide the RF engineer with a useful tool — a model with which he can simulate the many different device responses the SAW resonator has been found able to produce. In Part I the theory of the model is presented, along with a listing for the TI-59 calculator equipped with a printer. In Part II we manipulate the model to produce various devices and develop a good feeling for how performance depends on design and material parameters.

The first SAW resonator was a single pole device — a pair of reflecting structures forming a single cavity. Each reflecting structure consists of a repetitive set of lines and gaps — a grating. The grating is formed in various ways but always involves the use of vacuum deposition of metal (mostly aluminum) or occasionally a dielectric, and photolithographic exposure, developing and etching. Sometimes the stripes of the reflector are patterned in etched aluminum; the more reliable technique used today is one in which grooves are plasma etched directly out of the quartz substrate. Each line and groove is one quarter wavelength long in the direction of propagation of the wave, and is typically 50-200 wavelengths wide, at the designated center frequency. Each pair of line and groove has a very low coefficient of reflection, purposely: too large a coefficient and the surface wave would quickly scatter into the bulk and dissipate. A distributed reflector consisting of several hundreds of lines (sometimes more than a thousand) produces a very efficient phase matched coupling between a SAW wave traveling in one direction and a reflected wave. As we shall see in some of the examples in Part II, the reflectivity can be very nearly 100%. Two such reflectors can form a cavity whose length is an integer number of half wavelengths. This is a Fabry-Perot cavity, and is the fundamental structure known as the single pole resonator. Place an interdigital transducer in the cavity (at the proper position, of course) and we have a way to dump electrical energy into this acoustic cavity through the piezoelectric coupling coefficient of the substrate. Remember that crystal quartz, lithium niobate, zinc oxide and many other materials are piezoelectric. Read my two previous articles[1,2] for a bit more background, or plow through the rich literature on the subject if you have a few years.

We needn't stop with a single pole resonator. Refer to Fig. 1. A third reflective array properly placed in line with the other two forms a second cavity — the two-pole SAW resonator. This may be continued indefinitely. The calculator is dumb and will not mind. But we, as engineers, can play the program included here like an arcade game and produce interesting and varied results. First, I'll describe the theory behind the program. Second, familiarize yourself with initial data entry procedures and device design. Then, next month, we'll start to build a succession of

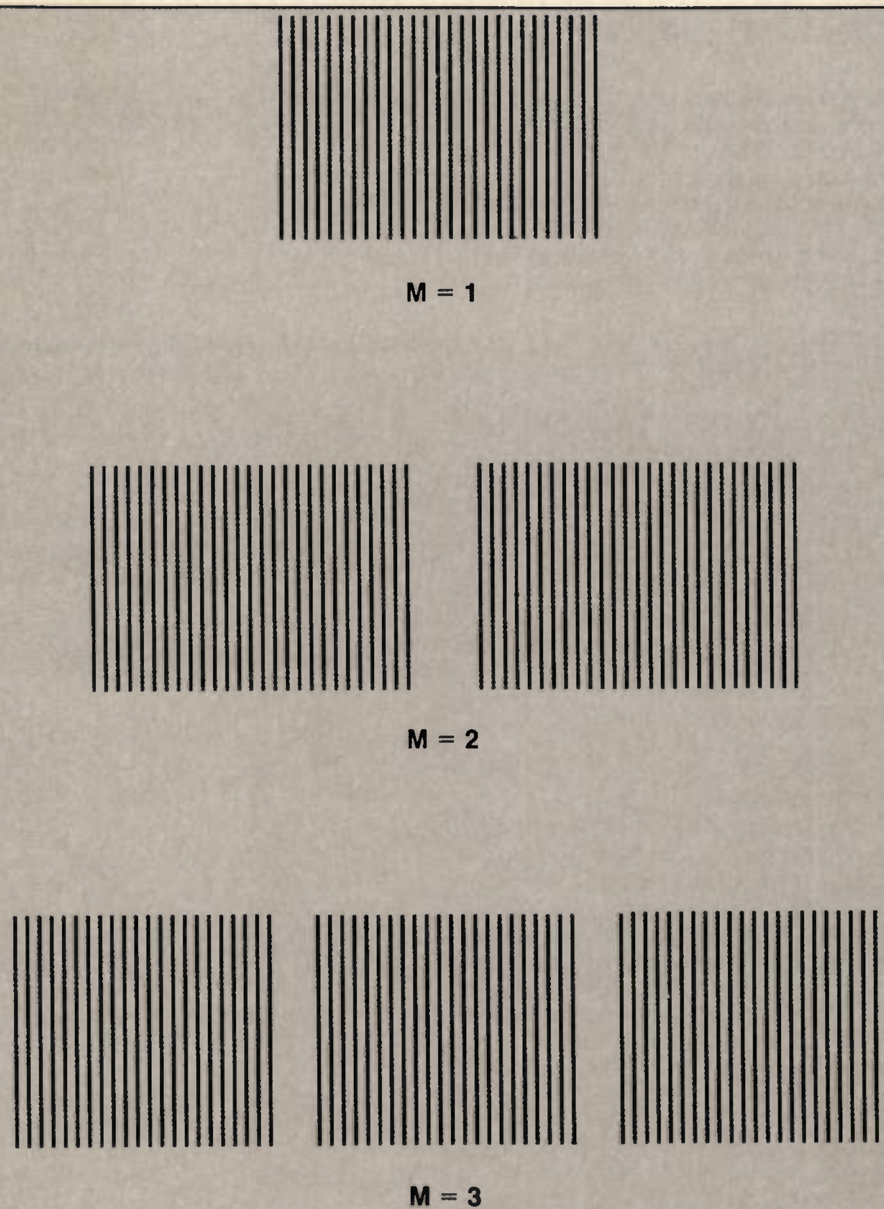

FIGURE 1. Basic structures for SAW resonators using cascaded reflector arrays forming a single array (M = 1), (M = 2) single pole and (M = 3) two pole resonator.

devices and look at the power transmission and reflection characteristics of each one and, for a few selected cases, the change in performance of a single design as we make small changes in one of the parameters.

The program comes in two versions. The first one produces a listing of transmitted and reflected power as a function of frequency. The second version, which is run by replacing the last part of the program, will list the phase of the transmitted and reflected waves versus frequency. Unfortunately the TI-59 does not have enough memory to compute both and still be "user friendly" enough to handle all the I/O commands for data entry and listing on the printer. As a serious TI-59 programmer, you could generate more available memory by loading all the data off-line, eliminating the print commands to list them (jot them down elsewhere), and leave only the appropriate RUN/STOP commands to read important computed parameters as the program generates them at the beginning — you'll understand what I mean when we cover data entry. If you do all this, there should be enough memory space left to compute magnitude *and* phase of transmitted and reflected waves. I have chosen instead to rely on the automation features available on the TI-59 when used with the printer.

An Overview of the Program Architecture

After initial data entry, the program accomplishes its task by transmission line matrix computation methods. The 2x2 transmission matrix (T[1]) of a single line and gap segment is computed. The eigen values of this matrix are determined and the matrix T[N] of an array of N such segments is computed using Sylvester's Theorem (3). This theorem states that if T is a jxj matrix (in this case 2x2), then any polynomial matrix expression in powers of T may be written as:

$$P(T)=\sum_{r=1}^{j}\left\{P(\lambda r)\prod_{\substack{s=1\\ s\neq r}}^{j}\left(\frac{T-\lambda_s I}{\lambda_r-\lambda_s}\right)\right\},\quad I=\begin{bmatrix}1&0\\0&1\end{bmatrix} \qquad (1)$$

where I is the 2x2 identity matrix, λr is the r'th eigenvalue of the matrix T, and $P(\lambda r)$ is the same polynomial as before, but in powers of λr, instead of the matrix T. For our 2x2 situation, j=2, T is the matrix of one section (a line and a gap), and $P(T)=T_N$. Then:

$$T^N=\lambda_1^N\left(\frac{T-\lambda_2 I}{\lambda_1-\lambda_2}\right)+\lambda_2^N\left(\frac{T-\lambda_1 I}{\lambda_2-\lambda_1}\right) \qquad (2)$$

$$=T\left(\frac{\lambda_1^N-\lambda_2^N}{\lambda_1-\lambda_2}\right)+I\left(\frac{\lambda_1\lambda_2^N-\lambda_1\lambda_1^N}{\lambda_1-\lambda_2}\right)$$

The eigenvalues λ_1 and λ_2 are found by setting the determinant of T–I equal to zero and solving Eq. 2. This approach enables the closed-form, single pass calculation which is independent of the number of sections N in the grating array. The original version of this calculation did not use Sylvester's Theorem and relied instead on a recursive calculation which consumed time proportional to the size of the grating number N(4).

The matrix T[g] representing the gap of length l_g (normalized relative to the wavelength at the specified reference frequency f_o) is computed and the structure cascaded by multiplication of the two matrices

$$T[N]\times T[g]=T[N+g] \qquad (3)$$

The composite matrix is then solved for its eigenvalues and Sylvester's Theorem is used again to find the net transmission matrix of M such sections, which form M-1 cavities, or an (M-1) — pole resonator:

$$(T[N+g])^M=T[M] \qquad (4)$$

Again, we must compromise because of the calculator's capacity. A practical device could have several cavities with different values of l_g, and the grating arrays between these cavities, referred to as coupling relfectors, might have different sizes. Nevertheless, the symmetric devices we are able to design are instructive, and represent the great majority of designs that have been practically implemented over the past 10 years.

The program assumes the transmission line structure is lossless, i.e., the impedance values are not complex. Making provisions for a complex impedance requires an ability to manipulate them in matrix multiplication, which the TI-59 does not do directly, or doubling the dimension of matrices and increasing the size of the calculation, which we can't afford. We also assume that the characteristic impedance of the source and load at either end of the grating are the same, and equal to that of the gaps between lines in a grating and between grating arrays where we have formed cavities, i.e., Z(load) = Z(source) = Z(gap) = 1.

Data entry procedures are summarized in the flow diagram in Table 1. After l1, l2, n2 and f0 are entered, fc, the "center frequency" at which the first maximum in reflectivity occurs, is computed:

$$fc=\frac{f0}{2(l1+n2\bullet l2)} \qquad (5)$$

Other reflectivity maxima occur at odd harmonics of fc. The fractional "phase length" of a strip relative to a strip gap pair is

$$t=\frac{n2\bullet l2}{l1+n2\bullet l2} \qquad (6)$$

If t = 0.5, l1 = n2*l2 and each segment has equal "optical," or phase thickness. The fractional difference in phase thickness between a gap and a strip is 1-2•t.

Armed with this input and a starting frequency, we may proceed to compute the transmission matrix of a strip-gap pair:

$$T[1]=\begin{bmatrix}A1&B1\\C1&D1\end{bmatrix} \qquad (7)$$

where

$$A1=\frac{(Z+1)\cos\gamma}{2}-\frac{(Z-1)\cos(1-2t)\gamma}{2} \qquad (7a)$$

$$B1=j\left(\frac{(Z+1)\sin\gamma}{2}-\frac{(Z-1)\sin(1-2t)\gamma}{2}\right) \qquad (7b)$$

$$C1=j\left(\frac{(Z+1)\sin\gamma}{2Z}+\frac{(Z-1)\sin(1-2t)\gamma}{2Z}\right) \qquad (7c)$$

$$D1=\frac{(Z+1)\cos\gamma}{2Z}+\frac{(Z-1)\cos(1-2t)\gamma}{2Z} \qquad (7d)$$

and

$$\gamma=\ Pi\bullet f1/fc. \qquad (8)$$

Once T[1] is obtained, we must find its eigenvalues in order to compute T[1] ∧ N = T[N], the equivalent of cascading N sections. We define the quantity 0,

$$\cos\Theta=\frac{A1+D1}{2} \qquad (9)$$

$$\lambda_1=\cos\Theta+\sqrt{\cos^2\Theta-1}$$

$$\lambda_2=1/\lambda_1$$

If $\cos^2\Theta-1$ is zero or positive, the eigenvalues of t[1] are real. However, it is entirely possible that (A1 +D1)/2<0, in which case the eigenvalues are a complex conjugate pair. The distinction is made because the program branches to handle each case differently. If the eigenvalues are real, we obtain:

$$[TN]=\begin{bmatrix} AN & BN \\ CN & DN \end{bmatrix} \tag{10}$$

where

$$AN= A_1\frac{\lambda_1^N-\lambda_2^N}{\lambda_1-\lambda_2} - \frac{\lambda_1^{N-1}-\lambda_2^{N-1}}{\lambda_1-\lambda_2} \tag{11a}$$

$$BN= jB_1\frac{\lambda_1^N-\lambda_2^N}{\lambda_1-\lambda_2} \tag{11b}$$

$$CN= jC_1\frac{\lambda_1^N-\lambda_2^N}{\lambda_1-\lambda_2} \tag{11c}$$

$$DN= D_1\frac{\lambda_1^N-\lambda_2^N}{\lambda_1-\lambda_2} - \frac{\lambda_1^{N-2}-\lambda_2^{N-1}}{\lambda_1-\lambda_2} \tag{11d}$$

If the eigenvalues are complex, we have instead

$$AN= \frac{D \sin N\Theta}{\sin \Theta} - \frac{\sin (N-1)\Theta}{\sin \Theta} \tag{12a}$$

$$BN= \frac{jB1 \sin N\Theta}{\sin \Theta} \tag{12b}$$

$$CN= \frac{jC1 \sin N\Theta}{\sin \Theta} \tag{12c}$$

$$DN= D1' \frac{\sin N\Theta}{\sin \Theta} - \frac{\sin (N-1)\Theta}{\sin \Theta} \tag{12d}$$

where Θ is obtained from (9).

Having constructed a grating array [TN], we must now compute the transmission line that will make up the cavity between two reflectors. The matrix for this section is simple:

$$[Tg]= \begin{matrix} \cos\gamma & jZ1'\sin\gamma \\ \dfrac{j\sin\gamma}{Z1} & \cos\gamma \end{matrix} \tag{13}$$

where

$$\gamma=2\pi\left(\frac{f_1}{f_c}\ lg\right) \tag{14}$$

and Z1=1.

The matrix for the cascaded reflector and gap is simply obtained using (1). The same calculation is applied to T[N+g] to find its eigenvalues, and then the composite structure is cascaded M times to build a transmission line with M reflectors and M-1 cavities. Note that the tail end of the structure contains a length of transmission line l_g. This will have no effect on the

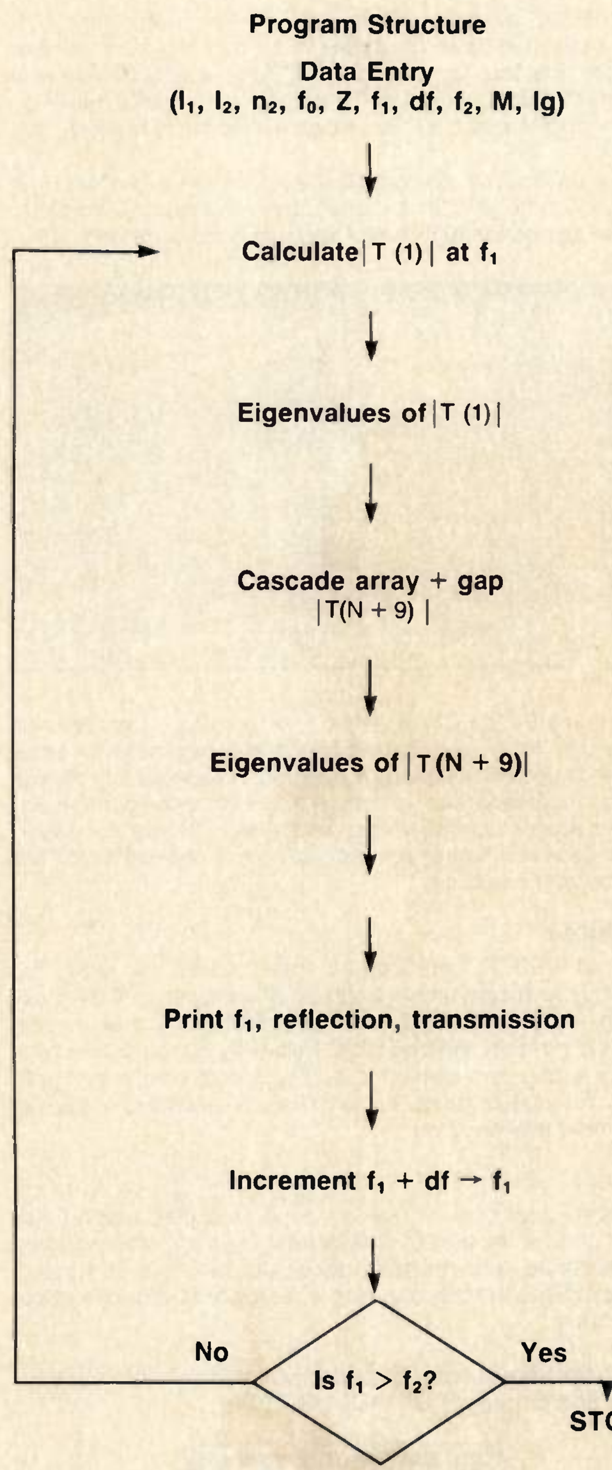

TABLE 1

magnitude of the power transmitted or reflected, but only a phase shift in the transmitted wave.

Once the transmission of matrix T of the entire structure has been computed, the normalized transmission and reflection amplitudes Tf and Rf are easily computed:

$$Tf = \frac{2}{A'+B'+C'+D'} \qquad (15a)$$

$$Rf = \frac{A'+B'-C'-D'}{A'+B'+C'+D'} \qquad (15b)$$

Since the device is assumed to be lossless only one coefficient need be calculated, say Tf, and

$$RF^2 = 1 - Tf^2. \qquad (16)$$

Using the Program for Design and Analysis

The program is listed in Table II. Partition the TI-59 for 3op17 (719.29) and load the program. Two magnetic cards are needed to store it. Enter the data as shown in Table III. Each input parameter is printed as it is entered. After f_o is entered and printed, f_c is computed and it too is printed. This is done to aid the user in choosing an appropriate frequency range for analysis. After all input data has been entered, calculation commences, resulting in a listing of the frequency and corresponding normalized reflected and transmitted power (in dB). A complete cycle takes about 20 seconds. The computation is then repeated at the next frequency until the entire frequency domain has been examined. While the program chugs away, take a break.

The user may FIX the number of decimal places desired at the beginning or at any point during data entry, since, for example, the reflection or transmission loss may only be interesting to 0.1 dB accuracy. Care must be taken, however, since the printed listing of input parameters or frequency may appear truncated to less accuracy than was originally specified.

Join us next month for Part II. We will use the program to examine the properties of reflective arrays, single and multiple cavities. As an added bonus, a BASIC version is also provided for the growing number of microcomputer users.

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TABLE III
Data Entry

Parameter	Enter	Press
gap length	l_1	A
line length	l_2	R/S
veolocity index	n_2	R/S
reference frequency	f_0	R/S
impedance ratio	Z	B
number of sections	N	R/S
start frequency	f_1	C
frequency increment	df	R/S
stop frequency	f_2	R/S
number of relfectors	M	R/S
cavity size	lg	R/S

Table II

000	76	LBL	065	69	69	130	99	PRT
001	50	I x I	066	43	RCL	131	91	R/S
002	43	RCL	067	04	04	132	76	LBL
003	12	12	068	92	RTN	133	12	B
004	22	INV	069	53	(	134	42	STO
005	39	COS	070	43	RCL	135	10	10
006	42	STO	071	00	00	136	99	PRT
007	04	04	072	55	÷	137	91	R/S
008	43	RCL	073	02	2	138	42	STO
009	11	11	074	54	)	139	11	11
010	42	STO	075	32	X ⇆ T	140	42	STO
011	00	00	076	53	(	141	29	29
012	71	SBR	077	43	RCL	142	99	PRT
013	38	SIN	078	00	00	143	53	(
014	42	STO	079	55	÷	144	43	RCL
015	27	27	080	02	2	145	06	06
016	53	(	081	54	)	146	65	x
017	43	RCL	082	59	INT	147	43	RCL
018	11	11	083	67	EQ	148	07	07
019	75	—	084	00	00	149	55	÷
020	01	1	085	90	90	150	53	(
021	54	)	086	43	RCL	151	43	RCL
022	42	STO	087	04	04	152	05	05
023	00	00	088	94	+/–	153	85	+
024	71	SBR	089	92	RTN	154	53	(
025	38	SIN	090	43	RCL	155	43	RCL
026	42	STO	091	04	04	156	06	06
027	28	28	092	92	RTN	157	65	x
028	61	GTO	093	76	LBL	158	43	RCL
029	18	C'	094	11	A	159	07	07
030	76	LBL	095	42	STO	160	54	)
031	38	SIN	096	05	05	161	54	)
032	53	(	097	99	PRT	162	54	)
033	53	(	098	91	R/S	163	42	STO
034	43	RCL	099	42	STO	164	12	12
035	00	00	100	06	06	165	53	(
036	65	x	101	99	PRT	166	43	RCL
037	43	RCL	102	91	R/S	167	10	10
038	04	04	103	42	STO	168	85	+
039	54	)	104	07	07	169	01	1
040	38	SIN	105	99	PRT	170	54	)
041	55	÷	106	91	R/S	171	42	STO
042	43	RCL	107	42	STO	172	16	16
043	04	04	108	08	08	173	53	(
044	38	SIN	109	99	PRT	174	24	CE
045	54	)	110	55	÷	175	75	—
046	92	RTN	111	53	(	176	02	2
047	76	LBL	112	02	2	177	54	)
048	45	Y^x	113	65	x	178	42	STO
049	53	(	114	53	(	179	17	17
050	43	RCL	115	43	RCL	180	53	(
051	01	01	116	05	05	181	01	1
052	50	I x I	117	85	+	182	75	—
053	45	Y^x	118	53	(	183	02	2
054	43	RCL	119	43	RCL	184	65	x
055	00	00	120	06	06	185	43	RCL
056	54	)	121	65	x	186	12	12
057	42	STO	122	43	RCL	187	54	)
058	04	04	123	07	07	188	42	STO
059	43	RCL	124	54	)	189	18	18
060	01	01	125	54	)	190	91	R/S
061	32	X ⇆ T	126	54	)	191	76	LBL
062	00	0	127	95	=	192	13	C
063	77	GE	128	42	STO	193	42	STO
064	00	00	129	09	09	194	13	13

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INFO/CARD 35

Table II *continued*

195	99	PRT	260	19	19	325	16	16	390	24	24	455	54	)	520	43	RCL
196	91	R/S	261	53	(	326	85	+	391	35	1/X	456	55	÷	521	05	05
197	42	STO	262	53	(	327	53	(	392	42	STO	457	53	(	522	42	STO
198	14	14	263	43	RCL	328	53	(	393	25	25	458	43	RCL	523	19	19
199	99	PRT	264	15	15	329	43	RCL	394	43	RCL	459	24	24	524	92	RTN
200	91	R/S	265	38	SIN	330	15	15	395	11	11	460	75	-	525	76	LBL
201	99	PRT	266	65	x	331	65	x	396	42	STO	461	35	1/x	526	48	EXC
202	53	(	267	43	RCL	332	43	RCL	397	00	00	462	54	)	527	53	(
203	24	CE	268	16	16	333	18	18	398	53	(	463	54	)	528	43	RCL
204	85	+	269	75	—	334	54	)	399	53	(	464	42	STO	529	13	13
205	43	RCL	270	53	(	335	39	COS	400	53	(	465	28	28	530	99	PRT
206	14	14	271	53	(	336	65	x	401	43	RCL	466	76	LBL	531	85	+
207	54	)	272	43	RCL	337	43	RCL	402	24	24	467	18	C'	532	43	RCL
208	42	STO	273	15	15	338	17	17	403	42	STO	468	53	(	533	14	14
209	26	26	274	65	x	339	54	)	404	01	01	469	43	RCL	534	54	)
210	91	R/S	275	43	RCL	340	95	=	405	71	SBR	470	19	19	535	42	STO
211	42	STO	276	18	18	341	55	÷	406	45	Yˣ	471	65	x	536	13	13
212	02	02	277	54	)	342	02	2	407	54	)	472	43	RCL	537	43	RCL
213	99	PRT	278	38	SIN	343	55	÷	408	75	-	473	27	27	538	02	02
214	91	R/S	279	65	x	344	43	RCL	409	53	(	474	75		539	42	STO
215	42	STO	280	43	RCL	345	10	10	410	43	RCL	475	43	RCL	540	11	11
216	03	03	281	17	17	346	95	=	411	25	25	476	28	28	541	53	(
217	99	PRT	282	54	)	347	42	STO	412	42	STO	477	54	)	542	02	02
218	98	ADV	283	54	)	348	22	22	413	01	01	478	42	STO	543	65	x
219	76	LBL	284	55	÷	349	71	SBR	414	71	SBR	479	05	05	544	43	RCL
220	14	D	285	02	2	350	49	PRD	415	45	Yˣ	480	53	(	545	15	15
221	70	RAD	286	54	)	351	61	GTO	416	54	)	481	43	RCL	546	65	x
222	53	(	287	42	STO	352	48	EXC	417	54	)	482	20	20	547	43	RCL
223	89	π	288	20	20	353	76	LBL	418	55	÷	483	65	x	548	03	03
224	65	x	289	53	(	354	49	PRD	419	53	(	484	43	RCL	549	54	)
225	43	RCL	290	53	(	355	00	0	420	43	RCL	485	27	27	550	42	STO
226	13	13	291	43	RCL	356	32	X⇄T	421	24	24	486	54	)	551	27	27
227	55	÷	292	15	15	357	53	(	422	75	-	487	42	STO	552	39	COS
228	43	RCL	293	38	SIN	358	53	(	423	35	1/x	488	06	06	553	42	STO
229	09	09	294	65	x	359	43	RCL	424	54	)	489	53	(	554	24	24
230	54	)	295	43	RCL	360	19	19	425	54	)	490	43	RCL	555	43	RCL
231	42	STO	296	16	16	361	85	+	426	42	STO	491	2$	21	556	27	27
232	15	15	297	85	+	362	43	RCL	427	27	27	492	65	x	557	38	SIN
233	53	(	298	53	(	363	22	22	428	53	(	493	43	RCL	558	42	STO
234	53	(	299	53	(	364	54	)	429	43	RCL	494	27	27	559	25	25
235	43	RCL	300	43	RCL	365	65	÷	430	11	11	495	54	)	560	53	(
236	15	15	301	15	15	366	02	2	431	75	-	496	42	STO	561	43	RCL
237	39	COS	302	65	x	367	54	)	432	01	1	497	07	07	562	19	19
238	65	x	303	43	RCL	368	42	STO	433	54	)	498	53	(	563	65	x
239	43	RCL	304	18	18	369	12	12	434	42	STO	499	43	RCL	564	43	RCL
240	16	16	305	54	)	370	53	(	435	00	00	500	22	22	565	24	24
241	75	—	306	38	SIN	371	24	CE	436	53	(	501	65	x	566	75	-
242	53	(	307	65	x	372	33	X^2	437	53	(	502	43	RCL	567	43	RCL
243	53	(	308	43	RCL	373	75	—	438	53	(	503	27	27	568	20	20
244	43	RCL	309	17	17	374	01	1	439	43	RCL	504	75	-	569	65	x
245	18	18	310	54	)	375	54	)	440	24	24	505	43	RCL	570	43	RCL
246	65	x	311	54	)	376	42	STO	441	42	STO	506	28	28	571	25	25
247	43	RCL	312	55	÷	377	23	23	442	01	01	507	54	)	572	54	)
248	15	15	313	02	2	378	22	INV	443	71	SBR	508	42	STO	573	42	STO
249	54	)	314	55	÷	379	77	GE	444	45	Yˣ	509	08	08	574	05	05
250	39	COS	315	43	RCL	380	50	I x I	445	54	)	510	42	STO	575	53	(
251	65	x	316	10	10	381	53	(	446	75	-	511	22	22	576	43	RCL
252	43	RCL	317	54	)	382	43	RCL	447	53	(	512	43	RCL	577	19	19
253	17	17	318	42	STO	383	12	12	448	43	RCL	513	07	07	578	65	x
254	54	)	319	21	21	384	85	+	449	25	25	514	42	STO	579	43	RCL
255	54	)	320	43	RCL	385	43	RCL	450	42	STO	515	21	21	580	25	25
256	55	÷	321	15	15	386	23	23	451	01	01	516	43	RCL	581	85	+
257	02	2	322	39	COS	387	34	√X	452	71	SBR	517	06	06	582	43	RCL
258	54	)	323	65	x	388	54	)	453	45	Yˣ	518	42	STO	583	20	20
259	42	STO	324	43	RCL	389	42	STO	454	54	)	519	20	20	584	65	x

585	43	RCL	650	85	+	652	43	RCL
586	24	24	651	43	RCL	653	07	07
587	54	)	652	07	07	654	54	)
588	42	STO	653	54	)	655	55	÷
589	06	06	654	33	x^2	656	53	(
590	53	(	655	95	=	657	43	RCL
591	43	RCL	656	35	1/x	658	05	05
592	21	21	657	65	x	659	33	x^2
593	65	x	658	04	04	660	85	+
594	43	RCL	659	95	=	661	43	RCL
595	24	24	660	42	STO	662	06	06
596	85	+	661	28	28	663	33	x^2
597	43	RCL	662	94	+/−	664	75	-
598	22	22	663	85	+	665	43	RCL
599	65	x	664	01	1	666	07	07
600	43	RCL	665	95	=	667	33	x^2
601	25	25	666	28	LOG	668	75	-
602	54	)	667	65	x	669	43	RCL
603	42	STO	668	01	1	670	08	08
604	07	07	669	00	0	671	33	x^2
605	53	(	670	95	=	672	54	)
606	43	RCL	671	99	PRT	673	54	)
607	22	22	672	43	RCL	674	22	INV
608	65	x	673	28	28	675	30	TAN
609	43	RCL	674	28	LOG	676	95	=
610	24	24	675	65	x	677	99	PRT
611	75	-	676	01	1	678	53	(
612	43	RCL	677	00	0	679	43	RCL
613	20	20	678	95	=	680	06	06
614	65	x	679	99	PRT	681	85	+
615	43	RCL	680	98	ADV	682	43	RCL
616	25	25	681	43	RCL	683	07	07
617	54	)	682	13	13	684	54	)
618	42	STO	683	32	X⇆T	685	55	÷
619	08	08	684	43	RCL	686	53	(
620	43	RCL	685	26	26	687	43	RCL
621	05	05	686	67	EQ	688	05	05
622	42	STO	687	19	D'	689	85	+
623	19	19	688	43	RCL	690	43	RCL
624	43	RCL	689	29	29	691	08	08
625	06	06	690	42	STO	692	54	)
626	42	STO	691	11	11	693	94	+/−
627	20	20	692	61	GTO	694	22	INV
628	43	RCL	693	14	D	695	30	TAN
629	07	07	694	76	LBL	696	95	=
630	42	STO	695	19	D'	697	99	PRT
631	21	21	696	43	RCL	698	98	ADV
632	43	RCL	697	26	26	699	43	RCL
633	08	08	698	91	R/S	700	13	13
634	42	STO	699	00	0	701	32	X⇆T
635	22	22				702	43	RCL
636	71	SBR	638	60	DEG	703	26	26
637	49	PRD	639	53	(	704	67	EQ
638	53	(	640	02	2	705	19	D'
639	43	RCL	641	65	x	706	43	RCL
640	05	05	642	53	(	707	29	29
641	85	+	643	43	RCL	708	42	STO
642	43	RCL	644	08	08	709	11	11
643	08	08	645	65	x	710	61	GTO
644	54	)	646	43	RCL	711	14	D
645	33	x^2	647	06	06	712	76	LBL
646	85	+	648	75	-	713	19	D'
647	53	(	649	43	RCL	714	43	RCL
648	43	RCL	650	05	05	715	26	26
649	06	06	651	65	x	716	91	R/S

The Phase/Frequency Detector

An analysis of phase-locked loop design employing phase frequency detectors.

By James Crawford

The controversial subject of "Divider Time Delay"[1] in recent *RF Design* issues has prompted the following discussion which was presented at a Hughes Aircraft Co. in-plant class on phase-locked loop design. The following analysis is an endorsement of Dr. Egan's explanation[2] where he states that the appearance of the delay-like term is due to the sampling process which is taking place in the phase-locked loop, not the transport delay or any other delay through the divider.

The delay-like terms which was mentioned above is shown in equations (3) and (4) of reference [3]. In this reference it is suggested that "the discrepancy between theory and experiment (in phase-locked loop design) was found to be attributed to divider delay which caused a decrease in phase margin significant enough in many cases to cause unstable loop performance." A decrease in loop phase margin does indeed occur in these phase-locked loops but the sole mechanism is a result of the sampling process which is taking place in the closed loop.

A rigorous analysis of phase-locked loop design employing phase-frequency detectors necessitates a detailed examination of the operation fundamentals. Rather than deal immediately with the specifics of phase-locked loop design using the phase/frequency detector, the problem will be dealt with using the following approach:

1) A general discussion of sampling phase-locked loops will be given which will display some of the differences between the true open-loop gain function, and the commonly used continuous approximation to the open-loop gain function.

2) With the sampling basics now developed, the transfer function for the phase/frequency detector will be found in some detail.

3) The phase/frequency detector transfer function is used to write an accurate impulse for the open-loop gain function. Given this function, a band-limited approximation of the open-loop gain function will be found using Z-transforms. The final band-limited expression can be used with conventional continuous transform (Laplace transforms) design methods for phase-locked loops.

Sampling Phase-Locked Loop Fundamentals

In contrast to the continuous mixer-type phase detector, the phase/frequency detector is a sampling phase detector. Phase error information is available at discrete time intervals which are spaced at exact intervals of T seconds, where T is the period of the reference frequency. The phase error at each instant is in the form of an impulse function whose area is proportional to the phase error. In reality, the impulses out of a phase-frequency detector such as the Motorola 4344 are of finite amplitude, but this fact is completely negligible in light of the RC filter time constants which follow the device. The phase detector output pulses may be mathematically viewed as ideal impulse functions of appropriate area. For the time being, the concept of the phase/frequency detector as an ideal impulse sampler will be deferred and developed momentarily.

The phase-frequency detector is modeled in Figure 1 as an ideal impulse sampler. The function H(s) represents some form of analog "hold" function such as the RC lowpass filters that customarily follow a phase-frequency detector. The function G(s) represents the normal loop filter transfer function.

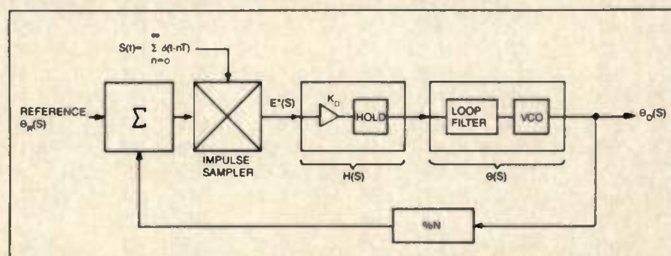

Figure 1. The general Sampled phase-locked loop employs an ideal impulse Sampler which must be followed by some form of "hold" device. (HS).

Before jumping into the loop details, as an aside, consider the time function f(t) which is sampled by an ideal impulse sampler. The sampled time function can be written as in (1) where the asterisk (*) represents the time-sampled form of the function.

$$f^*(t) = f(t) \sum_{n=o}^{\infty} \delta(t - nT) \qquad (1)$$

From Laplace platform and convolution theory, (1) may be written in Laplace transforms as in (2) where $F^*(s)$ and $f^*(t)$ are Laplace transform pairs. Note that F(s) and f(t) are also Laplace transform pairs.

$$F^*(s) = F(s) \star L\left\{\sum_{n=o}^{\infty} \delta(t - nT)\right\} \qquad (2)$$

The ★ in (2) represents convolution in the frequency domain. Equation (1) may be used with the definition of the forward one-sided Laplace transform to give yet another interpretation of the time-sampled function form in the frequency domain.

$$F^*(s) = \int_{o}^{\infty} f^*(t) \exp(-sT)dt \qquad (3)$$

$$= \int_{o}^{\infty} f(t) \sum_{n=o}^{\infty} \delta(t-nT) \exp(-sT)dt$$

$$F^*(s) = \sum_{n=o}^{\infty} \int_{o}^{\infty} \delta(t-nT) \exp(-sT)dt \qquad (4)$$

$$F^*(s) = \sum_{n=o}^{\infty} f(nT)\exp(-sT). \quad (5)$$

Equation (5) is actually the defining relationship for the Z-transform of f(t). This fact will be used later in this article for easy calculation of $F^*(s)$.

A very powerful relationship may be found by continuing the convolution calculation in (2). Since the convolution must be performed in the frequency domain, we must know the Laplace transform of the infinite series of impulse functions which are performing the sampling operation. Since

$$\delta(t) \leftrightarrow 1 \quad (6)$$

then

$$L\{\sum_{n=o}^{\infty}\delta(t-nT)\} = 1+\exp(-sT)+\exp(-2sT)+$$

$$= \frac{1}{1-\exp(-sT)} \quad (7)$$

The convolution of (2) may be rewritten as

$$F^*(s) = F(s) \star \frac{1}{1-\exp(-sT)}$$

$$= \int \frac{F(u)\,du}{1-\exp(sT-uT)} \quad (8)$$

$$= \int \frac{F(Z)}{1-\exp(sT)/Z}\,\frac{dz}{T\,Z}$$

where $Z = \exp(uT)$ and $du = dZ/(ZT)$.

Taking this process one step further and using the Residue theorem, this integral may be evaluated as in (9).

$$= \frac{1}{T}\int \frac{F(Z)\,dZ}{Z-\exp(-sT)} \quad (9)$$

$$= \frac{1}{T}\sum_{n=-\infty}^{\infty} F(s+j\,n\,Ws) \qquad \text{where } Ws = 2\,\pi/T.$$

Equation (9) is a valuable result and although it involves an infinite summation, it may be used to evaluate $F^*(s)$.

These previous transform tools will appear much more valuable if we now return to a discussion of Figure 1. As in classical PLL analysis, the most expedient first step in the loop analysis is to solve for the error function $E^*(s)$. We may write

$$\begin{aligned} E^*(s) &= (\Phi r - \Phi o)^* \\ &= \Phi r^* - \Phi o^* \\ &= \Phi r^* - [\,E^*(s)\,H(s)\,G(s)\,]^* \end{aligned} \quad (10)$$

Those unfamiliar with sampled systems will find [4] particularly useful and easy to understand. As developed in Chapter 4 of [4], the sampling operation in (10) may be brought within the brakcets because E(s) is already a sampled function. The sampled error function is then given by

$$E^*(s) = \Phi r^* - E^*(s)\,HG^*(s) \quad (11)$$

We finally obtain the desired result for the sampled loop error function.

$$E^*(s) = \sum_{n=-\infty}^{\infty} \frac{\Phi r(s+j\,n\,Ws)/T}{1+HG^*(s)} \quad (12)$$

In most cases, $\Phi r(s)$ can be assumed to be effectively bandlimited and aliasing of noise products can be neglected. This gives some simplication to (12) as given in (13).

$$E^*(s) = \frac{\Phi r(s)/T}{1+HG^*(s)} \quad (13)$$

where $\Phi^*(s) \sim \Phi r(s)/T$.

The asterisks would be absent in classical analysis of a phase-locked loop which neglected sampling effects. With rare exception, most systems which use the phase/frequency detector have a small bandwidth compared to the reference frequency in order to obtain reasonably low "sampling spurs." For this reason, the higher order terms (terms other than n=0) in equation (9) can largely be ignored for low bandwidth situations. This is precisely why classical analysis ignoring sampling effects still provides excellent results in small bandwidth situations. As the loop bandwidth is increased compared to the reference frequency, however, the higher order terms cannot be ignored.

For large loop bandwidth situations (bandwidth $> 0.1\,F_{ref}$), Z-transform techniques should be used to include the higher order effects. If there are true transport time delays within the loop, modified Z-transforms should be used. If the loop bandwidths remain small (say $< 0.1\,F_{ref}$), bandlimited forms of the open-loop gain function may be found which very accurately describe sampling effects without resorting to Z-transform analysis. Equation (9) which is repeated below as equation (14) will provide the menu for arriving at a bandlimited form of the open-loop gain function including sampling effects. The continuous Laplace transform impulse response, Gol(s), must first be found. The continuous open-loop gain function will be re-expressed in terms of Z-transforms and the assumption of small loop bandwidth imposed. The final result will be the bandlimited form of the open-loop gain function with first order sampling effects.

$$F(Z) = \frac{1}{T}\sum_{n=-\infty}^{\infty} F(s+j\,n\,Ws) \quad (14)$$

It will be shown that the so called "divider time delay" appears during this step and is solely a result of sampling.

Impulse Response of the Phase/Frequency Detector

A simplistic equivalent circuit of the phase/frequency detector is provided in Figure 2. No attempt has been made here to describe the frequency discriminator mode of operation. In many applications, the phase detector remains in its linear range of operation, because although the phase error may be very large at the VCO, it is reduced by N at the phase detector.

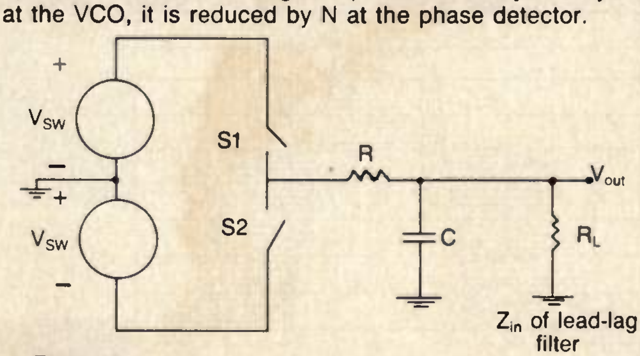

Figure 2

In steady-state operation, the switches in Figure 2 are open 95 percent of each reference period, only closing long enough to replenish the small discharge in capacitor C each reference period. (Since the 4344 type phase detector cannot resolve absolute time difference between the divider and reference pulse trains less than its own internal time delay, some built in offset is needed to avoid the detector's "dead zone" of operation at zero time difference between the two waveform trains.) During the period of frequency acquisition, the proper polarity switch is closed for a length of time which is defined by the time difference between the leading edge of the divide-by-N signal. This signal relationship is shown in Figure 3. The phase detector output pulse width is directly proportional to the phase error within the loop.

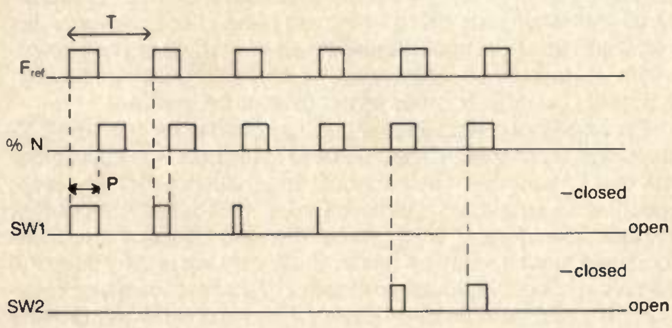

Figure 3

$$\Phi e = \frac{P}{T} 2\pi \tag{15}$$

or

$$p = \frac{T}{2\pi} \Phi e$$

The pulse widths out of the phase detector, p, are very small with respect to the reference period because a Type II loop is always used (zero steady-state phase error) and the VCO phase error is reduced by the divider ratio, N.

We are primarily interested in the impulse response of the phase detector/lowpass filter combination. The transfer function for the lowpass filter alone is given by (16).

$$FL(s) = \frac{R1}{R1 + R} \quad \frac{1}{1 + s\,\tau 1} \tag{16}$$

$$\text{where } \tau 1 = \frac{R1\,R\,C}{R1 + R}$$

A typical pulse response of the circuit in Figure 2 is presented in Figure 4. The rising edge is very linear because $p << \tau 1$. The output voltage, V_{out}, can be easily found from Figure 4. The output voltage during the next reference period is given by (17).

$$V_{out}(t) = V_o \exp(-t/\tau 1) + \frac{R1}{R1 + R} V_{sw}(1 - \exp(-t/\tau 1)) \tag{17}$$

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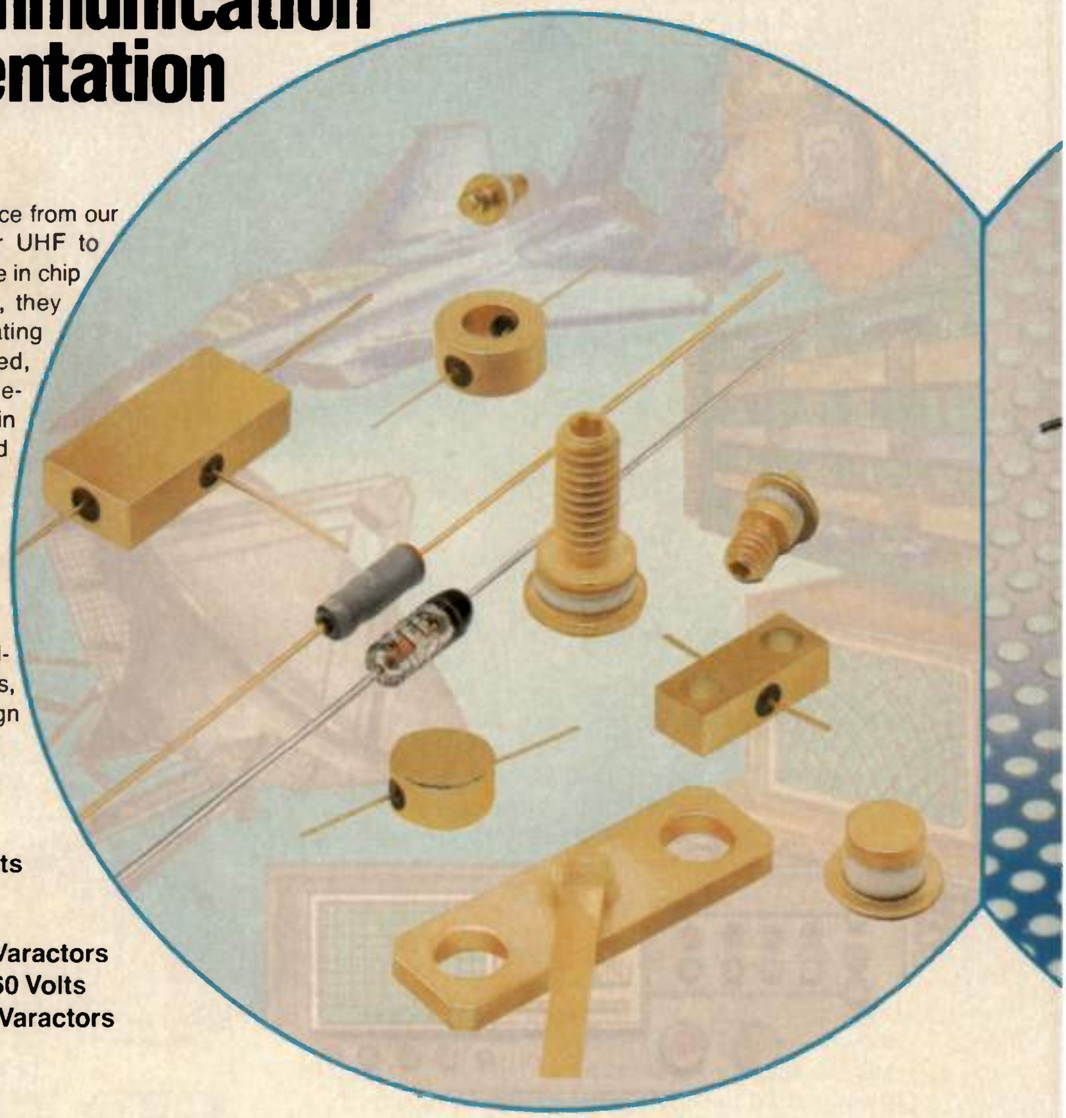

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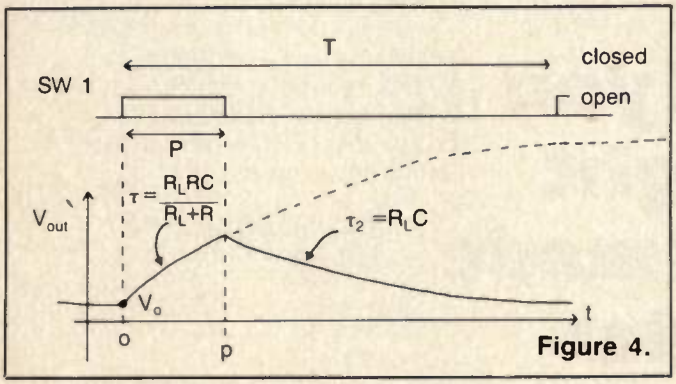

Figure 4.

for $0 < t <= p$
$V_{out}(t) = V_{out}(p) \exp(-t/\tau 2)$ for $p < t < T$.

In a properly designed Type II loop under normal linear operation, $p << \tau 1$ and equation (17) may be written in a more simple form without the first exponentials.

$$V_{out}(t) \sim V_o + \frac{R1}{R1 + R} V_{sw}(t/\tau 1) \quad (18)$$

for $0 < t <= p$
$V_{out}(t) = V_{out}(p) \exp(-t/\tau 2)$ for $p < t <= T$.

It is important to note once more that V_o represents the initial capacitor voltage due to any previous phase sample, Φe.

The Laplace transform transfer function can be found by using the above equations directly.

$$V_{out}(s) = L\{(V_o + \frac{R1}{R1 + R} V_{sw} \frac{p}{\tau 1}) \exp(-t/\tau 2)\} \quad (19)$$

$$= \frac{V_o}{s + 1/\tau 1} + \frac{R1\ V_{sw}\ \Phi e\ T}{(R1+R)\ \tau 1\ 2\ \pi\ (s+1/\tau 2)}$$

where the phase error is $\Phi e = 2\pi\ p/T$.

As stated earlier, V_o is a direct result of earlier samples of the phase error, Φe. Using this fact, it is possible to show that the output voltage as a function of the input phase error is given by (20).

$$\frac{V_{out(s)}}{\Phi e(s)} = \frac{Kd\ T}{(R1+R)/R1+sRC} \ \frac{1}{1-\exp(-sT)\ \exp(-T/\tau 2)} \quad (20)$$

where $Kd = V_{sw}/(2\pi)$

This is the final result for the phase detector impulse response. The factor T is a direct result of the sampling operation. Notice that if $T/\tau 2$ is not large, the second multiplicative factor cannot be ignored. In this case, the output voltage is a function of the present phase detector error as well as the previous error samples and Z-transform analysis is required. Since the intent of this analysis has been to eventually arrive at a band-limited form of the open-loop gain function, in that vein, $T/\tau 2$ will be assumed to be >> 1 such that Z-transform analysis will not be required in the final end result.

Derivation of the Continuous Band-Limited Open-Loop Gain Function with Sampling

The phase-frequency detector is always used in a Type II phase-locked loop in order to realize reasonable spurious performance and tuning range. In order to simplify the mathematics involved, however, an example using a Type I system will be used. Our approach will be to calculate Gol(Z) and compare it to the continuous form of Gol(s). This will reveal the effects of sampling upon the otherwise continuous open-loop gain expression.

In order to make any connection between an impulse sampled system and a continuous system, the sampled loop must have some form of "hold" device which effectively converts the phase detector impulse functions into smooth time waveforms which have a finite width in time, and a finite height. If the "hold device" is not present, the loop *must* be analyzed as a sampled system. No equivalent continuous system would exist for that case.

The "hold" device may be as simple as an RC lowpass filter, or as complicated as a true 0-order sample/hold. Consider a continuous Type I phase-locked loop with a low pass "hold" as given in (21).

$$Gol(s) = \frac{Kd\ Kv}{N\ s} \rightarrow \frac{Wn}{s} \quad \frac{1}{1+s\,\tau} \tag{21}$$

where
Kd=phase detector gain
Kv=VCO sensitivity
N =feedback divider ratio
τ =low pass filter time constant representing the "hold."

As shown earlier, the sampling effects upon a continuous function may be included by taking the Z-transform of the time function provided that the continuous function is correct of course. In the previous section, it was shown that the impulse response of the phase/frequency detector followed by a simple RC lowpass filter is given by (20). Therefore, assuming that T >> $\tau 2$ in equation (20), equation (21) must be multiplied by T to have proper form. Using a table of Z-transforms, equation (21) may be easily converted into Gol(Z).

$$\frac{Wn\ T}{s(1+s\tau)} \rightarrow Wn\ (1-\exp(-t/\tau))\ T \rightarrow \frac{Wn\ Z\ T}{Z-1} - \frac{Wn\ Z\ T}{Z-A} \tag{22}$$

Collecting terms in (22), the Z-transform for the Type I system is simply given by (23).

$$Gol(Z) = \frac{Wn\ Z\ (1-A)\ T}{(Z-1)(Z-A)} \tag{23}$$

We can effectively remove any significant effects of the "hold" device upon the system by allowing $\tau \rightarrow 0$, i.e., $A \rightarrow 0$. This is equivalent to making the RC filter time constant negligible compared to the reference period, T. In the limit as $A \rightarrow \Phi$,

$$Gol(Z) = \frac{Wn\ Z\ T}{(Z-1)(Z-0)} = \frac{Wn\ T}{(Z-1)} \tag{24}$$

Equation (24) may be expressed in terms of the more familiar complex frequency, s, by noting that Z= exp(sT). Doing so, we obtain (25).

Number of harmonic terms included in summation 5
Loop reference frequency 10000
Typ 1 loope Wn 2000
Loop LPF time constant, nsec 5000
APPROXIMATION TO SAMPLED OPEN-LOOP GAIN FUNCTION

	Summation of Gol Terms		Continuous Gol Exp(-ST/2)	
F	Gol,dB	Ang,Deg		
100	10.06	-91.20	10.06	-91.98
150	6.53	-91.80	6.54	-92.97
200	4.03	-92.40	4.04	-93.96
300	0.51	-93.61	0.51	-95.94
400	-2.00	-94.81	-1.98	-97.92
500	-3.94	-96.03	-3.92	-99.90
700	-6.89	-98.47	-6.85	-103.86
1000	-10.03	-102.21	-9.95	-109.80
1500	-13.65	-108.72	-13.47	-119.70
2000	-16.28	-115.74	-15.98	-129.60
3000	-20.07	-132.17	-19.52	-149.38
4000	-22.55	-153.18	-22.05	-169.16

Number of harmonic terms included in summation 10
Loop reference frequency 10000
Type I loop Wn 2000
Loop LPF time constatn, nsec 5000
APPROXIMATION TO SAMPLED OPEN-LOOP GAIN FUNCTION

	Summation of Gol Terms		Continuous Gol Exp(-ST/2)	
F	Gol,dB	Ang,Deg		
100	10.06	-91.46	10.06	-91.98
150	6.54	-92.19	6.54	-92.97
200	4.04	-92.93	4.04	-93.96
300	0.51	-94.39	0.51	-95.94
400	-1.98	-95.86	-1.98	-97.92
500	-3.92	-97.33	-3.92	-99.90
700	-6.84	-100.30	-6.85	-103.86
1000	-9.94	-104.79	-9.95	-109.80
1500	-13.45	-112.49	-13.47	-119.70
2000	-15.92	-120.54	-15.98	-129.60
3000	-19.24	-138.14	-19.52	-149.36
4000	-21.15	-158.08	-22.05	-169.16

Number of harmonic terms included in summantion 5
Loop reference frequency 1000
Type II loop Wn 2000
Loop damping factor, eta .707
APPROXIMATION TO SAMPLED OPEN-LOOP GAIN FUNCTION

	Summation of Gol Terms		Continuous Gol Exp(-ST/2)	
F	Gol,dB	Ang,Deg		
100	20.95	-156.41	20.90	-158.03
150	14.77	-147.09	14.67	-149.29
200	10.75	-139.68	10.60	-142.34
300	5.68	-129.45	5.46	-132.82
400	2.48	-123.29	2.22	-127.29
500	0.16	-119.51	-0.11	-124.14
700	-3.13	-115.77	-3.41	-121.69
1000	-6.45	-114.59	-6.72	-122.49
1500	-10.16	-117.17	-10.37	-128.23
2000	-12.79	-122.18	-12.92	-136.02
3000	-16.50	-136.40	-16.49	-153.68
4000	-18.84	-155.59	-19.03	-172.38

Number of harmonic terms included in summation 10
Loop reference frequency 1000
Type II loop Wn 1000
Loop LPF time constant, nsec 5000
APPROXIMATION TO SAMPLED OPEN-LOOP GAIN FUNCTION

	Summation of Gol Terms		Continuous Gol Exp(-ST/2)	
F	Gol,dB	Ang,Deg		
100	10.70	-139.13	10.60	-140.36
150	5.60	-128.39	5.46	-129.85
200	2.38	-121.69	2.22	-123.33
300	-1.73	-114.49	-1.93	-116.51
400	-4.46	-111.20	-4.67	-113.64
500	-6.51	-109.71	-6.72	-112.59
700	-9.53	-109.20	-9.75	-112.99
1000	-12.60	-111.03	-12.90	-116.22
1500	-16.21	-116.62	-16.46	-123.99
2000	-18.67	-123.59	-18.98	-132.82
3000	-21.97	-139.95	-22.53	-151.53
4000	-23.85	-158.98	-25.06	-170.77

$$Gol(s) = \frac{1}{j2}\,\frac{Wn\,\exp(-sT/2)T}{\sin(wT/2)} \tag{25}$$

For frequencies which are small compared to the reference frequency, $F_{ref} = 1/T$, the $\sin(x) \sim x$ approximation may be made, reducing (25) to finally (26). This is equivalent to the initial premise that the loop bandwidth is much less than the reference frequency.

$$Gol(s) = \frac{Wn\,\exp(-sT/2)}{s} \tag{26}$$

The final result for the bandlimited form of the open-loop gain function is given in (27). This expression includes the first order sampling effects. The appearance of the so-called time delay exponential occurred without introducing any transport time delay whatsoever, only the sampling effects.

$$Gol(s) = \frac{\exp(-sT/2)\,Wn}{s} \tag{27}$$

Generalizing, first order sampling effects for phase-locked loops which have a small percentage bandwidth compared to the reference frequency can be analyzed using classical Laplace transform methods provided the new "delay term" is included in the phase detector transfer function.

$$Kd\,\exp(-sT/2) \tag{28}$$

Further Proof

As further proof of our result above, we may compare this result with that obtained using (9). Only the first few terms of the infinite summation in (9) will be included. The computer program and sample run appear in Appendix I. Notice that the inclusion of the added exponential term of (28) with the normal Type I open-loop gain results in very good agreement between the two mathematical models for frequencies well within the closed-loop bandwidth. The phase of the open-loop gain function would be very inaccurate had the exponential term been left out. As the loop bandwidth increases with respect to the reference frequency, the approximation shows more and more deviation from the true open-loop gain calculated by (9). [Note that for all cases, $T/\tau 1 >> 1$ has been assumed with loop bandwidth $<< F_{ref}$.]

In order to be complete, the same calculation was performed for the Type II phase-locked loop with a phase-frequency detector and small RC lowpass filter "hold." The continuous form of the open-loop gain function is given in (29) where T is due to the phase detector transfer function.

$$Gol(s) = \frac{Kd\,T}{1 + s\tau}\;\frac{1+s\,\tau 2}{s\tau 1}\;\frac{Kv}{N\,s} \tag{29}$$

Our approximation to $G^*ol(s)$ is found using equation (28).

$$G^*ol(s) \sim \exp(-sT/2)\;\frac{Kd}{1+s\tau}\;\frac{1+s\tau 2}{s\tau 1\,N}\;\frac{Kv}{s} \tag{30}$$

The true function $G^*ol(s)$ is found again from substituting equation (29) into (9).

$$G^*ol(s) = \frac{1}{T}\sum_{n=-\infty}^{\infty}\frac{Kd\,T}{1+u\tau}\;\frac{1+u\,\tau 2}{u\,\tau 1}\;\frac{Kv}{N\,u} \tag{31}$$

where $u = s + jnWs$

Reiterating, the T following Kd is due to the phase detector transfer function, (20), whereas the 1/T is due to the leading coefficient in (14).

A second computer program and sample run are provided in Appendix I for this Type II phase-locked loop case. Once again, the bandlimited gain expression in (30) closely approximates the true gain function (31) for frequencies well within the closed-loop bandwidth.

In concluding this article, several statements stand out.

- In order to make any correlation between sampled and continuous systems, some form of analog "hold" device impulse response of the hold device is the interpolating waveform between sample points in the time domain.
- The appearance of sampling in any loop with the accompanying "hold" device, causes an exponential phase term to appear, exp(−sT/2).
- Sampling effects in small percentage bandwidth loop (wrt. F_{ref}) may be quite accurately described by the normal continuous open-loop gain function provided that the additional exponential term is included.

Sampling effects cause the appearance of the exponential delay-like term whenever quantities within the loop are only available at dicrete instants in time. Digital dividers within the feedback loop in an otherwise continuous loop will still cause the exponential term to appear. If digital feedback dividers and a digital phase/frequency detector are used within the phase-locked loop together, only one exp(−sT/2) term results (the continuous first order approximation remains unchanged). True transport delay within the loop is accounted for by another exponential delay term. (Here, true transport delay refers to delay through op-amps and propagation delay refers to delays through other components, including dividers. These quantities are available in component data books.)

Analysis of the phase/frequency detector in a phase-locked loop can be considerably more complex than the usual continuous analysis which is generally employed. If the loop bandwidth is, say, $< F_{ref}/40$, the loop can be considered continuous for all practical purposes. For higher percentage bandwidths, attention should be given to the added "delay-like" term shown in equation (28) and care should be given to insure that $T/\tau 2$ is > 3 in equation (20). [If $T/\tau 2 < 3$, another integrator in the form of a time variable filter is created which makes the situation much more complex. Of course, keeping $T/\tau 2 > 3$ will result in higher spurs and notch filtering will undoubtably be required. The time variable filter increases the gain within the loop bandwidth and adds substantial phase as well which can easily lead to instability. For best results, choose $T/\tau 2 > 3$.]

Although the cautious aspects of sampled phase-locked loop design have been brought out for the phase/frequency detector, sampled systems harbor much more capability than first glance indicates. For instance, a Type I sampled loop which employs a zero order sample and hold rather than the phase/frequency detector will theorectically perform phase-lock in only one sample period! An ideal Type II phase-locked loop with a zero order sample and hold phase detector is capable of performing phase-lock in only two sample periods. These speed-optimized phase-locked loops must be analyzed using Z-transforms.[5]

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5. *Microwaves & RF*, "Sampling Phase-Locked Loops for Frequency Synthesis," J.A. Crawford (to be published).

Appendix I

```
FILE: SAMPLL   ?1                                        PAGE 001

10 '**********************
20 '
30 '     Comparison of     Sum[  F(s + jnWs) ]  with Z-transforms
40 '
50 '**********************
60 DIM PTS(20),MAG(20),ANG(20)
62 PI=3.141592654#
70 FOR I%=1 TO 17
80       READ PTS(I%)
90 NEXT I%
100 DATA 100,150,200,300,400,500,700,1000,1500,2000,3000,4000,5000,7000
110 DATA 8000,9000,10000
120 '
130 INPUT "NUMBER OF HARMONICS TO INCLUDE ";NHARM%
135 INPUT "INPUT REFERENCE RATE, HZ  ";FREF
136 INPUT "INPUT THE TYPE I LOOP    WN  ";WN
137 INPUT "INPUT THE LOW-PASS FILTER   TIMECONSTANT, NSEC";TAU
138 TAU=TAU*9.999999E-10
140
150 FOR I%=1 TO 17
160      SUMR=0
170      SUMI=0
180      FOR J%=1 TO NHARM%
190               F=PTS(I%) + J%*FREF
200               GOSUB 1000
210               SUMR=SUMR + FR
220               SUMI=SUMI + FI
230               F=PTS(I%) - J%*FREF
235               GOSUB 1000
240               SUMR=SUMR + FR
250               SUMI=SUMI + FI
260      NEXT J%
270      F=PTS(I%)
280      GOSUB 1000
290      SUMR=SUMR + FR
300      SUMI=SUMI + FI
310      MAG(I%)=4.34294*LOG( SUMR^2 + SUMI^2 )
320      ANG(I%)=ATN(SUMI/(SUMR + 1E-08))
330      IF SUMR<0 THEN ANG(I%)=ANG(I%)-PI
333      ANG(I%)=ANG(I%)*180/PI
340 NEXT I%
350 PRINT CHR$(26)
351 LPRINT "Number of harmonic terms included in summation  ";NHARM%
352 LPRINT
353 LPRINT "Loop reference frequency  ";FREF
354 LPRINT
355 LPRINT "Type I  loop   Wn  ";WN
356 LPRINT
357 LPRINT "Loop   LPF  time constant, nsec  ";TAU*1E+09
358 LPRINT
360 LPRINT "APPROXIMATION TO SAMPLED OPEN-LOOP GAIN FUNCTION"
370 LPRINT "                                                      Continuous Gol"
371 LPRINT "                  Summation of  Gol Terms              Exp( -ST/2 )"
372 LPRINT
380 LPRINT "F                    Gol,dB          Ang,Deg  "
390 LPRINT "==============================================="
400 FOR I%=1 TO 17
401      F=PTS(I%)
402      GOSUB 1000
403      NORGAIN=4.34294 * LOG( FR^2 + FI^2 )
404      NORANG=B - W*.5/FREF
410      LPRINT USING "#######      ####.##      ####.##            ####.##     ####
.##";PTS(I%),MAG(I%),ANG(I%),NORGAIN,NORANG*180/PI
```

```
420 NEXT I%
430 STOP
1000 '****************
1010 '  OPEN LOOP GAIN FUNCTION, CONTINUOUS
1020 '****************
1030 W=F*2*PI
1040 A=WN/( W*SQR( 1 + (W*TAU)^2 ) )
1050 B=-PI*.5 - ATN(W*TAU)
1060 FR=A*COS(B)
1070 FI=A*SIN(B)
1080 RETURN


FILE: SAMPLL   T2                                          PAGE 001

10 '**********************
20 '
30 '    Comparison of    Sum[  F(s + jnWs) ]  with Z-transforms
40 '
50 '**********************
60 DIM PTS(20),MAG(20),ANG(20)
70 PI=3.141592654#
80 FOR I%=1 TO 17
90      READ PTS(I%)
100 NEXT I%
110 DATA 100,150,200,300,400,500,700,1000,1500,2000,3000,4000,5000,7000
120 DATA 8000,9000,10000
130 '
140 INPUT "NUMBER OF HARMONICS TO INCLUDE ";NHARM%
150 INPUT "INPUT REFERENCE RATE, HZ  ";FREF
160 INPUT "INPUT THE TYPE II LOOP    WN  ";WN
170 INPUT "INPUT THE LOOP DAMPING FACTOR  ";ETA
180 INPUT "INPUT THE LOW-PASS FILTER   TIMECONSTANT, NSEC";TAU
190 TAU=TAU*9.999999E-10
200 '
210 FOR I%=1 TO 17
220     SUMR=0
230     SUMI=0
240     FOR J%=1 TO NHARM%
250             F=PTS(I%) + J%*FREF
260             GOSUB 680
270             SUMR=SUMR + FR
280             SUMI=SUMI + FI
290             F=PTS(I%) - J%*FREF
300             GOSUB 680
310             SUMR=SUMR + FR
320             SUMI=SUMI + FI
330     NEXT J%
340     F=PTS(I%)
350     GOSUB 680
360     SUMR=SUMR + FR
370     SUMI=SUMI + FI
380     MAG(I%)=4.34294*LOG( SUMR^2 + SUMI^2 )
390     ANG(I%)=ATN(SUMI/(SUMR + 1E-08))
400     IF SUMR<0 THEN ANG(I%)=ANG(I%)-PI
410     ANG(I%)=ANG(I%)*180/PI
420 NEXT I%
430 PRINT CHR$(26)
440 LPRINT "Number of harmonic terms included in summation  ";NHARM%
450 LPRINT
460 LPRINT "Loop reference frequency  ";FREF
470 LPRINT
480 LPRINT "Type II  loop   Wn  ";WN
490 LPRINT
500 LPRINT "Loop damping factor, Eta  ";ETA
510 LPRINT
520 LPRINT "Loop   LPF  time constant, nsec  ";TAU*1E+09
530 LPRINT
540 LPRINT "APPROXIMATION TO SAMPLED OPEN-LOOP GAIN FUNCTION"
550 LPRINT "                                                   Continuous Gol"
560 LPRINT "                 Summation of  Gol Terms            Exp( -ST/2 )"
570 LPRINT
580 LPRINT "F                 Gol,dB          Ang,Deg  "
590 LPRINT "------------------------------------------------"
600 FOR I%=1 TC .7
610     F=PTS(I%)
620     GOSUB 680
630     NORGAIN=4.34294 * LOG( FR^2 + FI^2 )
640     NORANG=B - W*.5/FREF
650     LPRINT USING "#######       ####.##       ####.##            ####.##     ####
.##";PTS(I%),MAG(I%),ANG(I%),NORGAIN,NORANG*180/PI
660 NEXT I%
670 STOP
680 '****************
690 '   OPEN LOOP GAIN FUNCTION, CONTINUOUS
700 '****************
710 W=F*2*PI
720 A= (WN/W)^2 * SQR(  (1+ (2*ETA*W/WN)^2) / ( 1 + (W*TAU)^2 ) )
730 B=-PI + ATN(2*ETA*W/WN) - ATN(W*TAU)
740 FR=A*COS(B)
750 FI=A*SIN(B)
760 RETURN
```

PTS FREQUENCY SYNTHESIZERS

QUALITY & RELIABILITY that stand the test of time

AROUND THE GLOBE...

Along with offering the best performance/price in the industry, our goal at PTS has always been reliability. We believe, that with a yearly failure rate of 4%, we do indeed produce the most reliable synthesizer line.

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Choice of resolution; low phase noise, fast switching, fully programmable, BCD or IEEE BUS

NEW: Choice of table-look-up resolution with steady-phase switching.

PTS 500 shown with 0.1 Hz resolution, frequency standard, 3×10^{-9}/day: $7,300

PTS
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INFO/CARD 48

To detect noise, you need silence.

You can't detect spurious RF signals from your product if your measurement is being affected by noise.

You need silence—total silence.

For over 50 years Ray Proof has been a single-source supplier of noise-free RF enclosures for electronic test and measurement. In fact, we've designed, manufactured, installed and guaranteed more shielded enclosures for more applications than any other company in the world.

Ray Proof shielded enclosures meet or exceed government and commercial specifications concerning the design, construction and testing of RF-free enclosures. In fact, our System 100 design has pushed the standard to 100 GHz.

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WE CREATE SILENCE.

INFO/CARD 49

Some Questions You Should Ask Your EMI/RFI Test Equipment Supplier

How long has your company been in the EMI/RFI Testing Equipment business?

The Electro-Mechanics Company has been designing and manufacturing EMI/RFI Test Accessories for over 25 years.

We began with Magnetic Field Instruments and Radio Frequency Antennas for the military. Since the mid-sixties we have been working closely with the military and industry standard setting groups, and EMCO now has one of the broadest lines of Test Antennas and EMI/RFI Test Accessories in the World.

What exactly is your major product line?

EMCO's primary business is Test Antennas for use in Emissions and Immunity (Susceptibility) Testing as required for MIL Standard, FCC, VDE, and CISPR Test Procedures.

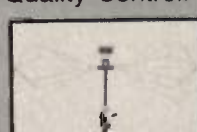
Typical Military Antennas for Radiated Immunity (RS) and Emissions (RE) Testing cover the frequency ranges from **30 Hz to 18 GHz**, and are noted in MIL STD 462, Notice 3, Table 1. EMCO currently manufactures **Magnetic Field Loops**, the 41" **Rod Antenna**, **Parallel Strip Line**, both **Biconical Antennas**, the **Conical Log Spirals** and the **Double Ridged Guide Antennas** shown on this table.

Antennas which are currently acceptable for use in FCC Volume II, Part 15 Emissions Testing include, **Adjustable Element Dipole Sets**, Broadband **Biconical Antennas** and Broadband **Log Periodic Antennas**. EMCO manufactures all of these separately or can include them as part of an FCC "Class A" and "Class B" **Antenna Test System**.

What differentiates your antennas from your competitors?

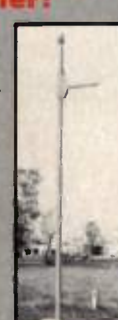
One major difference is Calibration. Each Antenna is calibrated using NBS Traceable Testing Equipment, on our own FCC open field test site. Calibration data includes Antenna Factor, Numeric Power Gain, and dBi Gain for each individual Antenna. For Immunity Testing Antennas we include Field Strength measurements in Volts Per Meter, and Radiation Patterns where applicable.

Another difference is Design and Construction. Each Antenna is designed to be durable and long-lasting, yet functional in varied applications, such as in Anechoic Chambers or Outside Test Sites. Antennas and accessories are machined and constructed "in-house" for Optimum Quality Control.



One last difference and maybe the most important, is EMCO's continual Product improvement thru Research and Development. For example, our **Dipole** and **Biconical Balun** design is much improved from the old DM-105 and military designs . . . and we are continually researching and redesigning to make EMI/RFI Testing simpler and more accurate.

What other Test Equipment and Accessories do you offer?



EMCO adds efficiency to EMI Testing with an **Antenna Positioning Tower** (1-6 meters) and an **Equipment Testing Turntable**. Both are suitable for outside or indoor use, come with a standard Digital Readout Controller and are available with **IEEE-488 Bus** Option.

For Conducted Emissions Testing, EMCO manufactures **Line Impedance Stabilization Networks** to satisfy FCC and VDE requirements. Our unique design allows production of as many as 4 separate lines (three phase) in one unit.

Other Related Equipment include: **Signal Rejection Networks, Acceptance Networks, Magnetic Field Intensity Meters, Magnetometers** and **Helmholtz Coil Systems.**

Why should my company buy your EMI/RFI Test Equipment?

The Electro-Mechanics Company is more than just another manufacturer. We realize that in order to grow and help improve EMI/RFI Testing we must constantly forge ahead . . . not live in the past.

As the FCC moves toward better and more Standardized Test Procedures, EMCO is staying close to ANSI (American National Standards Institute), NBS (National Bureau of Standards) and other standards groups so we can keep improving our equipment. Involvement with current and future industry needs also helps us plan for design of new equipment . . . an ongoing process at EMCO.

EMCO is committed to offering Technical Assistance, as well as Test Accessories, to help solve EMI Testing Problems. Part of that Technical Assistance is advice on purchasing only the equipment needed, not kits or systems with unnecessary items. We can also advise on various manufacturers of other complimentary test equipment.

If you have more questions and are looking for Helpful Answers, Call us at (512) 835-4684.

The Electro-Mechanics Company

P.O. Box 1546/Austin, Texas 78767/Telex 767187

INFO/CARD 50

"Hush-Hush" Technology Comes Out of the Closet

Keene Corp., Shielding Division

"Electronic soundproofing," once a low key technology used for security of government facilities, is coming out of the closet. Hastening its "coming out" is the boom in consumer electronics, medicine's fast-growing MRI* (Magnetic Resonance Imaging) miracle machine, and an expected change of heart by the FCC.

"The market has grown 25% a year since '79 and the pace is increasing," says Arnold Zais of Keene Corporation's Shielding Division. "In '84, the total market should top the $200 million mark. Our own sales should be up 20% this year."

Sometimes built invisibly within walls so outsiders don't know it's there, RF shielding blocks passage of radio waves like insulation blocks heat loss in your home. So it stifles deliberate electronic bugging and acidental radio interference. In RF shielded rooms, even the power lines and air vents are specially treated so stray radio waves don't pass through.

"For years, our main customers were government agencies and the aerospace industry, for security reasons," says Zais. "And secondarily, from industry for quality control testing."

But in the past five years, this has completely changed around. "Non-government/military sales now represent the majority of the business and is the fastest-growing segment," says Zais. "Part of the reason is that 'electronic hash' is growing at 50% a year.

"Literally, there's no end in sight — unless people like you and me give up on computers, video games and our electronic way of life."

One main impetus for growth of RF shielding is MRI. That's the $1 million-a-copy medical "imaging" tool that's said to be the most powerful diagnostic device ever developed. Some observers expect it to eclipse X-rays and CAT scanners. It shows more and eliminates the radiation hazard.

Every MRI must be installed in a shielded room to get high quality images. Recently, for instance, the University of Pennsylvania started up the nation's most advanced MRI clinical research facility — all enveloped in a $1.5 million special room cocooned with $100,000 worth of Keene shielding.

"Our MRI business tripled in '83," says Zais. "And this year, the FDA is expected to approve MRI as an accepted imaging modality. As a result, this business segment, which has nothing to do with security or defense, should continue to grow exceptionally for the forseeable future."

New FCC Product Safety Test

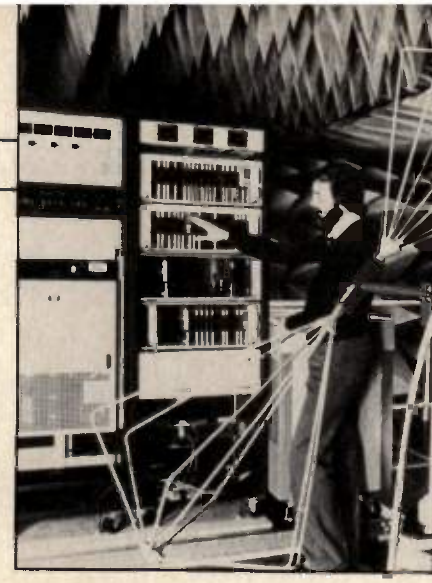
Also contributing to Keene Shielding's growth is the continuing boom in electronics and computers. Reason: before any electronic device can be marketed in the U.S., the FCC requires a test to ensure that it doesn't give off harmful or interfering emissions. Europe's Electromagnetic Compatibility Compliance testing requirements parallel the FCC's.

"Electronic manufacturers run emissions tests for their own purposes as well," says Zais. "They want to make sure their new product won't be 'zapped by a passerby with a CB or an automatic garage door opener or a local TV transmitter or a faulty arcing neon sign."

This year, many industry observers expect the FCC to change its longstanding regulation and give shielded anechoic test chambers a shot in the arm. For years, the FCC mandated "open site" testing for compliance testing — tests run out in the country, away from everything, where the environment is electronically "clear" but generally not. Recently, the major computer and electronics firms are buying shielded anechoic chambers for FCC testing. Although such chambers from Keene cost over $1 million they are more efficient, reliable and accurate than outdoor sites.

Everybody Wins

"This would benefit everybody," says Zais. "Shielded chamber testing is obviously more efficient and economical than trekking out to the desert with a truckload of equipment. Ironically, it also creates an electronically 'cleaner' environment because there's so much electronic clutter everywhere outdoors. So chamber test results are more reliable. I believe the FCC is simply letting the evidence and experience accumulate. And now that it has, they'll probably accept chamber testing as fully equivalent to open site testing. It could be much more cost effective for the electronics industry, with no tradeoff whatsoever to anybody. It's simply an idea whose time has come."



A typical testing application in a Keene shielded chamber.

Invisible Intruder, Invisible Barrier

Electronic RF shielding consists of constructing a complete metal room of thin metal panels. The panels are walls, floor and ceiling before the decorative surface is applied. Around all doors is an arrangement of interlocking metal linings that look like brass weatherstripping. Special RF filters go into all electrical and power lines. Air vents are designed to keep radio waves from getting through, too.

When the door closes on an RF-shielded room or chamber, the interior is cocooned in a continuous film of sheet metal. If there's even the tiniest breach, unwanted radio waves can leak through just like liquid finds the smallest leak in any container. MRI shielded rooms are made of special non-magnetic materials to block the radio waves with a structure that will not affect the MRI magnet field.

"Concern over electronic pollution, and even industrial espionage, has prompted some executives to cocoon their R&D labs, conference rooms, and computer centers in RF shielding," says Zais. One hotel in the Washington, DC area even considered shielding some meeting rooms to offer "something extra" in a security conscious age.

Keene's Shielding Division is also benefitting from development of "stealth" technology. Their recently-acquired subsidiary, Advanced Absorber Products, Amesbury, MA, makes absorber material that traps and attenuates radio waves.

"As long as electronics is here to stay, our 'invisible' business should do well," says Zais.

**Editor's note: MRI (Magnetic Resonance Imaging) is the new industry terminology for what was called NMR (Nuclear Magnetic Resonance).*

Serial RS-232 to GPIB Interface

Erbtec Engineering, Inc.

This application note describes a method for interfacing serial RS-232 compatible signals with the IEEE-488 bus (GPIB).

This capability can be used to satisfy the needs of a variety of applications such as:

- Interface of RS-232C compatible devices
- Bus extension
- Factory data collection
- Data communications and distributed systems
- Use in noisy environments

Two approaches to baud rate selection are described. One approach provides convenient selection of any commonly used baud rate from 50 to 9600. The second method provides a single baud rate which can be set by the user to any desired value.

The user can also select number of bits, odd/even or no parity and number of stop bits via a DIP switch.

Receipt of a general or device RESET command will cause the interface circuitry to be reset.

Hardware Description

The serial RS-232 to GPIB interface is implemented with a UART coupled with Erbtec's general purpose IEEE-488 bus interface module (EPI-120). The UART used in this design is the General Instruments AY-3-1015D. Any similar UART could be used in its place.

For optimum data transfer Port A of the EPI-120 is used for data input to the bus. Port B is used for parallel data transfer from the bus to the RS-232 serial output. Input handshakes are accommodated by directly tying the HSA-IN line on the EPI-120 to the Data Available line on the UART. The HSA-OUT line is tied to the RDAV line on the UART. Similarly, output handshakes are accommodated by directly tying HSB-IN to EOC and HSB-OUT to DTSTB. The RESET line on the EPI-120 is tied to the external reset (XR) on the UART through an inverter. Also the REMOTE line is tied to the RDE line on the UART through an inverter. Thus, receipt of a "GO TO LOCAL" command or loss of the REMOTE ENABLE signal will disable the UART.

Serial output from the UART is passed through a 1488 to establish proper RS-232 drive levels. Output from the 1488 is normally tied to pin 3 of a DB25 connector. Serial input from pin 2 is passed through a 1489 RS-232 receiver to the UART. The Request to Send (RTS) and Data Terminal Ready (DTR) lines are pulled up to +15 V through a 3.3K resistor.

The UART requires a clock pulse of 16 times the selected baud rate.

For optimum versatility a dual baud rate generator chip such as the AY-5-8116 can be used. An external DIP switch permits selection of any of the commonly used baud rates. Separate rates can be selected for receive and for transmit.

The second method uses a 555 timer chip as a simple clock generator. It generates a single common clock for both receive and transmit. Clock frequency must be adjusted by the user to 16 times the desired baud rate.

Software Description

A sample program which illustrates how very simple it can be to communicate between a bus control computer and an RS-232 terminal device is provided in Figure 1. The sample program is written using HP's BASIC for the HP85.

Line 130 sends the string A$ to device 01 on the Bus (select code 7). Assuming the EPI has its address select switches set to 1 it will be configured by the command string A$ as follows:

A1 — Accept data from Port A in 8 bit format and transfer to the GPIB unchanged
A9 — Interpret Port A logic levels as high true
B2 — Transfer data from the GPIB to Port B in 8 bit binary format.
B9 — Interpret Port B logic levels as high true
C4 — HSA-IN is high true; HSA-OUT is low true
D4 — HSB-IN is high true; HSA-OUT is low true
N2 — End of transfer condition signalled by two characters (when not specified they will default to carriage return and line feed)
Y1 — Enable next sequential address feature (Data on device address +1)

The command at line 210 sends the string "ENTER YOUR NAME" to the terminal device. Note the address is 702. This was enabled by the Y1 command in the initialization string A$.

The command at line 230 addresses the EPI as a talker and reads in the response from the RS-232 device.

Line 250 cuases the message USER NAME IS XXXXXX to be displayed on the bus control computer — where XXXXXX is the data entered at the remote RS-232.

Figure 1

```
100 ! CONFIGURE INTERFACE
110 DIM A$[23]
120 A$="A1, A9, B2, B9, C4, D4, N2, Y1"
130 OUTPUT 701 USING "K"; A$
200 !
210 OUTPUT 702; "ENTER YOUR NAME"
220 !
230 ENTER 701; N$
240 !
250 DISP "USER NAME IS"; N$
900 !
999 END
```

A One Transistor FM Transmitter

By William Rynone
Pegasus Data Systems

Last summer, I was requested to design a simple FM transmitter to meet the requirements for a convenient, low cost method of testing a large number of vendor supplied FM receivers that were to be incorporated into a digital data transmission system. The test that had to be performed was intended to make a subjective check of the accuracy of the tuning dial setting and the sensitivity of each receiver unit. Since it might become necessary to perform field tests, interconnecting various pieces of bulky and heavy test equipment was considered to be an undesirable alternative.

To meet the requirement, the transistor circuit shown below was designed, built and tested. The 2N2222 circuitry is a three element phase shift oscillator circuit, designed to yield a 1000 Hz sine wave. The 1000 Hz sine wave is then applied to the TCG-610 varactor diode (6 pF at 4 volts) which changes the tank capacitance, thus varying the RF oscillator frequency at a 1000 Hz rate. The 1000 ohm potentiometer in the collector circuit may be adjusted to enable desired frequency modulation level.

The Hartley RF oscillator, which is designed around a readily available MPF-102 JFET, has an output that should be relatively stable if it is not enclosed (but without an antenna). When enclosed, a BNC or F connector can be used to feed the RF to a small loop. If you decide to build this unit, be careful. The FCC has regulations regarding the radiation of RF.

One of my colleagues, Bohden Stryzak, modified the transmitter by eliminating the sine wave oscillator portion and replaced it with a carbon microphone as shown below. His children then had a three dollar portable transmitter that could be used with any portable FM receiver as a walkie-talkie.

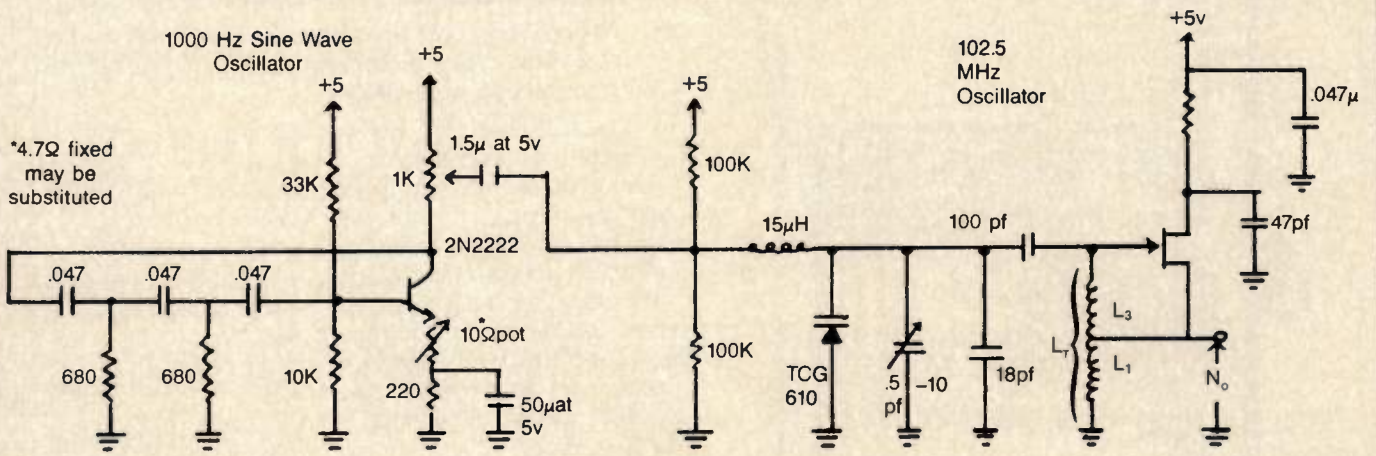


Figure 1

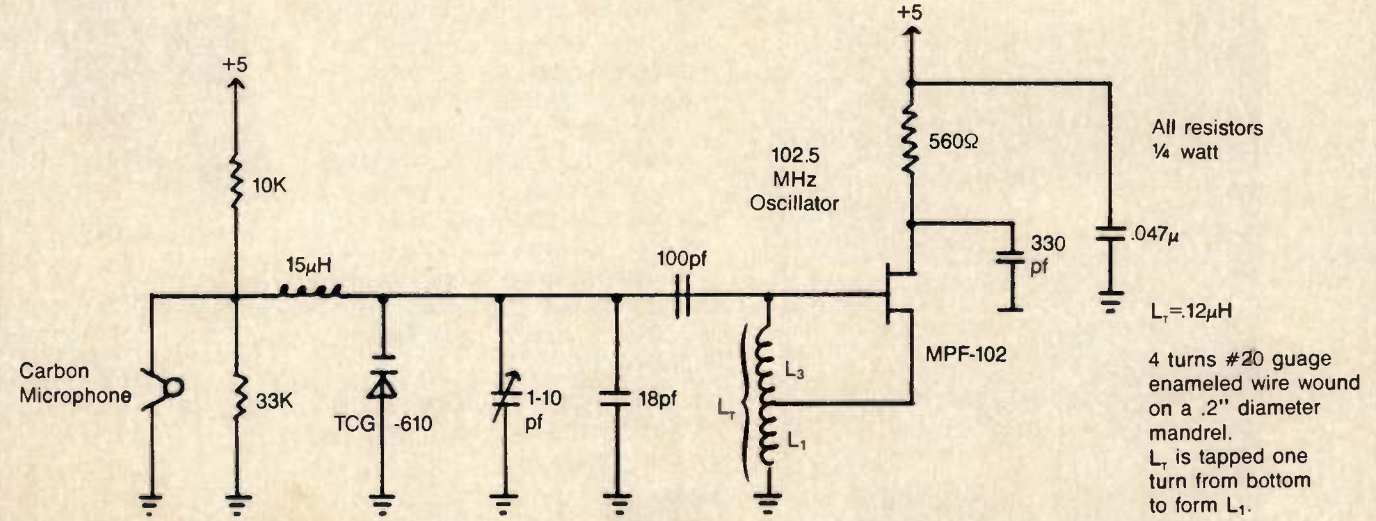
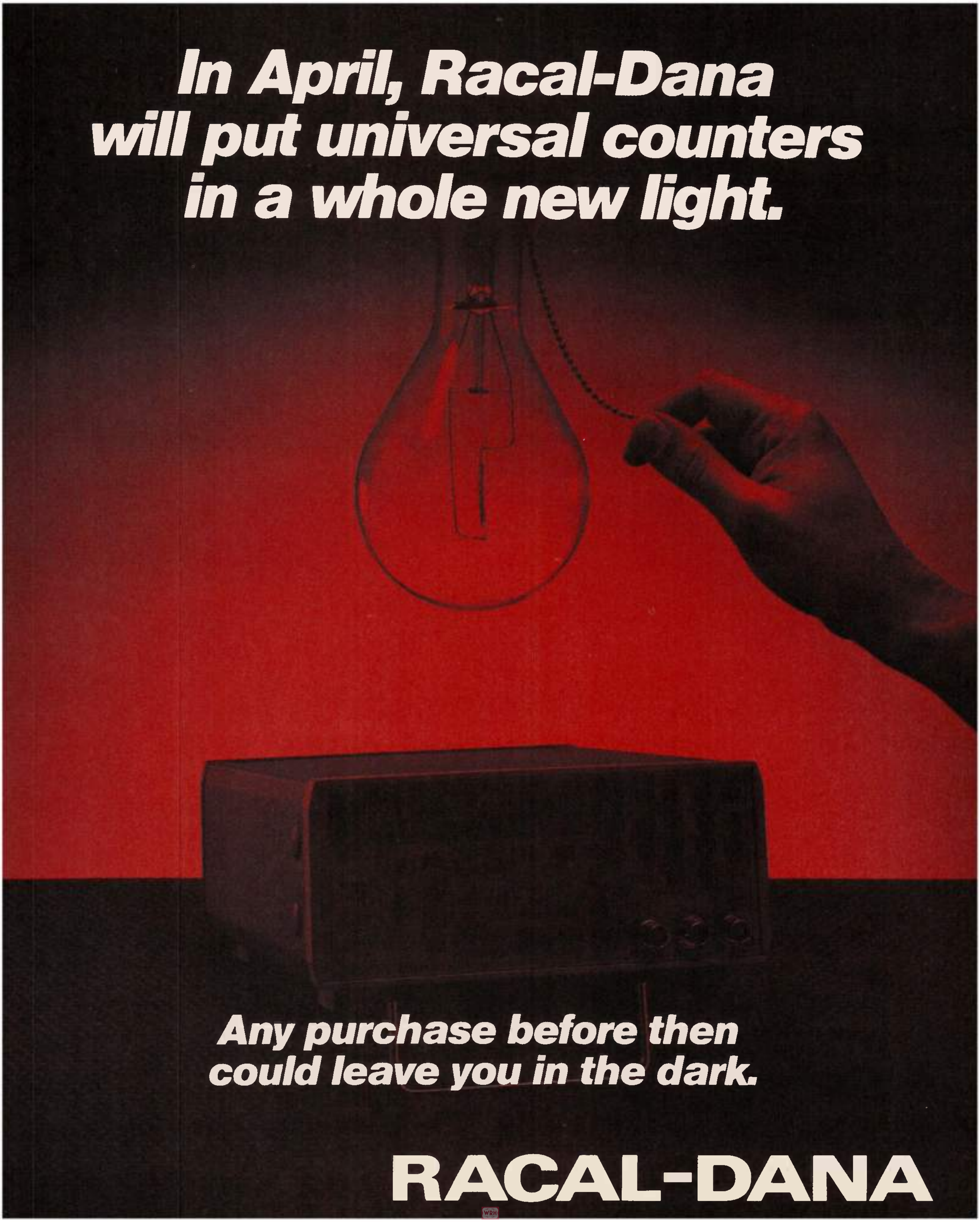


Figure 2.


In April, Racal-Dana
will put universal counters
in a whole new light.
Any purchase before then
could leave you in the dark.
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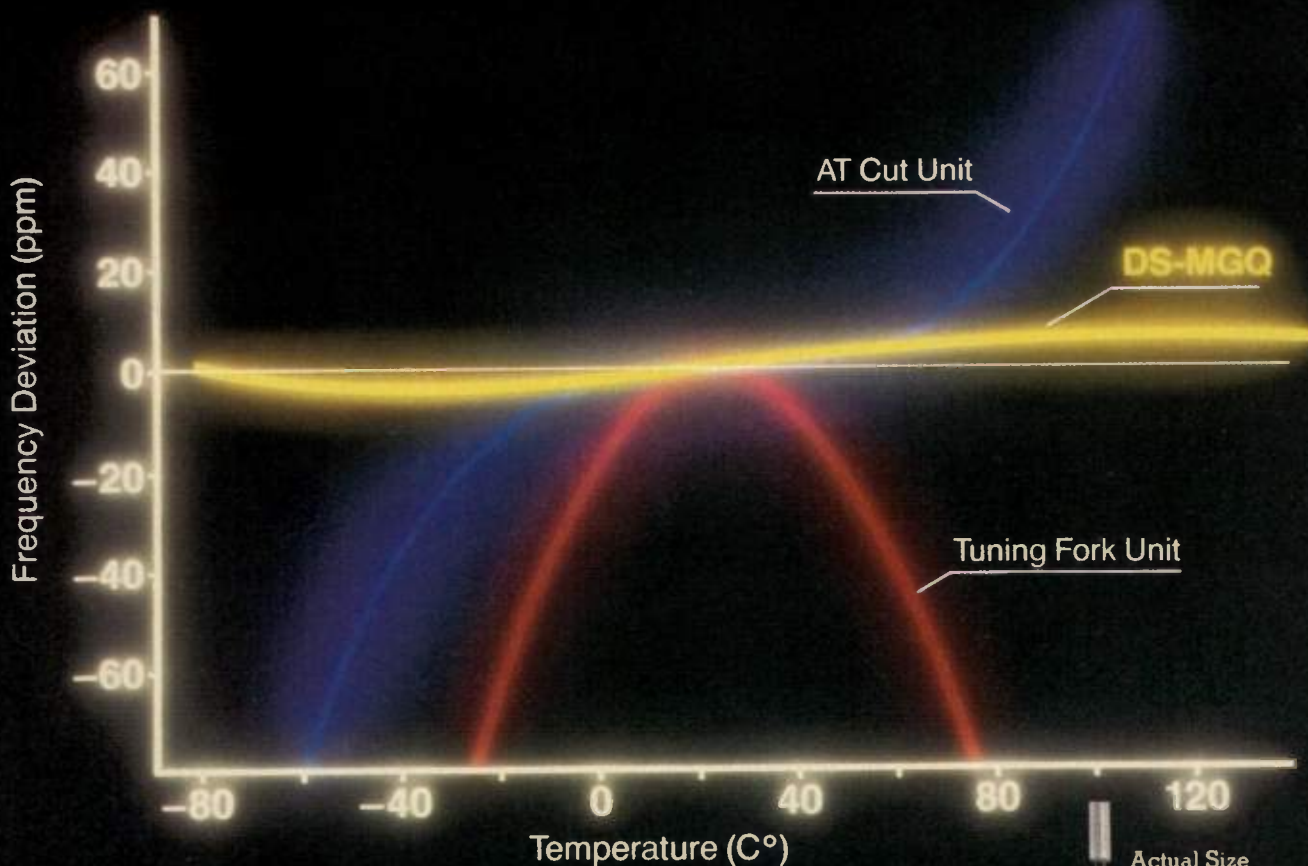
Our Figures Speak For Themselves.



Actual Size

The DS-MGQ Quartz Crystal From Seiko Instruments.

Exceptional stability over a wide temperature range puts these DS-MGQ crystals in a class by themselves. So does the world's smallest package.

In fact, our ultra-miniatures use 95% less real estate than a standard HC-33 enclosure. Combine this with low power consumption and high resistance to shock and you have an ideal crystal that meets all your design requirements.

These high-reliability crystals come in a choice of 20 off-the-shelf frequencies. Custom frequencies are also available on request. Imagine the exciting possibilities in your present and planned products. Then write or call today for specifics.

KEY SPECIFICATIONS

Frequency Range	1.0 to 3.0 MHz
Load Capacitance	10pf standard (other settings on request)
Quality Factor	150,000 to 300,000*
Effective Series Resistance	35Ω to 100Ω*
Frequency Temperature Stability (–30°C to +70°C)	±5ppm to ±100ppm
Drive Level (Max)	3 to 20μW*
Aging (First Year +25°C)	1.0ppm (typical)

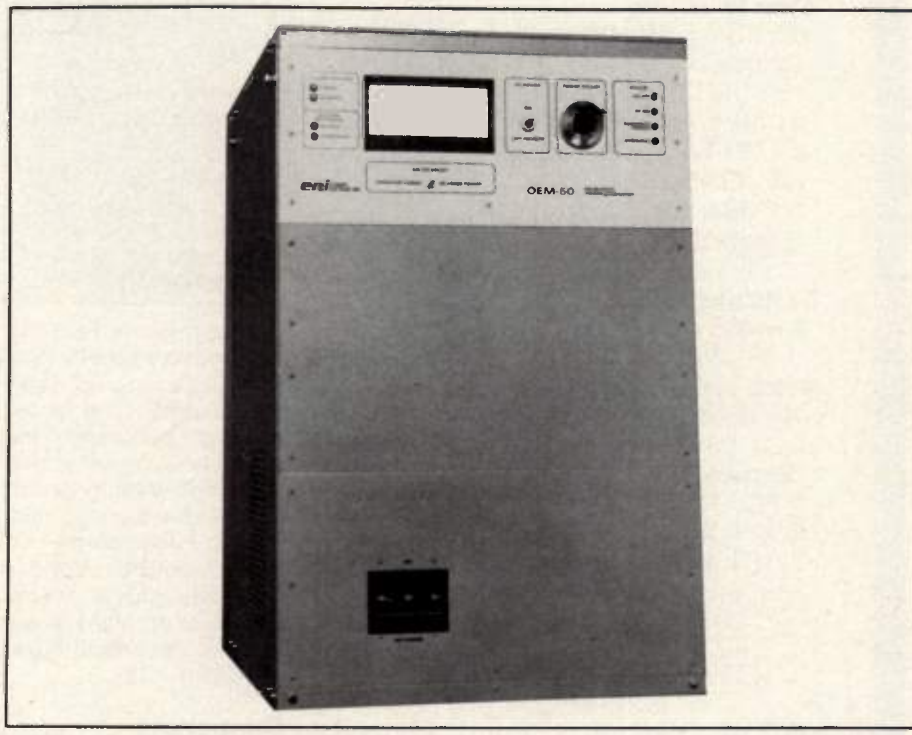
*Depending on Frequency

SEIKO INSTRUMENTS U.S.A., INC.
2990 West Lomita Blvd., Torrance, CA 90505
Telephone: (213) 530-8777, FAX: (213) 539-8621
TWX: 910-347-7307 SEIKO INST. TRNC.

SEIKO INSTRUMENTS

Power Generator

With its 5000 watt power output at 13.56 MHz, the OEM-50 is the highest power all solid state generator in the world. Although the OEM-50 is an order of magnitude smaller (5.5 cubic feet) than its vacuum tube counterparts, nothing has been left out in terms of operating features and versatility. All solid state, high reliability, accurate RF power control, fast pulse operation, stable RF power with line voltage variations, linear analog power meter with compatible digital readout, full remote control functions and built-in diagnostic test equipment are just some of the outstanding attributes of the OEM-50. If your semiconductor processing, sputtering or industrial application calls for the state-of-the-art in a 5 kilowatt source, the OEM-50 was designed just for you.



Automatic Power Control

The reliable operation of any solid state power generator is directly influenced by the sophistication of its power control circuitry. The OEM-50 automatic power control module measures forward RF power, reflected RF power and the current draw of each RF power amplifier module. Should any of these parameters exceed a preset limit, the automatic power control will immediately fold back its RF output power so that the components always remain within their safe operating limits. Besides assuring safe operation of the OEM-50, the automatic power control module will provide constant RF power output level to within 3% of the matched power setting regardless of the plasma load VSWR. In addition, the automatic power control eliminates power output drift due to line voltage variations, component aging and reduces output hum and ripple to insiginficant levels. An external DC voltage or pulse fed into the rear panel connector will permit the power output of the OEM-50 to be accurately controlled by a computer program that includes end point detection information.

Computer Compatibility

The OEM-50 is provided with an external computer interface bus that is compatible with TTL logic levels. This interface bus permits RF power to be turned on or off, indicates to the computer when the unit is developing its maximum power and indicates lack of water cooling or RF power. In addition, external analog voltages are available at the interface connector for both forward and reverse power indications. These voltages are calibrated precisely at 1.00 volt per kilowatt and therefore a digital panel voltmeter will read power directly in kilowatts.

Safe Easy Maintenance

The use of conservatively rated solid state components and automatic power control insures the user of reliable and continous performance with an absolute minimum of maintenance. A built-in diagnostic servicing switch permits the service technician to read out both the voltage and current draw of each individual module directly on the front panel meter. Should service be required, all of the plug-in modules are easily removed for replacement or repair. The very low DC voltages used in the OEM-50 greatly reduce the potential hazards associated with its servicing when compared with vacuum tube equipment.

Use It Anywhere

A wide range of AC line voltages is readily accommodated by the multitap AC line transformer and the connections verified by a built-in test meter indicator. The OEM-50 may be rack mounted, using the rack mounting kit, into any 19 inch relay rack or operated remotely within the plasma system cabinetry.

No RFI Problem

The OEM-50 is provided with an extremely well shielded and filtered power supply virtually eliminating conducted line leakage. An extremely sharp low pass filter at the output of the unit insures that all harmonics are reduced to very low levels. Extensive use of shielding and RF suppression techniques permits the unit to more than meet FCC requirements for ISM equipment at the same time that it eliminates any RF susceptibility problems for associated plasma system circuitry. **ENI Power Systems, Inc., Rochester, NY 14623-2881. INFO/CARD #113.**

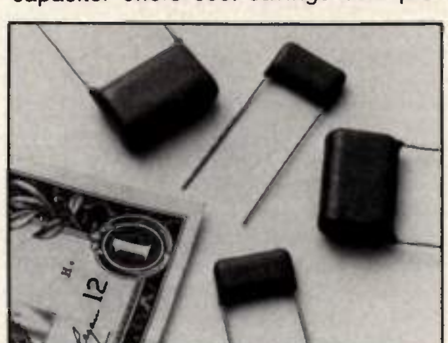
Electro-Static Interference Simulator

The Model 2600 will simulate Electro-Statics, Electro-Magnetics, Electro-Overstress, and Electro-Impulse, in quantifi-

able, repeatable energy levels. Features include positive or negative polarity from 0-25 kV, and an adjustable ramp up, delay, and ramp down capability. The Model 2600 also features single or multiple pulse selector, pulse interval adjustment, digital voltage meter, handheld pistol grip with built-in tripod and durable carrying case with remote controller. Pulse networks for human or inanimate simulation, E and H field attachments, Ion source attachments, and Electro-Static attachments are available. **IMCS Corp., Mountain View, CA 94043. INFO/CARD #137.**

Metallized Capacitors

Called the MDD, this series of capacitors is specifically designed for application in blocking, coupling, filter and bypass circuits of the industrial, electronics, telecommunications, and automotive industries. This resin-coated, epoxy-dipped capacitor offers cost savings over pre-



viously available molded plastic-type polyester capacitors. This new metallized polyester film features high insulation resistance, dielectric strength, and resistivity against humidity. Capacitance ranges from .01 mF to 2.2 mF are available in voltages from 100 to 630 volts DC. These are radial lead capacitors with tin-plated copper wires. Copper-coated iron leads can be made available for automotive requirements. Temperature range –40°C to +85°C. Most products supplied standard with ±10% tolerance. **ITT Components, Santa Ana, CA 92705. Please circle INFO/CARD #136.**

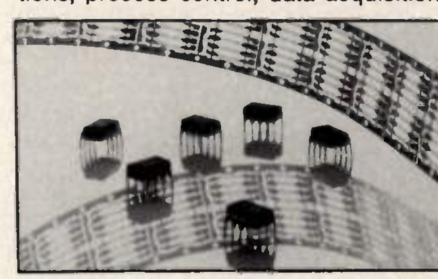
High Speed SPDT Switch

A high speed SPDT switch covers the 10-2000 MHz frequency range in a single unit. The SW-118 provides 50 dB isolation with only 0.8 dB of insertion loss, typical. The switch contains an integral TTL driver and is packaged in an 0.775" x 0.755" x

0.230" plug in package. **Adams-Russell Co., Inc., Anzac Div., Burlington, MA 01803. INFO/CARD #135.**

Optically-Coupled FET Driver

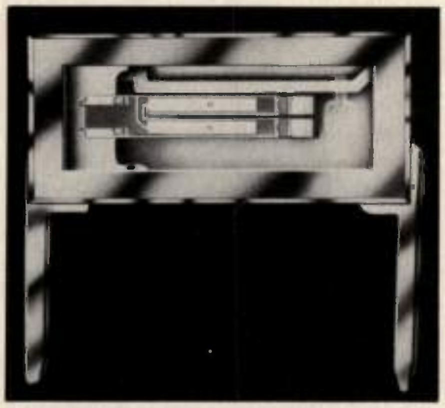
Without requiring any additional circuitry, the new FDA-200 meets the requirements for isolated FET operations that are demanded by telecommunications, process control, data acquisition,



and ATE. In its normal work load, the FDA-200 drives either one large FET or two independent FETs that can work simultaneously, in series, or in anti-parallel for AC loads. **Theta-J Corp., Wakefield, MA 01880. INFO/CARD #133.**

Miniature Quartz Crystal Resonator

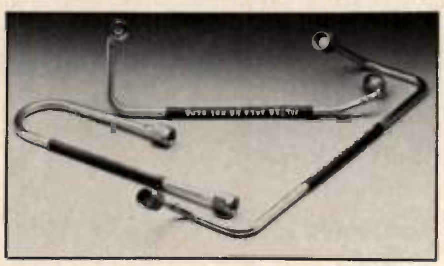
Miniature quartz crystal tuning fork resonators operating in the 10-600 MHz frequency range feature low aging, high stability, low power consumption and high shock resistance. Model CX-LV resonators, designed for use in Pierce oscillators, are available in a rugged



ceramic package. Operating parameters include: temperature operating ranges — (industrial) — 40°C to 80°C; (military) — 55°C to 125°C; shock survival 1000-5000g, 1 ms, ½ sine; vibration survival 20g, rms 10-2000 Hz. Power consumption is 1mW. **ETA Industries, Inc., New York, NY 10020. INFO/CARD #132.**

High Pass Coaxial Cable Filters

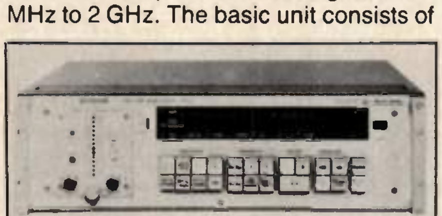
Lower frequency capabilities in semi-rigid coaxial cable are now possible with new High-Pass Filters. The new High-Pass Filters cut off transmissions below



Fc and allow high frequency transmissions to pass. The filters are designed for use with .141 O.D. cable. **Uniform Tubes, Inc., Collegeville, PA 19426. Please circle INFO/CARD #134.**

10 Hz to 2 GHz Vector Analyzer

Model ZPV Vector Analyzer with 3 new modular plug-in tuners providing frequency coverage from 10 Hz to 2 GHz. Previous models provided coverage from .1 MHz to 2 GHz. The basic unit consists of



a dual-channel vector voltmeter measuring according to magnitude and phase and a microprocessor-controlled analyzer section, weighting, normalizing and converting the measured voltage vectors into the desired complex quantity. **Polarad Electronics, Inc., Lake Success, NY 11042. INFO/CARD #131.**

Active Bias Source

The BT500 active bias thermal tracking device provides excellent thermal tracking and requires only limited external circuitry for operation. It is the first such device to be available in the standard hermetic TO-60 package; other packages are also available. The BT500 can be screened to TRW RF Devices Division's new "TX" high reliability screening specifications for MIL-S-19500 applications. The price of the BT500 is $15.60 each in 100 piece quantities. Availability is immediate. **RF Devices Division, TRW Electronic Components Group, Lawndale, CA 90260. INFO/CARD #178.**

INFO/CARD 55

Push-Pull High Power Bipolar Amplifier

The TPA0102-130 device provides 130 watts of CW linear power in broadband applications. Gain is over 9 dB at 162 MHz and 28 volts. The device is usable over a 30 to 175 MHz frequency range. The price of the TPA0102-130 is $123.45 each in 100 piece quantities. They are available now. **RF Devices Division, TRW Electronic Components Group, Lawdale, CA 90260. Please circle INFO/CARD #127.**

EM Shielding for Plastics

Known as X-COAT 210-2, the new material typically covers 400 square feet per gallon at thicknesses of 1.5 to 2.5 mils, and adheres readily to most substrates. X-COAT 210-2 is the most versatile of the company's line of EMI shielding products. It can be cured at elevated temperatures for maximum production rates, or allowed to dry at ambient temperatures. It will adhere to a wide variety of plastics, using specially formulated thinner systems. Electrical resistance of less than one ohm per square assures excellent shielding effectiveness; X-COAT 210-2 is an Underwriters Laboratories recognized component on a wide variety of commonly used plastic substrates. X-COAT 210-2 provides very low cost shielding, as it contains no silver or other precious metals. Typical applications include instruments and computers where RF shielding and electrostatic discharge protection are required. **Electro-Kinetic Systems, Inc., Boulder, CO 80302. INFO/CARD #129.**

Zero Bias Coaxial Detector/Mixer

The new RF Detector/Mixer Model DM-51-SMA/M features a replaceable, reversible zero bias Schottky diode, 10 pF output capacity, .5mV/μV sensitivity, and SMA male to SMA female connectors. It operates over the frequency range of one to 4.2 GHz, and is usable to 10 MHz with external IF bypassing. It has a VSWR of 1.35:1 nominal and 3:1 maximum at 4.2 GHz. Size is .4 in. diameter by 1.6 in. long. **Elcom Systems, Inc., Boca Raton, FL 33431. INFO/CARD #130.**

Surface Mounted Microcoil Line

Unique to the microcoil design (designated series MC) is a solderable edge that allows visual inspection of the reflow solder joint. The new Surface Mounted Microcoils feature a high self-resonant frequency for use at greater frequencies than currently available in surface mounted coils. **Standex Electronics, Cincinnati, OH 45209. INFO/CARD #128.**

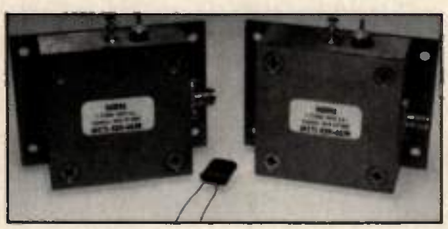
Hybrid TCXO

The Model ZT-254 holds a stability of $\pm 1 \times 10^{-6}$ over −55 to +85°C and is packaged in a compact 1.4 x .8 x .35" (only .39 cu. in.) resistance-welded package. Many other stability vs temperature range options are also available. The oscillator is available at any frequency between 1 and 20 MHz and is designed to drive up to 10 CMOS loads. It is also compatible with TTL for 1 or 2 standard loads. The oscillator operates from an input voltage of +8.5 to +16 VDC with a typical input current of 5 mA at 5 MHz. Units plug into standard 24 PIN DIP sockets and meet an

aging rate of better than 1 ppm/yr. Center frequency adjustment is by way of an external potentiometer. **Greenray Industries, Inc., Mechanicsburg, PA 17055. INFO/CARD #179.**

Crystal Oscillators

The XT-1000 is designed for use in microwave systems as a low phase noise reference for phased-locked oscillators. The XT-1000 comes in a rugged aluminum housing that measures 2 in. long x 2 in. wide x 7/8 in. high (51 x 51 x 22 mm). It has a flush mounting bracket enabling



easy system integration. The XT-1000 can cover 1 MHz to 125 MHz, has +7 dBm output, SMA connector and requires +6 to +15 VDC. Model XT-1000 has a stability of <±15 ppm over a temperature of 0 to +55 degrees C. Model XT-1000 has <±3 ppm stability over the same temperature range. Both models exhibit phase noise of >–140 dBc at 10 KHz from carrier. **Microwave Research & Mfg., Upton, MA. 01568. INFO/CARD #126.**

Detector/Preamp Hybrid

The SD-9007 Detector/Preamp Hybrid is offered in a hermetic T0-5 package with internal feedback resistor at under $25 in quantities over 50. The SD-9007 has a 10 kHz bandwidth and a transfer function of 3 x 10^7 volts/watt with 940 nm incident radiation. Custom options include bandwidth to 2 MHz and Blue or UV enhancement. **Silicon Detector Corp., Newbury Park, CA 91320. INFO/CARD #125.**

SPDT Coaxial Switch

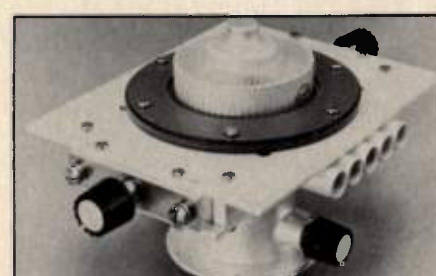
These SPDT latching or failsafe switches can be mounted conveniently by holes between the ports in the RF portion of the switch. Both inboard and outboard mounting can be provided on the same switch for increased versatility. **Teledyne Microwave, Mountain View, CA 94043. Please circle INFO/CARD #121.**

Remotely Controlled Signal Source

This signal source for antenna ranges or other uses can be controlled from a hand-held transmitter from distances up to 2,000 feet. The primary remote control transmitter allows selection of frequency and ON/OFF control of the signal output while the auxilliary transmitter provides control of up to 16 housekeeping functions external to the signal source. The frequency synthesized signal source can be provided to cover frequencies from 40 MHz to 200 MHz in steps as small as 10 KHz. Power output is typically 0.5 watt. FM modulation can be provided as an option. **Remcon, Oceanside, CA 92054. Please circle INFO/CARD #124.**

915 MHz Range Cavity Amplifiers

These two amplifier cavities are designed specifically as inexpensive sources of 915 MHz energy. Characterized by simple electrical and mechanical design, the EIMAC CV-2805 and CV-2811 cavities provide dependable RF power for



scientific, industrial, communication, and medical applications. Both units feature a high-gain design allowing use of solid-state drivers. The amplifier cavities are cathode driven and are forced-air cooled. Relatively compact, the cavities measure approximately 8 inches (20.3 cm.), by 5 inches (12.7 cm.), by 5 inches (12.7 cm.) **Varian EIMAC, San Carlos, CA 94070. Please circle INFO/CARD #123.**

Spectrum Analyzer With "Signal Search"

Designated the MS710A, the instrument has a frequency range to 23 GHz and a wide, 100 dB, dynamic range. It is designed for easy operation and features memory presets, GP-IB interface for direct plotting, an internal preselector and dual

memory for trace processing. Special "signal search" functions enable rapid location of the desired signal. The PEAK-CENTER key allows the operator to zero in on the peak value and center it on the screen instantly. With other digital keys, the view can be slowly scanned left or right, or quickly shifted by half-screen increments or one entire span. Specifications include: frequency range 10 MHz to 23 GHz (in two, preselectable ranges, 10 MHz to 2 G, and from 1.7 G to 23 GHz); dynamic range 100 dB (1.7 GHz to 23 GHz), 24-pin GP-IB interface for remote operations (meets IEEE488, IEC625-1); average noise level to +30 dBm over the measuring range; resolution 1 kHz to 3 MHz in a 1, 3, 10 sequence; sweep 2 ms/div to 10 sec/div (may be selected manually or automatically coupled to frequency span, resolution bandwidth, and video bandwidth); trigger selections, single, free run, line, video and external; average noise level to +30 dBm over the measuring range; sideband noise ≤–75 dB; CRT display are 80 mm x 100 mm. **Anritsu America, Inc., Oakland, NJ 07436. INFO/CARD #122.**

Turret Attenuators

Series 5000A and 7500A Turret Attenuators operate over a very broad frequency range and are well suited for bench setups, field use, or incorporated into test instruments. RF system applications include navigation and communication receivers. The Series 5000A Turret At-

tenuators cover the DC to 2000 MHz frequency range. The positive detent action provides long life for 50Ω applications such as general purpose test and measurement instrumentation (both military and commercial), Two-Way Communications and general laboratory accessories. DC to 1000 MHz frequency range coverage makes the Series 7500A perfect for CATV and TV applications. Their configuration is identical to the Series 5000A; however, due to the reduction in frequency coverage, some specifications will be improved over the Series 5000A. The Series 5000A and 7500A Turret Attenuators have standard BNC female connectors. Other connectors (such as Type F or female connectors) may be ordered at no additional cost. **Wavetek Indiana, Inc., RF and Microwave Components, Beech Grove, IN 46107. Please circle INFO/CARD #120.**

1.5 GHz Sweep Generator

The LSW-359 sweep generator covers the range of 1 MHz to 1.5 GHz in three bands. The sweeper is designed for laboratory analysis of frequency versus ampli-

tude characteristics for communications, radar, satellite i-f, and telemetry equipment. Featuring full-band sweep, start-stop sweep, delta sweep and CW operating modes, the generator also includes a versatile bypass marker system. A calibrated pulse-type marker, adjustable to any frequency within the selected band, is available in the full-band mode. In addition, birdie (comb-type) markers are available at 1, 10, 50 and 100 MHz spacings. Options include up to three spot-frequency markers and internal 1 kHz sine-wave amplitude modulation. Remote control of primary functions is easily effected, and modulation options make the unit double as a wide range signal generator. **Leader Instruments Corp., Hauppauge, NY 11788. Please circle INFO/CARD #119.**

Broadband 10 dB Coupler

Offered is a broadband 10 dB coupler ±1 dB (model CO518-10) with a range from 0.5 GHz to 18 GHz. Insertion loss, excluding coupling loss, is 1.2 maximum over the full frequency range. VSWR is

1.4:1 maximum, while directivity is 15 dB minimum and coupling flatness is ±0.8 dB. The unit is 4.5" x 0.7" x .38", including SMA connectors and termination. **Sage Laboratories, Inc., Natick, MA 01760. Please circle INFO/CARD #118.**

Micro-Ohmeter

The Model 510, a low cost, 4½digit, micro-ohmeter is designed to measure the resistances of switch and relay contacts, transformer and motor windings, connectors, or any other low resistance devices. It has five ranges from 19.999 milliohms to 199.99 ohms, full scale, 1 micro-ohm resolution, and a basic accuracy of 0.02%. Three measurement modes are provided. The continuous DC mode is useful for making measurements on inductive components and the switched DC mode removes the effect of thermal voltages, the largest source of error in low resistance measurements. A pulsed mode is provided for thermally sensitive devices such as fuses. The standard unit comes with 4-terminal Kelvin test

clips and a parallel BCD interface. **Cambridge Technology, Inc., Cambridge, MA 02140. INFO/CARD #117.**

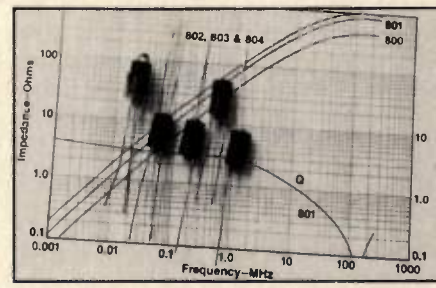
New Crystal Oscillator

The XO-43 crystal oscillator features low profile, resistance welded metal packaging, with a grounding to minimize RFI. The new, hermetically sealed unit is now available at any discrete frequency be-

tween 250 kHz and 60 MHz. Models may be ordered at any of five different frequency stabilities (±.005%, ±.01%, ±.05%, ±.1% and ±1%) over an operating temperature range of 0 to +70°C. Designed to withstand flow soldering without problems, the XO-43 has a hermetically sealed, all metal package (nickel plated base with stainless steel cover) which resists corrosion and provides maximum protection against humidity. The new unit is suitable for dense packaging. It has a maximum aboveboard seated height of only .225" with a length of .815" and width of .515". The XO-43 has a TTL compatible output and will drive fanout of 10 TTL loads. Input voltage requirements is +5 VDC, ±10% at 65 mZ. To minimize RFI, pin 7 is connected to ground. **Dale Electronics, Inc., Tempe, AZ 85282. Please circle INFO/CARD #116.**

Multi-Hole Ferrite Bead Chokes

Inexpensive multi-hole ferrite bead chokes that avoid resonance problems in filtering applications have been introduced. Because low Q and other non-resonant characteristics are maintained

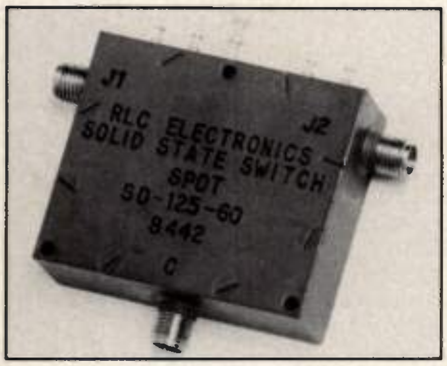


over a wide range with these chokes, resonance — common with air core and other choke types — is not a problem. With high resistive impedance in the

30-300 MHz range, the chokes are effective in eliminating unwanted RF while presenting a low impedance to audio and DC. Unit costs begin at $0.11 in production quantities. Prototypes are readily available and custom modifications can be provided. **South American Development Corp., Hyde Park, NY 12538. Please circle INFO/CARD #115.**

Diode Switches

A new line of solid state diode switches which cover a range of .020 to 18 GHz are designed for low power and moderate speed applications. Two independent TTL



drivers are included for maximum versatility. Close tolerance printed circuit techniques and precision bonding of diodes ensure uniform operation under extreme environmental conditions. **RLC Electronics, Inc., Mount Kisco, NY 10549. INFO/CARD #114.**

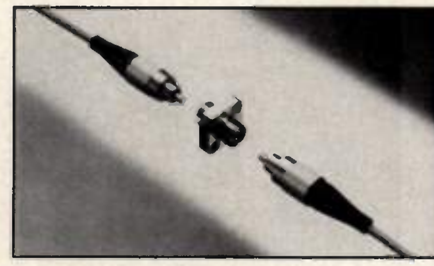
Programmable 1 into 8 Switch

With a frequency range of DC-1000 MHz the programmable 1 into 8 switch has one common input switchable to one of eight outputs and all unused ports are internally 50 ohm terminated. Other options are avilable, for example 1 into 10 switch. The switching is accomplished by means of TO-5 type relays with a switching speed <6 msec.

This programmable switch is capable of an insertion loss of <2.0 dB at 1000 MHz, VSWR < 1.5:1 at 1000 MHz and Isolation >30 dB at 1000 MHz. It has a standard 12 volt operating voltage but is also available in 5, 6, 9, 18 & 26 volts. These are all at an operating temperature range of –55° to +71°C. **Wavetek Indiana, Inc., RF and Microwave Components, Beech Grove, IN 46107. Please circle INFO/CARD #180.**

Fiber Optic Connectors

Single and multi-mode fiber optic connectors providing a consistent loss of less than one dB per mated pair, are now available. These connectors are FC-type Nippon Telephone and Telegraph (NTT) compatible.



They are sold without cable attached as well as in pigtails and jumpers. Connector inside diameters are available in six standard sizes ranging from 123 to 128 microns. **Kyocera Industrial Ceramics Division, San Diego, CA 92123. Please circle INFO/CARD #181.**

Toroidal Mixer Series

This series accommodate RF and local oscillator frequencies from 1 MHz to 3 GHz. These devices are designed for 50

rf testing minus the if's.

Why mix and match the tools you use for rf testing?

Instead, you can equip your entire test loop with instruments from Amplifier Research that have been thoroughly tested and work well with our high-performance broadband rf amplifiers.

From 1W to 10kW, 10 kHz to 1,000 MHz, in 32 standard models, AR amplifiers give you optimum power, bandwidth, and versatility for your cw, sweep, and pulse requirements. Each model provides instantly available bandwidth without bandswitching or tuning, is completely immune to load mismatch, and won't shut itself down when you may need it most.

But a high-quality test presumes high-quality test equipment throughout. So we also supply leveling preamplifiers, field sensor systems, fiber-optic telemetry links, matching transformers, directional couplers, and power combiner/dividers.

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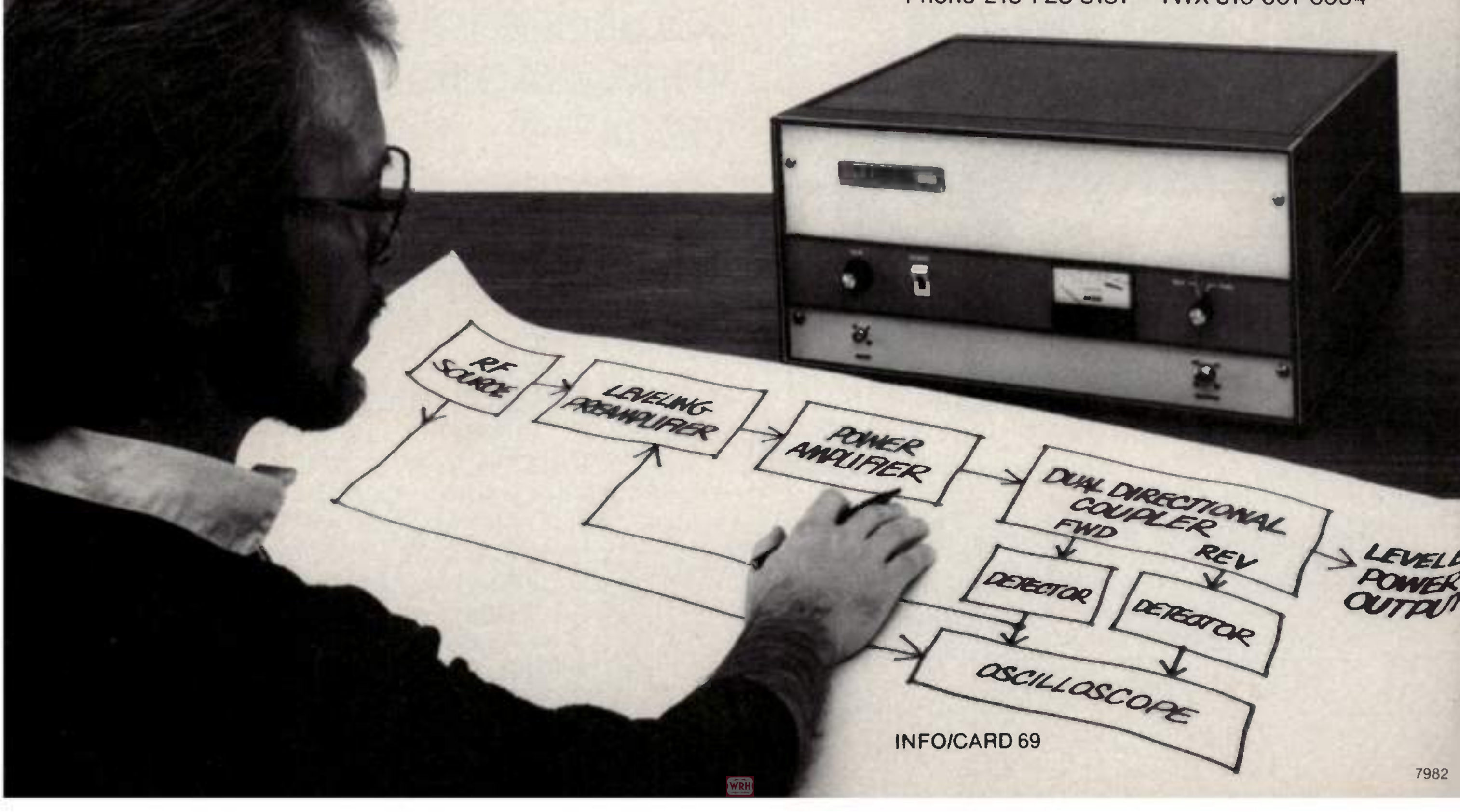

INFO/CARD 69

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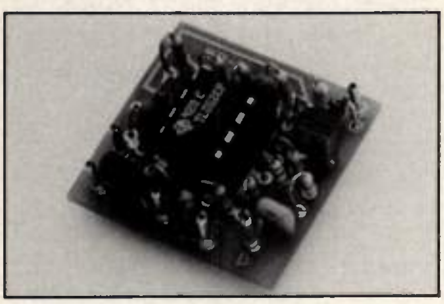
ohm systems. Typical conversion loss values range from 5.0 dB to 7 dB depending upon the device. Isolation between various ports ranges typically from 30 dB to 50 dB. These devices are designed for operation from −55°C to +100°C. **KDI Electronics, Whippany, NJ 07981. Please circle INFO/CARD #131.**

Reverse Burst Acessory

The RB-1 eliminates the long squelch tail heard with some reed type and other sub-tone decoders. When used in conjunction with decoders that offer squelch tail elimination, the RB-1 will delay



transmitter turn off time and reverse the phase of the encoded tone. This immediately stops the decoder and eliminates the squelch tail. The RB-1 is available from stock and sells for $14.95. **Communications Specialists, Inc., Orange, CA 92665-4296. INFO/CARD #**130.

Lithium Power Cell

The AL125 high-energy/density Lithium Thionyl Chloride Power Cell features a 1.4 amp-hr. capacity in a flat disk design that is well suited for limited-space requirements. The AL125's compact size, 1.27"x .38"/3.23 cm x .97 cm, makes it a natural choice in printed circuit design where it can be board-mounted to deliver a standard open circuit voltage of 3.6 VDC. The cell additionally features rugged stainless steel construction and a patented ceramic-to-cell seal that assures operation in hazardous environments where temperatures can range from −40°C to +70°C. With a shelf life of more than 10 years, the AL125 is unaffected by spin, altitude or position and meets the most stringent military safety standards while offering the highest energy density at high discharge rates of any lithium cell available. Nominal capacity of the AL125 is 1.4 A-hr. at the 24-hr. rate, at 20°C, to a 2.5 V cut-off. **Altus Corp., San Jose, CA 95112. INFO/CARD #159.**

EMI/RFI Shielded Instrument Case

These 19-inch EMI/RFI cases are available in heights of 3 to 28 inches and depths of 16, 20 and 24 inches. Case width of 24 inches are available as modified orders. The cases achieve 55dB nominal shielding effectiveness through the use of beryllium copper gasketry. Tests performed at an independent laboratory between 30-1,000 MHz showed attenuation values at varied frequencies ranging up to 77dB. **Scientific-Atlanta, Inc., Atlanta, Georgia 30348, INFO/CARD #186.**

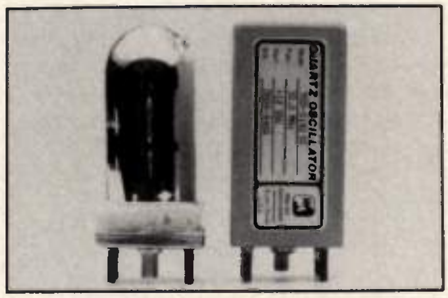
Optical Power Meter

A digital optical power meter for highly accurate direct measurements, designated the ML 93A, is now available. Two optical power sensors cover a wavelength range from 0.38 to 1.8 μm and provide wide power sensitivity, from −90 to +10 dBm, with overall accuracy of ± percent. The unit features automatic zeroing, averaging function, GP-IB interface (IEEE 488), digital display, and excellent interchangability — any of seven optical power sensors can be connected without readjustment. The meter includes sensor include sensor connecting cords and is available in 120 VAC, 240 VAC models. A rechargable battery pack and charger (optional) provide up to four hours of con-

tinuous operation. A lower cost, analog unit, designated the ML 94A, and a handy, portable, digital unit, designated the ML96A are also offered. The optical power sensors for high levels (MA 97A/98A) use large active area elements for optical power reception so that the optical input can be easily modified. Available are a small active area sensor (MA911A), a slim style sensor (MA 912A) and a moderate power sensor (MA 913A) **Anritsu America, Oakland, NJ 07436. Please circle INFO/CARD #185.**

Low Power Oven Oscillator

A miniature low power oven oscillator provides ultra-low phase noise for frequencies in the 3 to 11 MHz range. A vacuum flask insulator allows the "Small Fry" oscillator to consume less than 1 watt at 25°C while maintaining excellent temperature stability of $\pm 5 \times 10^{-9}$ from -25°C to +65°C. SSB phase noise can be specified to -140 dBc (10 Hz) for 5 MHz oscillators and to -135 dBc for 10 MHz. 1 KHz noise is better than -165 dBc. **Wenzel Associates, Inc., Austin, TX 78759. Please circle INFO/CARD #188.**



Linear Bipolar Chip

The chip, named Samson, provides a 1 A npn darlington output and a 1 A diode with 80 V breakdown voltage, two 200 mA npns, 6 general-purpose npns, three lateral pnps, one 5.8 V buried zener, one epi pinch FET, two base-emitter pinch resistors and 24 resistors (total resistance 54 kohms).

Samson replaces hybrids because it carries its own high-power output capability. It thus reduces costs, lowers the parts count and so improves reliability. **Polycore Electronics Inc., Newbury Park, CA 91320. Please circle INFO/CARD #190.**

SSMA to SMA Adpters

The interseries adapters use the WPM-4 (Weinschel Precision Miniature) coaxial connector which incorporates

dielectric support beads at its interface to keep the internal surfaces dirt-free and to provide a rigid support for the center conductor in both male and female versions. Frequency range is from DC to 40 GHz. Maximum VSWR (per mated pair) is 1.20 to 18.0 GHz, 1.30 from 18 to 26 GHz, and 1.40 from 26 to 40 GHz. Insertion loss per mated pair is 1 dB maximum. **Weinschel Engineering, Gaithersburg, MD 20877. Please circle INFO/CARD #191.**

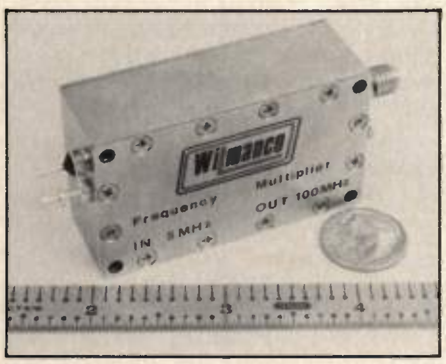
AC/DC Hipot Tester

New Model HC3-AT-AD AC/DC Hipot Tester with Automatic Controls can be operated in Manual, Automatic or Automatic-Remote mode. For operator's safety all high voltage connections are on unit's rear panel allowing use of a simple

probe for lab use or a variety of optional test fixtures for production line applications. Standard input is 115 V, 50/60 Hz, 100 VA with 220 V also available. Output Voltage is 0-3000 V ac and 0-4000 V dc with a variable rate of rise of 100 to 500 V/sec, current of 5 mA and distortion of less than 5% THD. **Hipotronics, Inc., Brewster, NY 10509. INFO/CARD #192.**

Clock Multiplier

Models WFM 5-1400 and WFM 10-1400 high order frequency multipliers are capable of multiplying 5 or 10 MHz up to 1400 MHz or above. These multipliers are perfectly suited for NAVSTAR Clock Multipliers to multiply 10.23 MHz to 1432.2



MHz. All units are Thick Film Hybrid construction for small size and light weight, and provide a minimum output of +10 dBm with a power consumption of 150 mA at +15 to 32 VDC. Spectral Purity is excellent, with Harmonics and spurs typically >–60 dBc. **Wilmanco, Northridge, CA 91324. INFO/CARD #193.**

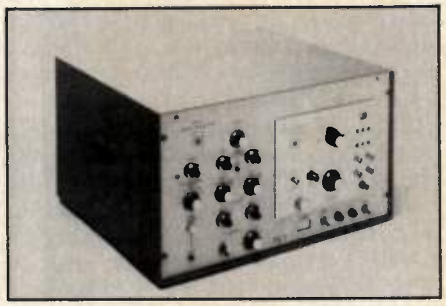
Digitally-Tuned UHF Preselector

This device, part number SDTA-200/400-N/N, has a tunable center frequency from 200 MHz to 400 MHz with a 3 dB bandwidth of 0.4%-5.0% and rejection of 18 dB per octave. Insertion loss is dependent on the bandwidth; 2.5 dB maximum at 225 MHz with a 0.4% bandwidth and 1.0 dB maximum at 400 MHz with a 0.8%

bandwidth. Typical VSWR is 1.5:1 maximum and normal power handling capability is 50 watts. The device has a center frequency accuracy of typically .1%. The control logic interface is available in a serial format, RS-232/300 baud standard, or a parallel format using BCD, Binary, or GPIB (IEEE-488) BUS. Control voltage is 24-28 VDC, though other voltages are optional. Tuning time is typically 3-6 seconds. Standard connectors are type N. **K&L Microwave Inc., Salisbury, MD 21801. INFO/CARD #194.**

0.5 to 30 MHz Gated Amplifier

The Model 515A RF Gated Amplifier features a 500 kHz to 30 MHz frequency range and provides 3 kW RMS pulse power output from 0.5 MHz to 10 MHz, 2.5 kW from 10 to 20 MHz, and 2 kW from 20 to 30 MHz. Producing sequences of coherent, high power RF pulses with stepped or continuously variable width and



separation, it plugs into the firm's Model 5100 Gating Modulator.

Accepting CW input levels from less than 10 mV to over 100 mV with no change in output, the Matec Model 515A RF Gated Amplifier provides an on-off ratio greater than 140 dB and a .002 maximum duty cycle for rated power output. It also accepts external pulse programs for NMR studies. **Matec Instruments, Inc., Warwick, RI 02886. Please circle INFO/CARD #202.**

EMI Absorber

CHO-SERBS reduce radiated EMI for compliance with FCC and VDE emission limits, while reducing susceptibility to ESD. Unlike cable shields, CHO-SORBS do not require grounding and will not affect the data being transmitted as filters or filter pin connectors often do.

This development in EMI absorbers is made of a sleeve of specially formulated ceramic material providing a minimum of 8 dB of EMI attenuation on data and power cables in the 30-500 MHz frequency range. CHO-SORBS are available in two standard sizes, one for cables up to ¼" in diameter, and one for cable diameters up to ½". By molding a connector boot or cable jacket *over* the CHO-SORB Absorber, time and assembly costs can be saved. **Chomerics Shielding Technology, Woburn, MA 01888. INFO/CARD #203.**

Ground Plane Cable

The new Series 65 ground plane planar cable features high density and extremely stable, electrical characteristics, making this type of cable ideal for applications in high speed computers, medical instruments, and other equipment that is sensitive to undesirable EMI radiation. Series 65 ground plane cable reduces crosstalk to 1.7% near end and 3.9% far end on a ten-foot sample with 5 ns rise time. The impedance rate is 65 ohms nominal and capacitance is 25pF/foot.

Single or double drain wire option increases the grounding capacity in the cable-to-connector interface. Cable preparation is easy and efficient. A blue tracer on the number one conductor ensures positive connector polarization. Precise center-to-center spacing on the 28 AWG cable secures the conductors to the connector with no scoring or nicking.

The Series 65 ground plane cable is available in 10 or 64 conductors and the grey PVC insulation is flame retardant, UL style 2682 recognized. Delivery is four to six weeks. **Midland Ross Corp., San Jose, CA 95110. INFO/CARD #204.**

Automatic Voltage Regulator

New line of voltage regulators has input voltage range of ±20% for ±1% output accuracy. All standard service line voltages available, single and three phase, at currents ranging from 40 to 1000 amps. Optional features include individual phase control, by-pass switch, and transient suppression. **Hipotronics, Inc., Brewster, NY 10509, please circle INFO/CARD #205.**

Ultraminiature Double Balanced Mixers

Identified as RHG "DMR" models, the compact "Hermix" series meet high density system requirement and are designed to drop in to integrated MIC assemblies. Removable connectors permit DMR models to be tested without special jigs and fixtures. Mounting centers are consistent with other industry MIC compatible mixer packages.

Model DMR8-12 is priced at $655. Model DMR2-26 is priced at $995. Delivery is 90 ARO. **RHG Electronics Laboratory, Inc., Deer Park, N.Y. 11729. INFO/CARD #206.**

Power Line Disturbance Meter

The Model T1007 is a compact rugged portable instrument designed for field use. It measures the three basic parameters of an AC power line, i.e. voltage, frequency and interference. The T1007 has a built-in 4-digit interference pulse counter, 4 selectable levels of transient pulse voltage threshold (10, 50, 100 and 200 V), 50nS transient pulse capture time, and monitor of either 90-135VAC or 200-260VAC and 35-65 Hz line frequency. **Tactical Electronics Corp., Melbourne, FL 32902. INFO/CARD #207.**

Miniature RF Chokes

Series 55X-4399 RF chokes are available in either loose piece lots or in tape mounted bandoliers for fast, automatic insertion. These miniature RF chokes offer a space saving advantage over standard molded chokes. The inductance range is from .1 microHenry to 100 microHenrys. The Series 55X-4399 RF choke is conformally coated and solvent resistant. Solder durability is 260°C in accordance with MIL-STD-810/202 and is flame retardant to UL94V-0. Color coding of these miniature devices is in accordance with MIL-STD-1285. Delivery is stock to twenty weeks. **Midland-Ross Corporation, San Jose, CA 95110. IN-INFO/CARD #195.**

Miniature Power Line Filters

This line includes a total of 18 different series products with current ratings up to 30 amps. Included in the line are a full range of filters ranging from low cost general purpose common mode filters to premium performance multiple section units. Particularly well suited for switching power supply applications, these filters enable equipment to comply with FCC EMI/RFI regulations, along with VDE, CSA and UL safety standards.

Delivery of these products is stock to 6 weeks and they will be available shortly through SFE's franchised distributors. **SFE Technologies, San Fernando Electric Division. INFO/CARD #196.**

Semiconductor Fuse

The 6JX fuse for 600VAC, 0.1A to 30A applications offers a low cost alternative to other semiconductor fuses of the same rating. The 6JX is manufactured to tight specifications and features plated terminals, a ceramic body and pure silver elements. The 6JX is UL listed. The 6JX features low watt loss with fast clearing times. Interrupting capacity is rated at 2,000,000 amps RMS. **Carbone-Ferraz, Inc., Parsippany, N.J. 07054, please circle INFO/CARD #197.**

Shielded Ribbon Cables

A family of extruded shielded ribbon cables for use with SDL connectors has been developed. A precision extrusion system allows tight tolerance control on construction widths from 4 to 24 conductors. Available in 24, 26 & 28 AWG, these cables provide 100% RFI shielding as well as easy stripability for high volume applications. **Phalo Corporation, Westborough, MA 01581, please circle INFO/CARD #198.**

Miniature Oscillator

Less than 0.8 cubic inches in volume, the dielectrically stabilized oscillator operates at a fixed frequency of 5495 ± MHz. Output power is 10 milliwatts min.; power variation with temperature is 1 dB max.; frequency stability is ±5 ppm/°C typical and ≏10 ppm/°C max. Load VSWR may be up to 2.5:1 max. (any phase) and VSWR pulling is ≏ 1.5 MHz max. Harmonic output is −30 dBc; spurious is >90 dBc; input voltage is −15 VDC and input current is 35 ma, max. Specifications are guaranteed from −54° to +85°C. Size is 1.1 x 9.5 x .68 inches (27.9 x 24.1 x 17.3 mm) nominal, excluding tuning screw, terminals and output cable. RF connectors are SMA. DC connectors are solder pins. **TRAK Microwave Corporation, Tampa, FL 33614. INFO/CARD #199.**

Isolated Power Divider

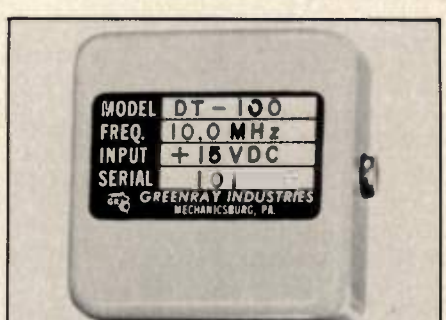
Model IPD-65 is an economical solution to the problems of using two satellite receivers with no downconverter interaction. The IPD-65 combines a 2-way power divider with ferrite isolators to offer more than 65dB of isolation.

A feature unique to the IPD-65 is an LED indicator that allows verification of power to the LNA. Automatic LNA power switching and DC block circuits are included to simplify downconverter hookup.

Inherent reliability, quality materials, and careful design make the IPD-65 the component of choice for combining two satellite receivers. **Avcom of Virginia, Inc., Richmond, VA 23236, please circle INFO/CARD #200.**

Digitally Compensated Crystal Oscillator

The DT-100 offers frequency vs. temperature stabilities approaching those of ovenized oscillators while consuming only a small fraction of the input power required to operate an oven. The DT-100 is on frequency instantly, eliminating the lengthy wait for an oven to stabilize. The DT-100 can be ordered at any frequency

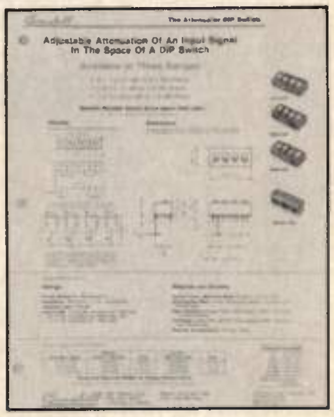


between 3 MHz and 30 MHz. Over the operating temperature range of −55 to +85°C, the frequency stability is typically ±1 x 10^{-7}. (±3 x 10^{-7} max). The unit requires a power supply of +15 VDC ±10% and typcially draws 13 mA of input current. (20 mA max.) **Greenray Industries, Inc., Mechanicsburg, PA 17055. Please circle INFO/CARD #201.**

Test & Measurement Instruments Catalog

A short-form product catalog, featuring test and measurement instrumentation for telecommunications, fiber optics, microwave and general purpose applications is now available. The 8-page catalog provides brief descriptions and general specifications on the most popular instruments in their line. **Anritsu America, Oakland, NJ 07436. INFO/CARD #150.**

Anritsu



Grayhill

Adjustable Attenuator DIP Switch

Adjustable Attenuator DIP Switches, described in new product bulletin No. 361, regulate input signals in the space of an eight position DIP switch. The switches are available in three ranges: 0.1 to 1.5 dB; 1.0 to 15 dB; and 1.5 to 22.5. Bulletin No. 361 provides complete attenuators DIP switch dimensions, electrical rating information, materials, finishes and prices. **Grayhill, Inc., LaGrange, IL 60525. INFO/CARD #149.**

High-Efficiency Power Amplifiers

This short course brings RF design engineers up to speed on high-efficiency power-amplification techniques. Theory, practical considerations, and design procedures for amplifiers of classes A, B, C, D, E, F, and S are covered thoroughly. Envelope elimination/restoration and other techniques for combining PAs to achieve greater efficiency and/or linearity are included. Nonlinear transistor models and simulation techniques for CAD are presented. The instructor, Dr. F.H. Raab, is coauthor of *Solid State Radio Engineering*. The course is usually conducted at an in-plant location. **Green Mountain Radio Research, Winooski, VT 05404. INFO/CARD #148.**

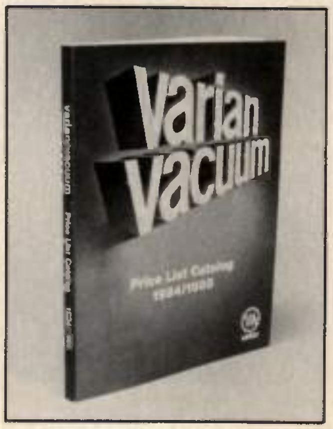
Stop, Look, Listen

Three new booklets designed to help buyers evaluate and compare low-cost analog and digital multimeters have been published. Titled "STOP Before You Buy Another DMM," "LOOK At the Leaders" and LISTEN To Why BBC is Your Best Choice," the three booklets points out many of the factors to consider when buying a multimeter. **BBC-Metrawatt/Goerz, Broomfield, CO 80020. INFO/CARD #147.**

Chip Capacitors

The *Chip Capacitor Selection Guide* is a 2-page, 4-color brochure describing multilayer ceramic capacitor chips. A center-fold chart allows simplified selection of capacitance VS chip size for 3 different families of Class I and Class II type dielectric materials. It also contains descriptions of the dielectric characteristics for each family. **Johanson Dielectrics, Inc., Burbank, CA 91505. INFO/CARD #146.**

Johanson



Varian

Vacuum Products

The catalog includes the most current pricing information, technical information and dimension drawings for 15 vacuum product categories plus details of training curses and support services. Technical notes for nine of the product lines provide a reliable reference for applications, performance features, operation, and design. Also included is a reference section on general vacuum units and formulas. **Varian, Lexington, MA 02173. Please circle INFO/CARD #145.**

RFI/EMI Organic Coating Effectiveness

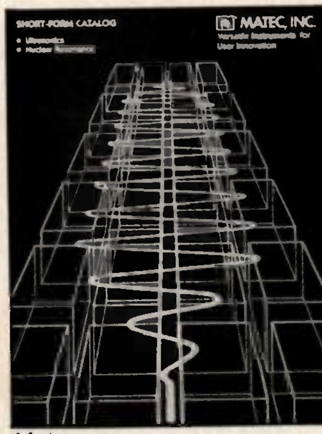
A Product Bulletin corresponding to the chemical and physical building blocks of RFI/EMI Conductive Coatings; titled "Particle-Size Compaction." It deals with the conductive pigment types used, particle size achieved, structure and shape of particle, degree of loading and dispersion methods that vary the degree of effectiveness of an applied RFI/EMI organic shielding coatings. **Advanced Coatings & Chemicals, Temple City, CA 91780. Please circle INFO/CARD #143.**

UHF/VHF Ground to Air Radios

This new four-color brochure describes GCA-1000 Series Ground to Air Radios for use in Military ATC Systems, Ground Control Approach systems and air Defense Tactical Communications Systems. Offering 1440 VHF channels in 116 MHz to 151.975 MHz in 25 KHz increments and 7000 useable UHF channels, 225 MHz to 399.975 MHz; coverage is enhanced by permanent memory capacity for 20 channels. Packaged in 19" rack-mount chasis the Series components, depending on mission requirements can be used together, coupled to a single antenna, as a transceiver; or seperately. Receiver sensitivity is 10 dB (s+n)/n at 3uV, 30% modulation. Transmitter output power is 25 W (VHF AM carrier) and 20 W (UHF AM carrier). **Aydin Vector Division, Newtown, PA 18940. INFO/CARD #142.**

Ultrasonics and MR Instrumentation

A new catalog that describes a variety of instruments and accessories for performing conducting pulsed ultrasonics and magnetic resonance studies is being offered. The 6-page Short-Form Catalog of Ultrasonics and Magnetic Resonance Instruments describes a module RF gated amplifier system; broadband gated amplifiers and receivers; a modular pulse modulator and a receiver with RF pulsed oscillator plug-ins and a variety of other instruments and accessories. **Matec Instruments, Inc., Warwick, RI 02886. INFO/CARD #141.**



Matec

Polarad

Vector Analyzer

This 16-page brochure describes the Model ZPV Vector Analyzer with 3 new modular plug-in tuners. Frequency coverage is 10 Hz to 2 GHz; previous models provided coverage from .1 MHz to 2 GHz. The Vector Analyzer ZPV implements a completely new, elegant technique for the measurement of complex quantities. The basic unit consists of a dual-channel vector voltmeter measuring according to magnitude and phase and microprocessor-controlled analyzer section, weighting, normalizing and converting the measured voltage vectors into the desired complex quantity. **Polarad Electronics, Inc., Lake Success, NY 11042. INFO/CARD #140.**

Coils and Inductive Components

This colorful 28-page 8½" x 11" catalog lists primary operational and physical parameters of a wide array of molded, shielded or unshielded coils as well as variable RF coils with inductive values from .022μH to 150,000μH. Also included is a line of toroidal inductors ranging from .10 to 10.0μH. A wide variety of Micro-i (R) miniature inductors with values from .010μH in low profile design for use on thick film Hbyrid packages are described. High current filter chokes for applications up to 15 amps and other power chokes with inductance values from 1.0 to 15,000 μH are also listed. **Delevan Division, American Precision Industries, East Aurora, NY 14052-0130. INFO/CARD #139.**

Solid State Relays

A new two-page bulletin, "Solid State Relays, Series F-DC Output," is available describing the new Series F Relays which are available SPST (NO) or SPST (NC). The illustrated bulletin has schematic, mechanical arrangement, and inductive load suppression diagrams, as well as charts showing load current versus temperature for both modes. **Douglas Randall, Division of Kiddee, Inc., Pawcatuck, CT 02891-0506. INFO/CARD #138.**

Capabilities Brochure

A 16-page full-color brochure describing the capabilities of Varian EIMAC Salt Lake is now available from the company. The division specializes in the design and manufacture of power grid tubes and switch tubes used in communications, broadcast, and defense, and its special-purpose, X-ray generating tubes for medical diagnostics applications. **Varian EIMAC, Salt Lake City, UT 84104. INFO/CARD #144.**

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