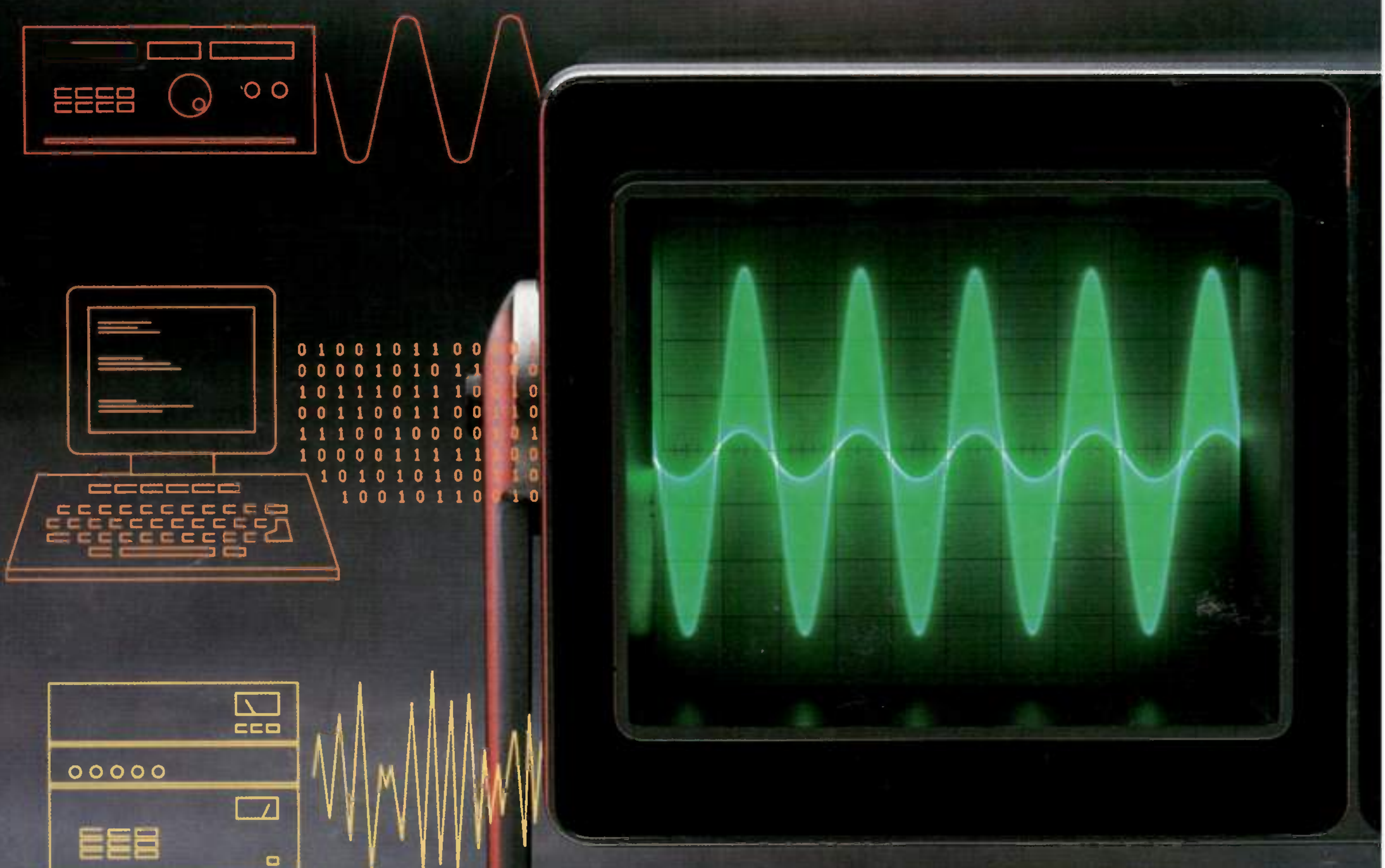
rf design

engineering principles and practices

September [illegible]

Featured Technology

Test and Measurement Techniques



Industry Insight

Inductors, Ferrites, Iron Powders

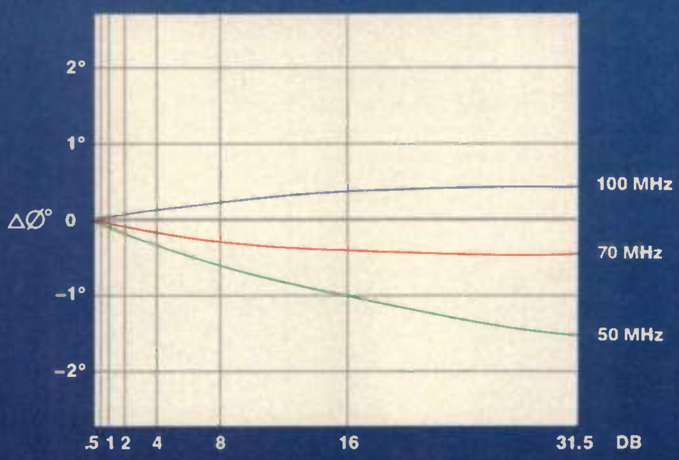
Design Awards

High Power Directional Coupler

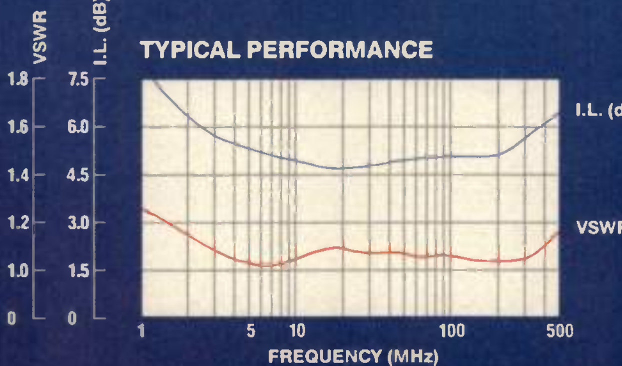
TWEAKING

DAICO
Constant Insertion Phase Attenuators Eliminate Tweaking.

PHASE CHANGE VS. ATTENUATION



TYPICAL PERFORMANCE



OPERATING CHARACTERISTICS

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

For systems that demand constant insertion phase, ordinary digital attenuators won't cut it—but the DAICO DAO616 will.

The DAO616 is a 6 bit, high speed, phase compensated attenuator designed to hold nearly constant insertion phase across its entire attenuation range.

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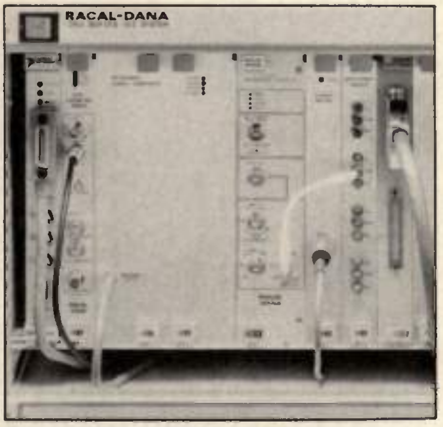
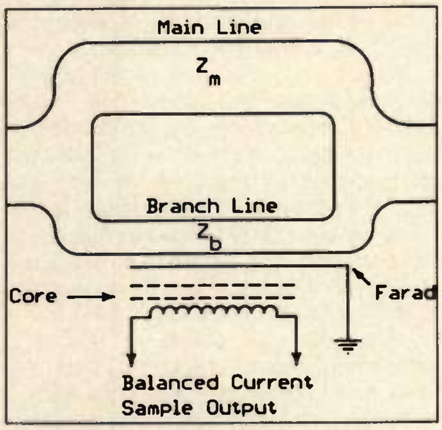
INFO/CARD 2

rf design

September 1989



Page 32 — VXIbus Applications



Page 35 — Directional Coupler

```
1190 I2=I:GOSUB 1230:GOSUB 1260:RETURN
1200 GOSUB 1250:R1=2*R:I1=2*I:GOSUB 1230
1210 GOSUB 1260:RETURN
1220 R=R1*R2-I1*I2:I=I1*R2+R1*I2:RETURN
1230 D=R2*R2+I2*I2:R=(R1*R2+I1*I2)/D
1240 I=(I1*R2-R1*I2)/D:RETURN
1250 R=V*COS(DTR*U):I=V*SIN(DTR*U):RETURN
1260 IF ABS(R)<ER AND ABS(I)<ER THEN 1370
1270 IF R=0 THEN V=ABS(I) ELSE 1300
1280 IF I>0 THEN U=90 ELSE U=-90
1290 RETURN
1300 IF R<0 AND I=0 THEN 1380
1310 Z=I/R:U=SQR(1+Z*Z)
1320 V=ABS(R)*U:U=U+1
1330 U=360/PI*ATN(Z/U)
1340 IF R<0 AND Z<0 THEN 1390
1350 IF R<0 AND Z>0 THEN 1400
1360 RETURN
1370 V=0:U=0:RETURN
1380 V=ABS(R):U=180:RETURN
1390 U=U+180:RETURN
1400 U=U-180:RETURN
1410 R1=R-50:I1=I:R2=R+50:I2=I
1420 GOSUB 1230:R4=R:I4=I:RETURN
1430 PRINT:PRINT"S11 =";M1;
1440 PRINT USING"#####.####";A1
```

Page 44 — S-Parameter Program

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rf editorial

Reflections on the Engineering Profession

By Gary A. Breed
Editor

At a recent meeting for high school students and parents, the dean of a university engineering department gave a talk promoting engineering as an academic and career option for young men and women. Although most of his comments and statistics have been used over and over, I feel that some deserve examination and discussion:

There's a shortage of engineers — over 5000 right now, maybe a quarter-million by the year 2000. Well, engineers with an RF specialty seem to be in short supply, but that sure is not the case with civil engineers, petroleum engineers, nuclear engineers, and some EEs specializing in digital hardware. Prospective students need more information than this kind of generalized statement.

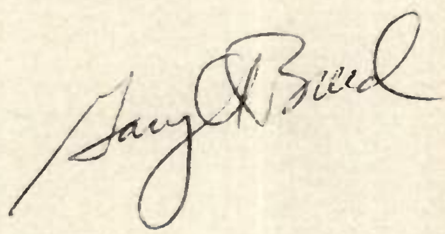
Engineers are well-paid — a new BS graduate earns $30,000, and an MS or MBA raises that to $38,000. These are averages, which means plenty of new engineers make less, and many make more. However, these figures generally correspond to the results of our own reader surveys.

Engineering is a tough curriculum — 30-40 percent of the students quit during or after their Freshman year. Amen! This matches my own experience. The good news is that after the initial shock wears off, relatively few of the remaining students quit. After graduation, the profession of engineering requires that we never stop being students. Continued study, formal or informal, will always be necessary.

Engineering is creative — a fact that is hard to get across to high school students. One definition of *create* is "to bring about through imaginative skill," a perfect definition of engineering. The opportunity to be creative in engineering is every bit as great as it is in art, theater, or music. But, because most people only think of the arts as being creative, the idea can be very hard to explain.

This country runs on technology — engineers are the ones who make technology work for us. Anthropologically speaking, mankind is distinct from other creatures because we are "tool users." As such, our existence is defined by our ability to create objects or mechanisms that we can use. That's the definition of technology, and technology is the job of engineers.

Yes, we need plenty of teachers, policemen, doctors, and merchants. We also need plenty of good engineers. I hope some of those students and parents got the message.



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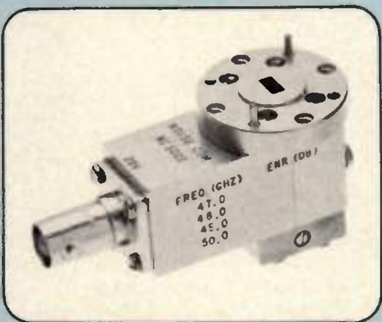

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NC 6107	up to 100 MHz
NC 6108	up to 500 MHz
NC 6109	up to 1 GHz
NC 6110	up to 1.5 GHz
NC 6111	up to 2 GHz
NC 6218	up to 18 GHz

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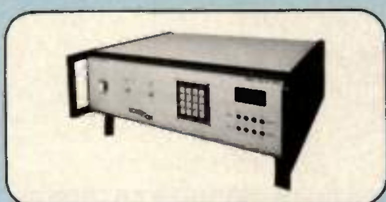

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NC 7110	up to 1.5 GHz
NC 7111	up to 2 GHz
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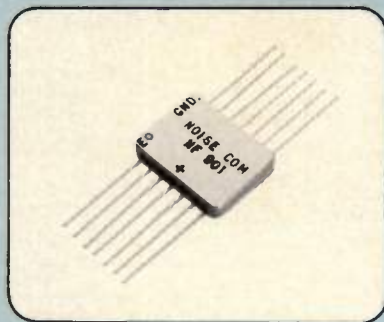

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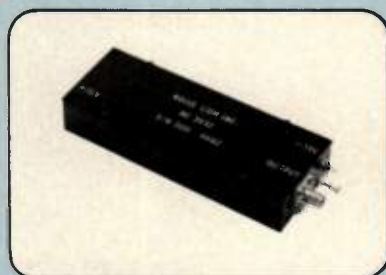

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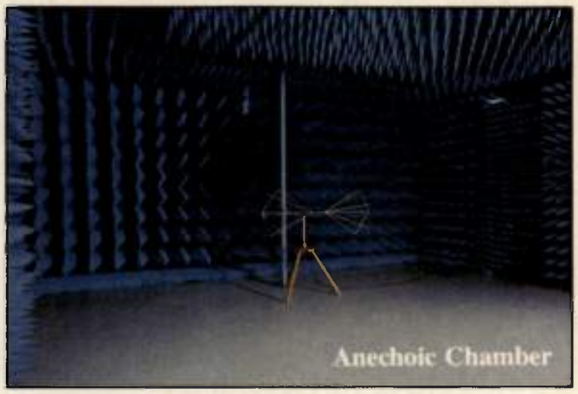
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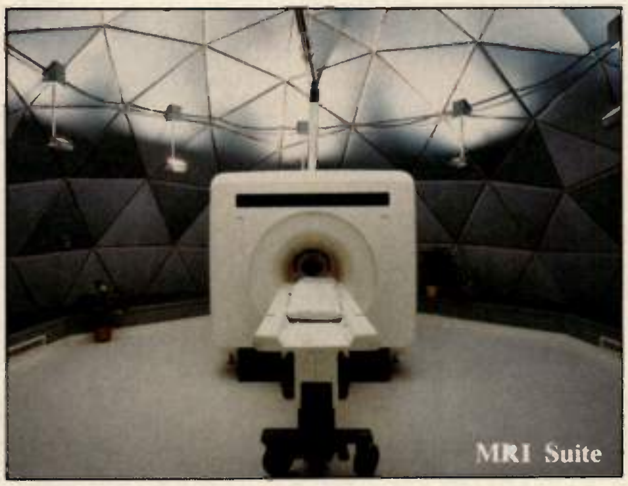
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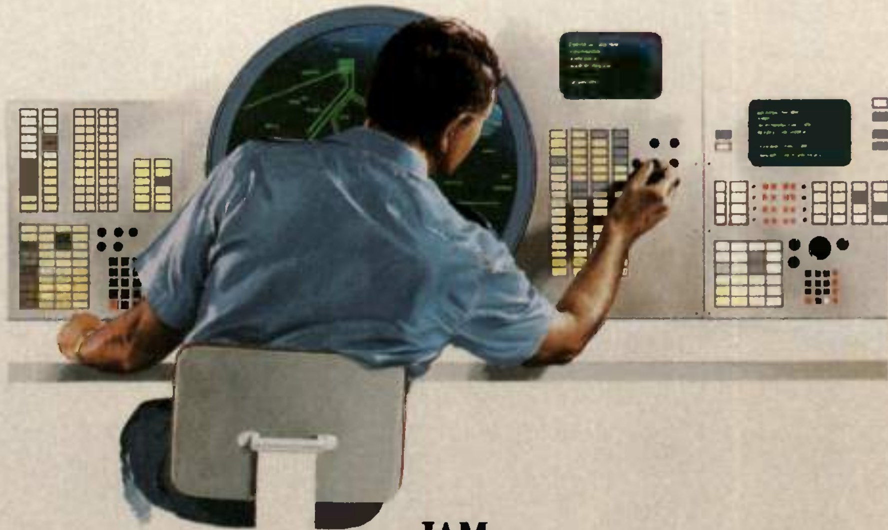

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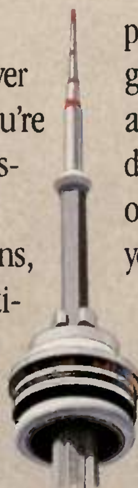

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POWER SOLUTIONS

Correction

The telephone number for the National Association of Radio and Telecommunication Engineers (NARTE) was given incorrectly in Reference 1 of "The Navy's Program for Excellence in EMC" (August 1989, *RF Design)*. The correct phone number is (503) 581-3336.

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

Easy Path Loss Calculations

Editor:

Would you like to be able to estimate path loss in your head and at the same time forget all those constants, one for each distance unit? Then read on!

You must first believe that the path loss for any given number of wavelengths (regardless of frequency) is the same. Solving for the loss at one wavelength of three different frequencies:

MHz	1WL	20log(F) + 20log(D) + K = Loss
0.6	500	−4.436 + 53.979 − 27.558 = 21.985
30	10	29.542 + 20 − 27.558 = 21.984
1500	0.2	63.522 − 13.979 − 27.558 = 21.985

Now, starting at one wavelength (22 dB), add or subtract 6 dB or 20 dB every time the number of wavelengths changes by a factor of 2 or 10.

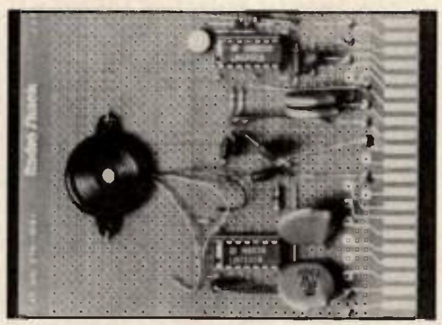
Example 1: 20 wl = 22 + 6 + 20 = 48 dB
Example 2: 50 wl = 22 + 40 − 6 = 56 dB

For distances that are not a factor of 2 or 10, use the following formula, derived as follows. Frequency is only used to find its wavelength. Therefore, the first term of the classic formula 20log(F) + 20log(D) + K is no longer needed. Distance in the second term is now the number of wavelengths. Add K, the attenuation at one wavelength (22 dB), and our simplified formula is: Loss (dB) = $20\log(N_{wl}) + 22$

As an example, consider the path loss at 100 MHz for a 30 km distance between antennas.

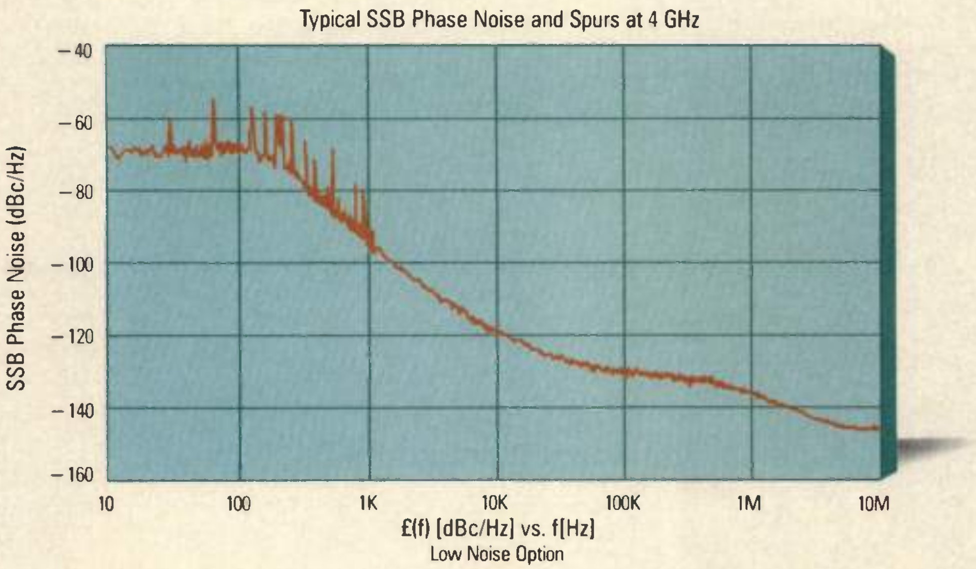
F = 100 MHz
Wavelength (in meters) = 300/100 = 3 m
No. of wavelengths (N_{wl}) = 30 km/3 m = 10,000
Loss (in dB) = 20log(10,000) + 22 = 102 dB

Bob Ripley
OSM Engineering
Inglewood, CA



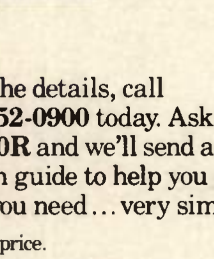
*Pictured above is a photograph of the circuit described in "Quartz Watch Time Base Monitor" (*RF Design*, Aug. 1989). The U.S. Postal Service delayed its arrival in time for that issue, but we thought we'd print it anyway!*

RF testing to 4.2 GHz



pure

and simple.



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rf calendar

September 18-19, 1989
1989 IEEE Bipolar Circuits and Technology Meeting
Marriott Hotel, Minneapolis, MN
Information: Conference Coordination Services, 6611 Countryside Drive, Eden Prairie, MN 55346. Tel: (612) 934-5082

September 25-28, 1989
21st International SAMPE Technical Conference
Inns at the Park, Atlantic City, NJ
Information: SAMPE, P.O. Box 2459, Covina, CA 91722. Tel: (818) 331-0616

September 25-28, 1989
Electrical Electronics Insulation Coil Winding Exposition
Hyatt Regency O'Hare and Rosemont Exposition Center (Chicago), Rosemont, IL
Information: Frank McGuinn, P.O. Box 35395, Minneapolis, MN 55435. Tel: (612) 942-7388

October 2-5, 1989
Electronic Imaging East 89
Hynes Convention Center, Boston, MA
Information: MG Expositions Group, 1050 Commonwealth Avenue, Boston, MA 02215. Tel: (800) 223-7126; (617) 232-3976

October 3-6, 1989
1989 IEEE Ultrasonics Symposium
Montreal, Quebec, Canada
Information: LRW Associates, 1218 Balfour Drive, Arnold, MD 21012. Tel: (301) 647-1591

October 9-12, 1989
Annual Old Crows Meeting
Sheraton Washington Hotel, Washington, DC
Information: Association of Old Crows, 1000 N. Payne Street, Alexandria, VA 22314. Tel: (703) 549-1600

October 9-13, 1989
Antenna Measurement Techniques Association 11th Annual Meeting and Symposium
Doubletree Inn, Monterey, CA
Information: Cheryl Komer, 1989 AMTA Symposium, Lockheed Missiles and Space Co., 1111 Lockheed Way, O/62-42 B/076, Sunnyvale, CA 94089-3504.

October 16-19, 1989
SCAN-TECH 89
New San Jose Convention Center, San Jose, CA
Information: AIM USA, 1326 Freeport Road, Pittsburgh, PA 15238. Tel: (800) 338-0206; (412) 963-8588

October 17-19, 1989
Northcon/89
Portland Memorial Coliseum, Portland, OR
Information: Northcon/89, 8110 Airport Boulevard, Los Angeles, CA 90045-3194. Tel: (213) 772-2965

October 24-26, 1989
RF Expo East 89
TropWorld, Atlantic City, NJ
Information: Kristin Hohn, Cardiff Publishing Company, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel: (303) 220-2600; (800) 525-9154

rf courses

The George Washington University

Electromagnetic Pulse and Its Effects on Systems
October 2-4, 1989, Washington, DC
Numerical Techniques in Electromagnetics: An Introduction
October 2-5, 1989, Washington, DC
Lightning Protection
October 5-6, 1989, Washington, DC
Modern Receiver Design
October 9-13, 1989, Washington, DC
Introduction to Modern Radar Technology
October 11-13, 1989, Washington, DC

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

University Consortium for Continuing Education

Sonar Signal Processing
September 18-22, 1989, Washington, DC
Modern Microwave Measurements
October 16-19, 1989, Seattle, WA

Information: University Consortium for Continuing Education, 16161 Ventura Boulevard, M/S C-752, Encino, CA 91436. Tel: (818) 995-6335

EEsof, Inc.

Computer-Aided Engineering/Drafting for Microwave Circuits (Academy)
September 18-20, 1989, Westlake Village, CA
Nonlinear FET Model Parameter Extraction (Xtract)
October 16-18, 1989, Westlake Village, CA

Information: Sande Scoredos, Training Coordinator, EEsof, Inc., 5795 Lindero Canyon Road, Westlake Village, CA 91362. Tel: (818) 991-7530, ext. 197

Hewlett-Packard Co.

Designing for Electromagnetic Compatibility (EMC)
September 21-22, 1989, Fullerton, CA
October 16-17, 1989, Andover, MA

Information: Hewlett-Packard Co., 3000 Hanover Street, Palo Alto, CA 94304. Tel: (800) 2HP-EDUC

Integrated Computer Systems

Introduction to Fiber Optic Communications
September 26-29, 1989, San Francisco, CA
September 26-29, 1989, Washington, DC
Introduction to Datacomm and Networks
September 26-29, 1989, Washington, DC
October 3-6, 1989, San Francisco, CA
C Programming Hands-On Workshop
September 26-29, 1989, Boston, MA
October 10-13, 1989, Cincinnati, OH

Information: John Valenti, Integrated Computer Systems, 6053 W. Century Boulevard, P.O. Box 45974, Los Angeles, CA 90045-0974. Tel: (800) 421-8166; (213) 417-8888

Interference Control Technologies, Inc.

Intro to EMI/RFI/EMC
September 26-28, 1989, Orlando, FL
EMC Design and Measurement
October 2-6, 1989, Washington, DC

Information: Penny Caran, Registrar, Interference Control Technologies, Inc., State Route 625, P.O. Box D, Gainesville, VA 22065. Tel: (703) 347-0030

EMC Services

Filter Design for Switching Supplies
October 2-3, 1989, Washington, DC
EMI Control for Switching Supplies
October 4-6, 1989, Washington, DC

Information: Sonya Nave, EMC Services, 11833 93rd Avenue North, Seminole, FL 34642. Tel: (813) 397-5854

Henry Ott Consultants

Electromagnetic Compatibility Engineering
October 10-12, 1989, Palo Alto, CA

Information: Henry Ott Consultants, 48 Baker Road, Livingston, NJ 07039. Tel: (201) 992-1793

R & B Enterprises

Understanding and Applying MIL-STD-461C
October 11-13, 1989, Chicago, IL
EMI/EMC in the Automotive System
October 16-18, 1989, Dearborn, MI

Information: Registrar, R & B Enterprises, 20 Clipper Road, West Conshohocken, PA 19428. Tel: (215) 825-1966

Research Associates of Syracuse, Inc.

ELINT Analysis
September 20-22, 1989, N. Syracuse, NY
ELINT Interception
September 25-27, N. Syracuse, NY

Information: Research Associates of Syracuse, Inc., Hancock Army Complex, 510 Stewart Drive, N. Syracuse, NY 13212. Tel: (315) 455-7157

Liberty Labs, Inc.

EMC Laboratory Quality Assurance and Assessment Seminar
October 17-19, 1989, Baltimore, MD

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

UCLA Extension

Analog MOS Integrated Circuits
September 25-29, 1989, Los Angeles, CA

Information: UCLA Extension, P.O. Box 24901, Department K, Los Angeles, CA 90024-0901. Tel: (213) 825-3344

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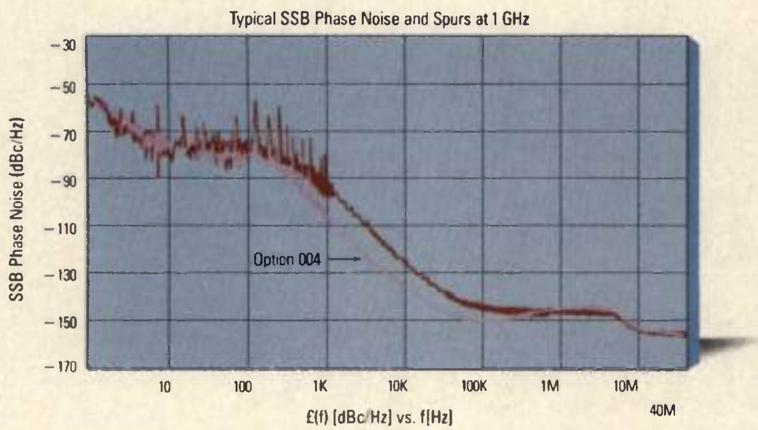

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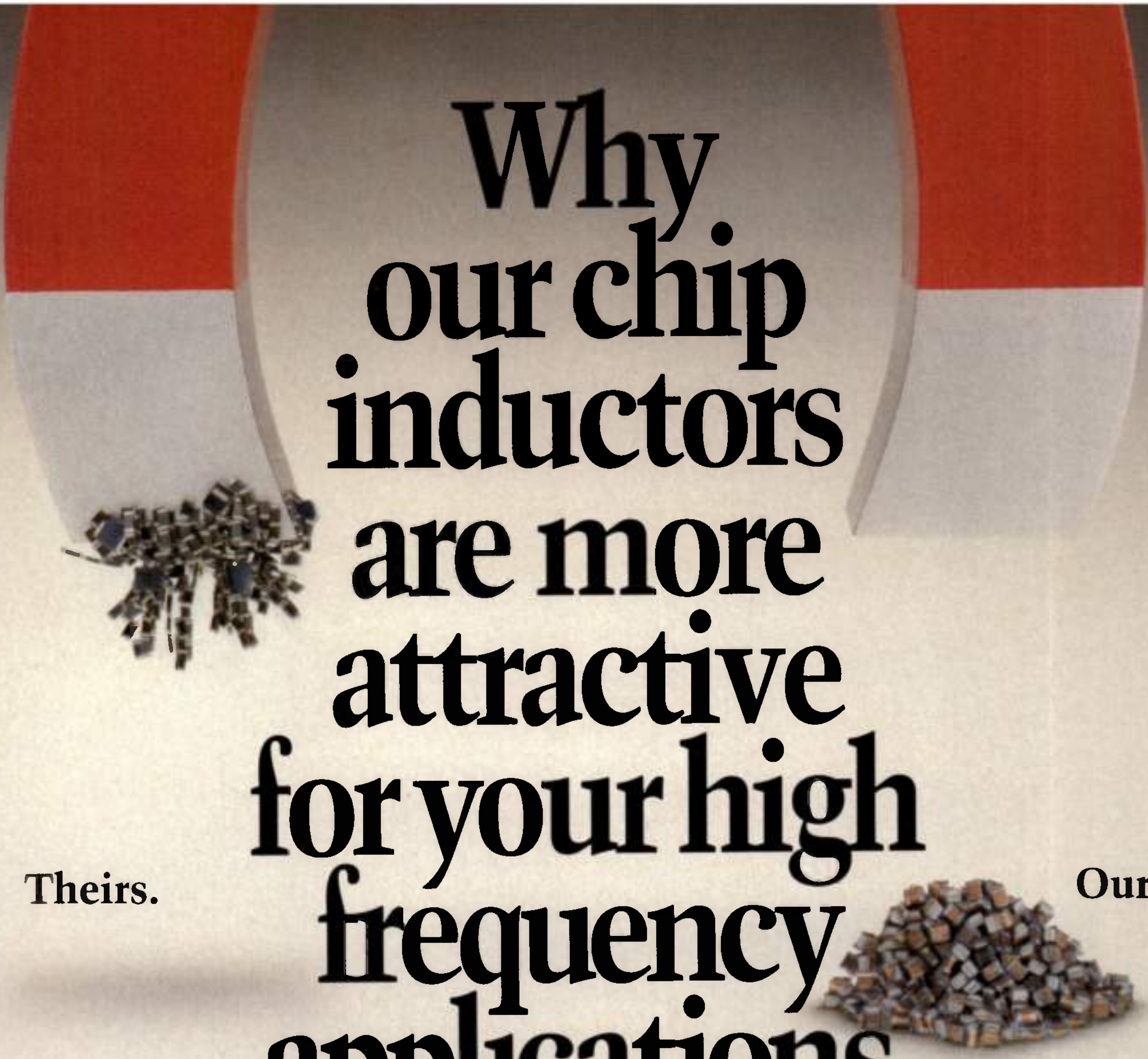

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INFO/CARD 15

A Market Overview of Inductors and Magnetic Materials

Industry Reports Activity in Surface-Mount Packaging and Market Growth

By Mark Gomez
Technical Editor

Magnetic materials have offered solutions to various RF problems over the years. Tighter government regulations are one reason that these products are seeing a surge in market activity. "We are involved in the use of ferrites for attenuation for EMI suppression. This continues to be a growing field as the limits of allowable emissions are lowered," says Richard G. Parker, president of Fair-Rite Products Corporation. At Ferroxcube, Terry Parisian, manager of marketing services, shares this opinion. He says, "We feel that one of the greatest market growth areas is the RFI suppression and EMI market." His company is currently undergoing a research program with the hopes of serving this market further. John Chabria, president of Xtalonix, expects to see a nominal growth of 5 to 7 percent over the next year.

This apparent increase in market size for magnetic materials is also felt in the related inductor industry. Manufacturers of inductors are also attributing parts of their growth to the new tighter governmental regulations. "The FCC tightening down on regulations has led to a tremendous growth in the coil business," explains Paul Liebman, marketing manager at Coilcraft. "There is very rapid growth in the need to filter noise, particularly data line noise," he adds. Inductors, because they are widely used components in RF design, are also directly affected by growing markets such as cellular and paging.

There is an immense amount of activity in surface-mount packaging in both the magnetic material and inductor industries. "You are going to see an increase in the use of surface-mount packaging," remarks Mark Sullivan, director of marketing and R&D at Toko America, Inc. He notes that the profiles for fixed chip inductors are continually getting smaller. He then goes on to say that the variety of low-profile adjustable inductors is going to continue to be more significant. "This is because of expanding markets such as cellular radio and wrist-watch pagers."

Mack Windham, vice-president of marketing at Nytronics Components Group, says, "The only change I see in inductors is the trend towards surface-mount." This view is shared by Richard Parker. "I do not see much activity in the RF ferrite industry other than the miniaturization of parts down to surface-mount," he observes. Denis Kohlhagen, sales manager at American Precision Industries — Delevan Division, says that the industry is leaning towards surface-mount and more custom design type products.

In the iron powder core industry, the only changes noted for the RF world are various applications that incorporate plastics and iron powder. "This is a means of getting some of the more complex shapes that are difficult to manufacture through the normal processes," says Jim Cox, president of Micrometals. Sullivan from Toko America says that the performance and cost of moving to plastic materials will improve dramatically. "Over the next two or three years, you will see the use of plastic ferrite materials in monolithic designs," he predicts. "There is talk about composite materials that consist of plastic and magnetic materials," says Chabria. He notes that an advantage in this technology is the potential for reduced weight. "Plastic ferrite materials, as I interpret them, amount to ferrite particles embedded in plastic," explains Parker. "We have yet to see this as a viable approach."

In general, the RF industry has indicated a downward trend in prices. This seems to be reflected in both inductors and magnetic materials. "Prices are definitely continuing to come down," says Liebman. "Prices on inductors came down when companies like ours went offshore in search of inexpensive labor. The key behind lowering prices now is the increased levels of automation and sophistication," he explains. "This also translates into higher levels of quality." According to Sullivan, customers should see a small reduction in prices coupled with substantial increases in performance. "The use of extremely precise numerically controlled robots is something that is allowing manufacturers to push the limits," he adds. "We are beyond the point of doing it slower with hand-operated winding machines." Ferroxcube's Parisian notes that we should see a trend towards lower prices because more and more people are getting into the business.

While some companies are predicting a downward trend in pricing, others anticipate either stable or increasing prices. "We see stable pricing for the next few years," notes Kohlhagen. "The aggressive pricing that is out there is mostly geared towards standard commercial type products and we do not necessarily fall into that category," he explains. Parker from Fair-Rite also sees stable pricing. He notes, "The material costs have given us some hiccups, with the price of nickel having doubled." A three to five percent increase in price is predicted by Mack Windham of Nytronics. He blames increases in material and labor costs.

In general, it is safe to conclude that this rather important segment of the industry is going to see continued growth. Coupled with this are lower prices, or a marginal increase in special cases, and higher levels of quality. Finally, performance is a key word. RF applications require it. rf

Printed Circuitry Molded Onto 3-D Parts

July's issue of *Research and Development* magazine describes a new technology which makes possible the incorporation of printed circuitry directly onto (or within) a three-dimensional molded part, such as an automobile dashboard or a radio housing. The technology was developed at Allen-Bradley of El Paso, Texas. The process begins with the screening of a conductive polymer material on a thin plastic sheet, or decal. The decal is then placed in an injection die cavity before a part is molded.

In what is called the "transfer decal" process, the decal is peeled off after the three-dimensional molding cycle, leaving the circuit embedded in the surface of the molded device. The "captured decal" process molds both circuitry and decal into the part, for multilayer device applications. This technology offers flexibility in choosing substrate materials to meet mechanical, electrical and environmental requirements. In addition, the development permits circuit operation in a variety of harsh environments.

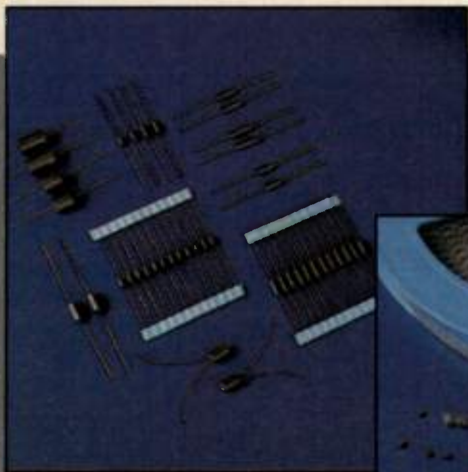
NASA Research Yields Multichannel Active Lowpass Filters—Research at NASA's Jet Propulsion Laboratory in Pasadena, Calif., has resulted in a multichannel, multistage, active lowpass filter with matched gain and phase characteristics obtained by cascading integrated circuit operational amplifiers. The concept, developed by Caltech researcher James J. Lev, is described in the July 1989 issue of *NASA Tech Briefs*. The design makes use of the electrical equality of essentially identical circuit elements made on the same chip. An operational amplifier set for unity gain makes up each stage in each channel of the device. The filter was developed for a radar-target simulator processing Doppler modulation, for use at frequencies from 200 Hz to 450 kHz. Other areas where this concept could be of use include test instruments, communication circuits and equipment for electronic countermeasures.

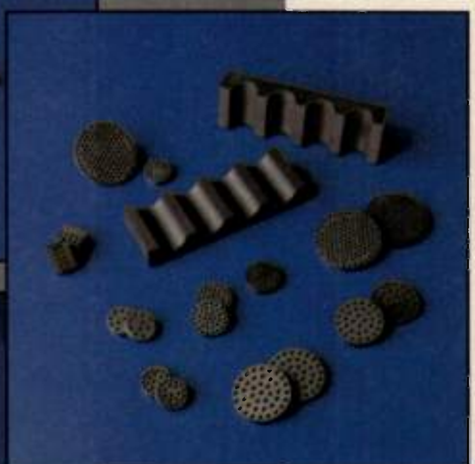
Record Efficiency for Solar Cell Module—Researchers at Sandia National Laboratories in Albuquerque, N.M., have obtained an efficiency of 20.3 percent for a photovoltaic concentrator module — a record conversion efficiency for this type of device. The design consists of 12 silicon solar cells, onto which a dozen plastic lenses focus sunlight at 100 times its ordinary intensity. The lenses have an anti-reflective coating which increases efficiency. A prismatic cover molded onto the silicon cell reduces reflection losses, and the cells are soldered directly onto copper heat spreaders to reduce cost and improve performance. The new design is seen as an important step in making photovoltaic technology a more affordable means of generating electricity.

RAM Receives First U.K. Radio Channels for Mobile Data—RAM Mobile Data, Ltd., a subsidiary of RAM Broadcasting Corp., has been awarded a radio frequency channel allocation by the Department of Trade and Industry (DTI) for the development of a national two-way mobile data communications network to serve the United Kingdom. This is the first such allocation to have been made by the DTI. Earlier this year, AMDC, another RAM subsidiary, was allotted three years by the Federal Communications Commission to construct a mobile data network to serve the 50 largest U.S. cities.

Mobile data systems transmit data using packet switching technology, greatly enhancing the capacity and efficiency of radio channels, and supporting such advanced applications as computer-aided dispatch, mobile telemetry and database access from handheld and vehicular terminals. These applications allow terminals, previously connected by wires to mainframe and mini-computers, to communicate from any point in the area covered by the mobile data system, while away from the office or a fixed telephone line.

NIST Probe Adapted for Commercial Use—A tiny, broadband electric field probe designed, tested and calibrated by engineers at the National Institute of Standards and Technology





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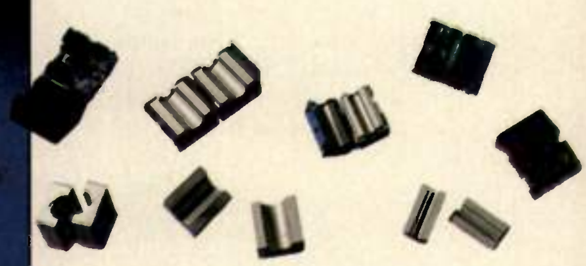

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(NIST) has been adapted into commercial products by the Electro-Mechanics Co. (EMCO), of Austin, Texas and Aeritalia of Turin, Italy. The probes are used for electromagnetic interference testing and non-ionizing radiation hazard measurements. NIST developed ultra-broadband resistively loaded dipoles and used the Denver Research Institute, Denver, Colo., to provide the sensor element. NIST fabricated an ultra-broadband electric field probe using these dipole elements, which can measure fields of 1 to 1600 V/m over a range of 100 kHz to 18 GHz. The development of the probe was first announced in the *IEEE Transactions on Microwave Theory and Techniques*, February 1987.

Report Examines Standards in China—A publication from the China Electronics Standardization Institute describes for U.S. electronics manufacturers and exporters the standardization system in place in the People's Republic of China. The report, *The Effect of Chinese Standardization on U.S. Export Opportunities*, is available through the National Technical Information Service. Information is provided on the role of the China State Bureau of Standards in the standards coordination process, as well as on the impact of China's quality program on U.S. export opportunities. Copies of the report, PB 89-166128/AS, are available from: National Technical Information Service, Springfield, VA 22161.

Antenna Specialists Issued Patent for On-Glass Antennas—The U.S. Patent Office has issued to the Antenna Specialists Co. a patent covering its cellular ON-GLASS[R] antennas and similar antennas used at or above 800 MHz. The design covered by the patent is a mobile antenna system with a collinear radiator mounted on one surface of a dielectric (e.g., a vehicle's window) and a tunable coupling circuit mounted on the opposite surface of the dielectric. The coupling circuit acts as a counterpoise for coupling RF energy between the radiator and a transmission line connected to a transceiver. The new patent, No. 4,839,660, acknowledges the existence of a previous patent (also held by Antenna Specialists) for glass-mounted antennas.

First Half 1989 Electronic Shipments Up 5.3 Percent—U.S. factory shipments of electronic equipment, components and related products totaled $127.7 billion for the first half of 1989, excluding imports, according to preliminary figures released by the Electronic Industries Association (EIA). This represents an increase of approximately 5.3 percent over the 1988 first half industry sales figure of $121.2 billion. The figures are being viewed as a sign of the continuing vitality of the U.S. electronics industry, despite forecasts for a slight slowdown in the overall economy.

A breakdown of U.S. factory sales by industry group indicates that electronic components shipments totaled $25.9 billion, up more than 8 percent from the 1988 total of $24.0 billion. The computers and industrial electronics sector registered $41.0 billion, nearly 4 percent over last year's figure. The communications equipment sector's first half sales increased to $33.2 billion, up 4.8 percent from last year's $31.7 billion. The consumer electronics sector registered $15.2 billion (including imports) for the first half of 1989, 6.4 percent above last year's first half figure of $14.3 billion. U.S. factory sales of consumer electronics, excluding home information products, totaled $2.4 billion for the first half of 1989.

Sales of other electronic related products and services were $25.1 billion year-to-date, increasing 5.4 percent over sales of approximately $23.8 billion reported during the first half of last year.

U.S. sales of defense electronics are estimated at 21 percent of total U.S. electronic shipments, or approximately $27 billion during the first half of 1989.

New Component Operation—A new entry into the signal processing components market covering the frequency range from 10 kHz to 3.0 GHz began operations in May 1989. The company, Vortex Microwave Corp., will specialize in ferrite core technology products such as double balanced mixers, power dividers, hybrids, modulators, voltage-controlled attenuators, and phase shifters. The company will be led by David P. Berry, formerly president of Synergy Microwave Corp. Vortex Microwave Corp. is located at 100 Manhattan Avenue, Suite 1809, Union City, NJ 07087. Tel: (201) 330-1971

GE Selects HP Modular Measurement System—The Automated Systems Department of GE Aerospace has selected Hewlett-Packard (HP) Company's HP 70000 modular measurement system (MMS) for the U.S. Navy's Consolidated Automated Support System (CASS) RF suite of instrumentation. GE Automated Systems is the prime contractor for CASS, the Navy's new standard maintenance test system. MMS will be incorporated in the CASS RF subsystem. MMS, a subset of measurement systems architecture, uses the HP-developed open architecture modular system interface bus (MSIB). Test functions included in the CASS RF subsystem are spectrum analyzers, network analyzers, signal generators, and power meters.

HiTc Superconco Receives SBIR Award—HiTc Superconco has been selected for a Small Business Innovation Research (SBIR) award from the U.S. Department of Energy (DOE). The Phase I award for $50,000 was made for a patented HiTc process to produce flexible superconductive wires and cables. The award is designed for the development of flexible superconducting filaments through the use of conventional textile processes, produced by utilizing over-capacity in existing plants. Potential areas of application include data communications, high-strength magnets, nearly zero energy consumption motors, frictionless magnetic bearings and magnetic energy storage. The superconducting wire may also affect low electric current carrying applications such as microwave communications, radio frequency cavities, magnetic shielding and dipole antennas.

Multichannel Satcom for QE2—The luxury superliner Queen Elizabeth 2 was recently fitted with a four-channel satellite communications terminal from Magnavox, which will provide the ship's passengers with a wide array of advanced telecommunications services, including telephone, fax, electronic mail and dial-up databases. The Magnavox MX 2400/4 multichannel satcom system provides simultaneous access to four separate INMARSAT satellite channels, each of which can be used independently for computer data and facsimile transmission as well as telephone and telex calls. The multichannel satcom system was developed by Magnavox under contract from Communications Satellite Corp. (COMSAT).

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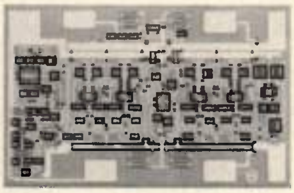

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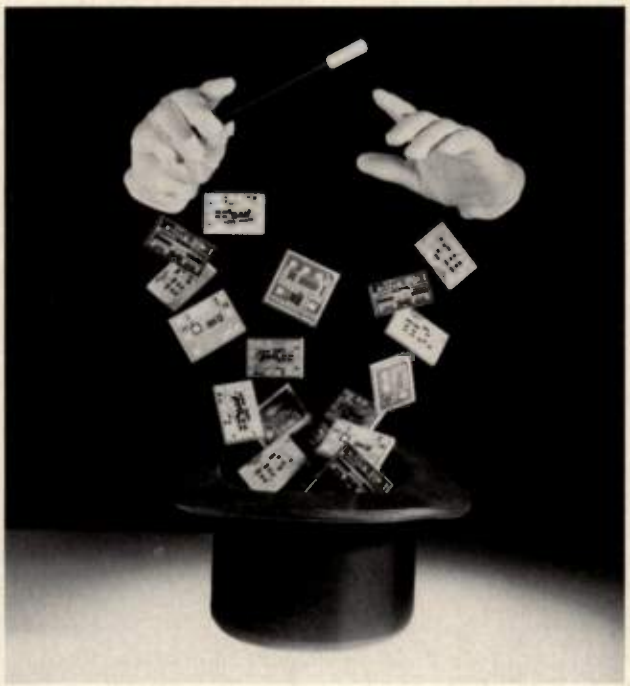

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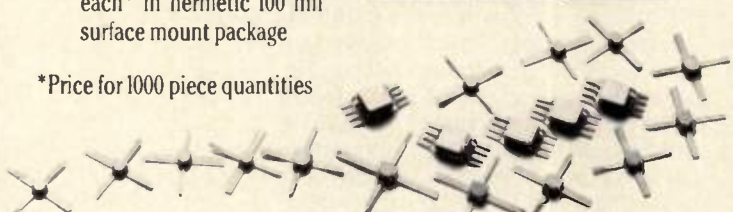

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INFO/CARD 38

Software-Assisted Characterization of Large-Signal Device Models

By Dr. Jeremy M. Bunting
EEsof, Inc.

Circuit simulation is a powerful tool in RF and microwave design. State-of-the-art simulator programs allow the design engineer to accurately predict the performance of a circuit before fabrication. In this way, costly redesign/refabrication cycles may be reduced or even eliminated. Versatile features such as component value optimization allow the engineer to meet circuit specifications efficiently. More recently, yield optimization and design centering help tie circuit design procedures more closely to component and fabrication tolerances (1,2).

But there is more to effective circuit simulation than versatile and efficient simulator programs. The most significant contribution to a correct simulation is the accuracy of the data used to represent the circuit elements. This may be in the form of measured data or equivalent circuit models. Models that use analytical expressions to generate an equivalent circuit response are also used.

Among the most difficult circuit responses to model is the behavior of active elements under large-signal conditions. This article describes an accurate method for characterizing MESFETs and fitting large-signal models for use in EEsof's Libra™ and Microwave SPICE®, and for linear circuit simulation in Touchstone®. The programs ANACAT™ and Xtract™, also from EEsof, automate the data acquisition and model parameter extraction process and provide the engineer with a powerful means of generating and analyzing large-signal MESFET models. The same capability is currently under development for large-signal BJT modeling.

Large-Signal Modeling

Linear simulation is very useful in the prediction of small-signal gain, stability, bandwidth, noise and impedance effects. But circuits such as power amplifiers, mixers and oscillators are dependent on the nonlinear characteristics of their active devices for operation. The simulator has to be able to predict effects such as gain saturation, harmonic generation, modulation, power-dependent impedance and limiting. So, to accurately simulate these circuits, models that represent the nonlinear behavior of FETs and BJTs are required.

A popular and effective way of modeling nonlinear effects in MESFETs is to incorporate the bias dependencies of current generators, capacitors and resistors into an equivalent circuit model of the device (3,4). In this way, the model not only represents the effect that the bias applied to the device has on the element values, but also calculates the instantaneous element values encountered by a time-variant signal. Simulators with sophisticated convergence schemes then provide circuit performance solutions in either the frequency or time domain based on these instantaneous values.

Such a large-signal MESFET model is the EEFET model available with Libra and Microwave SPICE, and also with Touchstone for small-signal analyses. The equivalent circuit model used by EEFET combines both an AC and a DC model and is shown in Figure 1. The dominant function in the DC model represents $I_{DS}(V_{DS},V_{GS})$, and was originally proposed by Statz et al.(5).

EEFET, however, has an enhanced AC model that incorporates the full two-dimensional bias dependence of g_m, R_{ds}, R_i, C_{gs} and C_{gd}. Previous models have only characterized g_m as a function of both V_{ds} and V_{gs}. Normally C_{gs} and C_{gd} are represented by single-dimensioned functions that do not fully represent the bias dependence of these elements, and the bias dependence of R_{ds} and R_i is usually ignored.

The incorporation of these dependencies has significantly enhanced the simulation accuracy of harmonic generation analysis. Figures 2(a) through 2(e) show measured data for an NEC71000 MESFET compared with simulation data using the EEFET model and the Curtice Cubic large-signal MESFET model (3).

For the large-signal model to accurately represent a specific device, the model parameters that correspond to that device have to be derived. This is normally achieved through measurements on the device and through additional software that optimizes model parameters to fit the measured data.

Model Parameter Extraction

In 1978, Willing and Rauscher proposed a method for deriving the bias dependence of equivalent circuit elements in a large-signal MESFET model from small-signal measurements (6). The method was shown to be feasible and accurate. Large-signal devices could be characterized without the need for complicated and time-consuming transient and harmonic measurements. However, the large quantity of data acquisition and processing that was

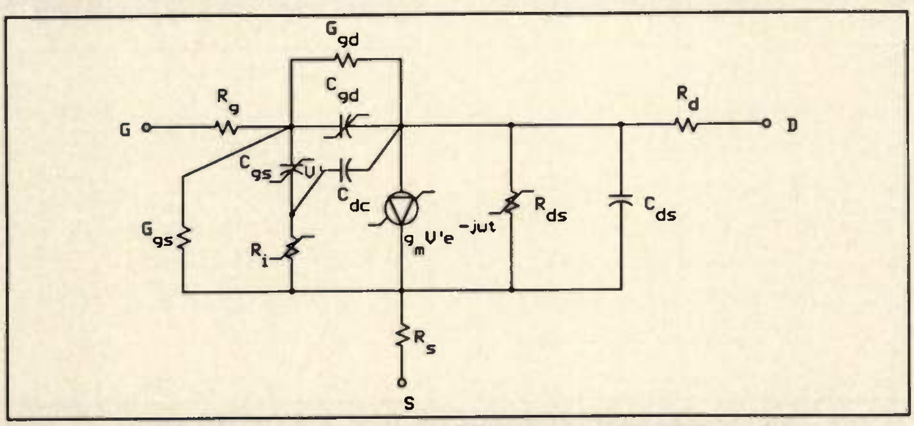

Figure 1. Equivalent circuit of the EEFET GaAs MESFET model.

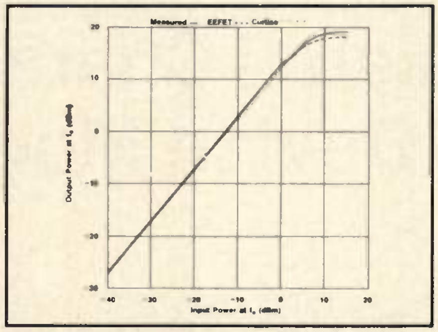

Figure 2(a). Comparison of data at fundamental frequency.

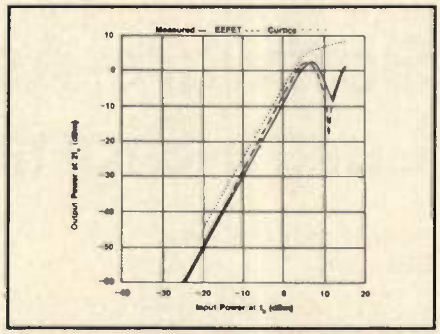

Figure 2(b). Comparison of data at second harmonic.

required made the method impractical at that time. More recently, advances made in computing power available with personal computers and engineering workstations has made computer-aided test (CAT) and large-scale parameter optimization a reality.

The measured small-signal parameters — such as S-parameters — of a FET will vary with bias and frequency. The intention is to fit a single equivalent circuit model to the measured data that fully represents the frequency and bias-dependent properties of the device. An accurately designed equivalent circuit topology will scale with frequency, so that element values extracted at a single frequency will model the device's performance over a broad bandwidth. EEFET has been tested to 40 GHz, as shown in Figure 3. Good agreement has been found between measured and simulated data using model parameters extracted at just 1 GHz.

The model's bias dependence may be incorporated by optimizing a small-signal model to measured data at a number of bias points over the operating region of the device. Analysis of the model element values at each discrete bias point shows that the significant bias dependence is in just five elements: g_m, R_{ds}, R_i, C_{gs} and C_{gd}. EEFET maintains its accuracy and efficiency in the simulator by fitting analytical expressions as a function of the two independent contact voltages, V_{ds} and V_{gs}, to the values of the five bias-dependent elements. The remaining elements in the model are considered to be bias-independent. A function is also fitted to the measured bias curves $I_{DS}(V_{DS},V_{GS})$ to create the DC model. Figure 4 shows an example analytical fit of $C_{gs}(V_{ds}, V_{gs})$ to the linear values of C_{gs} that were optimized to small-signal measurements.

Data Acquisition

The large-signal model parameter extraction method requires a large amount of measured data. This may be up to 256 measured bias points and 256 sets of small-signal S-parameter measurements vs. frequency. To make such an array of measurements practical, the measurement procedure was automated, controlled all the measurement instruments, and allowed the user the flexibility of choosing arbitrary bias points for measurement. ANACAT has been created for this application, designed specifically to extend the capabilities of vector network analyzers (VNAs). It performs measurement, calibration, de-embedding, and control of bias and other ancillary instruments. It

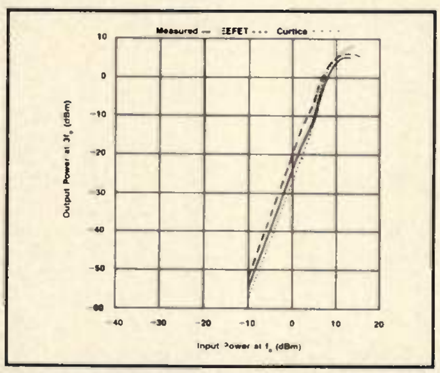

Figure 2(c). Comparison of data at third harmonic.

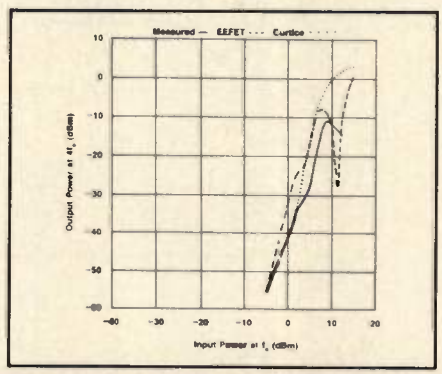

Figure 2(d). Comparison of data at fourth harmonic.

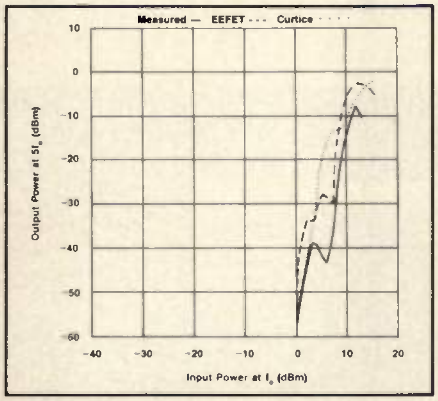

Figure 2(e). Comparison of data at fifth harmonic.

is compatible with a range of VNAs including the Wiltron™ 360 and the Hewlett-Packard 8510.

Two features in ANACAT that make it particularly suitable for this application are its ability to control and organize large amounts of measurement data and its automated test procedures. The measurement required for large-signal model extraction can generate an ASCII file of over 500 Kbyte. A special file using the Measurement Data Interface Format (MDIF), developed in conjunction with Cascade Microtech, is used to collect data and deliver it to Xtract for model parameter extraction (7).

ANACAT also contains a language known as the Measurement Language Format (MLF) for users to write their own device drivers and for generating automated test procedures that control ANACAT functions. MLF is very much like BASIC and includes a full-screen editor, an interpreter to speed program execution, and an interactive debugger (8). This language may be used easily to set up a measurement in preparation for model extraction.

High-precision DC analyzers are used to maintain accuracy in bias measurements. Also, RF measurement accuracy is improved by using ANACAT's user-defined calibration techniques. These are especially useful in creating very broadband measurement sweeps for wafer measurements that combine both Open-Short-Load (OSL) and Line-Reflect-Line (LRL) methods. The user can instruct the program to measure bias and S-parameters at any range or point of bias before running the automated test procedure. The measurement time is typically one-tenth the time taken by a manual procedure.

Extraction Software

Xtract, shown in Figure 5, is a program designed for large-signal MESFET model parameter extraction. The program is highly interactive and incorporates powerful graphics, automatic optimizers and interactive parameter tuning. Measurement data is taken directly from ANACAT, and model data files are prepared that may be read by Libra, Microwave SPICE and Touchstone.

The structure of Xtract comprises a shell that consists of all the data and user interface functions. Underneath the shell lies the model kernel, which includes the mathematical functions for each specific model. The models currently available are the EEFET model (4), the Curtice Cubic model, and the Statz et al. model. Since the shell is consistent, the extraction procedure is the same for all the models, which adds to the program's versatility.

The model parameter extraction procedure has three stages: the calculation of parasitic elements, the generation of a linear model at each discrete bias point, and the fitting of analytical functions to the linear data to complete the bias-dependent model.

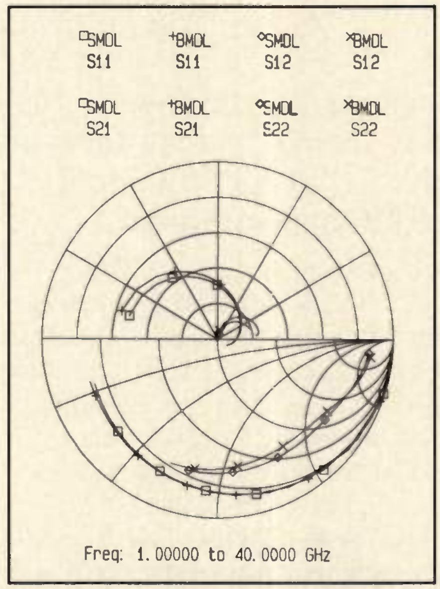

Figure 3. Measured and EEFET modeled S-parameters for a 0.5 micron gate MESFET.

After parasitic elements such as bonding inductances, and bulk and gate resistances are calculated, these values are used to de-embed the intrinsic FET model. The element values of this FET model are then optimized to the measured S-parameters at each bias point. Xtract incorporates a linear simulator that may be used to generate S-parameters from the linear model at any bias point. It can be used to graphically inspect the small-signal performance of the model at this intermediate stage. An interactive tuner modifies any model element value, at any bias point.

The final stage of the large-signal

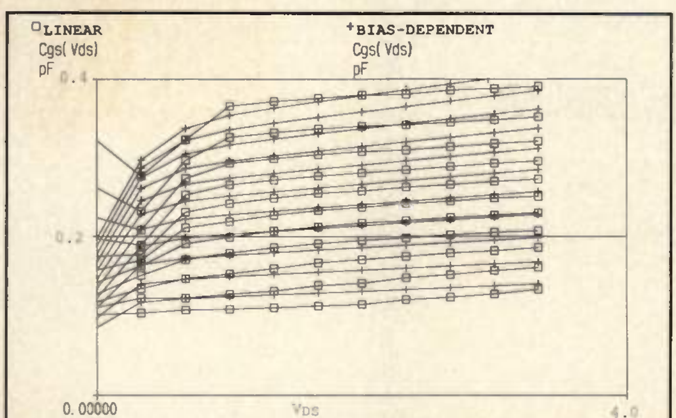

Figure 4. An analytical expression is fitted to the bias dependence of C_{gs}, as well as g_m, R_{ds}, R_i and C_{gd}.

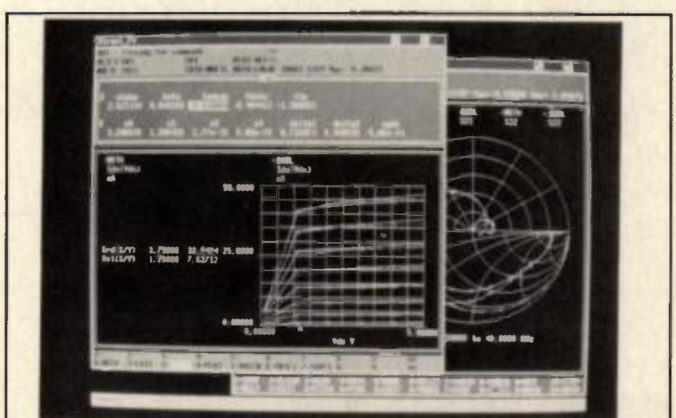

Figure 5. Xtract is used for large-signal and linear model extraction.

model extraction process is to simultaneously surface-fit functions for $g_m(V_{ds},V_{gs})$, $R_{ds}(V_{ds},V_{gs})$, $R_i(V_{ds},V_{gs})$, $C_{gs}(V_{ds},V_{gs})$ and $C_{gd}(V_{ds},V_{gs})$. Xtract allows the user to independently optimize individual parameters and to optimize any or all of the parameters over the full range or a sub-range of the measured data. A nonlinear simulator, also built into Xtract, can simulate the performance of the large-signal model for graphical comparison with the measured data. An important feature is the interactive tuner which can be used to vary individual model parameters. This is particularly useful if a model needs to be adapted to improve the fit in a localized region. In this way, Xtract can be used as a model analyzer in designing models suited to specific applications. Extracting a large-signal model takes as little as 10 minutes.

The combination of ANACAT, Xtract, and the simulators Libra, Microwave SPICE and Touchstone is a complete solution for RF and microwave large-signal modeling. The data format from ANACAT is directly compatible with Xtract, which creates model parameter files that can be read directly by the simulators. The same model is used by all the simulators, which also contributes to the user's convenience. The programs are available on a wide variety of PC and workstation platforms. rf

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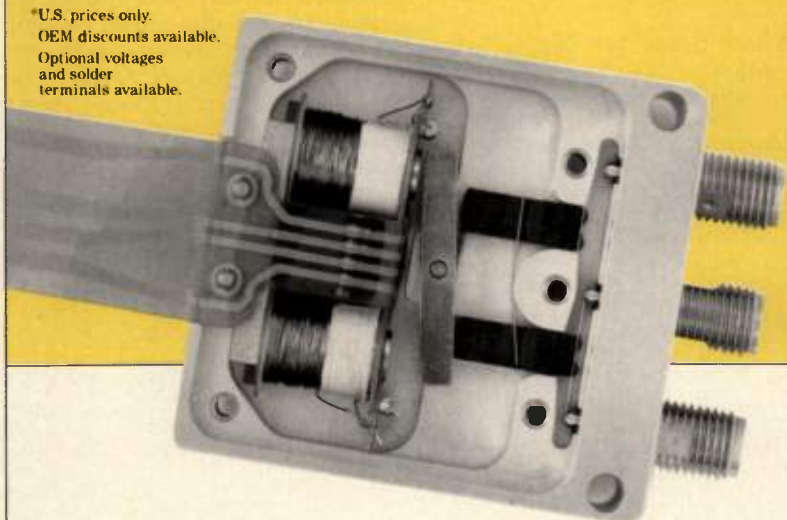

INFO/CARD 27

VXIbus: Benefits for RF Applications

By Malcolm Levy
Racal-Dana Instruments Inc.

The advent of automatic test systems several years ago greatly simplified the testing of RF devices and systems. Combining a computer controller, some RF switching and the necessary programmable instruments allowed a full-performance test to be conducted on the most complex of systems. The test results were accurate and repeatable, and required minimal operator intervention. Development of such test stands was further simplified with the standardization of interfaces such as IEEE-STD-488 and RS232, as well as the more recent development of test program generators.

While these standards continue to serve the test community well, they have a number of drawbacks that significantly affect testing, especially in the RF arena. For example, test systems comprising many instruments often must span multiple racks, requiring extensive cabling and increasing the signal losses inherent in an RF environment. In addition, the speed of the IEEE-STD-488 and RS232 interfaces is relatively slow when compared to contemporary computer busses.

In 1987, test equipment manufacturers, struggling with the limitations of current standards, realized that close cooperation would be required to develop a standard of benefit to everyone. To accomplish this, they set aside their differences and formed the VXIbus consortium. This consortium produced the VXIbus standard, which allows instruments-on-a card to be combined in a system. This concept reduces the size and weight of instruments, permits tighter timing coordination between instruments, and allows extended system support through multivendor solutions.

VXIbus and the RF Environment

When the concept of the VXIbus was first announced, some organizations expressed serious doubts about the functionality of RF instrumentation within the VXIbus system. Problems were predicted in areas such as the physical size constraints of VXIbus systems, accommodating RF and microwave circuits, and achieving the necessary levels of screening within an acceptable module size. The introduction of a number of RF and microwave devices for the VXIbus has put these concerns to rest.

It is important to note, however, that when test applications demand the ultimate in performance, the user must take care to choose a manufacturer who has paid particular attention to RF-specific issues. The manufacturer's adherence to the VXIbus specifications ensures EMI compatibility between the modules and chassis, but the specification does not govern the total performance of the system, nor that of the individual module. These concerns are left to the system integrator and module manufacturer, respectively.

A VXIbus Test Stand for RF Applications

As in any other automatic test equipment (ATE) design, the first step taken in developing a VXIbus ATE station is to define the inputs and outputs of the Unit Under Test (UUT) in terms of their digital, analog and RF requirements. Once these are determined, the necessary hardware can be specified.

Implementation of the VXIbus permits some interesting applications of the virtual instrument concept. For example, one might not need to specify a Distortion Factor Meter (DFM) and a Digital Multimeter (DMM) as two separate devices. The DFM consists of a switched tunable notch filter and AC voltmeter, which could be part of the DMM. Under software control, these components can be reconfigured and scaled for the necessary results.

Another benefit of the VXIbus is that the user can manufacture cards to sit alongside specialized instruments. The specifications are in the public domain, and fully define the mechanical parameters and interface requirements for the module. This allows integrators of a system to build their own unique filters, I/Q detectors, or other devices, and incorporate them directly into their particular system.

In fact, VXIbus allows a user to go beyond the concept of virtual instruments to a "virtual manufacturer." An instrument such as a signal generator could comprise components from different manufacturers. Figure 1(a) presents a block diagram of a signal generator as a stand-alone instrument, in which communication between blocks is internal to the instrument. VXIbus allows an

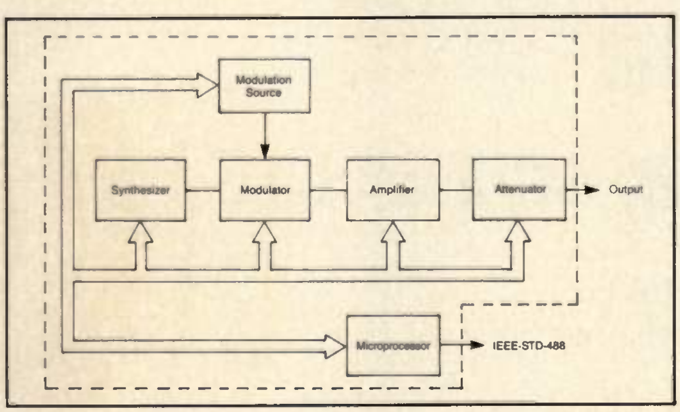

Figure 1(a). A signal generator as a stand-alone unit.

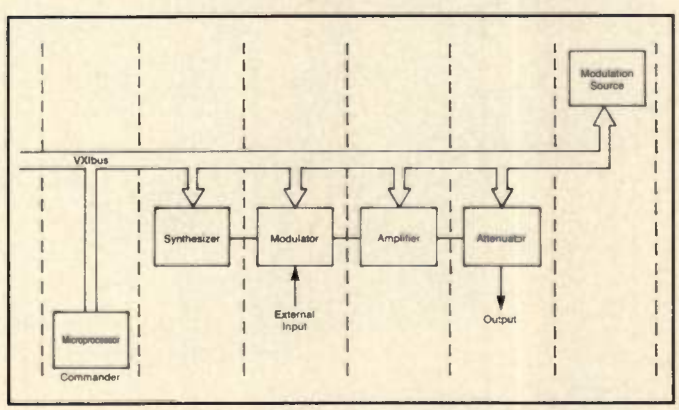

Figure 1(b). A signal generator in modular form.

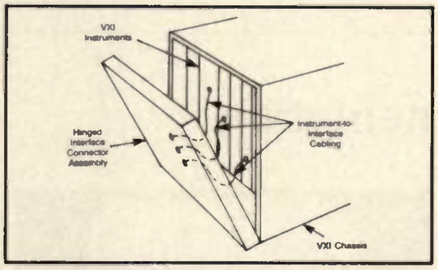

Figure 2. VXIbus chassis with UUT interface hinged to front.

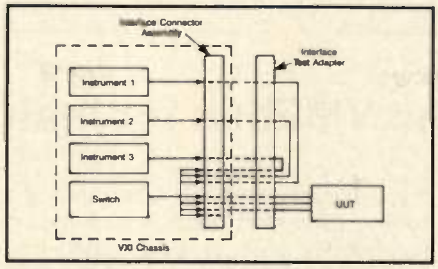

Figure 3(a). System interface for large ATE systems.

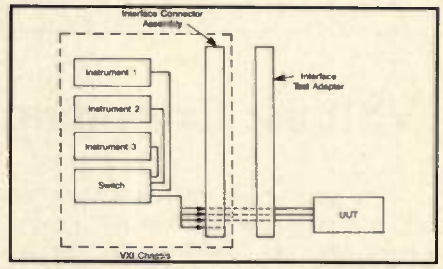

Figure 3(b). System interface for small ATE systems.

instrument set to be built consisting of a commander and servants, instead of being enclosed in one package. Figure 1(b) illustrates this arrangement. The device contains the same elements as Figure 1(a), but each component is on a separate card. Communication between blocks (in this case, individual modules) is over the VXIbus. The flexibility provided is especially valuable in making critical RF measurements. When future improvements are needed, such as enhanced noise performance, only the synthesizer need be replaced. A new synthesizer could be obtained from a different supplier, as long as it is in compliance with the VXIbus master/servant protocol.

Some manufacturers may choose to use the local bus rather than the master/slave arrangement. This still allows for an upgrade, but only from the original manufacturer. Either way, these arrangements reduce the obsolescence found in today's test stands: as the user's requirements change or the manufacturer's capability improves, only one part of the product becomes obsolete.

RF Interfacing

Interfacing to the UUT in RF applications presents further challenges. Impedance matching is crucial to prevent return loss, which results in wasted power or inaccurate measurements. In addition, cable lengths must be kept as short as possible to avoid undue signal loss and to reduce the effect of EM coupling of noise or unwanted signals.

Under VXIbus, these problems can be significantly reduced. If all the instruments reside in the same chassis, cabling between them will be minimized. Of course, there may still be devices not available in VXIbus format sitting elsewhere in the rack which need to be switched through to the UUT. In many RF applications, the switch needs to be placed directly at the interface, in order to reduce losses. With VXIbus, the interface to the UUT can be an integral part of the chassis. Such an arrangement is shown in Figure 2. A hinged front panel on the chassis can be used to mount custom connectors or relays. Cabling between these connectors and the instruments is now extremely short; all that is needed is a service loop to allow the panel to be dropped for access to the modules. The panel also serves as an additional RF screen.

The VXIbus also provides advantages in an environment where many different devices need to be tested. In this case, an easily changeable interface may be required. Large ATE systems make use of Interface Connector Assemblies (ICAs) and Interface Test Adapters (ITAs). Typically, a switch, with the system resources cabled into it, sits behind the ICA. Smaller scale systems can easily be incorporated into VXIbus, with both the switch and resources sitting directly behind an ICA. These arrangements are shown in Figures 3(a) and 3(b), respectively. The second method provides more flexibility than the first, but introduces more errors from propagation delay and insertion loss, due to the greater number of connections. These schemes work very well in systems up to about 3 GHz. Beyond that frequency, high-performance screw or bayonet connectors must be used.

High-Speed Communication

Many instruments today feature high-speed data acquisition capability. However, they are impeded in transferring the data by the slow speed of the interface bus. To overcome this problem, instruments often incorporate large memories, and dump results to the controller at a more leisurely rate. The VXIbus allows much more efficient use of the instruments' performance when the controller resides within the chassis.

The main computer bus in a VXIbus system is VME, which can run at rates up to 20 MHz. An embedded controller enables the system to realize the full potential of the VMEbus. For example, An 80386-based AT embedded in the VXIbus chassis and running at speeds up to 20 MHz can significantly improve most high-speed data handling problems. This capability will be very useful for signal processing applications, and even agile radio testing.

The controller for a VXIbus system can also reside outside the chassis. When located here, the controller takes on the classic role, and will normally communicate using IEEE-STD-488.1; this arrangement maintains compatibility with earlier systems.

The Future

VXIbus is still in its infancy, yet today there are already over 120 manufacturers who have signed up for manufacturer I.D.s. More than 40 products are on the market, with new ones added almost daily. Products include chassis (C and D), Slot 0 cards (GPIB and VME), DMMs, counter-timers, prototyping cards, A-to-D and D-to-A converters, RF power meters, 1553 analyzers, arbitrary waveform generators, digital word generators, pulse generators, and microwave frequency counters. Even 80386-based dual-width, C-size AT-compatible computers are available. It is estimated that within five years, at least one-third of the traditional rack-and-stack market will have crossed over to a chassis mainframe with modular instrumentation: the VXIbus. A summary of VXIbus standards is included on the next page. rf

About the Author

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VXIbus: Extending the VMEbus for Instrumentation

The goal of the VXIbus is to define a technically sound modular instrument standard based on the VMEbus (IEEE STD 1014) that is open to all manufacturers and is compatible with present industry standards. VXIbus is an abbreviation for VMEbus Extensions for Instrumentation.

The VXIbus specification details the technical requirements of VXIbus-compatible components such as mainframes, backplanes, power supplies and modules. The specification also provides for interconnecting and operating different manufacturers' products within the same card chassis.

To maintain compatibility with the existing VMEbus, the A and B card sizes of VMEbus were included as part of the VXIbus standard. In fact, VXIbus retains P1 and the center row of P2 exactly as defined by VMEbus. This includes the 5 V and ±12 V power pins on P1. To accommodate the circuitry necessary for high-performance instruments, two card sizes were added to the existing VMEbus specification. C size (approximately 13 in. deep and 9 in. high) has the same connectors as the VMEbus B size, but with all the pins on P2 fully defined. D size (approximately 13 in. deep and 14 in. high) may have an additional connector, P3, which adds many resources necessary for higher performance instrumentation.

The chassis inter-module spacing has been increased over that of the VMEbus to 1.2 in., to allow for large analog components and shielding between modules. A module may be a simple printed circuit card or an enclosed chassis assembly containing several printed circuit boards. If an instrument needs more than 1.2 in., it may take up multiple slots in a VXIbus mainframe.

A VXIbus system may have up to 256 devices, including one or more VXIbus subsystems. A VXIbus subsystem consists of a central timing and arbitration module, referred to as the Resource Manager or Slot 0, with up to 12 additional instrument modules. These 13 modules conveniently fill a standard 19 in. cabinet when mounted vertically on 1.2 in. centers. Although there is a maximum of 13 modules in a VXIbus subsystem, there is no minimum number. For example, a subsystem may contain just a resource manager with two or three modules.

As mentioned previously, a VXIbus subsystem defines all P2 and P3 pins. The VXIbus P2 adds a 10 MHz clock, ECL and analog supply voltages, ECL and TTL trigger lines, an analog sumbus, a module identification line, and a daisy chain structure called the Local Bus. P3 provides more of the above, and adds a 100 MHz clock and a star bus.

The *Clock Bus* provides the P2 and P3 clocks and a clock synchronization signal located on P3. All three signals are differential ECL. Both clocks and the synchronization signal are sourced from the Resource Manager and buffered through the backplane to each module individually.

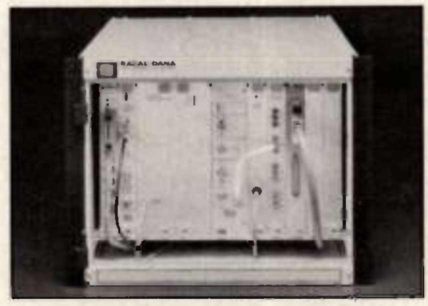
The *Trigger Bus* consists of eight TTL trigger lines and two ECL trigger lines, all of which are located on P2. Four additional ECL trigger lines are situated on P3. The trigger bus is used for general-purpose inter-module communication.

A *12-line Local Bus* on P2 provides a private module-to-adjacent-module communication bus. The purpose of the local bus is to decrease the need for ribbon cable jumpers between modules on the front panels, or for internal jumpers when multiple modules function as one instrument.

The *Analog Sumbus* is an analog summing node that is bussed the length of the chassis backplane and terminated in 50 ohms. It is used to sum outputs from sources in order to build up complex waveforms that can act as a stimulus for another module, or be output to a device under test.

The *Module Identification Lines* allow a logical device to be identified with a particular physical location or slot. Using the MODID lines, the resource manager can detect the presence of a module in a slot, even if it has failed.

The *Power Distribution Bus* can provide up to 268 W of power to a single module that has P1, P2 and P3. The power is delivered to the backplane as seven different regulated voltages, selected to meet most instrumentation needs.



A typical RF test stand on the VXIbus.

The *Star Bus* is located on P3. It is composed of two lines which are connected between each module and Slot 0.

The *Resource Manager* is known as the Slot 0 Controller, and is a common resource system module containing the VMEbus Resource Manager and the VMEbus System Controller. Many Slot 0 modules will include other functions that can be used by the system components (e.g., interfaces (IEEE 488.2) and system intelligence).

The VXIbus specification defines two types of modules that will be common implementations for instruments: register-based devices and message-based devices. Typically, register-based devices will be simple modules with no embedded intelligence that respond to register reads and writes over the backplane (e.g., switches, digital I/O cards, etc.). Message-based devices follow the VXIbus word serial communication protocol and are typically intelligent devices with embedded microprocessors that receive and execute ASCII commands. Most sophisticated instrument modules will be message-based devices.

The VXIbus specification fully defines the cooling requirements and radiated and conducted EMC for both mainframes and modules. Cooling requirements are specified to accommodate a wide range of system applications. Manufacturers of chassis and modules must specify airflow requirements and/or capability to allow the user to determine that a particular module is compatible with a specific mainframe.

A High Power Directional Coupler

Divided Line Approach Solves Design Problems

By Alan R. Carr
Alan Carr, Inc.

Simple techniques enable low-cost, high accuracy, RF power monitoring for multi-kilowatt VHF systems. This article, which earned a runner-up prize in the 1989 RF Design Awards Contest, describes a high-power directional coupler which uses a divided line structure to solve the problems of coupling ratio, directivity, precision and power handling. The circuit example provided was developed to meet a specific need, but the technique can be applied to many other RF power systems. Figure 1 illustrates the basic principle of the divided line and current transformer which together comprise the main departure from conventional practice.

In recent years the use of high-power pulsed amplifiers and transmitters in the tens to hundreds of kilowatts range has expanded significantly. These systems require measurement of forward and reflected power for monitoring of source degradation, load protection, or load failure detection.

For example, a 250 kW 50 MHz Wind Profiler transmitter may require multiple RF power monitoring points within its antenna system to pinpoint weather damage to one of its hundreds of elements. A 20 kW 64 MHz linear amplifier for magnetic resonance imaging (MRI) may be required to shut down automatically if overdriven, so that RF coils are not damaged.

Historically, the system designer has had to specify high average power rated directional couplers simply to obtain the peak voltage ratings required, even though only 5 percent or lower duty factors may be employed. Typically, these air-spaced coaxial transmission line devices are marvels of mechanical precision, but carry a high price tag.

The Problem

There appears to be a lack of low-cost, compact, accurate, high pulse power rated directional couplers for the VHF band. Related problems exist in the ISM (industrial, scientific and medical) plasma RF generator and laser driver industries. Industrial process users expect far higher power measurement accuracies than the 3 to 5 percent which they are usually offered.

Attempts to use HF techniques that employ wound ferrite toroid cores placed over the exposed dielectric material of coaxial transmission lines usually produce unacceptable results at higher frequencies. The necessary break in the outer conductor changes the type of transmission line configuration and raises the characteristic impedance value markedly above that of the system impedance.

The resultant mismatch causes significant reflection loss at VHF frequencies and contributes to measurement inaccuracy. Reducing physical spacings to lower the impedance is in direct contradiction with the need to withstand the many kilovolt potentials present.

Coupling ratios in the 40 or 50 dB range are often required, but are difficult to achieve over wide bandwidths. For a common reference impedance, coupling can be expressed as $20\log_{10} N$ in dB, where N is the number of secondary turns on the toroid (single turn primary). A 40 dB coupler would thus require 100 turns, and a 50 dB unit 316 turns.

Multi-layer windings increase interwinding capacitance and exacerbate the possibility of parasitic resonances in the passband. As inductance is proportional to turns squared, increasing the number of turns would seem to be a poor tradeoff for a linear increase in coupling ratio. Critical adjustment procedures, lack of unit-to-unit repeatability, and even smoke and flame are often the end result of applying this technique to the high-power VHF world.

On the other hand, attempting to use the common UHF technique of edge-coupled microstrip transmission lines makes the device undesirably large. These couplers work well when near a quarter-wavelength long, but at 50 MHz the designer is faced with a PC board about two feet long. Shorter couplers of this general type are indeed often used, but bandwidth and directivity are compromised.

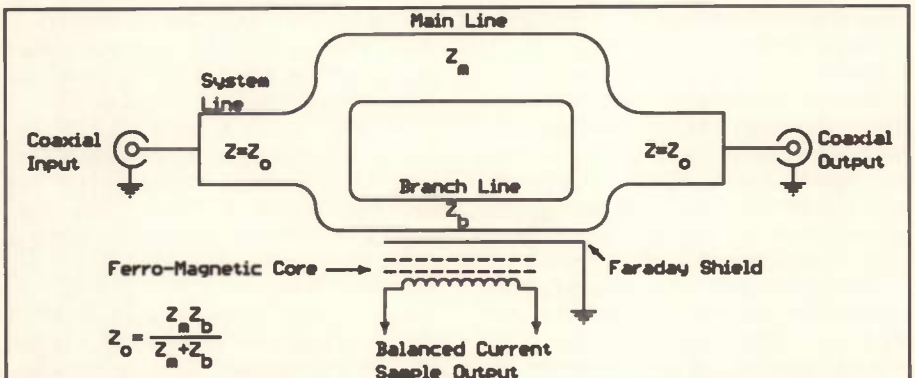


Figure 1. Divided line and current transformer.

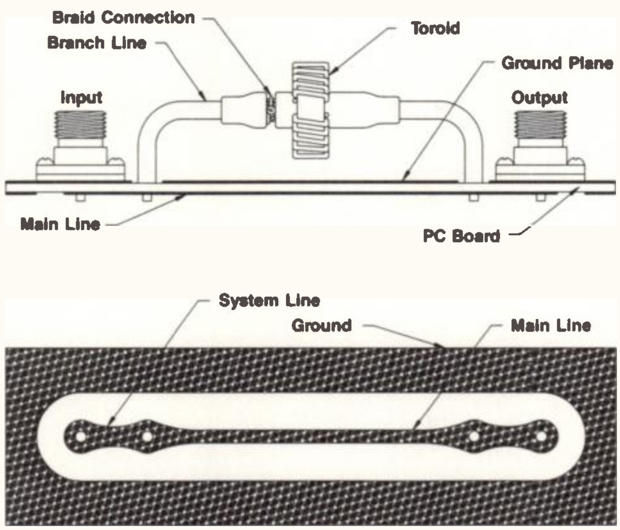


Figure 2. Prototype divided line/toroidal coupler: side view (a) and bottom view (b).

Direct-coupled (branch line) couplers suffer from even worse dimensional constraints. In addition, because they are forward (co-directional) devices, they have even narrower bandwidths for a given directivity.

Directivity, the ability to distinguish between forward and reflected signals, is not normally an intuitively obvious quality. But when one considers the equation (1),

Directivity =
Isolation – Coupling (log form)

it is easy to see that isolation between the high-power through line and the signal samples is of prime importance in achieving accuracy. A 40 dB coupler with 30 dB of directivity would require 70 dB of isolation, which is not easily achieved by any conventional microstrip coupler.

Simplified Dual-Directional Coupler Theory

To differentiate between power flowing at any instant in a given direction and the opposite, balanced current samples are used to provide in-phase and anti-phase signals to load resistors which convert the currents to voltages. An independent sample of the transmission line voltage is also applied to these resistors. The vector sums of the current and voltage samples appear across the loads.

When amplitudes and phases are correctly proportioned, the resultant voltage on one load is a measure of the forward power, and the voltage on the other load is a measure of the reflected power. The current and voltage samples may be taken with discrete lumped constant components or by distributed techniques. The loads may be external to the directional coupler when an RF sample is required, or may be internal with added detectors when phase information is unimportant and the amplitude envelope is sufficient.

A Solution

Toroidal couplers have advantages in size and directivity; microstrip transmission lines can be easily matched and are conducive to volume manufacturing. Combining the best of the two sets of properties can produce short, accurate and highly reproducible devices.

The key to solving the problem is to deliberately keep the toroid transmission line impedance high compared to the primary system impedance, and at the same time make this line the "quasi branch line" of a microstrip branch line coupler. Several benefits are achieved by this combination:

1) The total assembly can be precisely matched to the main system to avoid reflection losses.

2) Wide spacings can be used for good high-voltage safety margins.

3) The number of turns on the toroid can be significantly reduced, as part of the coupling ratio is derived via the branch line. The final coupling is the product of the individual stages.

4) Only a short PC board is necessary. The toroid carrying branch line is mounted above the ground plane and the main line is formed directly underneath, but on the opposite side.

5) Insertion loss due to path RF resistance is minimized.

6) Despite the use of a branch line, the device remains a true backward (contra-directional) coupler with inherent wideband potential.

Explanation of Terminology

The phrase "quasi branch line" is used here, since the circuit appears similar to the common branch line when drawn on a schematic diagram. In practice, it is not directly equivalent to the conventional branch line, as there are no terminating load resistors at the branch ends and there are no shunt arms.

The branch is simply one of two transmission lines connected in parallel. The two parallel impedances sum to the desired system impedance in a manner similar to resistors at DC. (For ultra-critical applications, this simplistic statement would need to be modified for phase velocity/path length differences.)

A Practical Example

An easily manufacturable power monitor system was required for a linear MRI amplifier operating near 64 MHz. The amplifier had separate 20 kW and 2 kW output ports, and was required to provide a DC analog voltage of forward and reflected power for each port to feed an analog-to-digital converter placed upstream of the control microprocessor.

Production goals were 20 dB minimum for forward power directivity with no RF adjustments other than one nulling device, and –20 dB maximum input return loss (S11). Reflected power accuracy was a moot point, since the amplifier normally had to operate at full power into loads with up to a 6:1 VSWR.

The maximum duty factor was equivalent to a 5 percent rectangular RF envelope, corresponding to 1 kW average power. The system had to shut down immediately if forward power exceeded 27 kW peak.

It was decided that two identical 40 dB dual-directional couplers with diode detectors would meet all requirements. A minimum isolation of 60 dB, plus allowances for production tolerances,

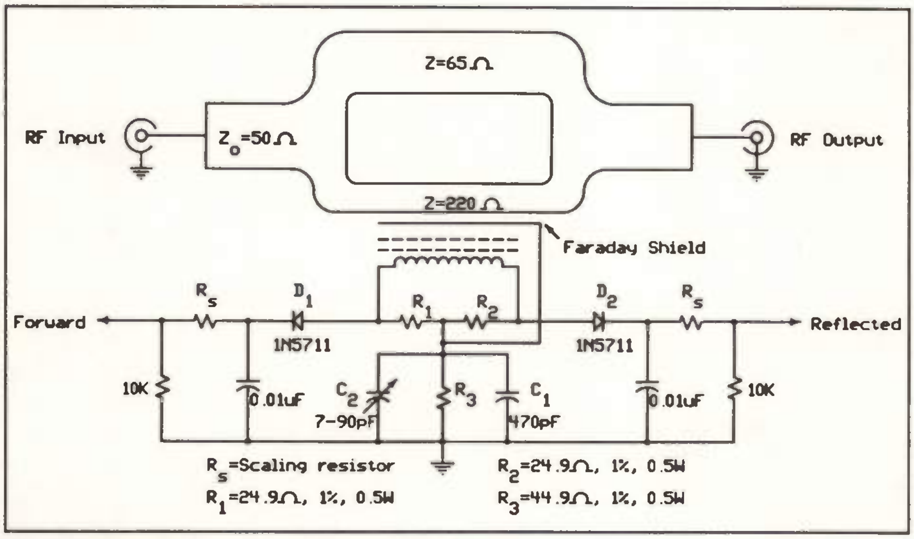


Figure 3. Coupler and schematic diagram.

was therefore necessary. The DC output voltage of the higher power channel would simply be resistor-scaled to accommodate the 10 dB power difference.

A prototype divided line/toroidal coupler was made as shown in Figure 2. A length of coaxial cable with PTFE dielectric material was used for the branch line. The thermal properties of the PTFE, combined with the silver-plated braid, made for easy soldering.

Portions of the braid were removed from the ends, as in conventional practice, but the remaining center section was used as both a Faraday shield and as the junction between the legs of a capacitive voltage divider. For this application, a single voltage sample was considered adequate and was derived through the 3.0 pF high-voltage capacitor formed between the coaxial cable center conductor and the short piece of braid. The Faraday shield operated slightly above ground potential, but the voltage pick-off was located at the midpoint of the branch line.

A ferro-magnetic core wound with 23 turns of solid #20 AWG PTFE coated wire was positioned at the center of the shield. The assembly was placed so that the parallel section of the coaxial cable was about 0.75 in. above the ground plane, in order to provide adequate clearance for the toroid winding. A measurement of the characteristic impedance yielded a result of 220 ohms, which was very close to the initial calculation. This measurement further emphasized the impedance matching problem of using only a main line/toroid technique.

Since the system impedance was 50 ohms, the main line to be used in parallel with the branch line was calculated to be 65 ohms. The coupling of the branch line was therefore 12.8 dB down from the system. When added to the 27.2 dB coupling due to the 23 turn toroid, this yielded the desired 40 dB total. The main line was formed using a trace width of 0.144 in. on the lower side of 2 oz, double-sided, 0.125 in. thick, FR4 PC material with a dielectric constant of 4.7.

The other components, including voltage divider capacitor C_1, amplitude trimmer C_2, load resistors R_1, R_2 and R_3, Schottky detector diodes D_1 and D_2, and the filtering section were then added in a conventional fashion as shown in Figure 3. This schematic diagram should be regarded as only one of many ways to use the technique.

Production Performance

The first 40 units were tested and calibrated manually with an Erbtec 20 kW linear 64 MHz pulsed amplifier, a Bird 70 dB 50 ohm power attenuator, and an HP spectrum analyzer/signal generator system. A Tektronix digital oscilloscope was used to set the DC output voltages to 4.00 V for 20 kW or 2 kW, as appropriate.

Directivity was typically 25 to 35 dB on the 20 kW forward power channel, with 35 to 45 dB on the 2 kW channel. S11 and S22 were typically close to −40 dB on all four 50 ohm ports, −38 dB being the worst case measured.

Bandwidth was measured at low power, using a tracking generator and spectrum analyzer, with the internal loads and diode detectors removed from a prototype coupler. The range was greater than an octave for the 20 dB directivity criterion.

The unit receives cooling air during normal usage, but was deliberately operated without cooling for prolonged periods. Without cooling, a unit expired at 160 percent average power rating after one hour of continuous operation when the 65 ohm trace overheated.

To test for voltage breakdown, the amplifier was retuned to provide 40 kW peak and operated into the coupler. No failures were experienced during at least ten 5 minute runs. One unit arced in the field due to incomplete etching of the copper from the region alongside the main arm trace.

Optional Improvements

For even greater directivity, more isolation can be obtained by additions to the Faraday shielding techniques and physical layout. The author has observed up to 60 dB directivity, at band center, on modified prototypes operating in the 64 MHz range.

For higher peak power or higher frequencies, the epoxy-glass PC material can be replaced with PTFE-glass-based substrates. Higher average power capability would come as a direct result of using the wider traces needed when using PTFE-based substrates with dielectric constants in the range of 2.2.

Acknowledgement

The techniques described here were developed as part of an extended consulting agreement between Erbtec Engineering Inc., Boulder, Colo., and Alan Carr Inc., Boulder, Colo. A patent application related to these techniques is being processed. Requests for licensing information should be directed to Erbtec Engineering Inc. at (303) 447-8750. rf

References

1. Howe, H. Jr., *Stripline Circuit Design*, Artech House, Inc., 1974, p. 157.

About the Author

Alan Carr is president of Alan Carr Inc., where he is a consultant and prototype designer engaged principally in the field of RF engineering. He was educated in England, and his background includes extensive work in oceanographic, atmospheric and space sciences. Currently, he is working on medical and geophysical applications of high-power RF systems. Mr. Carr can be reached at P.O. Box 3629, High Mar Station, Boulder, CO 80307. The telephone number is (303) 494-6441.

A Simple 49 MHz Transmitter

By Gary Carroll
GnuCo Technology Corp.

This note describes a minimum-cost solution for an RF data transmitter. Although it wasn't a prize winner, many engineers will find it useful for their applications, or at least, find its simplicity an interesting starting point for further development.

The circuit described here arose out of the need for a simple RF transmitter that could be thrown together from "junk box" parts or at least from parts available from the local Radio Shack. It is one of those circuits that is easy to build and very low cost. Most of the hard-to-get parts like the crystal, tank coil, etc., are scavenged from cheap walkie talkies. The logic is a high-speed CMOS version of the standard 7400 gate. There are four gates to a package, which makes this transmitter a single-chip device.

Figure 1 presents the schematic for this simple transmitter. The oscillator is one of the gates running in overtone mode. The inductor is one acquired from a Mouser Electronics RF choke kit (stock nos. 43LQ687 for the choke and 37-43LQ-2 for the choke kit). In single unit quantity, the choke is priced at $0.38. The capacitor is a micro-miniature ceramic trimmer, also from Mouser. The Mouser part no. is 24AA024 and cost is $0.86 each.

The oscillator can be gated to conserve power or reduce interference. The power amplifier is the remaining three gates hooked in parallel. Care must be taken not to run the voltage above 5 volts. This is done to avoid latching up the CMOS. Staying at or below 5 volts will help ensure proper operation.

The second input to the gates is used to gate the carrier with data. Data was run at 1200 baud. The final transformer is pulled out of a walkie talkie, along with the antenna inductor and antenna. Again, the same type of ceramic trimmer capacitor was used to tune up the final. Tune-up was accomplished by first turning on the oscillator and tuning for a midpoint where the oscillator ran at the third harmonic. Then, the final was enabled and tuned for maximum signal in a receiver. The receiver is just another walkie talkie without the audio circuit that comes with it. An op amp and comparator were used to improve response and speed for data recovery.

As can be seen, the circuit is quite simple and easy to build. The author has been able to receive good data at distances of 25 feet and to hear it at distances of more than 100 feet. Greater distances could likely be achieved with the use of a better receiver or transmitter antenna.

Figure 2 shows improvements to the circuit which the author made following entry of the design in the RF Design Awards Contest. Better stability is achieved by using a transistor in the oscillator (a 2N3904 works well here) and then using the 74AC00 as a buffer and gated amplifier. The output shown drives a 4 in. loop that is made to fit into a small plastic box and provides some directionality.

About the Author

Gary Carroll is founder and president of GnuCo Technology Corp., a firm providing custom engineering for RF and low-power CMOS applications, particularly in the fields of electronic identification and medical products. Mr. Carroll can be reached at GnuCo Technology Corp., 7490 Clubhouse Road, Suite 204, Boulder, CO 80301. Tel: (303) 530-7877

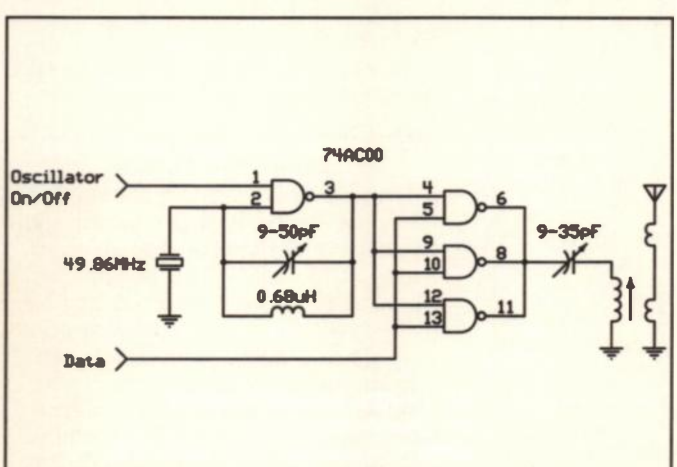


Figure 1. The schematic for the original 49 MHz transmitter.

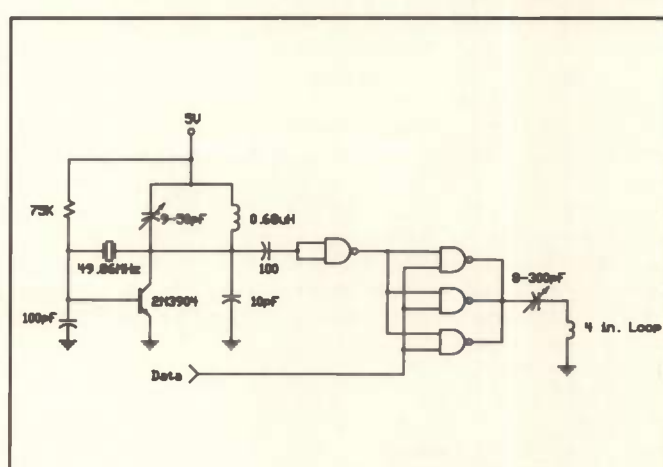


Figure 2. Improved stability is achieved by using a transistor oscillator.

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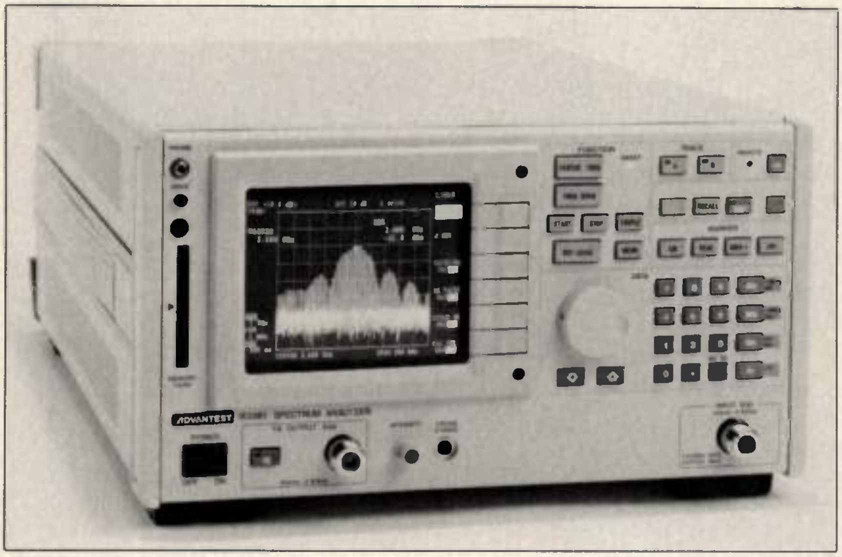

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Interference Susceptibility Testing With White Noise

By Bent Hessen-Schmidt
Noise Com, Inc.

One way to determine the susceptibility of all kinds of electronic equipment to electromagnetic (EM) interference is illumination with high levels of white noise. Since white noise is inherently broadband, it can be utilized to rapidly evaluate EM susceptibility over a wide range of frequencies, in place of the slow process of measurement at individual frequencies. Once the weak points of the equipment are determined, the equipment can be made resistant to EM radiation.

White noise has several benefits for interference susceptibility testing:

- It provides instantaneous broadband illumination.
- It simulates conditions caused by interference from several sources.
- It increases measurement efficiency.
- It allows rapid evaluation of the effects of the radiation.

The average power of a white noise source is evenly distributed at all frequencies; that is, its spectral density is constant. White noise takes its name from an analogy to white light, which contains equal amounts of the visible colors. White noise cannot contain equal amplitudes at all frequencies because "noise power" would be infinite. Rather, the spectrum of white noise is flat over a stated bandwidth, such as from 1 to 500 MHz. This flatness makes white noise an excellent reference on which to base measurements.

The broadband, flat response of commercial noise sources essentially envelops the equipment under test (if the equipment is irradiated) or fills the equipment's components (if injected in the equipment circuits) with this noise signal. This signal generally has a bandwidth greatly exceeding that of the equipment being measured. Consequently, the equipment's susceptibility to multiple interference sources anywhere in this bandwidth is simulated. This benefit is unique to white noise measurement.

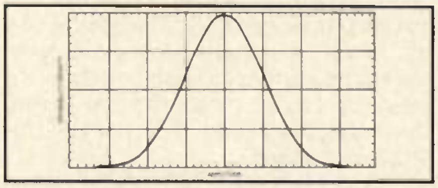

Figure 1. White noise voltage distribution .

Since all frequencies within the bandwidth of the noise source can be measured simultaneously, measurement time is dramatically reduced. Once the white noise test set-up is constructed, EM susceptibility can be evaluated at any point within the equipment's signal path, in the power supply, or in the digital section of an instrument or other complex system. Entrance of the noise into the equipment is easily recognized and isolated.

Expressing White Noise

White noise arithmetic can most simply be viewed from the familiar equation:

$$P = kTB$$

where P is the power in Watts, k is Boltzmann's constant (1.38 x 10E−23 Joules/degree Kelvin), T is the temperature in degrees Kelvin and B is the bandwidth in Hertz. This equation relates white-noise power (P) to a resistor at a specified temperature and bandwidth. It is valid for any value of resistance and assumes a matched load. This equation has its origin in the fact that a resistor, heated to a high temperature, will generate noise in a Gaussian distribution.

Certain types of diodes replicate this performance. The random voltage peaks of the white noise follow the Gaussian probability distribution function shown in Figure 1. When combined with attenuators, amplifiers, a switching system, and digital and analog control components, the technician has an inexpensive instrument that nevertheless performs a comprehensive array of tests.

The Tests

White-noise testing is performed by illuminating the equipment while measuring one or more performance characteristics. The equipment can be subjected to high-level white noise by any of the following methods:

- Irradiating the equipment with an antenna, as shown in Figure 2(a).
- Coupling noise into the power lines and cables that connect the equipment, as shown in Figure 2(b).
- Applying noise directly to parts of the equipment chassis.

When irradiating equipment with a white-noise signal, it is important that the tests be conducted in an environment that is well-characterized. This is typically an anechoic chamber. The noise source is amplified, then fed to a broadband antenna. In this test's simplest form, the electrical performance of the equipment is evaluated with and without the noise signal applied. The level of interference signal is increased until some changes in equipment performance are noted, or until some specification limit is reached.

Since the electrical characteristics of

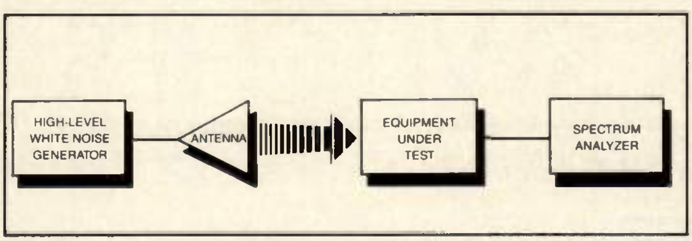

Figure 2(a). White noise can be injected by an antenna.

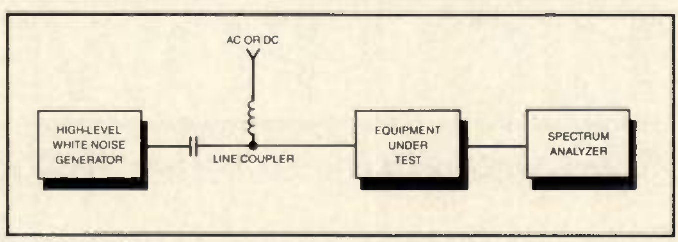

Figure 2(b). Power lines and cables that interconnect equipment can introduce white noise.

the measurement system, the white-noise signal, and the ambient environment are known, virtually any performance characteristic of the equipment under test can be de-embedded from the measurement results. In addition, individual sections of the equipment can be evaluated simultaneously.

When white noise is coupled into the system through its RF, power supply, and control ports, the test can be performed in an ordinary laboratory environment. The signal is merely injected like that from a standard signal generator, susceptibility is judged, and the change in performance characteristics is evaluated. Instruments required to measure this performance are a spectrum analyzer, oscilloscope, and multimeter. The method is the same for noise applied to the equipment chassis.

Selection of the parameter under test varies with the application, and can span from the state of digital outputs to sophisticated measurements such as Bit-Error-Rate. Among the equipment parameters that may be measured are:

- Bit Error Rate (BER)
- Signal to Noise Ratio (S/N)
- Noise Power Ratio (NPR)
- Unwanted emissions
- Noise or signal distribution in the equipment
- Crosstalk susceptibility
- Power-line isolation
- Grounding effectiveness

Once these sensitive areas have been isolated, a quantitative expression can be utilized to determine the improvement in interference resistance obtained when hardening measures are taken. The susceptibility to interference can be quantified as:

$$IS(dB) = 10 \log \frac{(P \text{ with noise applied})}{(P \text{ without noise})}$$

where IS is interference susceptibility and P the parameter under test. The improvement in interference susceptibility can be expressed in dB of improvement in IS. The amount of necessary improvement depends on the specifications which the equipment has to meet. By illuminating the equipment under test with noise equivalent to the levels of interference emission allowed by FCC, VDE, MIL-STD 461C and 462, or VCCI specifications, it is possible to determine whether adjacent equipment can cause undesirable interference.

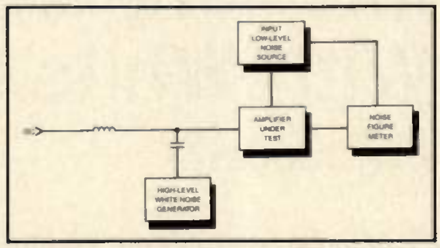

Figure 3. An example using power line white noise.

An Example

This example uses an amplifier to show how high-level white noise can be used to evaluate interference susceptibility of specific circuit blocks of a system. This is a good illustration, because amplifiers are usually located in the signal path where levels are very low. Consequently, the interference to the signal in this area will stand out from the background, and may be high compared to other places in the system.

If white noise with a noise-generating instrument is applied to the input of the amplifier, the results will be predictable—amplified noise. However, if white noise is applied to the amplifier power line, the measured output noise level with and without noise applied to the power line (Figure 3) will give a meaningful measure of one aspect of interference susceptibility.

The noise source uses a built-in coupling capacitor to provide DC-blocking and to provide a low impedance at high frequencies. In the same way, an inductor is inserted between the power supply and the device under test (DUT). This inductor has a high impedance at high frequencies and a low resistance at DC. The inductor ensures that the noise is not terminated with a low impedance at the power supply and reflected with a phase change created by the power supply cable.

Standard noise sources deliver voltage with a Gaussian distribution. For simulating other environments, clipped noise sources are available. With clipped noise, the peak voltage is limited. These voltage limits are programmable and adjustable.

Hardening the System

Keeping unwanted signals from entering electronic equipment can be extremely difficult under the best circumstances. This is especially true in the front panel of instruments and other systems utilizing digital displays, since this is an easy way for RF to enter. Nevertheless, even the most elusive EM radiation problem can be solved with attention to detail of construction and electrical design.

The time to consider resistance to stray RF is at the design stage, so that equipment can be configured and materials can be selected that will minimize or eliminate the problem. It is always far more difficult to seal an enclosure once it has been committed to a design.

Normal precautions for avoiding feedback through power lines will greatly reduce susceptibility to interference from this source. Although DC power supplies are barriers to interference injected via the power lines, the power supply's ability to filter the interference frequencies should be evaluated. High-level white noise can be used to rapidly perform this test in the same manner as other white-noise tests—by injecting the noise into the power line and measuring how much gets through to various stages of the supply. If there are significant levels of noise present in sensitive portions of the supply, the problem must be isolated to the source, and measures taken to eliminate it.

The equipment can also be shielded with filter connectors, and noise can be coupled into the equipment to evaluate the efficiency of the shielding. Good grounding as well as good routing and decoupling of power supply lines are other ways of increasing resistance to interference. rf

About the Author

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Calculating S-Parameters From Nodal Analysis

By Bert K. Erickson
General Electric Co.

The performance of linear and small-signal circuits is frequently tabulated with S-parameters to take advantage of the measurement procedure used at high frequencies. Normally, the reference impedance for the network analyzer is 50 ohms, to permit wideband measurements. When the source and load impedances for the network are the same as this reference impedance, the physical meaning of the reflection and transmission coefficients is quite clear. However, when the circuit is designed for source and load impedances that are not 50 ohms, the S-parameters usually need to be normalized before they can be compared to design specifications.

The software for network analyzers that store digital data usually includes routines to perform this normalization. This article describes a program for converting the elements in a schematic diagram to S-parameters that have a 50 ohm reference impedance which can be compared directly with the primary measurements. The fundamental part of this conversion is done with a nodal analysis program, and the remainder is done with the option included here. The advantage of making this conversion is that it can reduce the time needed to test a component by eliminating the normalization. From a design standpoint, having S-parameters for a network permits power and stability evaluations to be performed with S-parameter techniques.

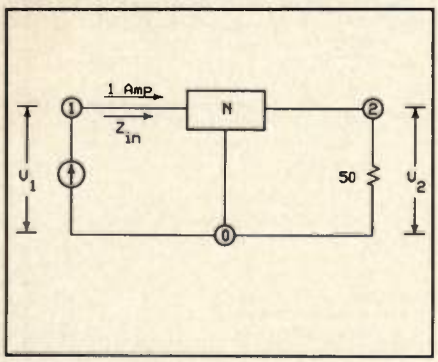


Figure 1(a). A current source is connected to the input terminals to obtain voltages required for S-parameter calculation.

In a previously published program on network analysis (1), the input impedance was calculated by connecting a current source to the input terminals as shown in Figure 1(a). This left the input impedance equal to the voltage at node 1. It is a simple matter to ask this program to continue and calculate the voltage at node 2. Notice that the normal load has been replaced with a 50 ohm termination to get the voltages required to calculate S-parameters. Certainly, no designer would connect a 1 ampere current source to a prototype circuit, but in a program for a linear circuit or one that has small signal parameters, 1 A. keeps the arithmetic simple.

To get the other two voltages needed to calculate S-parameters, the generator is connected to the output as shown in Figure 1(b). These voltages can be computed with the program previously mentioned or with a commercial nodal analysis program. The voltages for the examples described here are included in the data statements at the end of the program given in Figure 6; however, the nodal analysis program used to get them is not included in this article.

To demonstrate that S-parameters can be calculated and used to provide recognizable reflection coefficients, a series resistor, a transmission line, and a transistor circuit will be used as examples. The S-parameters can be determined by comparing the flow graphs in Figure 2. For a 200 ohm resistor, $S_{11} = S_{22} = 2/3$ and $S_{12} = S_{21} = 1/3$. If a 350 ohm resistor is connected to the output, the input reflection coefficient $S_{11}' = 5/6$. Figure 3 shows that the program calculates the same values.

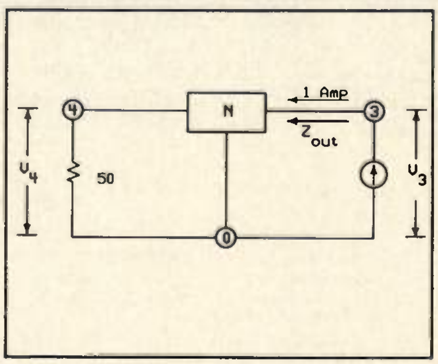


Figure 1(b). A generator is connected to the output to obtain the voltages required to calculate the other two S-parameters.

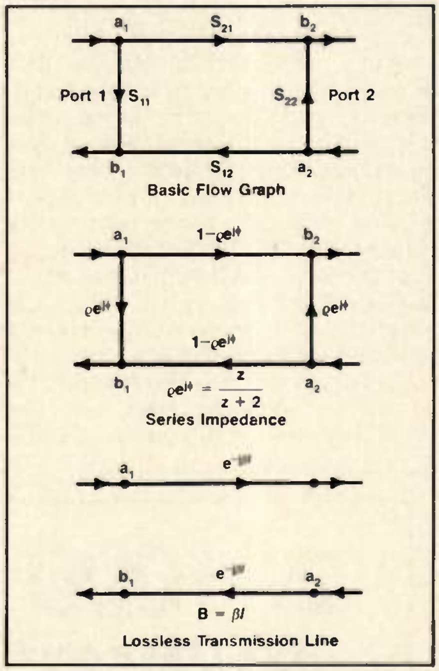
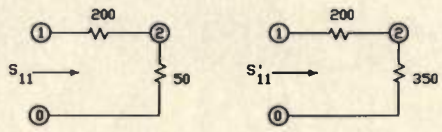


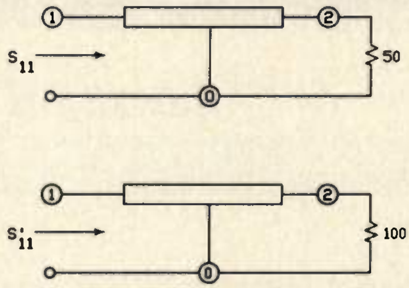
Figure 2. Flow graphs of some two-port networks.

In Figure 4, a 100 ohm load connected to a 50 ohm quarter-wave transmission line has a reflection coefficient $S_{11}' = -1/3$. While the S-parameters for these simple examples were obvious, the circuit between the input and output nodes will include additional nodes and a variety of components. S-parameters for all network elements are known but they are difficult to combine. To evaluate the parameters for a large network from diagrams like those shown in Figure 2 would require a handbook filled with diagrams. With the procedure described here, only the schematic diagram is




```
S11 = .6666667     0.0000
S21 = .3333334     0.0000
S12 = .3333334     0.0000
S22 = .6666667     0.0000
For RL+jXL =   350      0
    S11'   = .8333333        0.0000
For RS+JXS =   250      0
    S22'   = .8      0.0000
```

Figure 3. S-parameters for a series resistor.



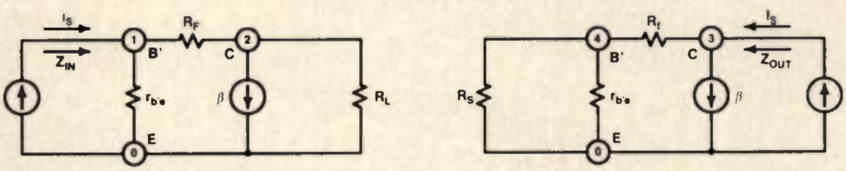

```
S11 = 0      0.0000
S21 = 1    -90.0000
S12 = 1    -90.0000
S22 = 0      0.0000
For RL+jXL =   100       0
    S11'   = .3333334   -180.0000
For RS+JXS =   25      0
    S22'   = .3333334        0.0000
```

Z_o = 50 ohms
f = 100 MHz
L = λ/4 = 0.25 m

Figure 4. S-parameters for a transmission line.

required and one program is used for all networks.

The bipolar transistor circuit shown in Figure 5 has a feedback resistor to reduce the input and output impedances. The coupling capacitors are not shown, and the component values have been adjusted to simplify calculating the nodal voltages and reflection coefficients. The voltages included in the last data statement of the program could be verified by substituting $R_S = R_L = 50$ in



$$\frac{V_1}{I_S} = \frac{R_L + R_f}{\Delta}$$

$$\frac{V_2}{I_S} = \frac{R_L[1 - \beta(R_f/r_{b'e})]}{\Delta}$$

$$\Delta = 1 + (\beta + 1)\frac{R_L}{r_{b'e}} + \frac{R_f}{r_{b'e}}$$

R_L = 5000 ohms
Z_{IN} = 75 ohms
Γ_{IN} = 0.2

β = 96.5
$r_{b'e}$ = 2.5k
R_f = 10k
R_L = 5k

$$\frac{V_3}{I_S} = \frac{R_S + R_f + (R_S R_f)/(r_{b'e})}{\Delta}$$

$$\frac{V_4}{I_S} = \frac{R_S}{\Delta}$$

$$\Delta = 1 + (\beta + 1)\frac{R_S}{r_{b'e}}$$

R_S = 75 ohms
Z_{OUT} = 2643.3121 ohms
Γ_{OUT} = 0.962870994

```
S11 = .933157009      0.0000
S21 = 3.70281316    180.0000
S12 = 9.6176966E-03     0.0000
S22 = .971627795      0.0000
For RL+jXL =   5000      0
    S11'   = .19999999       0.0000
For RS+jXS =   75      0
    S22'   = .962870994       0.0000

   FREQ           VX           UX          DB     PHASE       DELAY
1.00E+00      1446.0430      0.0000       63.2     0.0
```

Figure 5. S-parameters for a bipolar transistor circuit.

the equations. However, a nodal analysis program with nine-digit accuracy was used to get the values listed. With GWBASIC, the voltage will appear on the screen as shown in Figure 5. With the input and output impedances known for the 75 and 5000 ohm source and load impedances, the reflection coefficients can be accurately calculated.

After using the computer to get the S-parameters, the values for S_{11}' and S_{22}' should have the same values as

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these reflection coefficients. Notice that they agree through nine significant digits. If a few capacitors were added to the transistor circuit, it would be tedious and time-consuming to calculate the reflection coefficients analytically. In using the nodal analysis program, little additional effort is required to handle the capacitors, and the S-parameters can be used for other purposes.

The BASIC program in Figure 6 is intended as an option for a nodal analysis program. It is restricted to 50 ohm reference impedances and only S_{11}' and S_{22}' can be evaluated. However, this program can be expanded to any degree of refinement. Beginning at line 6000, the voltages in polar form are entered as V_1, U_1, etc. They are stored on a disk file by typing RUN 6000. The program can be started by typing RUN and then entering the name of the data file. As presented here, the nodal analysis program, called NTWK, is independent of the S-parameter program, SPAR. However, both programs have typical files for the transistor circuit of Figure 5. In the NTWK program, these files are called TRF and TRR; in the SPAR program, the file is called TRN. Circuit descriptions are stored on disk files. The keyboard is often used to change the frequency range and output node, but rarely to enter data directly.

The S-parameter program SPAR and the general-purpose nodal analysis program NTWK are available on disk from the RF Design Software Service. See Page 63 for details. The program listing (Figure 6) is on pages 54-55. rf

Reference

1. Erickson, B.K., "Network Analysis on the Personal Computer," *RF Design*, December, 1986, pp. 29-34.

About the Author

Bert Erickson is a senior engineer with the Government Electronic Systems Department of General Electric. He received his BSEE from the University of Wisconsin and his MSEE from Union College. Bert can be reached at the General Electric Co., CSP 5-H4, Syracuse, NY 13221. Tel: (315) 456-7741.

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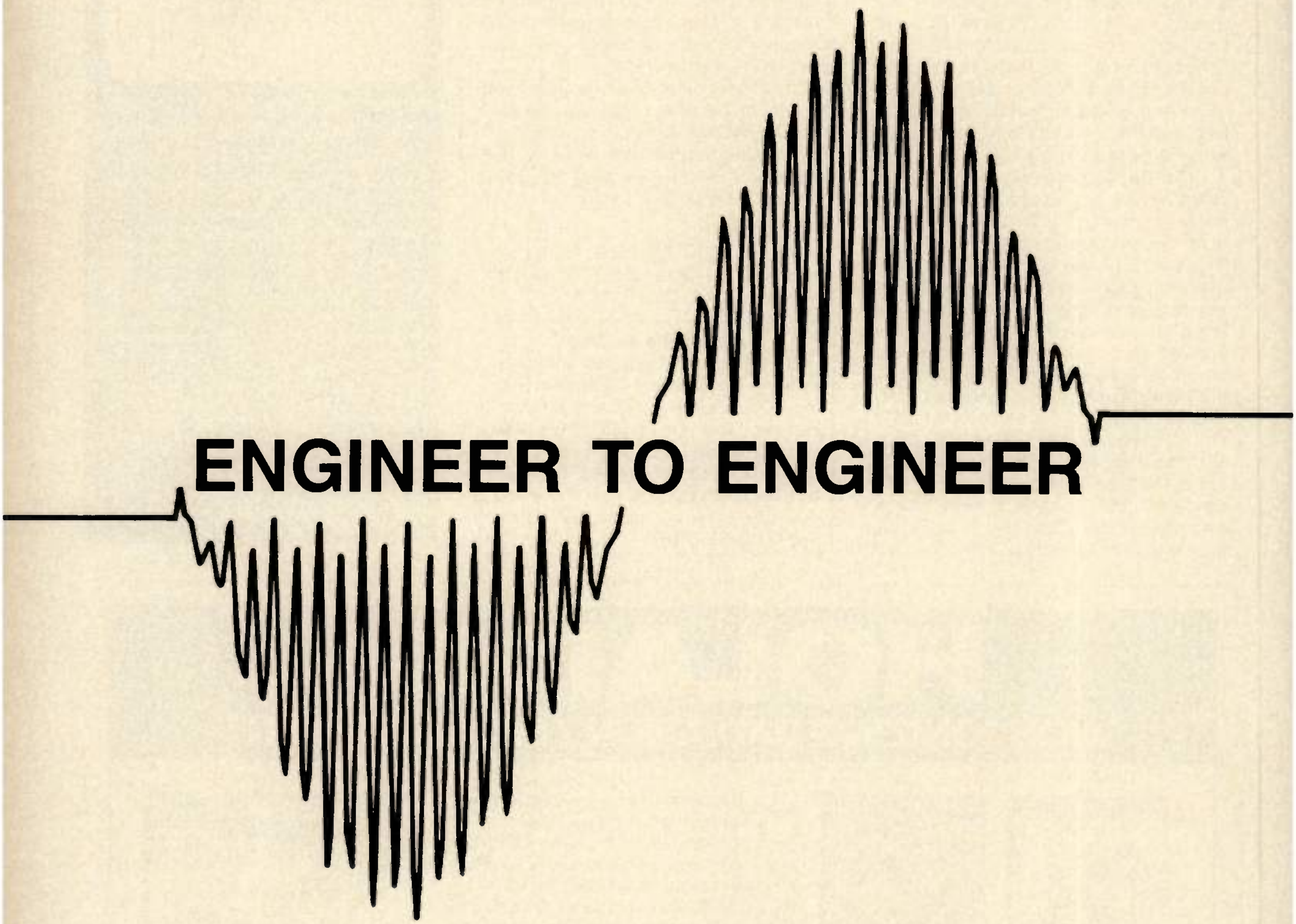

ENGINEER TO ENGINEER

October 24-26, 1989
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SPECIAL EVENTS

SPECIAL COURSES

FUNDAMENTALS OF RF Circuit Design Part I	FUNDAMENTALS OF RF Circuit Design Part II	Computer-Aided Filter Design
October 23, Monday, 8:30am-5:00pm Instructor: Les Besser	**October 24, Tuesday, 8:30am-5:00pm** Instructor: Les Besser	**October 23, Monday, 8:30am-5:00pm** Instructor: Randy Rhea

MARKETING SESSIONS: Developed by John McCrea of McCrea Mangement Consultants and Barry Manz of Manz Comm.

October 24, Tuesday, 9:00-9:30am RF marketing and sales for CEOs and marketing managers	**October 24, Tuesday, 9:30-10:15am** Marketing communications: Getting the technical message across	**October 24, Tuesday, 10:15-11:00am** Intelligent telemarketing
October 25, Wednesday, 9:00-9:20am Techniques for effective relationships between manufacturer and representative	October 25, Wednesday, 9:20-10:00am Open discussion of what the manufacturer can do to help companies and reps work more effectively together	October 25, Wednesday, 10:00-10:50am Selling to the European Community

MICROWAVE DAY

October 25, Wednesday, 8:30am-4:40pm
Co-sponsored by the New Jersey Rf and Microwave Industries Association, the America Electronics Association and MSN magazine.
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RFEE SESSIONS

Session A-1 8:30-11:30am **Filter Design**	**Session A-2 8:30-11:30am** **Modulators and Demodulators**	**Session A-3 8:30-11:30am** **IC Applications**
• Disk-Rod Filter Design • AN RF Active Elliptic Filter • An Electrically Tunable Bandpass Filter		• Op Amp for RF • 50 MHz Analog Multiplier for Mixer and AGC Applications • MMIC Applications
Session B-1 1:30-3:30pm **Power Amplifiers**	**Session B-2 1:30-3:30pm** **CAD Methods**	**Session B-3 1:30-3:30pm** **Frequency Synthesis**
• Switch-Mode Amplifiers and Resonant Power Converters • Understanding NMR/MRI Amplifier Specification	• Modeling Phase Noise Performance Using SPICE • Software Assists Characterization of Large-Signal Device Models	• Introduction to Direct Digital Synthesis • Direct Digital Synthesis
Session C-1 8:30-11:30am **Antenna Tutorial**	**Session C-2 8:30-9:30am** **Small-Signal Circuits**	**Session C-3 8:30-10:30am** **Receiver Design**
• Elements of Antenna Theory	• LNA Measuring Techniques	• Logarithmic Amplifiers for EW Systems • Design, Implementation and Test of a Wideband HF Receiving Subsystem
Session D-1 1:30-3:30pm **Transmission Systems**	**Session D-2 1:30-4:30pm** **Phase-Locked Loops**	**Session D-3 1:30-2:30pm** **Component Applications**
• A High Performance Hybrid Phase Shifter • Interference Investigations of Colocated Radio Terminals	• Analysis of an Analog PLL as a Sampled System • A Reference-Cancelling Phase/Frequency Detector • Phase/Frequency Discriminator	• Reed Relays Designed to Handle Fast Pulses and RF Applications
Session E-1 8:30-10:30am **Tuners and Combiners**	**Session E-2 8:30-11:30am** **Oscillators, Dividers**	**Session E-3 8:30-10:30am** **Antennas and Propagation**
• Applications of Power Combining in Communications Systems • HF Antenna Tuners	• Several New Design Techniques for OCXDs • Analog Frequency Dividers • Low Power Clock Oscillator	• VHF Multipath Propagation • Active Receive Antenna Technology

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☐ **Fundamentals of RF Circuit Design — Part II**
Session Date:
Oct 24, 1989
8:30 a.m.-5:00 p.m.

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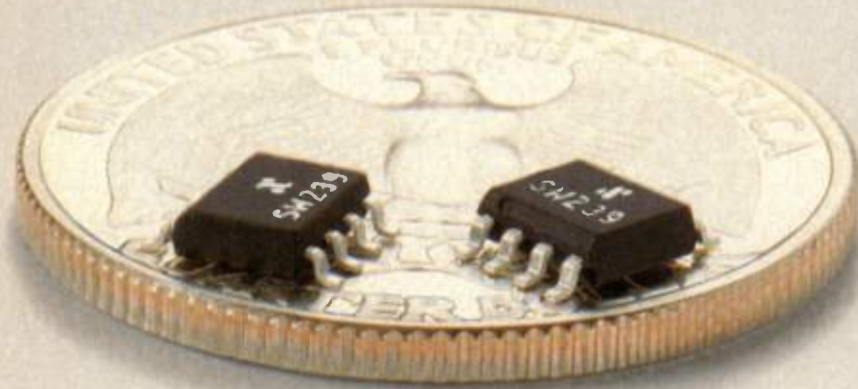
INFO/CARD 39

```
1000 'Name: SPAR  Date: 7/27/87
1010 'Converts nodal ckt to S parameters
1020 CLEAR:CLS:PI=3.14159265#:DTR=PI/180
1030 ER=5E-10:PRINT
1040 INPUT"Name of datafile is ";FL$
1050 OPEN "I",#1,FL$
1060 INPUT#1,PR,V1,U1,V2,U2,V3,U3,V4,U4
1070 INPUT"Want printed results   Y/N";Z$
1080 PR=0:IF Z$="Y"OR Z$="y"THEN PR=1
1090 V=V1:U=U1:GOSUB 1180:M1=V:A1=U
1100 V=V2:U=U2:GOSUB 1200:M2=V:A2=U
1110 V=V3:U=U3:GOSUB 1180:M3=V:A3=U
1120 V=V4:U=U4:GOSUB 1200:M4=V:A4=U
1130 V=M1*M3:U=A1+A3:GOSUB 1250
1140 R1=R:I1=I:V=M2*M4:U=A2+A4:GOSUB 1250
1150 R3=R1-R:I3=I1-I:GOSUB 1430
1160 INPUT"Want S11' with new ZL  Y/N";Z$
1170 IF Z$="Y"OR Z$="y"THEN 1670 ELSE 1780
1180 GOSUB 1250:R1=R-50:I1=I:R2=R+50
1190 I2=I:GOSUB 1230:GOSUB 1260:RETURN
1200 GOSUB 1250:R1=2*R:I1=2*I:GOSUB 1230
1210 GOSUB 1260:RETURN
1220 R=R1*R2-I1*I2:I=I1*R2+R1*I2:RETURN
1230 D=R2*R2+I2*I2:R=(R1*R2+I1*I2)/D
1240 I=(I1*R2-R1*I2)/D:RETURN
1250 R=V*COS(DTR*U):I=V*SIN(DTR*U):RETURN
1260 IF ABS(R)<ER AND ABS(I)<ER THEN 1370
1270 IF R=0 THEN V=ABS(I) ELSE 1300
1280 IF I>0 THEN U=90 ELSE U=-90
1290 RETURN
1300 IF R<0 AND I=0 THEN 1380
1310 Z=I/R:U=SQR(1+Z*Z)
1320 V=ABS(R)*U:U=U+1
1330 U=360/PI*ATN(Z/U)
1340 IF R<0 AND Z<0 THEN 1390
1350 IF R<0 AND Z>0 THEN 1400
1360 RETURN
1370 V=0:U=0:RETURN
```

Figure 6. SPAR S-parameter program listing.

```
1380 V=ABS(R):U=180:RETURN
1390 U=U+180:RETURN
1400 U=U-180:RETURN
1410 R1=R-50:I1=I:R2=R+50:I2=I
1420 GOSUB 1230:R4=R:I4=I:RETURN
1430 PRINT:PRINT"S11 =";M1;
1440 PRINT USING"#####.####";A1
1450 PRINT"S21 =";M2;
1460 PRINT USING"#####.####";A2
1470 PRINT"S12 =";M4;
1480 PRINT USING"#####.####";A4
1490 PRINT"S22 =";M3;
1500 PRINT USING"#####.####";A3:PRINT
1510 IF PR=0 THEN RETURN
1520 LPRINT"S11 =";M1;
1530 LPRINT USING"#####.####";A1
1540 LPRINT"S21 =";M2;
1550 LPRINT USING"#####.####";A2
1560 LPRINT"S12 =";M4;
1570 LPRINT USING"#####.####";A4
1580 LPRINT"S22 =";M3;
1590 LPRINT USING"#####.####";A3:RETURN
1600 LPRINT"For RL+jXL = ";R;"    ";I:RETURN
1610 LPRINT"    S11'   =";V;
1620 LPRINT USING"#####.####";U:RETURN
1630 LPRINT"For RS+JXS = ";R;"    ";I:RETURN
1640 LPRINT"    S22'   =";V;
1650 LPRINT USING"#####.####";U
1660 LPRINT:RETURN
1670 PRINT"RL + jXL Load Impedance is"
1680 INPUT R,I:IF PR THEN GOSUB 1600
1690 GOSUB 1410:R1=R4:I1=I4
1700 R2=R3:I2=I3:GOSUB 1220
1710 R5=R:I5=I:V=M1:U=A1:GOSUB 1250
1720 R5=R-R5:I5=I-I5:V=M3:U=A3:GOSUB 1250
1730 R1=R:I1=I:R2=R4:I2=I4:GOSUB 1220
1740 R1=R5:I1=I5:R2=1-R:I2=-I:GOSUB 1230
1750 GOSUB 1260:PRINT"S11'=";V;
1760 PRINT USING"#####.####";U
1770 PRINT:IF PR THEN GOSUB 1610
1780 INPUT"Want S22' with new Z0  Y/N";Z$
1790 IF Z$="Y"OR Z$="y"THEN 1800 ELSE 1910
1800 PRINT"RS + jXS Source Impedance is"
1810 INPUT R,I:IF PR THEN GOSUB 1630
1820 GOSUB 1410:R1=R4:I2=I4
1830 R2=R3:I2=I3:GOSUB 1220
1840 R5=R:I5=I:V=M3:U=A3:GOSUB 1250
1850 R5=R-R5:I5=I-I5:V=M1:U=A1:GOSUB 1250
1860 R1=R:I1=I:R2=R4:I2=I4:GOSUB 1220
1870 R1=R5:I1=I5:R2=1-R:I2=-I:GOSUB 1230
1880 GOSUB 1260:PRINT"S22'=";V;
1890 PRINT USING"#####.####";U
1900 IF PR THEN GOSUB 1640
1910 END
6000 OPEN "O",#1,"RES"
6010 WRITE#1,0,250,0,50,0,250,0,50,0
6020 WRITE#1,"E":CLOSE #1:END
6030 OPEN "O",#1,"TXL"
6040 WRITE#1,0,50,0,50,-90,50,0,50,-90
6050 WRITE#1,"E":CLOSE #1:END
6060 OPEN "O",#1,"TRN"
6070 WRITE#1,0,1446.04317#,0,2769.78417#,180
6080 WRITE#1,3474.57627#,0,16.9491526#,0
6090 WRITE#1,"E":CLOSE #1:END
7000 OPEN "O",#1,"H1"
7010 WRITE#1,0,86.87728,-85.19763,111.828,73.75988
7020 WRITE#1,188.8689,-62.08838,7.945627,.3734131
7030 WRITE#1,"E":CLOSE #1:END
7050 OPEN "O",#1,"H2"
7060 WRITE#1,0,68.12068,-83.87384,89.88579,69.68846
7070 WRITE#1,155.2671,-63.23554,7.789484,-6.595429
7080 WRITE#1,"E":CLOSE #1:END
8000 OPEN "O",#1,"H3"
8010 WRITE#1,0,55.36917,-82.46109,75.31893,65.60941
8020 WRITE#1,131.7353,-63.61157,7.535013,-12.27997
8030 WRITE#1,"E":CLOSE #1:END
```

Two Bits.



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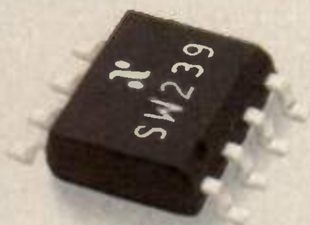

The SW-239 SPDT RF switch features nanosecond speed with only microwatts of DC power. Utilizing an 8-Lead SOIC package these units come ready for full automatic insertion.

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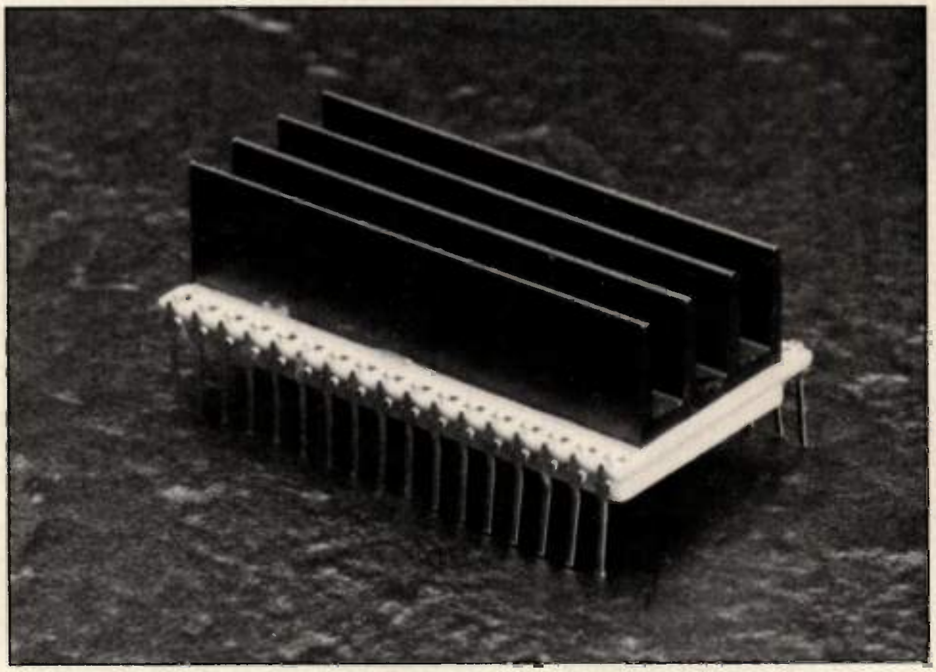
INFO/CARD 43

A 0 to 25 MHz Hybrid DDS From Stanford Telecom

The STEL-1375 is a complete direct digital synthesizer in a single DIP package measuring 1.7 in. X 0.9 in. It is a thick film hybrid which uses the STEL-1175 modulated numerically controlled oscillator (MNCO) chip driving a high-speed 10-bit digital-to-analog converter to generate an output signal. The device is guaranteed to operate at clock frequencies up to 60 MHz over the 0 to 70 degrees C temperature range, giving an output frequency range of 0 to 25 MHz with a frequency resolution of 14 mHz (32 bits).

The device features both phase and frequency modulation capabilities at up to 25 percent of the clock frequency. The phase modulation capability allows either digital (PSK) or linear PM with up to 12 bits of resolution.

Spurious is measured at −60 dBc. Price for the STEL-1375 is $435 in quantities of 100. **Stanford Telecommunications, Inc., Santa Clara, CA. INFO/CARD #230.**



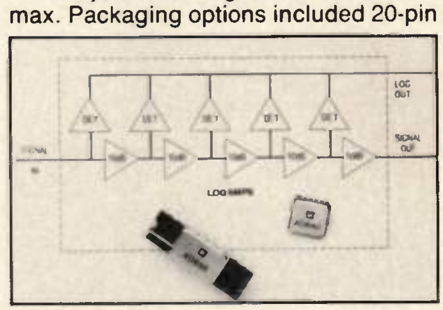
CTS Introduces RF Hybrid Amplifiers

This series of cascadable thick film hybrid two-stage RF amplifiers features transformer coupled outputs. The series offers five units with varying specifications. Model 901786 features a 1 to 30 MHz frequency range, minimum gain of 30 dB, output for 1 dB gain compression of 0 dBm and gain flatness of ±1 dB. Maximum VSWR is 2:1 and maximum noise figure is 6 dB.

Another product in the series, Model 901781, has a 2 to 150 MHz range. Other specifications include a maximum gain of 25 dB, output at the 1 dB compression point of +17 dBm, maximum gain flatness of 1 dB, maximum VSWR of 2:1, and an 8 dB noise figure. In small quantities, prices range between $125 and $140 each. **CTS Corp., Elkhart, IN. INFO/CARD #229.**

Logarithmic Amplifier

The AD640 is a monolithic logarithmic amplifier that provides up to 50 dB of dynamic range from DC to 120 MHz. The device uses a successive detection scheme to provide an output current proportional to the logarithm of the input voltage. It comprises five cascaded DC coupled amplifier/limiter stages, each having a small-signal voltage gain of 10 dB and a −3 dB bandwidth of 350 MHz. Linearity at +25 degrees C is ±0.6 dB max. Packaging options included 20-pin



LCCs and ceramic DIPs. In 100-piece quantity, price for the AD640B is $63.59. **Analog Devices, Inc., Norwood, MA. INFO/CARD #228.**

120 MHz Frequency Counter

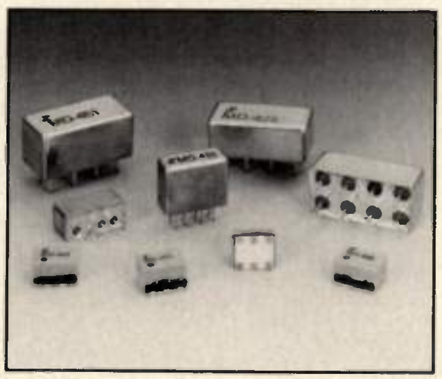
John Fluke Mfg. introduces the PM 6662 120 MHz frequency counter. The counter provides at least seven digits for a one second measuring time, for signals up to 120 MHz standard on Channel A or up to 1.3 GHz optional on Channel B. Included are built-in automated features including trigger-level setting, and automatic selection of high-frequency and low-frequency input. The instrument is priced at $645. **John Fluke Mfg. Co., Inc., Everett, WA. Please circle INFO/CARD #227.**

HF Antenna Coupler

The RF-2601 is a 1 kW PEP/average, 1.6 to 30 MHz antenna coupler. Tuning time for previously stored frequencies is less than 50 ms and on-the-air memory tuning time is less than 25 ms, providing a low probability of intercept. Protection is provided for high input VSWR, low enclosure pressurization, high temperatures, control-line lighting surges and RF voltages. **Harris Corp., Rochester, NY. INFO/CARD #226.**

RF Mixers

The Anzac Division of Adams-Russell introduces a set of mixers. They cover an RF/LO frequency range of 0.1 to 3000 MHz, and an IF range of DC to 1250 MHz. A selection of relay header and surface-mount package styles is



available. The mixers range in price from $5.90 to $49.90. **Adams-Russell Components Group, Anzac Div., Burlington, MA. INFO/CARD #225.**

Monolithic Buffer Amplifier

The CLC110 buffer features closed-loop, unity-gain operation with −3 dB bandwidth of 730 MHz. It settles to 0.2 percent in 5 ns, and has −65 dBc of distortion at 20 MHz. Typical applications include flash A/D conversion, high-speed communications, power buffers and IF processors. **Comlinear Corp., Fort Collins, CO. INFO/CARD #224.**

Miniature Log Amplifier

Varian RFSD unveils the MCL-2, 3, 4 Series of monolithic log amplifiers. The amplifiers are ultra-miniature ICs configurable to cover the 10 to 250 MHz range. Input dynamic range is 0 to −70 dBm and log linearity is ±1 dB. Dimensions are 0.72 in. X 1.3 in. X 0.17 in., and when purchased in small quantities, price is under $1000 each. **Varian RF Subsystem Div., Beverly, MA. Please circle INFO/CARD #223.**

SMT Terminations and Resistors

This line of surface-mount terminations and resistors have a power rating of 100 W CW up to 3 GHz. Standard values are 50 ohm and 100 ohm. The devices come standard for solder-in microstrip applications. **RF Power Components Inc., Middle Island, NY. Please circle INFO/CARD #222.**

Temperature Stable Coaxial Cable

Rogers Corp. introduces the ISO-CORE™ Series 100 semi-rigid cable. It is made with a dielectric which virtually eliminates the expansion and contraction found in standard PTFE dielectrics. Electrical properties include 70 percent propagation velocity, a nominal impedance of 50 ohms, a nominal capacitance of 29 pF/ft, and a continuous operating voltage of 1500 to 3000 volts RMS and cutoff frequency of 20 to 60 GHz depending on cable diameter. The center conductor is silver-plated copper. Three options are available for the outer conductor: bare copper, silver-plated copper or tin-plated copper. **Rogers Corp., Chandler, AZ. Please circle INFO/CARD #221.**

Downconverter/AGC Amplifier

This downconverter/AGC amplifier utilizes high-efficiency planar mixer technology. The input can be specified from 2 to 18 GHz, IF output from 2 to 6 GHz, and LO input from 8 to 14 GHz. Noise figure is less than 12 dB, gain is 22 dB, gain control is 30 dB, power output at the 1 dB gain compression point is +10 dBm, third order intercept point is +18 dBm, input VSWR is 2.9:1 and output VSWR is 2:1 or less. The package measures 3 in. X 2 in. X 0.5 in. **Loral Microwave—Narda West, San Jose, CA. INFO/CARD #220.**

Mixer-Preamplifier

Miteq unveils the Model M0310U-0110 mixer-preamplifier that has an RF/LO frequency of 3 to 10 GHz with IF bandwidth of 0.05 to 1.0 GHz. SSB noise figure is typically 7 dB, RF/IF gain is 10 dB nominal and dynamic range is +20 dBm. **Miteq, Inc., Hauppauge, NY. INFO/CARD #219.**

Portable Spectrum Analyzers

Hewlett-Packard introduces the HP 8590B RF spectrum analyzer and HP 8592B microwave spectrum analyzer. Expanded capabilities of these instruments are available on the HP 8591A and HP 8593A. The HP 8592B covers from 9 kHz to 1.8 GHz and the HP 8592B covers from 9 kHz to 22 GHz with an option to increase it to 26.5 GHz. The HP 8591A and HP 8593A provide synthesized accuracy of ±220 kHz at 1 GHz and ±2.1 kHz at 18 GHz. The 8591A covers from 9 kHz to 1.8 GHz and the 8593A covers from 9 kHz to 22 GHz, with an option to extend the range to 26.5 GHz. The spectrum analyzers are priced at $8,995, $12,000, $19,000 and $24,000 for the HP 8590B, 8591A, 8592B and 8593A, respectively.

Also available is the HP 8560A spectrum analyzer that covers the 50 Hz to 2.9 GHz range, and the HP 8561B that covers the 50 Hz to 6.5 GHz range. Both instruments feature resolution bandwidths from 10 Hz to 2 MHz. The HP 85640A tracking generator can be combined with both instruments to allow scalar network measurements. The 8560A is $23,900 and the 8561B is $29,000. **Hewlett-Packard Company, Palo Alto, CA. INFO/CARD #218.**

High Frequency Buffer

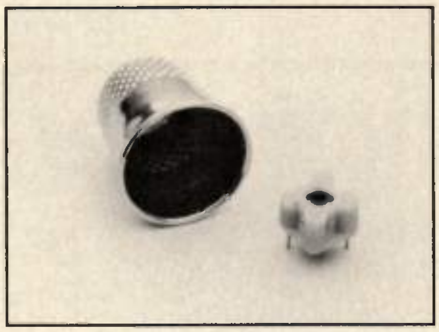
This unity-gain closed-loop buffer features a −3 dB bandwidth of 450 MHz and distortion of −65 dBc at 20 MHz. Settling to 0.2 percent is achieved in 5 ns and differential gain is 0.17 percent. Gain flatness is under 0.4 dB from DC to 50 MHz. Applications include video signal routing, telecommunications, digital video and HDTV transmission systems. **Siliconix, Inc., Santa Clara, CA. INFO/CARD #217.**

Monolithic Distributed Amplifier

A monolithic, distributed amplifier that delivers 13.5 dB and 17 dBm output power at 1 dB gain compression from 2 to 6 GHz is available from Texas Instruments. VSWR is less than 2:1. Small signal gain ranges from 13 dB at 2 GHz to 14 dB from 3 to 8 GHz. Gain at 10 GHz is typically 8 dB, and noise figure is under 5 dB from 5 GHz to 8 GHz. Output power at 1 dB gain compression is greater than 16 dBm at 2 GHz. Output at the third-order intercept point is 27 dBm at 6 GHz. **Texas Instruments, Inc., Semiconductor Group, Dallas, TX. INFO/CARD #216.**

Miniature Variable Coil

The Toko MC-131 is a precision molded coil for RF and IF applications in the 30 to 200 MHz or 200 to 500 MHz range. The design offers a 6 mm high profile. The polypropylene coil forms are designed for self-tapping by a lubricated



screw core, with an internally splined body to match the tuning slug. Inductance ranges from 0.03 uH to 0.19 uH. In 1000-piece quantity, price is $0.84 each. **Toko America, Inc., Mt. Prospect, IL. INFO/CARD #215.**

Directional Antennas

Antel introduces a directional antenna for the 800/900 frequency band. It is designed as a "W" shaped corner reflector antenna and offers 20 dBd gain with a pencil beamwidth of 14 degrees in both horizontal and vertical planes. VSWR is 1.5:1 and antenna input power is 500 W with a type N female connector. Using the EIA 7/8 connector, input power can be increased up to 2000 W. Standard electrical beamtilt is 1.25 ±0.2. A nulfill of 5 percent is standard. Model HGC 82020 has an 820 to 895 MHz range, and Model 89020 has an 890 to 960 MHz range. **Antel, Inc., Crofton, MD. INFO/CARD #214.**

Portable Spectrum Analyzer

The Tektronix 497P is a portable spectrum analyzer that covers the 100 Hz to 7.1 GHz range. Measurement accuracy is 0.0001 percent and dynamic range is 90 dB. Noise sidebands are measured at less than or equal to −105 dBc/Hz at 30 kHz offset. Base price for the 497P is $25,000. **Tektronix, Inc., Beaverton, OR. INFO/CARD #213.**

Programmable Power Amplifiers

Avantek introduces a series of AT&T-Autoplex™-compatible programmable power amplifiers for 860 to 900 MHz cell-site transmitters. These units are equipped for either remote transmit power adjustment, or for dynamic power control. Designated the AWP-905 Series, the output power is variable via a TTL control line from approximately 70 mW to 45 W in seven 4 dB steps. Additionally, maximum power level can be set between 7 and 45 W. **Avantek, Inc., Milpitas, CA. INFO/CARD #212.**

RF Digital Attenuator Module

Model PS-1050 is a 2-bit RF step attenuator that operates over the 10 to 1000 MHz frequency range. Insertion loss is typically 2 dB with a 10 to 30 dB attenuation range. Switching speed is 1 us. In quantities of 1 to 9, the price is $49.95. **Phoenix Microwave Corp., Telford, PA. Please circle INFO/CARD #211.**

Digital Power Meter With Analog Meter

The HP 437B digital power meter now has an analog indication for applications such as tuning components for maximum power. Option H36 is now offered for the HP 437B which provides a small meter on the right front panel. This option in not retro-fittable and is priced at $100. **Hewlett-Packard Company, Palo Alto, CA. INFO/CARD #210.**

Evaluation/Prototyping Board

FP1 is a double-sided FR-4 board with plated through holes. It is useful for breadboarding commonly used mixers and power dividers in a flatpack package. It will accommodate any standard 0.30 in. X 0.510 in. flatpack. It features a recess for inserting the device which provides a low inductance path for leads to be soldered flush to the ground plane and 50 ohm microstrip lines. Mounting holes for four SMA or SMB connectors are provided.

Also being offered is the TO8MX1 double-sided FR-4 (high temperature G10) board with plated through holes,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Measure power directly and accurately with Bird's laboratory-grade directional RF Power Meter

Now, with Bird's Model 4421, you can measure power directly over a wide range of inputs with precision — and without charts, external couplers or attenuators.

- ☐ High accuracy ±3%-of-reading
- ☐ Wide power and frequency input range — 100mW to 10kW and 1.5MHz to 1GHz
- ☐ Modular configuration for flexibility, expansion and options

The compact display unit and separate RF power sensors deliver readings in either Watts or dBm at the push of a button, with instant recall of minimum and maximum values. Make VSWR measurements automatically too, with the same speed and convenience. Optional interface cards allow the 4421 to be combined with computers and other instrumentation for complete, custom test systems.

ALSO AVAILABLE WITH ANALOG DISPLAY. *Bird's model 4420 is a cost-effective alternative to the model 4421 where a traditional analog readout is preferred. Same microprocessor-based architecture, two-piece design and sensor compatibility.*

SMART POWER SENSORS CORRECT READINGS AUTOMATICALLY. The brains of the 4421 power meter are the individual RF power sensors — each with its own wideband calibration profile — that can be inserted anywhere in a 50-Ohm line. Since data is stored in the sensor rather than in the display, you can connect any present or future Bird sensor with the assurance that the display won't become obsolete.

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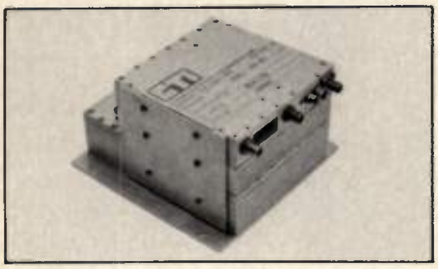
INFO/CARD 49

which is useful for breadboarding and evaluating commonly used 4-pin TO-8 mixers. Connections to SMA or SMB PCB connectors are via 50 ohm CPWG lines. Mounting holes for three SMA or SMB connectors are provided. A high-frequency socketed version, TO81MX1S, is also available. **RF Prototype Systems, San Diego, CA. Please circle INFO/CARD #209.**

VHF Synthesizer

This synthesizer is available as a stand-alone VHF synthesizer or as part of a microwave frequency synthesizer. The VHF synthesizer is available (in bands) for frequencies from 30 MHz to 500 MHz. The microwave synthesizer is



available, in bands, from 500 MHz to 23 GHz. The tuning range of any one unit is limited to approximately 10 percent segments at frequencies less than 7 GHz and 500 to 700 MHz for frequencies greater than 7 GHz. **Communication Techniques, Inc., Whippany, NJ. INFO/CARD #208.**

Absorption Wattmeter

Bird Electronics introduces a line of high power Termaline[R] absorption wattmeters with power ratings from 1.5 to 10 kW and calibrated frequency ranges of 54 to 890 MHz. It is available with 3 1/8 in. EIA flanged and unflanged connectors. All power levels except 10 kW models are available with both convection cooling and blower forced air cooling; the 10 kW versions have forced air cooling only. **Bird Electronic Corp., Cleveland, OH. INFO/CARD #207.**

Multilayer Ceramic Packaging

TriQuint unveils two packages for GHz speed digital LSI applications and an 8-port Micro-S package designed for MMIC applications. The MLC132/84, a

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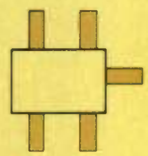

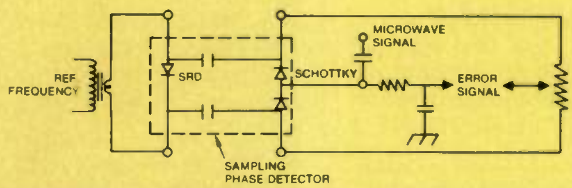

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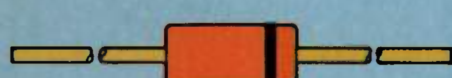

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INFO/CARD 52

132-pin/84-signal package, and the MLC196/128, a 196-pin/128 signal package, are designed for the high-speed environment required by GaAs and advanced silicon LSI ICs. The packages have bandwidths greater than 2.5 GHz and will support edge rates of less than 250 ps. The Micro-S package supports a bandwidth of 12 GHz. **TriQuint Semiconductor, Beaverton, OR. Please circle INFO/CARD #206.**

550 MHz Counter

Model 1804 from B&K-Precision Div. is a frequency counter that performs measurements from 10 to 550 MHz. Features include an eight-digit LED display, low-pass filter, 1 second and 0.1 second gates and an overflow indicator. Resolution is 10 Hz on prescale and 1 Hz for direct mode using the 1.0 second gate. Input impedance is 1 M Ohm, shunted by less than 40 pF. For the prescale range, impedance is 50 ohms to match communications applications. The frequency counter is available at a price of $295. **B&K-Precision Div., Chicago, IL. INFO/CARD #205.**

Electrically Conductive Coating

A silver-filled, electrically conductive coating material that provides EMI/RFI shielding is available from Carroll Coatings. Spectraguard C-608 has a surface resistance of 0.02 ohms/square at 1.5 to 2.0 mil dry film thickness. It provides shielding up to 83 dB from 1 MHz to 3 GHz. **Carroll Coatings Company, Providence, RI. INFO/CARD #204.**

Coaxial Switch

This single-pole, double-throw coaxial switch is hermetically sealed to provide uses in harsh environment applications including space operation. It is laser sealed and filled with an inert gas to provide an internal controlled atmosphere. Gold-plated field-replaceable RF connectors are also available. **K & L Microwave, Inc., Salisbury, MD. Please circle INFO/CARD #203.**

Tower-Mount Preamplifier

This preamplifier covers from 10-900 MHz. Gain is 25 dB and noise figure is 3.1 dB typ. **Wi-Comm Electronics, Inc., Massena, NY. INFO/CARD #202.**

rf software

Analog/Microwave Design Software

The Analog Products Group of the David Sarnoff Research Center announces the availability of MIDAS and NANA analog microwave simulators. MIDAS, a linear circuit and system simulator, supports user-defined modeling, optimization and tolerance analysis features, multiple-coupled microstrip and strip lines, time domain analysis, and other features. NANA is a harmonic balance program for analyzing the steady-state behavior of nonlinear circuits. It couples to MIDAS and Super Compact™. NANA's features include a load-pull contour simulator and large-signal parameter extraction. Computers supported include SUN, HP Series 300, Apollo and DEC VAX. **David Sarnoff Research Center, Princeton, NJ. Please circle INFO/CARD #201.**

Single-Ended Resonant Power Converter Program

RESOCAD, a single-ended resonant power converter simulation and optimization program, offers nine topologies of single-ended resonant DC/DC power converters or DC/AC inverters. It computes the steady-state periodic response of the circuit, optimizes the design, computes data for transfer functions and control functions, and automatically generates a preliminary circuit design to meet the user-specified goals. This circuit is the basis for design optimization. **Design Automation, Inc., Lexington, MA. INFO/CARD #200.**

Software for EMI Measurements

The HP 85869A electromagnetic-interference (EMI) measurement software is a general-purpose program for automatic measurements of commercial and military emissions. It includes EMI conducted and radiated emissions tests, such as MIL-STD 461A/B/C, FCC and FTZ/VDE. A built-in routine that discriminates between narrowband and broadband signals is one of the new features on this program. The software controls various HP receiver systems, spectrum analyzers and accessories. **Hewlett-Packard Company, Palo Alto, CA. Please circle INFO/CARD #199.**

rf literature

Measuring Equipment and Accessories Catalog

Bird introduces a full line catalog of RF power measuring equipment and accessories that includes photos, detailed descriptions, specifications and ordering information. Products featured include high accuracy, peak reading, high power, low power, multi-power level and low frequency wattmeters, calorimeters, plug-in elements, line sections, QC-connectors, RF loads, attenuators, switches, directional couplers, and accessories from 50 ohm adapters to carrying cases. **Bird Electronic Corp., Solon, OH. INFO/CARD #198.**

EMC Shielding Videotape

Instrument Specialties is offering a 30-minute videotape on controlling electromagnetic and radio-frequency interference (EMI/RFI) in shielded enclosures. Details presented include information on how to effectively shield enclosures for sensitive electronic equipment. Also covered are enclosure apertures, shielding effectiveness of various materials, and secondary considerations such as closure force, compression, galvanic corrosion and gasket selection. The tape is priced at $19.95. **Instrument Specialties Co., Inc., Delaware Water Gap, PA. Please circle INFO/CARD #197.**

Fiber Optic Brochure

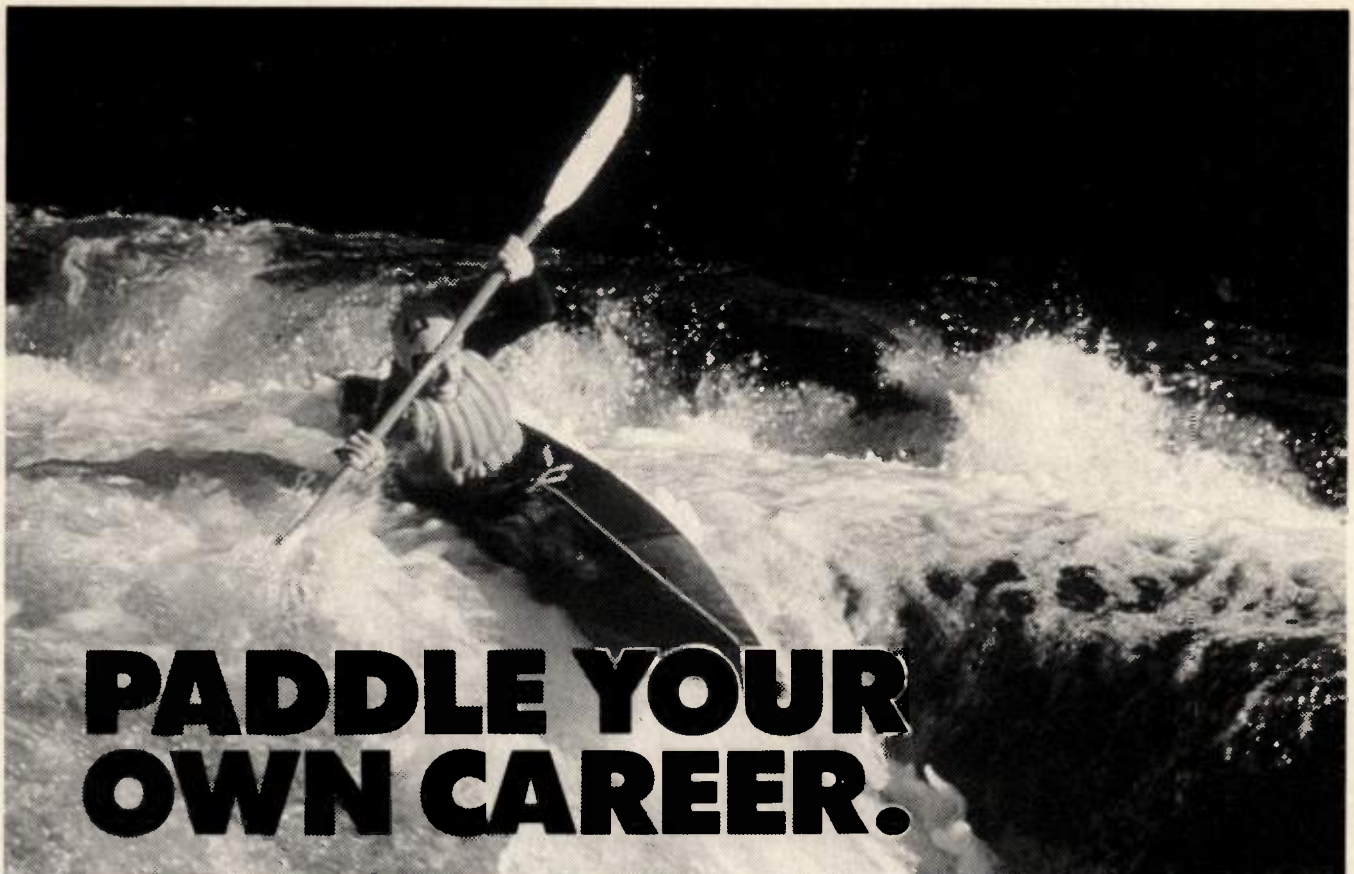
Microwaves in a New Light is a brochure from Ortel that provides information on the company's laser fiber optic products for RF and microwave applications. It includes application diagrams and charts summarizing typical link performance levels and other advantages of analog fiber optic links. Outlines for typical applications such as satellites, delay lines, shipboard EW systems, phased array radars, remote antenna links, nanosecond measurements, test equipment and antenna ranges are featured. **Ortel Corp., Alhambra, CA. INFO/CARD #196.**

Catalog Features PIN Diode and MMIC Drivers

New England Micronetics has published a catalog detailing specifications for PIN diode and MMIC switch drivers. Other information covered includes driver definitions, including logic types, output current, spiking, speed and quality assurance provisions, applications notes, and procedures for modifying the output pulse to change peak and average current. In addition, package outlines are presented. **New England Micronetics, Inc., Hudson, NH. Please circle INFO/CARD #195.**

Oscillator Catalog

K&L Oscillatek announces the availability of a new product catalog which features detailed specifications. It covers precision crystal oscillators including OCXOs, TCXOs, VCXOs and miniature hybrid clock oscillators. **K&L Oscillatek, Olathe, KS. INFO/CARD #194.**



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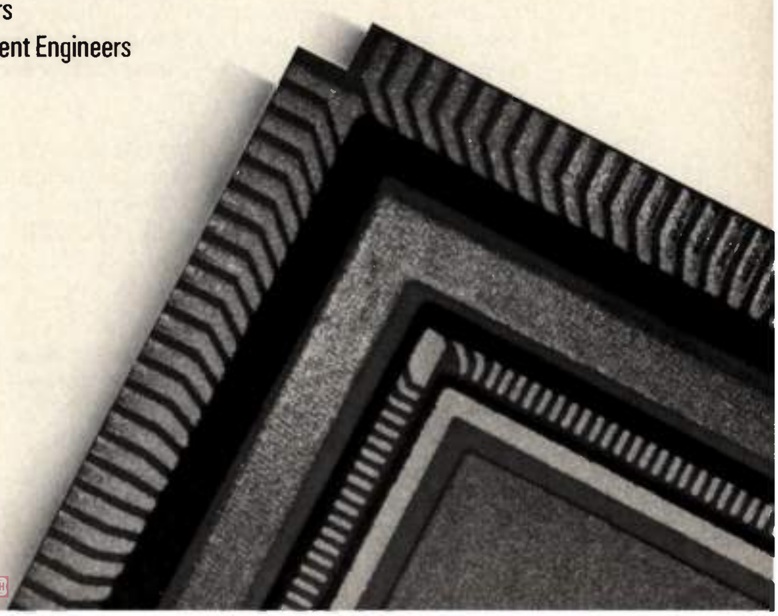

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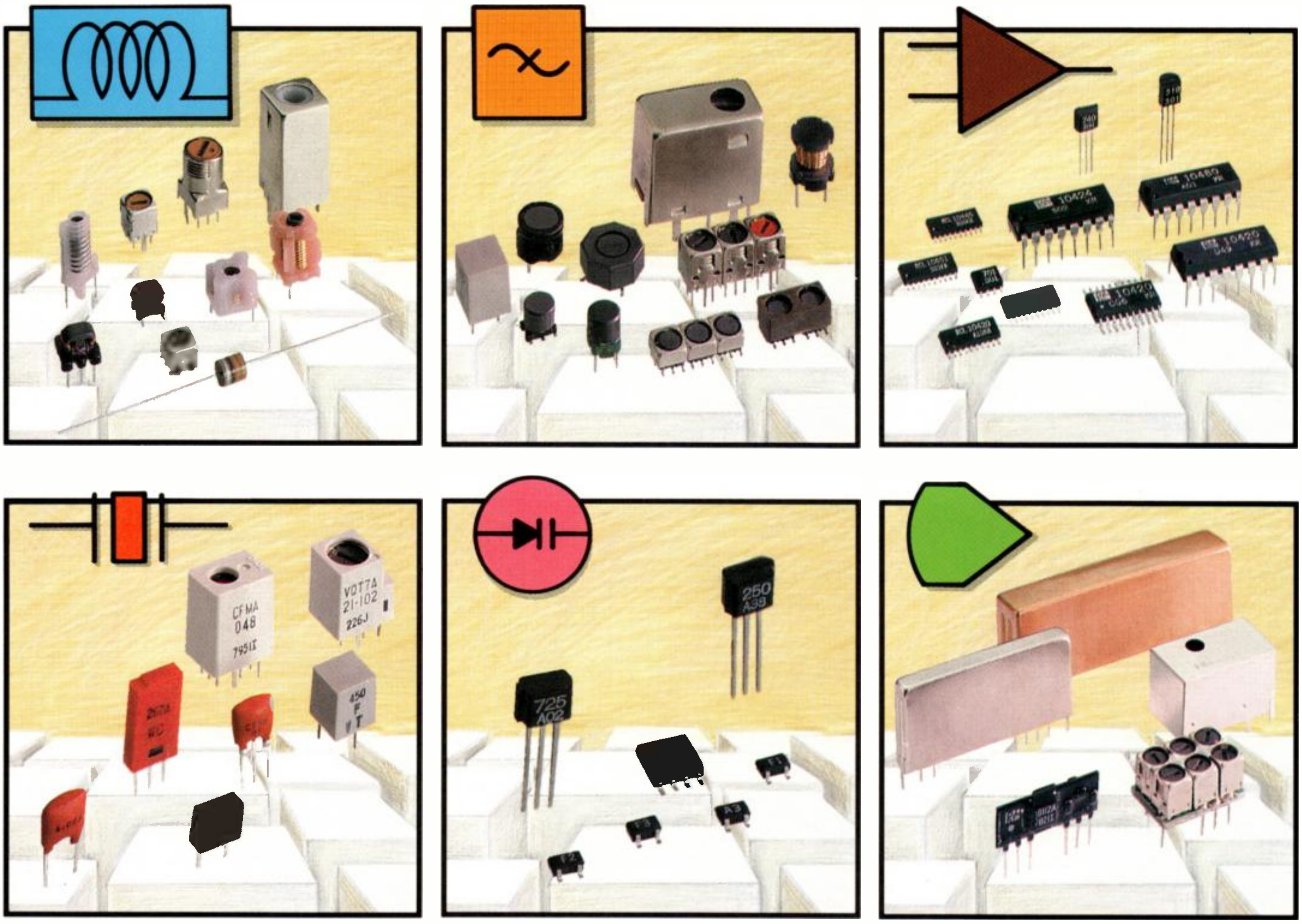

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