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engineering principles and practices

June 1989

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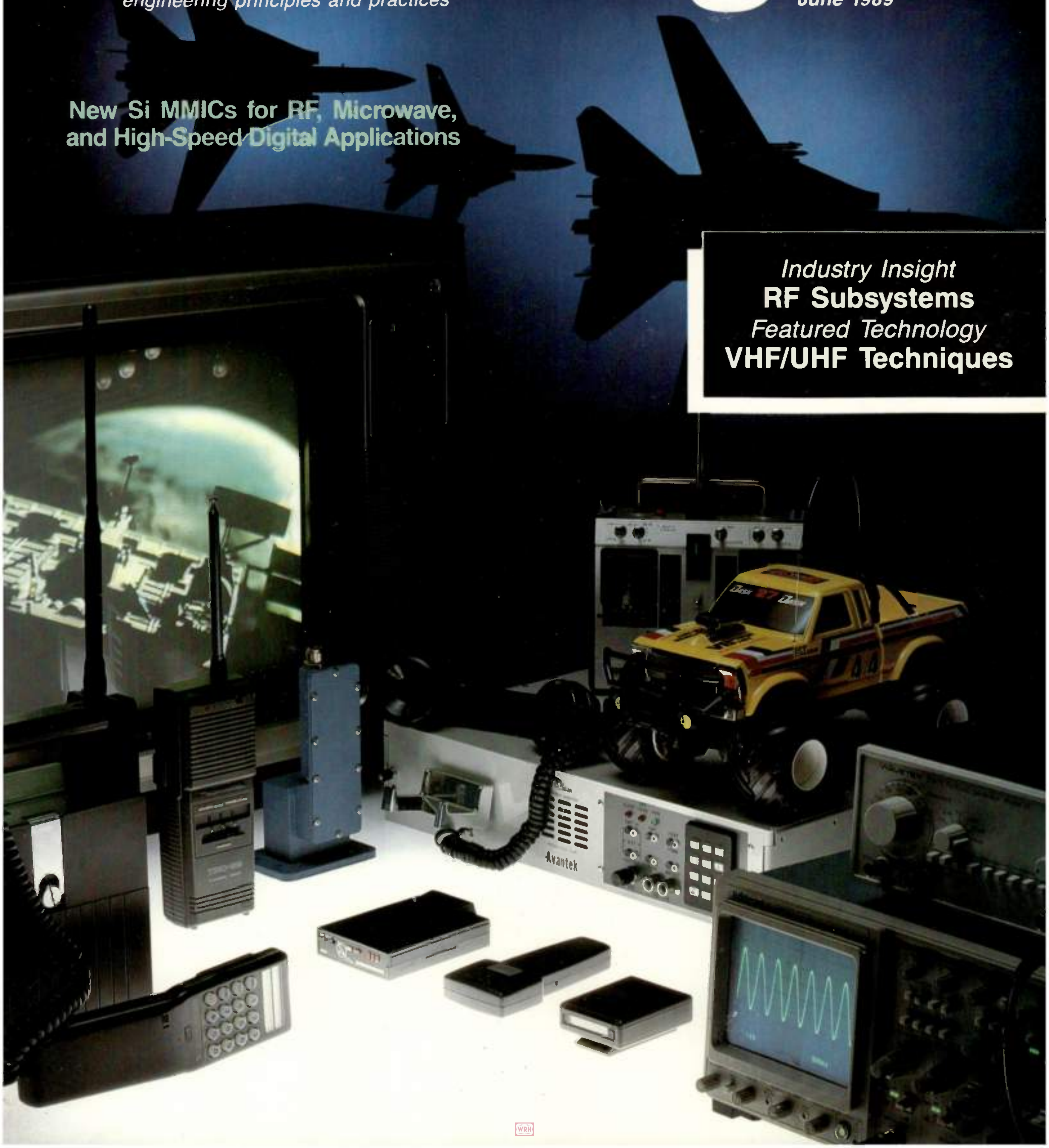
Industry Insight
RF Subsystems
Featured Technology
VHF/UHF Techniques



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Log slope, over operating temp. and freq. range	(%)	≤10			
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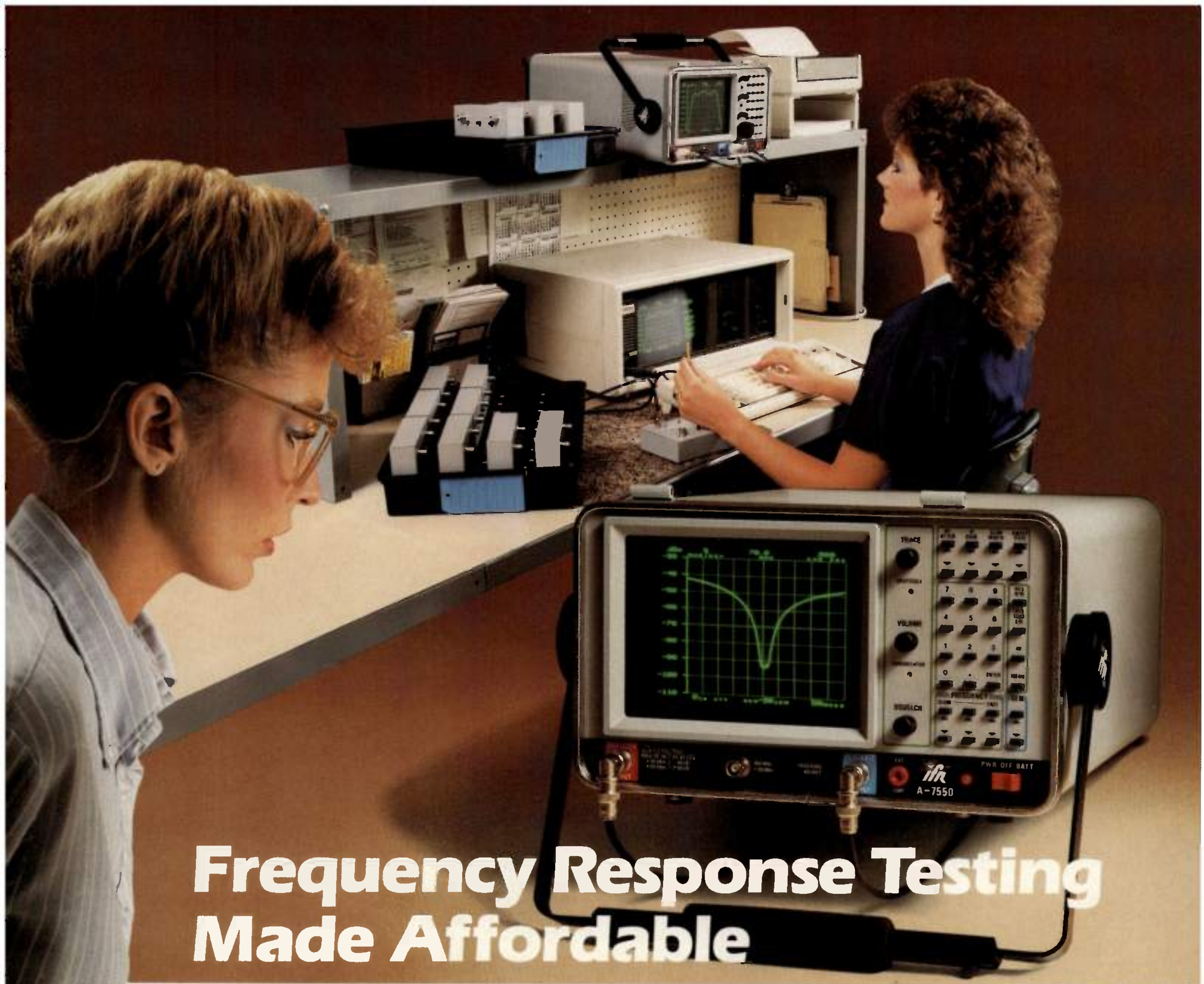

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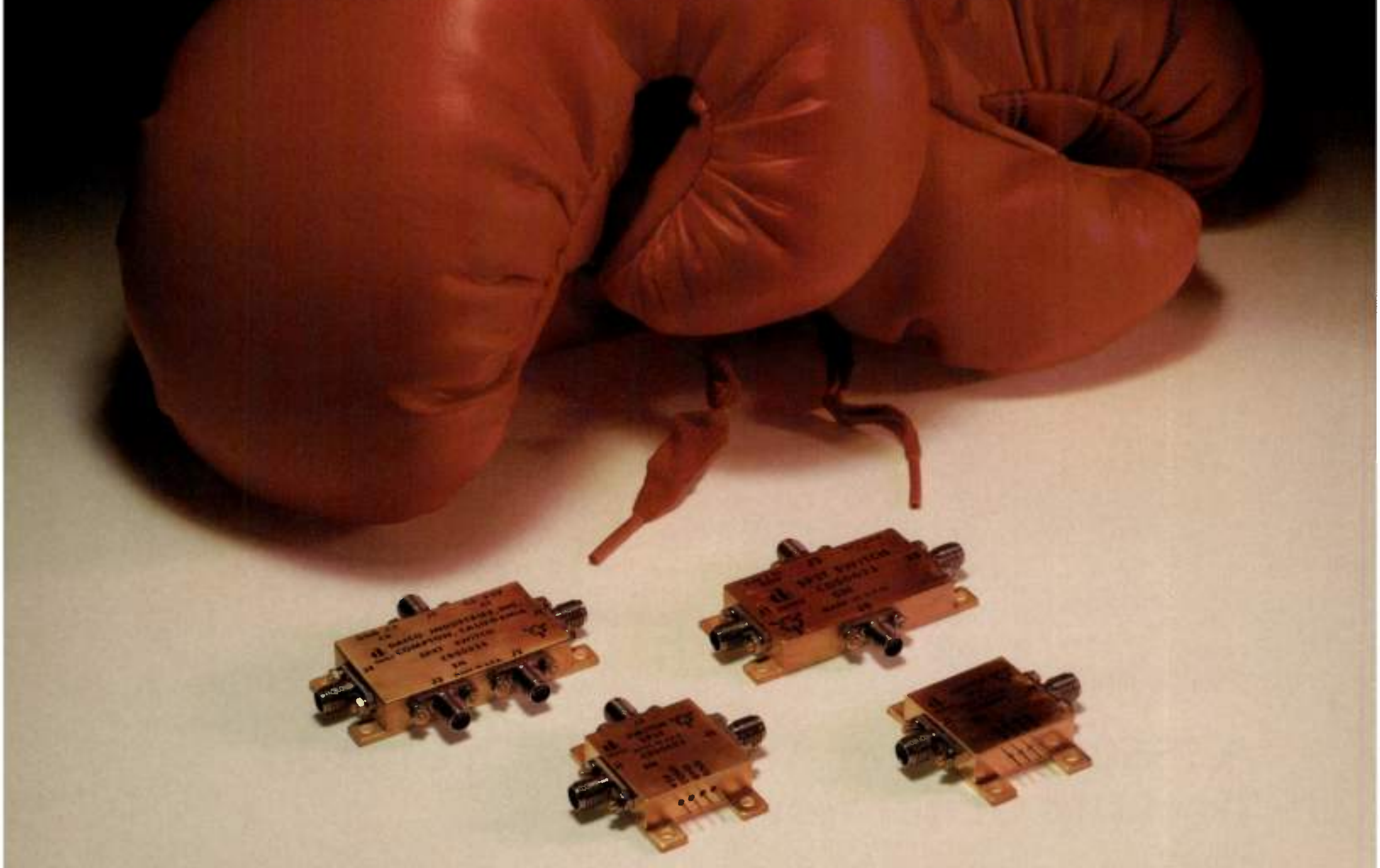
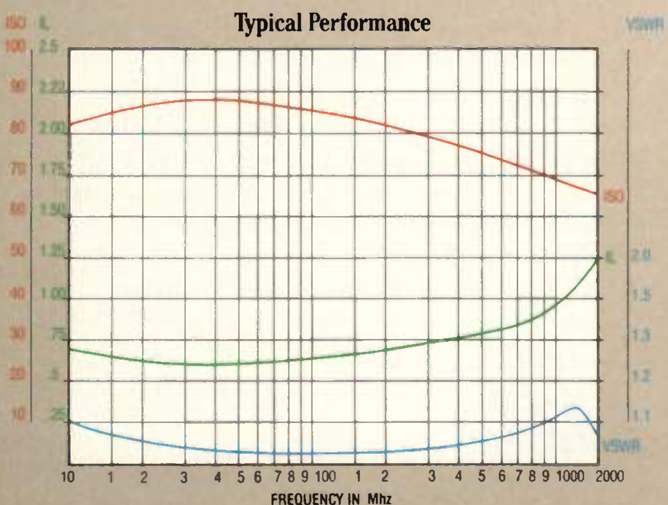


Typical Performance



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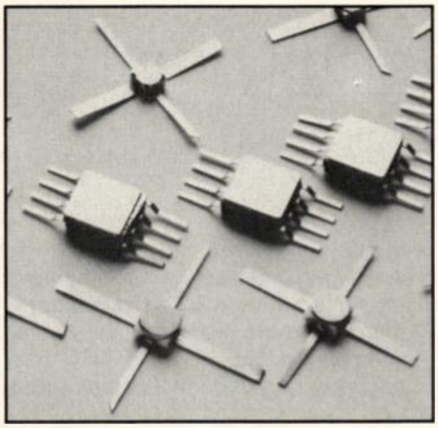

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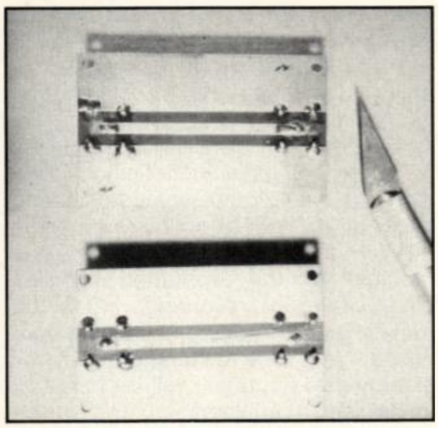
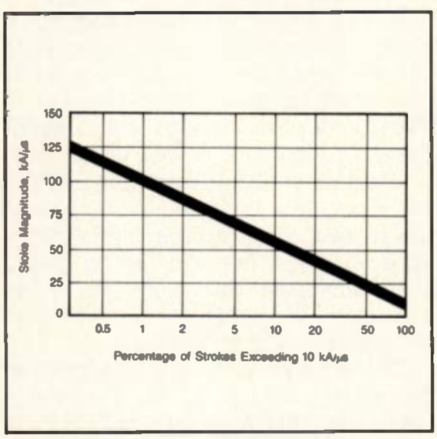


Page 52 — Edge-Coupled Lines



Page 62 — Lightning Protection

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rf editorial

HDTV: Can We Bring Order Out of the Chaos?

By Gary A. Breed
Editor

Now that HDTV (or ATV, or ACTV, or your own favorite acronym) has become a political "cause," the rules of the game have been changed. The technology has reverted to a chaotic state as the pressure mounts to create an American HDTV system that is as non-Japanese as possible. Both policy and engineering are part of the principal problem, which is the mandate that HDTV broadcasts be compatible with the current NTSC system.

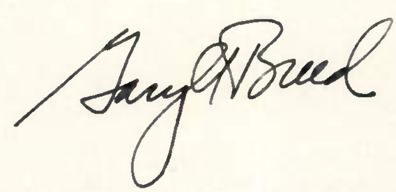
The most obvious interpretation of the term "compatible" is that transmitted HDTV signals must be usable on current TV sets. To do this, the basic NTSC signal is enhanced through complex signal processing, with most proposed systems using additional spectrum to transmit the extra picture information for HDTV receivers. This downward-compatible concept has one major problem: it is based on the same technology that was used for the first TV broadcast in 1939. With power-wasting sync pulses, plus high power video and audio carriers located near the edges of the channels, TV stations now require wide frequency or distance separation to avoid interference.

Compatibility means something different to Zenith Corporation. Their HDTV entry is termed "spectrum compatible," but I think "peaceful coexistence" is a better description. Their idea is that a brand new HDTV broadcast system can operate on unoccupied TV channels without interfering with existing stations. Since the system would not be tied to the antiquated NTSC system, new spectrum-conserving modulation and processing schemes can be used. An added benefit is the same coverage with less transmitted power. Zenith demonstrated such a system at the recent National Association of Broadcasters convention, with an impressive demonstration of the ability of their system to exist without interference.

It is my firm belief that enhancing NTSC to get *medium* definition television is a short-sighted solution. Instead, we need to explore entirely new transmission methods for this exciting visual medium. Whether distributed via broadcast, cable, or recording, HDTV demands that its quality not be compromised. Yes, I do understand that this side-by-side approach will be harder to implement than upgrading the current system, but there just isn't much room for improvement in NTSC.

Finally, anyone who thinks that HDTV is many years away from common usage should remember the compact audio disc. The CD was only developed in 1981, and while it hasn't yet replaced the vinyl album, it is well on its way. Prices have steadily decreased, too. The CD's success is based on improved quality over vinyl records; HDTV offers an even bigger improvement in quality over broadcast television and video cassettes. We can only assume that consumers will react similarly.

Tell the politicians and regulators to get moving quickly, or we *will* have a Japanese HDTV system to compete with.



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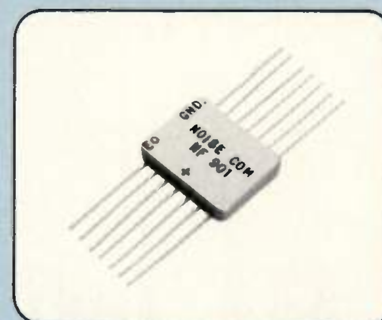

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Main Office:
6300 S. Syracuse Way, Suite 650
Englewood, CO 80111 • (303) 220-0600
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Publisher
Kathryn Walsh

Editor
Gary A. Breed

Technical Editor
Mark Gomez

Assistant Editor
Katie McCormick

Consulting Editors
Andy Przedpelski
Robert J. Zavrel, Jr.

Advertising:
National Accounts Manager
Mary Bandfield
1341 Ocean Ave., Ste. 58
Santa Monica, CA 90401
(213) 458-6683
Fax: (213) 458-0335

Account Executive
Bill Pettit
Main Office

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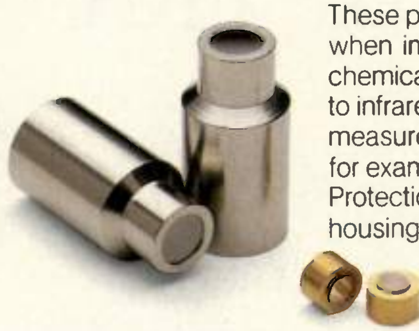

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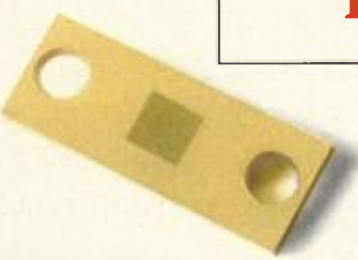

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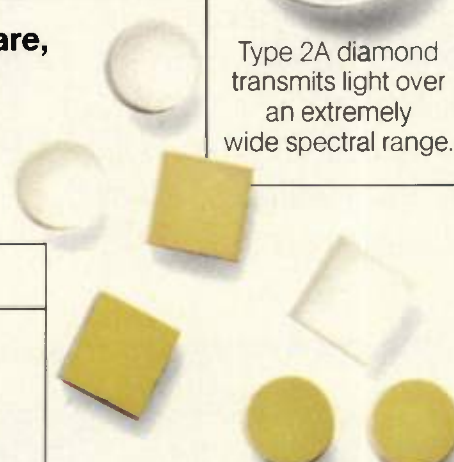

Standard sizes:

Code	Copper cylinder		Diamond	
	Ø mm	Thickness	Ø mm	Thickness
C 3013	3.00	1.30	0.70	0.50
C 3030	3.00	3.00	0.70	0.50
C 4033	4.00	3.30	0.80	0.50
C 5050	5.00	5.00	0.95	0.50

Other shapes and sizes available on request.

□ or Ømm	Thickness mm					
0.2	0.1	0.25				
0.25	0.1	0.25				
0.4	0.1	0.25	0.4			
0.5	0.1	0.25	0.4	0.5		
0.75	0.1	0.25	0.4	0.5	0.75	
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rf letters

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

EMI Measurement Comments

Editor:
I am writing in regard to "EMI Signal Measurement Automation," which appeared in the January 1989 issue of *RF Design*. It is great, after all these years, to know that the "ideal receiver" for EMI measurement has finally been found! Before accepting that assertion at face value, however, one must consider the EMI measurement environment and its interaction with the measurement instrument.

Frequently, EMI at the microvolt or sub-microvolt level must be measured in the presence of many signals and noises in the measurement environment which have levels in the millivolt and volt range. The array of signals and noises at the input connector of the EMI measurement receiver often has an instantaneous dynamic range of more than 100 dB and a frequency span from a few hertz to hundreds of megahertz or more. How can a spectrum analyzer whose input circuits will virtually collapse when subjected to such a spectrum be considered an "ideal" receiver for EMI measurements?

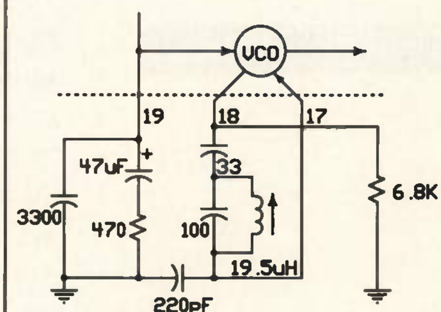
Adding a preselector to the spectrum analyzer will solve part of this problem, resulting in an instrument that is usable yet far from ideal. But by adding the preselector, we have created an instrument that is no more frequency-agile than any other computer-controlled EMI analyzing receiver.

The concept behind Mr. Southwick's software is interesting and the approach has merit. However, it would be far more useful to the EMI community if it were generalized to drive any IEEE-488 or IEC-625 compatible EMI analyzing receiver.

Edwin L. Bronaugh
Electro-Metrics
Amsterdam, New York

Correction

"Easy Phase-Noise Measurement" (Apr. 1989, *RF Design*) contained an error in Figure 4, p. 55. The corrected version is shown below.



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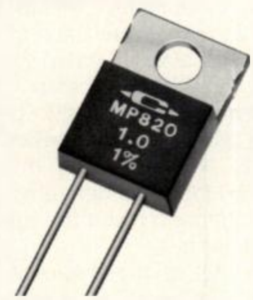

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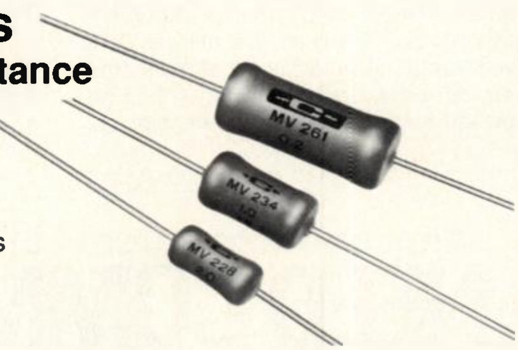

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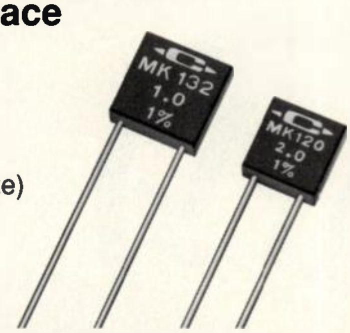

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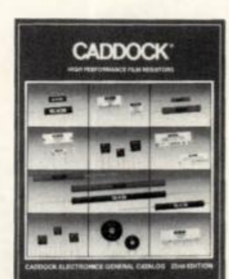

IEEE/MTT-S Symposium Convenes in Long Beach

The 1989 IEEE/MTT-S International Microwave Symposium and Exhibition will be held June 13-15, 1989 at the Long Beach Convention Center in Long Beach, Calif. Taking place in conjunction with MTT-S are the 1989 Microwave and Millimeter-Wave Monolithic Circuits (MMMC) Symposium (June 12-13) and the 33rd Automatic RF Techniques Group (ARFTG) Conference (June 15-16).

Sponsored by the IEEE Microwave Theory and Technique Society, this year's MTT-S Symposium promises to present attendees with a broad range of technical sessions and activities from which to choose. More than 300 microwave companies will be on hand to display their products and to meet with those attending this year's exhibition. Over 200 papers will be presented in the 41 technical sessions, addressing a variety of microwave topics. The following are some highlights:

Biological Effects and Medical Applications (Session D): This session emphasizes innovative medical applications of microwaves, including microwave angioplasty, radiometry and hyperthermia.

Computer-Aided Modeling and Design of Active Circuits (Session O): The modeling and application of active devices to circuit design is the focus of this session. Linear, quasi-linear and nonlinear design methods are presented.

Filter Applications (Session T): Some novel filter structures are discussed, including a miniaturized hairpin resonator filter and thin-film, lumped-element microwave filters. Also presented is a technique for improving the response of parallel-coupled microstrip filters and a multiplexer structure using single- and dual-mode dielectric resonators.

Advances in FET Amplifiers (Session CC): This session examines FET amplifier performance and design considerations. A unique distributed 2 to 18 GHz amplifier with 2.95 dB average noise figure is presented, and a 1 to 40 GHz MESFET hybrid distributed amplifier with good gain flatness is also discussed.

Time Domain and Electromagnetics (Session JJ): This session describes recent advances in the solution of electromagnetic problems in the time domain. Applications include the analysis of high-speed digital and pulsed circuits.

FET Devices and Applications (Session KK): Topics ranging from FET design and processing issues to FET-based circuit design, modeling and implementation are covered.

Solid State Circuits (Session QQ): This session presents some recent developments in solid-state circuit concepts. Among the topics covered are a broadband millimeter wave VCO; a FET circuit with conversion gain; a monolithic 5-bit digital attenuator operating from DC to 1-6 GHz using MESFET technology; and an upconverter using a balanced HEMT configuration.

In addition to the technical sessions, there will be a total of seven panel sessions plus six day-long workshops, covering a broad spectrum of subjects. Among the scheduled panel discussions are MMIC Design Approaches for Low-Cost, High Volume Application; Heterojunction Devices, Circuits and Reliability; and Microwave Education: Present and Future Trends. Workshop sessions offered include High Frequency Interconnections, and MIC Package Standards and Progress in Packaging. Open Forums on Tuesday and Thursday afternoon will feature nearly 90 additional papers.

The impact of superconductivity on the microwave field is the focus of several events in the technical program. Microwave Properties of Superconductors (Technical Session N) addresses the characterization of high T_c superconductors in terms of microwave properties such as surface impedance, critical power level and magnetic field behavior. Also included in this session is a paper covering RF properties of high T_c superconductors.

A second technical session, Microwave Applications of Superconductors Session R), examines the use of high T_c superconducting materials for simple passive devices such as delay lines, resonators and detectors. Application of these materials to SAW filters and superdirective antennas is also being discussed in this session.

For further information regarding the IEEE/MTT-S Symposium, the MMMC Symposium or the ARFTG Conference, contact LRW Associates, 1218 Balfour Drive, Arnold, MD 21012. Tel: (301) 647-1591

rf news Continued

Report Analyzes U.S. Military Test Equipment Market—The U.S. armed forces will be spending $6.4 billion a year on test systems and instruments by fiscal 1993, says a new study from the New York market research firm of Frost and Sullivan Inc. *Military Test Equipment Market in the U.S.* predicts that despite what will probably be less-than-robust military budgets over the next few years, the field of testing products will fare quite well. In constant dollars, the analysis estimates the fiscal 1988 market, in which $4 billion went into test systems and another $1 billion into instruments, will rise to a $5.1 billion level in test systems and $1.3 billion in test instruments by fiscal 1993.

"The electronic content of weapons systems has steadily increased," the study notes, "... and as weapons systems increase in complexity, reliable automatic testing is crucial to sustain operational readiness in a cost-effective manner." The report also notes a continuing shortage of maintenance personnel along with a decrease in the educational level of the manpower available. This situation, coupled with tremendous advances in the complexity of avionics, signals a clear and increasing need for automatic test equipment. *Military Test Equipment Market in the U.S.* (A2006) is available for $2,250 from: Frost and Sullivan Inc., 106 Fulton Street, New York, NY 10038. Tel: (212) 233-1080

Researcher Proposes FM Voice/Data Detector—A Caltech researcher working for NASA's Jet Propulsion Laboratory in Pasadena, Calif., has proposed a novel detector for FM voice or digital signals. The work, done by Faramaz Davarian of the California Institute of Technology, is detailed in the April 1989 *NASA Tech Briefs*. The proposed detector would demodulate analog audio (voice) signals or digital signals sent by differential minimum-shift keying (DMSK). Voice/data switches would determine the proper operating mode, based on signal bandwidth and other properties. The detector would be capable of operating at baseband, eliminating the need for bandpass filtering at the intermediate frequency. According to the article, the detector's performance would be comparable to that of conventional limiter/discriminator FM detectors. Potential areas of application include mobile communications, where there is increasing interest in integrated voice/data service.

CPEM '90 Call for Papers—The 1990 Conference on Precision Electromagnetic Measurements (CPEM '90) will take place June 11-14, 1990 in Ottawa, Canada. 1990 will be the first year of a consistent international realization of the units of voltage and resistance, and the technical program of CPEM '90 will be organized to reflect this fact. Authors are invited to submit papers concerned with precision electromagnetic measurements and related fundamental constants. Papers in the following fields are regarded as particularly appropriate for this conference: direct current and low frequency; fundamental constants and special standards; time, time interval and frequency; RF, microwaves and millimeter waves; lasers; cryoelectronics; dielectrics and antennas; and advanced instrumentation including new sensors, automated instrumentation and novel measurement techniques. Interested authors should submit a summary (500 to 1000 words) and abstract (50 words) to the Conference Secretary by January 8, 1990.


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Additional information and an author's kit for the preparation of a summary can be obtained from: H. Lacoste, Conference Secretary, Conference Services, National Research Council, Ottawa, Canada K1A 0R6. Tel: (613) 993-9009; Fax: (613) 957-9828

Review of MIL-STD-1772 Applicability to QPL Oscillators Underway—At its annual meeting in February 1989, the Quartz Devices Subdivision of the Electronic Industries Association (EIA) established a committee to facilitate industry and governmental examination and potential modification of MIL-O-55310 Revision B provisions which require certification and qualification of QPL oscillator vendors to MIL-STD-1772. To arrange for participation and/or provide technical input, manufacturers and end-users of oscillators affected by these standards are urged to contact committee chairman Martin J. Kiousis by June 30, 1989. He can be reached at: M-tron Industries Inc., Attn. 1772/55310, 100 Douglas Avenue, Yankton, SD 57078. Fax: (605) 665-1709

RTI Researcher Wins Award to Study EMI—J. Harold White, a senior research engineer at Research Triangle Institute (RTI), will collaborate with researchers at North Carolina State University to develop computer-aided design (CAD) tools for predicting electromagnetic interference (EMI) from printed circuit boards. White is the recipient of a 1989 RTI Professional Development Award, part of an awards program supporting RTI staff members in scientific activities that are beyond the scope of their regular contract research responsibilities.

Regulations recently imposed by the Federal Communications Commission (FCC) limit the amount of EMI which computer equipment can generate. White's work will focus on the technology necessary for development of CAD tools for predicting EMI from printed circuit boards. He will investigate electromagnetic radiation from common printed circuit board wiring geometries, using "larger than life" scale models. The data gathered will support ongoing research at North Carolina State University into digital signal propagation through printed wiring and the accompanying electromagnetic emissions.

Motorola Files Complaint Against Tandy Corp.—Motorola Inc. has filed a patent infringement complaint with the U.S. International Trade Commission and the U.S. District Court for the Northern District of Illinois. The complaint is made against Tandy Corp., Nokia Corp., and various subsidiaries of the two companies. They are charged with selling cellular telephone products in the United States which infringe on Motorola patents, and an injunction is being sought by Motorola.

Raytheon Orders Components from W-J—Watkins-Johnson Co. has announced the receipt of orders valued at more than $1 million from Raytheon Co. Watkins-Johnson will deliver signal-processing components for the AN/ALQ-184(V) electronic countermeasures pod being built by Raytheon to protect of U.S. Air Force fighters from surface-to-air missiles, radar-directed anti-aircraft artillery, and airborne interceptors.

rf calendar

June 13-15, 1989
1989 IEEE/MTT-S Exhibition
Long Beach Convention Center, Long Beach, CA
Information: Chuck Swift, Symposium Steering Committee Chairman, C.W. Swift and Associates, 15216 Burbank Boulevard, Suite 300, Van Nuys, CA 91411. Tel: (818) 989-1133

June 19-22, 1989
ATE and Instrumentation Conference East
World Trade Center, Boston, MA
Information: MG Expositions Group, 1050 Commonwealth Avenue, Boston, MA 02215. Tel: (800) 223-7126; (617) 232-3976

June 25-29, 1989
26th ACM/IEEE Design Automation Conference
Las Vegas Conference Center, Las Vegas, NV
Information: DAC Registration, 7490 Clubhouse Road, 102, Boulder, CO 80301. Tel: (303) 530-4333

June 26-30, 1989
IEEE AP-S International Symposium and URSI Radio Science Meeting
Red Lion Inn, San Jose, CA
Information: Dr. Ray King, Lawrence Livermore National Laboratory, L-156, Livermore, CA 94550. Tel: (415) 423-2369

June 28-30, 1989
World Tech 89
Jacob Javits Convention Center, New York, NY
Information: Wendy Morris, AETEC, 225 W. 34th Street, Suite 906, New York, NY 10122. Tel: (212) 563-5350

July 24-27, 1989
1989 SBMO International Microwave Symposium/Brazil
Maksoud Plaza, Sao Paulo, Brazil
Information: Dr. Octavio M. Andrade, IMT—Escola de Engenharia Maua, Estrada das Lagrimas 2035, 09580 S. Caetano do Sul, SP., Brazil. Tel: (011) 442-6944; Telex: 1145234 AUAT BR

August 1-3, 1989
EMC Expo 89
Sheraton Washington Hotel, Washington, DC
Information: EMC Technology, P.O. Box D, State Route 625, Gainesville, VA 22065. Tel: (703) 347-0030

August 14-17, 1989
Triennial URSI International Symposium on Electromagnetic Theory
Royal Institute of Technology, Stockholm, Sweden
Information: S. Strom, Organizing Committee Chairman, Department of Electromagnetic Theory, Royal Institute of Technology, S-100 44, Stockholm, Sweden.

August 22-25, 1989 1989
International Symposium on Antennas and Propagation
Nippon Toshi Center, Tokyo, Japan
Information: Dr. Takashi Katagi, Mitsubishi Electric Corp., 325 Kamimachiya, Kamakura, 247 Japan. Tel: (0467) 44-8862; Fax: (0467) 47-2005

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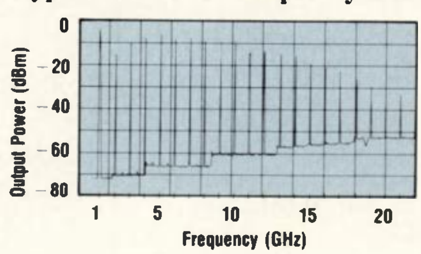

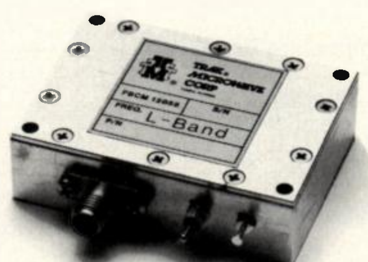

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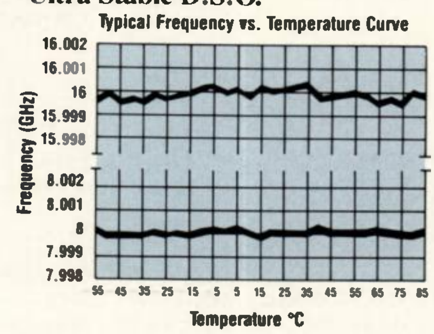

rf courses

Georgia Tech Education Extension

Fundamentals of Electronic Defense
July 12-14, 1989, Atlanta, GA

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

The George Washington University

Electronic Countermeasures
June 19-23, 1989, San Diego, CA
Radar Operation and Design
June 26-29, 1989, Washington, DC
Sonar System Design and Prediction
July 17-21, 1989, Washington, DC

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

Compliance Engineering

EMI
June 20, 1989, Chicago, IL
Safety
June 21, 1989, Chicago, IL
ESD
June 22, 1989, Chicago, IL
Telecom
June 23, 1989, Chicago, IL

Information: Compliance Engineering, 629 Massachusetts Avenue, Boxboro, MA 01719. Tel: (508) 264-4208

EEsof Inc.

Computer-Aided Engineering for Linear Microwave Circuits (Touchstone)
June 19-21, 1989, Westlake Village, CA
Computer-Aided Drafting for Microwave Circuits (MICAD)
June 22-23, 1989, Westlake Village, CA
Nonlinear FET Model Parameter Extraction (Xtract)
July 17-19, 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

Integrated Computer Systems

Fiber Optic Communication Systems
June 20-23, 1989, San Francisco, CA
June 27-30, 1989, Washington, DC
C Programming Hands-On Workshop
June 20-23, 1989, San Francisco, CA
July 11-14, 1989, San Diego, CA
Introduction to Telecommunications
June 20-23, 1989, Washington, DC
July 18-21, 1989, Los Angeles, CA
Image Processing and Machine Vision
June 20-23, 1989, Los Angeles, CA
July 11-14, 1989, Toronto, Ontario, Canada
Digital Signal Processing: Techniques and Applications
June 27-30, 1989, San Diego, CA
July 11-14, 1989, Washington, DC
Troubleshooting Datacomm and Networks
June 27-30, 1989, Washington, DC
July 11-14, 1989, San Diego, CA
C Advanced Programming Techniques and Data Structures
June 27-30, 1989, San Francisco, CA
June 27-30, 1989, Washington, DC

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.

Practical EMI Fixes
June 19-23, 1989, Orlando, FL
July 17-21, 1989, Washington, DC
TEMPEST Design and Measurement
June 20-23, 1989, Washington, DC
July 11-14, 1989, Palo Alto, CA
Grounding and Shielding
June 27-30, 1989, Washington, DC
July 25-28, 1989, San Diego, CA
EMC Design and Measurement
July 10-14, 1989, San Diego, CA
August 7-11, 1989, Orlando, FL

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

Research Associates of Syracuse Inc.

ELINT Analysis
July 19-21, 1989, N. Syracuse, NY

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

Technology Service Corporation

Advanced Photonics and Optical Signal Processing Applied to Imaging and Communications Systems
July 25-28, 1989, Boulder, CO

Information: Course Registrar, Technology Service Corporation, 962 Wayne Avenue, Suite 600, Silver Spring, MD 20910. Tel: (800) 638-2628; (301) 565-2970

UCLA Extension

Microwave Circuit Design I: Linear Circuits
June 19-23, 1989, Los Angeles, CA
Microwave Circuit Design II: Nonlinear Circuits
June 26-30, 1989, Los Angeles, CA

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

University Consortium for Continuing Education

Electronic Warfare
July 12-14, 1989, Santa Monica, CA

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

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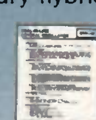

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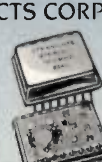

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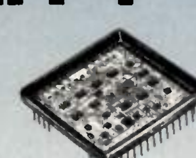

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Settling Time	μSec	1.5	2.0	14.0	13.0	1.0	0.4
Offset Drift	μV/°C	0.5	3.0	0.1	0.3	2.0	0.2
Gain	V/μV	2.5	5.0	30.0	3.0	0.6	1.8
Noise	nV/Hz	3.4	6.0	3.8	7.0	10.0	3.0
Slew Rate	V/μSec	20.0	8.0	0.8	7.0	8.0	35.0
Bandwidth	MHz	35.0	8.0	1.4	4.0	8.0	10
Supply Current	mA	8.0	4.0	1.2	6.5	1.9	3.0
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	Cerdip	•	•	•	•	•	•
	TO-99			•		•	

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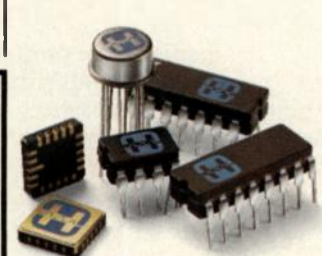

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Is RF Shifting to Subsystems?

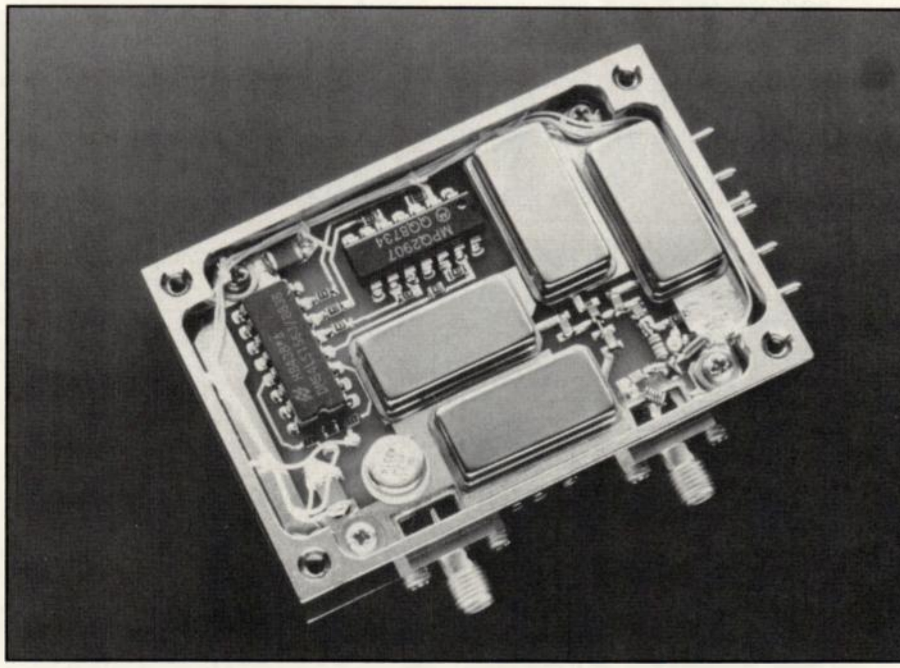
By Mark Gomez
Technical Editor

The general consensus in the RF industry is that there is a shift toward subsystems. Various reasons are being cited for this transition. "There are value-added and performance-related issues that drive it," says Dave Strange, director of marketing for the amplifier division of Acrian. In other words, manufacturers who build components or devices could be inclined to build higher levels of subassemblies or subsystems because the value added is greater for more complex products. "The market has shifted," comments Terry Simons, vice-president of sales, major programs at Microwave Modules and Devices. "Instead of big corporations building subsystems themselves, they are actually purchasing them at this point in time."

As with any industry, cost is a driving force in RF. Cost-related issues no doubt play a heavy part in the decision whether to build or buy subsystems. "The general trend is towards subassemblies, but the major decision about whether to use a subassembly or to stay with components is cost-effectiveness," comments Shmuel Ravid, manager of subassemblies at the Anzac division of Adams-Russell. He believes that subassemblies will be more cost-effective in the future, especially with the increasing use of MMICs as building blocks.

The risk level of purchasing a subsystem is obviously much lower than if a company were to build it. "The cost and risk level goes down because they can purchase the parts rather than make them themselves," remarks Terry Simons. Tom Roberts, senior vice-president and marketing director at Trak Microwave, shares this opinion. "Sometimes at the system level, it is less risky to subcontract out a portion of a system to a specialist. Then, it can be purchased at a fixed cost."

Faster turnaround time is another key reason for going with subsystems. "One of the benefits of using subsystems is that it tends to speed up the design project," observes Frank H. Perkins Jr., vice-president of marketing at RF Monolithics. "It certainly reduces the design cost and gets your system into test and production quicker," he adds. "A relatively small company has a greater rate of flexibility and can usually turn around new designs faster and at a better price than system houses," states Roberts.



A frequency synthesizer subsystem (photo courtesy of RF Monolithics).

The lack of properly trained RF engineers often translates into a company's need to purchase subsystems. Since it takes a rather long time to train engineers to design specific functions, it is usually more cost-effective to purchase subsystems than to build them if the particular expertise is not readily available. Roger Druhan, director of business development in the RF products group at Mirage Systems, stresses that there is a shortfall of engineering talent. "The toughest part is finding trained RF/digital engineers," he says, "and it takes a long time to train a young engineer." Tom Roberts shares this viewpoint by saying that he feels there is a shortage of skilled engineers in both the RF and microwave fields. RF Monolithics' Perkins points out that it would be a real challenge to take a team of people and turn them into experts in different areas.

When a contractor farms out certain facets of a system design to a company with that particular expertise, the end product is usually a system built by experts. Perkins notes that with subsystems, the contractor is able to delegate the more exotic circuit design of subassemblies to people who do it every day. "This way, all the contractor needs to know is what the system has to do, what the subsystems are, and be capable of doing the required integration," he notes. Simons observes that the market has shifted from big system-type suppliers into subcontractor levels.

Package size is usually reduced when subsystems are utilized in system design. "Size reduction and higher integration levels are factors that drive the subassembly industry," says Ravid. Perkins claims that a benefit of going with subsystems is the smaller package that is achievable.

Where are prices headed? In general the RF industry anticipates more competitive pricing over the next year. This view is also evident in subsystems. "There is always a drive to get lower prices," says Simons, "but I think you will see prices change and go back the other direction because companies are working with some very advanced technology that is very expensive to produce." Pricing and sophistication no doubt go hand-in-hand. If the capabilities of a product increase, this will have a rising effect on prices. Ravid points

out that although there is a large push to reduce prices, the real price driver is how complicated the subassemblies will be. "It is important for the industry to find ways to reduce cost but maintain prices as much as they can be maintained so companies can continue to make a reasonable profit margin," says Strange. According to Dr. Donald Steinbrecher, founder and CEO of Steinbrecher Corporation, the industry has to get down to a level that is commensurate with the value that is added. "This is much more true in the HF, VHF and UHF area than it is in the microwave and millimeter-wave area," he observes. Prices are also governed by volume. However, volume will not readily increase if prices are dropped. "If we took our millimeter-wave amplifiers and cut the price by a factor of ten, probably no more people would buy them now than the people who are buying them now," says Steinbrecher. "This is simply because the applications are not there at this point in time," he explains.

Although the subsystem market has been governed by the military in the past, the commercial industry seems to be headed in this direction as well. "We see opportunities for subsystems in both the commercial and military markets," notes Strange. "It is our current policy to target the military market but we are starting to do some industrial and communication subassemblies," says Ravid. Perkins observes that the military is where the subsystem concept was tried out and found to be successful. "The desire for subsystems certainly started with the military," he says, "but the commercial side is starting to adopt this philosophy."

Future trends in the subsystem industry will include the use of more MMICs, more sophisticated packaging techniques, and more functions in the same package. "What you are going to see is more people taking advantage of MMICs and higher levels of integration," says Perkins. "Incorporating MMICs into an assembly creates a hybrid assembly," notes Ravid. "And, the hybrid will be around for a while," he adds. Packaging, a nagging RF problem, will also see improvements for subsystems. "There is some exciting work going on in packaging and I think that we will see some results of that being used in subsystems in the not-too-distant future," states Strange. Druhan forecasts that the industry will see more hybrid circuits, higher power levels and innovative uses of materials in subsystems.

Performance without quality is not a growing trend. Quality has to be one of the prime considerations on any product introduced into the subsystem market. Steinbrecher believes that manufacturers will be working very closely with suppliers on the quality issue to get the ultimate cost down. "A simple supplier problem can cost a subsystem integrator a tremendous amount of money," he remarks.

In conclusion, it seems that the RF industry is shifting towards subsystems. This shift can be attributed to the various advantages that were highlighted in this report. It also needs to be pointed out that it is the process of design and supply that is changing. Component manufacturers need not be concerned, for example, since the change in direction involves *who* is building a given subsystem, not *what* goes into it.

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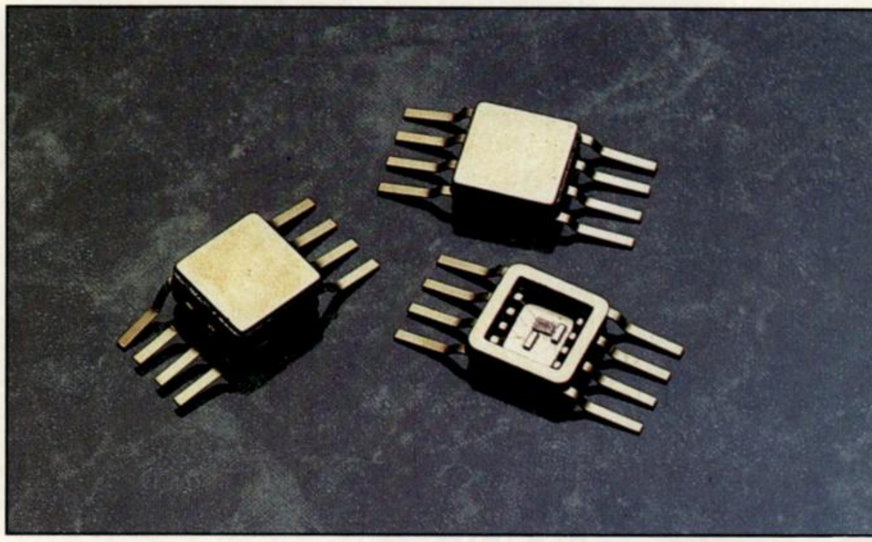
INFO/CARD 28

rf cover story

New Range of RF and High-Speed Digital MMICs

By Northe K. Osbrink and
the Advanced Bipolar Products staff
Avantek, Inc.

Second-generation silicon MMIC technology is now producing low-noise amplifiers, variable gain amplifiers, active mixers and ECL prescalers offering high-quality performance in the GHz range. Their low cost makes them practical for consumer as well as commercial and military applications.



The past seven years have seen the development of silicon monolithic microwave integrated circuits (MMICs), providing low-cost gain blocks and related functions for the RF side of a system. Now there is a convergence of the "digital/analog" and the MMIC worlds — an area where conventional and microwave IC technologies are overlapping. This overlap is a product of a second-generation silicon MMIC technology that is capable not only of producing higher performance in simple RF/microwave circuits, but of allowing the integration of up to 1000 transistors on a single chip. This makes possible an entirely new range of high-frequency ICs, ranging from complex analog functions to digital logic. Like the "conventional" analog and digital ICs, these new MMICs are low enough in cost to permit their use in consumer products.

Avantek's family of second-generation products, called MagIC™ silicon integrated circuits, are fabricated using Avantek's Isosat-1™ technology, which employs a combination of nitride self-alignment, submicron lithography, trench isolation, ion implantation, gold metallization and polyimide inter-metal dielectric and scratch protection. This bipolar process produces analog transistors with 10 GHz f_T and 25 GHz f_{max} and digital transistors with 15 GHz f_T.

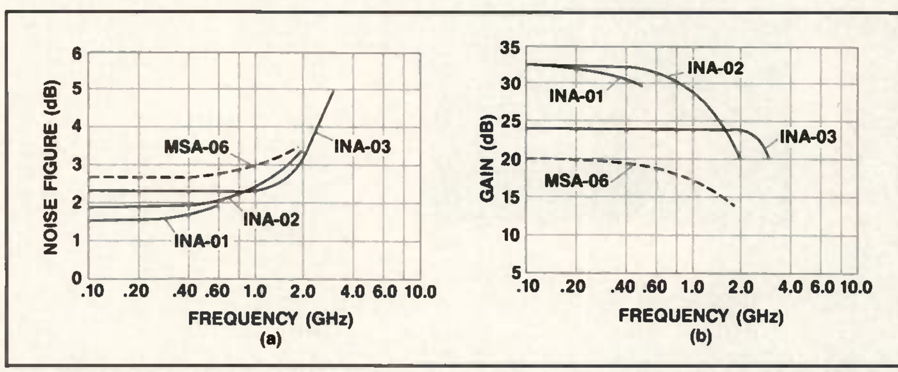


Figure 1. Performance curves for the new MagIC™ low-noise amplifiers: noise figure (a) and S_{21} gain (b).

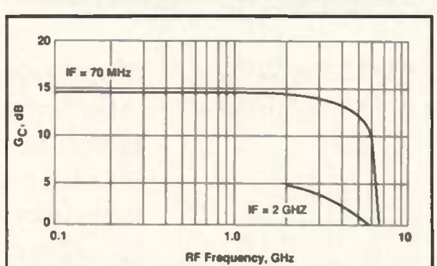


Figure 2. Conversion gain versus frequency for the IAM-82018 active mixer. LO power is 0 dBm, with low side injection.

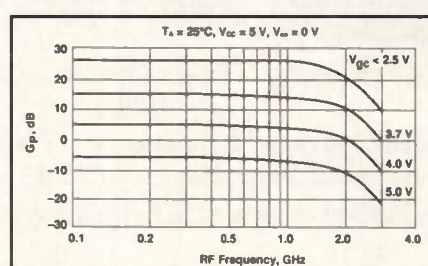
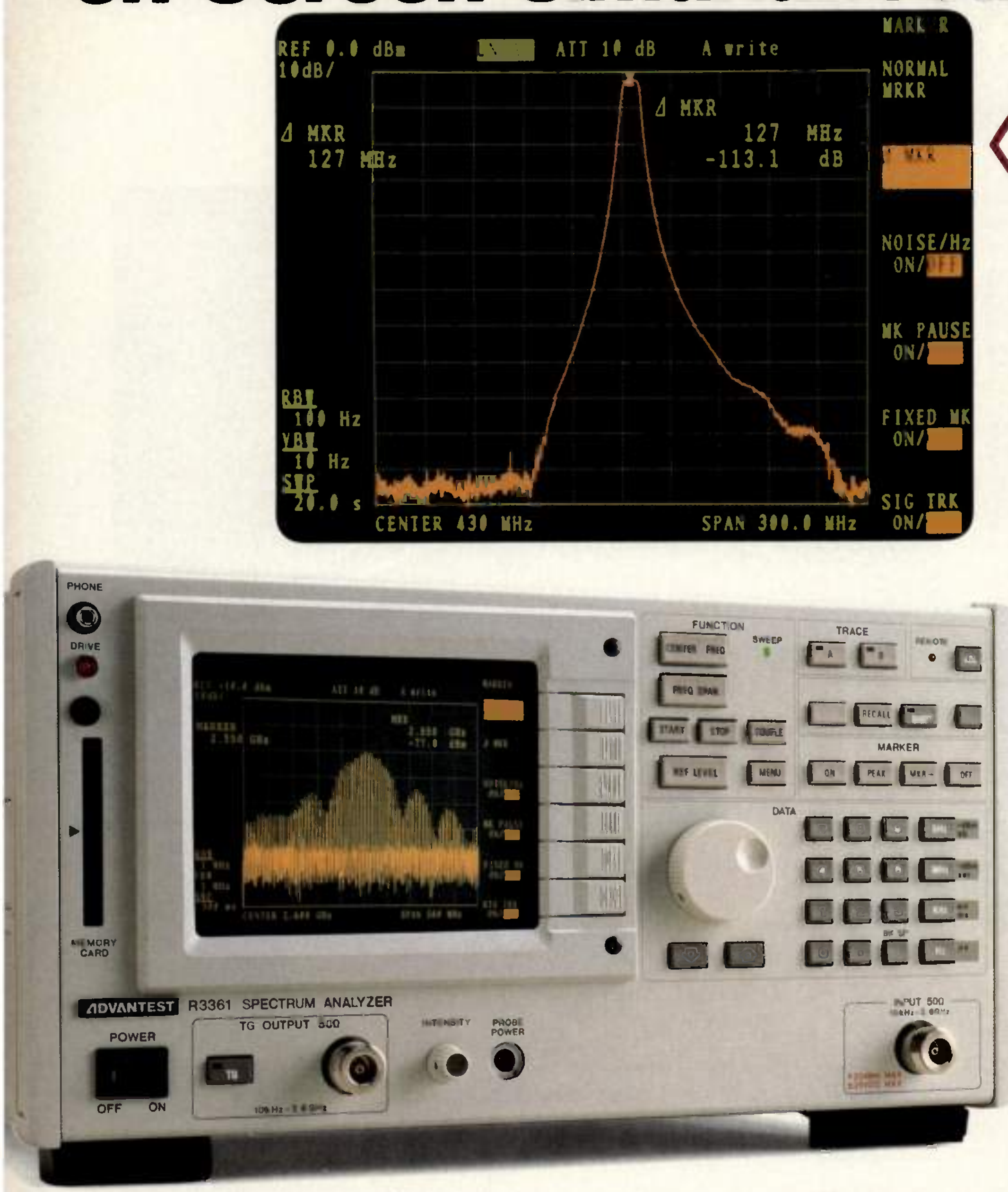


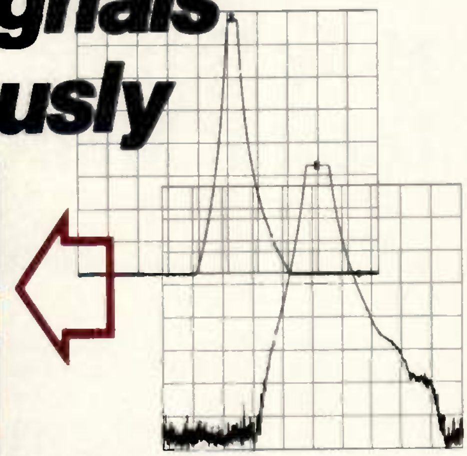
Figure 3. Gain vs. frequency for the IVA-05118 variable gain amplifier. The DC to 1.5 GHz bandwidth is suitable for up to 2.4 Gbps.

Low-Noise Gain Blocks

Second-generation silicon MMIC technology is now offering convenient, broadband gain blocks that offer noise figures low enough for many applications, combined with a remarkable amount of gain in a single transistor package. The first general-purpose LNAs feature a 3 dB bandwidth of DC to 1 GHz, 1.7 to 2.5

A Dynamic Range of 120dB puts High and Low Level Signals on Screen Simultaneously





The R3261/3361 series synthesized spectrum analyzers are compact, lightweight, synthesized analyzers covering the frequency ranges of 9kHz to 2.4GHz (R3261A/3361A) and 9kHz to 3.6GHz (R3261B/3361B). They represent the combination of ADVANTEST's many years of experience in RF circuit technology with the latest in software calibration technology. The bottom line for the user is a guaranteed overall level accuracy of 1dB. In addition, these analyzers feature: stop, start, and center frequency resolution to 1Hz, together with a built-in frequency counter, also with 1Hz resolution. The result is a truly powerful analyzer in an amazingly compact package.

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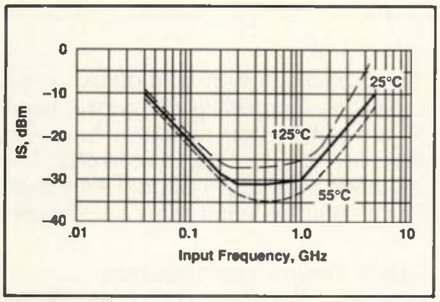


Figure 4. Input sensitivity vs. frequency for the IFD-50010 divide-by-four IC.

dB typical noise figures and 20 to 25 dB typical gain (Figure 1). Power outputs are +10 or +11 dBm, typical. The current process will be able to provide useful bandwidths up to 6 GHz.

Active Mixers

These first second-generation bipolar active double-balanced mixer ICs provide 8 and 15 dB of conversion gain for RF and LO frequencies up to 6 GHz, with IF outputs from DC to 1 or 2 GHz. Both units feature low LO power requirements (−5 dBm and 0 dBm) and operate from single-polarity bias supplies. Using a Gilbert cell design, the ICs require no balun transformers and a minimum of external components (Figure 2).

These mixers are packaged in a 0.180-inch-square glass-metal package designed for use in 50 ohm microstrip circuits. Capacitors incorporated in the mixer packages provide sufficiently low impedance for LO and RF operation down to 50 MHz; connections are provided to allow the use of external capacitors to extend the low-frequency limit. The low-frequency response of the IF port is limited only by the value of the output blocking capacitor. Improved noise figure and dynamic range techniques are being developed.

Variable-Gain Amplifiers

A variable-gain amplifier (VGA) is a useful functional block for many applications, such as the AGC circuit in analog or digital fiber-optic and microwave communications. The current version from Avantek features a 3 dB analog bandwidth of DC to 1.5 GHz, and operation at data rates of up to 2.4 Gbps. It provides up to 26 dB of power gain (typ.), controllable over a 30 dB range, and both single-ended or differential output capability (Figure 3).

The VGA IC operates from a single 5 VDC, 40 mA source, and uses a 0 to 5 V control range (3 mA, max). The unit is packaged in a hermetic 180 mil surface-

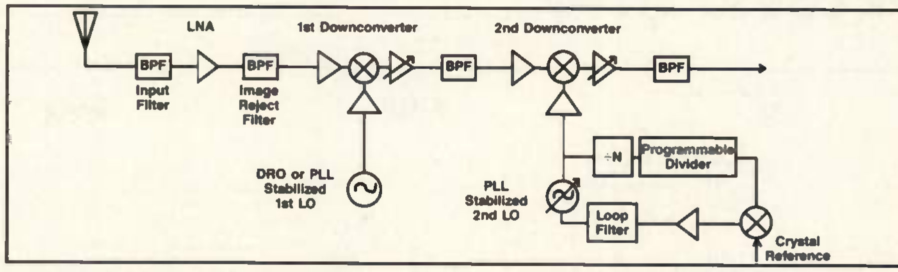


Figure 5. Block diagram of a typical double-conversion RF/microwave receiver.

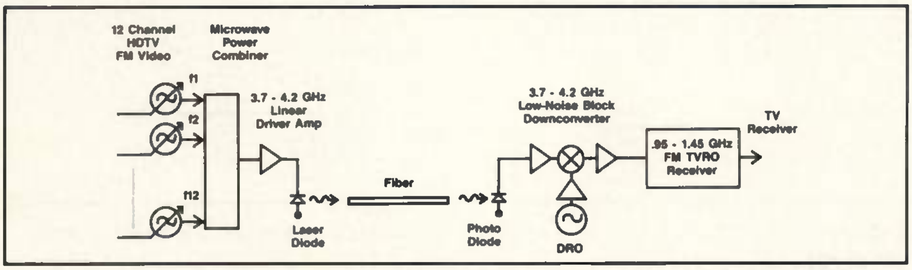


Figure 6. Block diagram of a proposed fiber optic HDTV transmission system.

mount package with gold-plated leads, and is fully compatible with conventional 50 ohm microstrip systems. A version with DC to 3.0 GHz bandwidth, and operation at up to 5.0 Gbps is scheduled for introduction in the immediate future.

Static Frequency Dividers

Today, the most commonly used frequency dividers are from high-speed CMOS and TTL families, operating at up to several hundred MHz, and the "conventional" ECL logic families, operating in excess of 1 GHz. Within the past year or so, however, the available frequency range has increased substantially with commercially available "scaled ECL" silicon dividers operating up to 4.5 GHz or higher. "Scaled ECL" is the phrase coined by Avantek to describe the combination of dimensional scaling, with geometrical features in the 0.5 μm range, and current- and voltage-level scaling, using reduced logic swings to cut down power dissipation and increase speed.

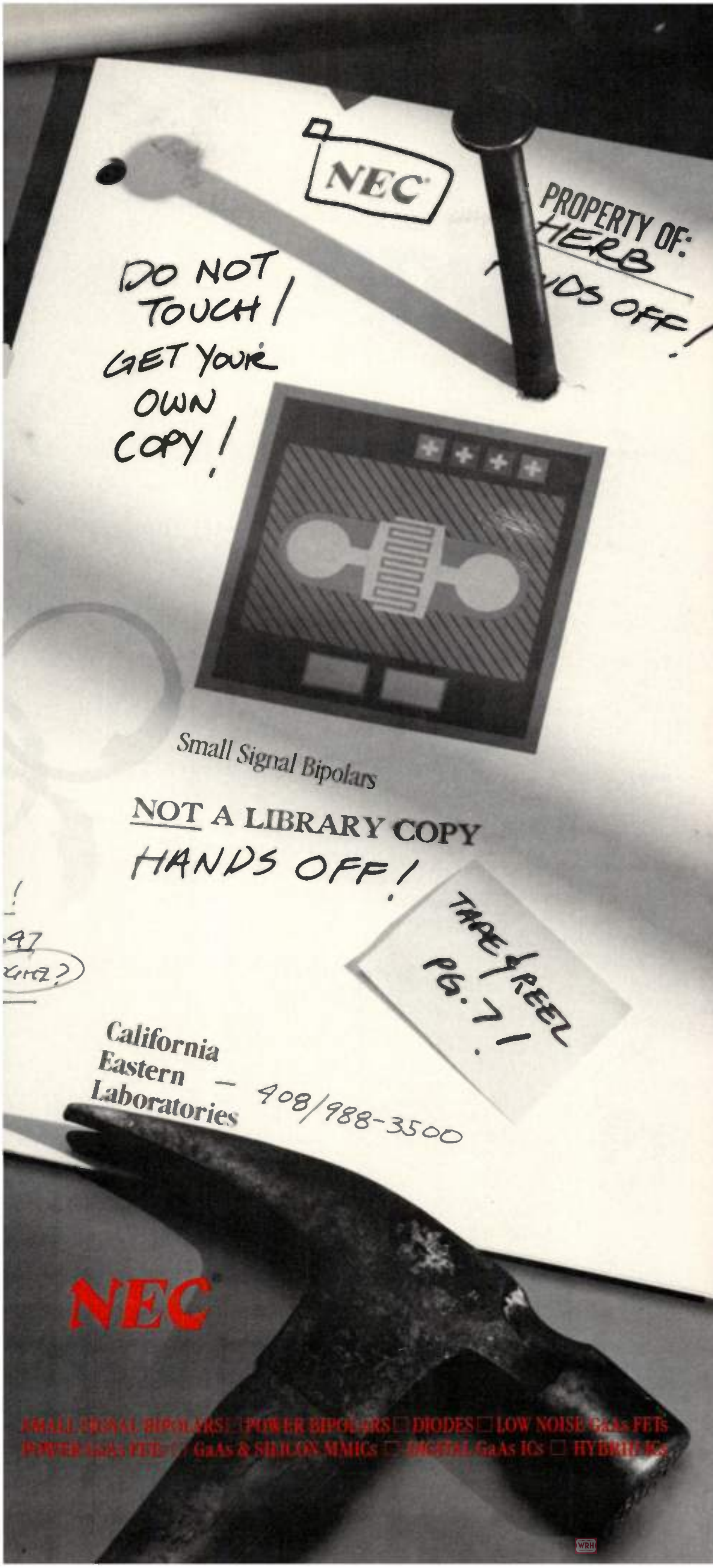
The scaled ECL frequency divider features a typical sensitivity of 10 mV_{p-p} at 1 GHz (Figure 4) and phase noise of −140 dBc/Hz at 1 kHz offset from carrier. It dissipates only 125 mW, from a single +5 VDC source, and requires only a single clock input. The circuit is packaged in a 4-lead 100-mil hermetic surface-mount package.

Applications

Figures 5 and 6 represent applications for current first- and second-generation technology, and for second-generation parts that will become available within the next two years. In the receiver (Figure 5), the programmable divider, crystal reference oscillator and mixer in the second LO would probably be built with conventional discrete components and ICs; the first and second LOs could use first- and second-generation silicon MMICs.

The digital fiber-optic system of Figure 6 combines present and future silicon technology. Currently, components are available for the AGC amplifier and, depending on the data rate, for the transimpedance amplifier. The multiplexer, laser driver, decision circuit, clock recovery circuit and demultiplexer will be available in the next two years.

For further information on Avantek's MagIC IC products, contact Avantek Inc., M/S M82, 481 Cottonwood Drive, Milpitas, CA 95035 or telephone (408) 943-3038. Information may also be obtained by circling INFO/CARD #170.



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1989 RF Design Awards
Contest Results to be Announced in July

To RF Design Readers:

As this issue was being prepared for publication, the judges for the Fourth Annual RF Design Awards Contest were completing their evaluations. We at RF Design want to thank all of the engineers who sent in the finest collection of entries in the history of the contest. You have made the judging very difficult!

Next month, the six prize winners will be announced, with the Grand Prize winner featured on our cover, as has become our tradition. The top entry will be published in the July issue, with all other prize winners and other interesting entries published in following months.

In fact, we have so many good ideas that we will begin featuring a contest entry every month in a new RF Design Awards column. You can look forward to seeing your colleagues' best new ideas in every issue of RF Design.

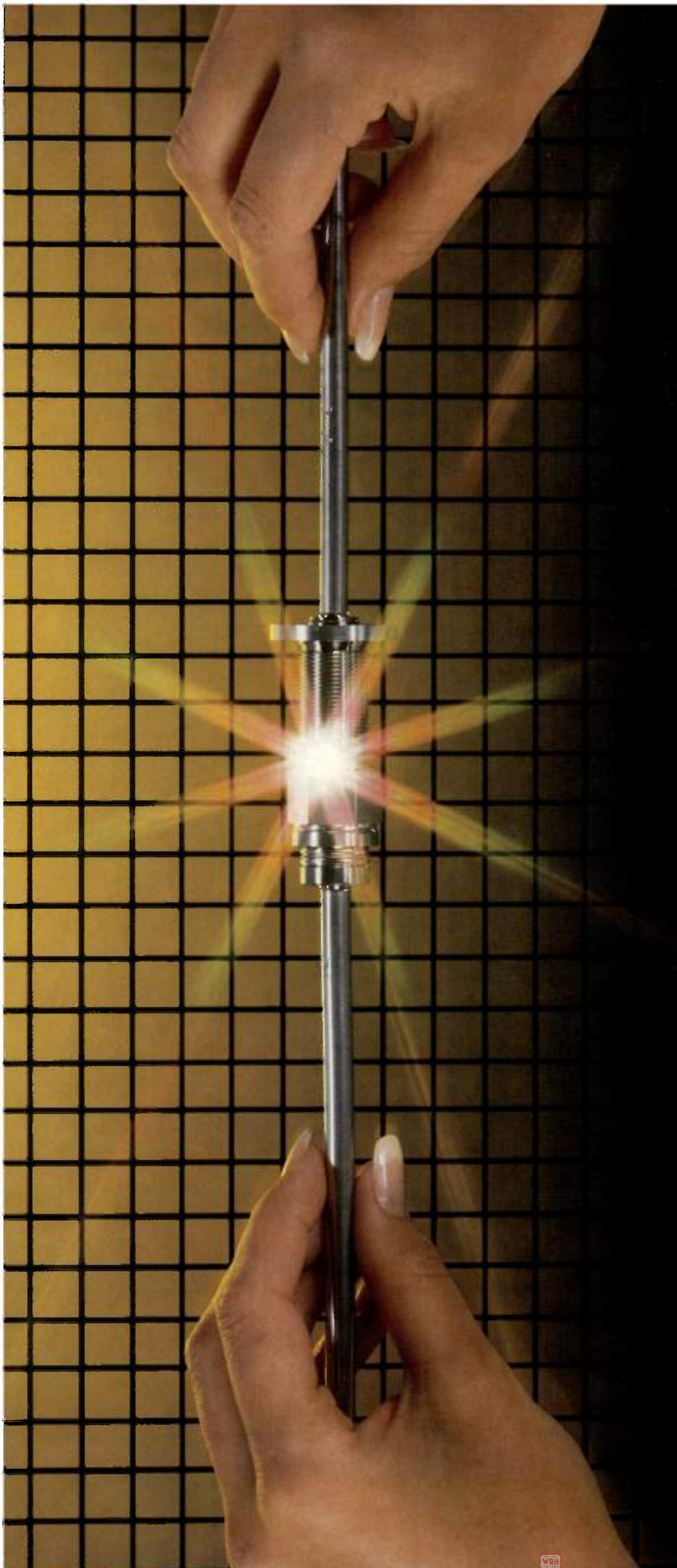
I'd like to take this opportunity to recognize Webb Laboratories and John Fluke Mfg. Company for their support of this year's contest. Prizes for the next contest will be announced in the July issue, nine months before the entry deadline. With this much warning, you won't be able to use the excuse, "I don't have enough time to get my entry done!"

So, be ready for next month's big announcement, and look for more great ideas every month in RF Design!

Thank you for your support,

Gary

Gary A. Breed
Editor



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The new MagIC™ series of silicon bipolar MSI integrated circuits offer the best performance available from silicon ICs yet. The broadband, high frequency performance of these high-speed silicon ICs make them cost-effective alternatives to more expensive GaAs ICs. Avantek MagIC silicon ICs are manufactured with Avantek's proprietary 10-15 GHz F_t, 25 GHz F_{max} Isosat™ process for unsurpassed integration and performance at microwave frequencies. Avantek's MagIC series ICs presently consists of four product families: low noise amplifiers, active mixers, variable gain control amplifiers, and prescalers. These low-cost, high-speed silicon ICs are Avantek's magic solutions to your RF, microwave and lightwave system performance and cost problems.

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The IAM-series of active mixer/amplifiers presently consists of two models, offering:

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The IVA-series of variable gain control amplifiers presently consists of two models, offering:

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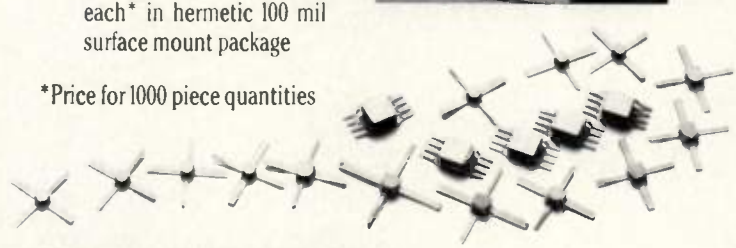

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INFO/CARD 38

S-Parameters in Spice

Improving the RF Capabilities of This Popular Program

By Thomas B. Mills
National Semiconductor

Spice is commonly used to simulate circuits from DC to hundreds of megahertz. Above about 100 MHz, conventional Spice models of transistors become less accurate. At these higher frequencies, S-parameters are easy to measure and accurately reflect device performance. This article describes how to generate the four S-parameters in a Spice simulation.

Spice is a commonly used circuit simulator program originally designed for linear monolithic circuit simulation. To this end, it uses the nonlinear Ebers-Moll or Gummel Poon model of the bipolar transistor. At low frequencies, this is practical and accurate, but above 100 MHz, model parameters estimated from the data sheet do not provide accurate performance. It is useful to use measured S-parameters as a goal for these models. Then, Spice S-parameter simulations of the device can be run and the model adjusted to more nearly approach the measured S-parameters.

Measuring S-Parameters

Figure 1 shows the test set up to measure S-parameters. S11 and S22 are the ratios of forward power to reflected power at the input and output ports of the device under test (DUT), while S21 and S12 are the ratios of power delivered to a load from the DUT relative to the power available from a matched (to the load) generator in both forward and reverse directions.

$S11 = VB1/VA \tan^{-1} VB1/VA$

$S21 = VB2/VA \tan^{-1} VB2/VA$

At high frequencies, directional couplers are used to measure these powers. Errors in the couplers and associated hardware can be removed by calibrating into perfect components and subtracting out the errors. These S-parameters are accurate and easily measured over almost any frequency range.

Once obtained, it is desirable to compare these S-parameters with Spice simulations of the model of the device. Acquiring the forward and reverse S-parameters, S21 and S12, is fairly straightforward using the simulation circuit shown in Figure 2. Here S21 (or S12) is the ratio of the output voltage (magnitude and phase) to the voltage the generator would deliver to a matched load (R_s = R1, usually 50 ohms). In Spice,

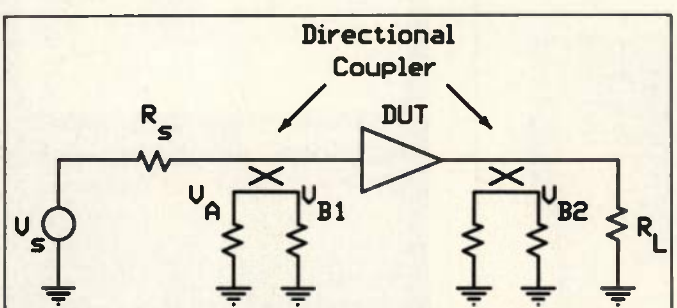

Figure 1. S-parameter measurement.

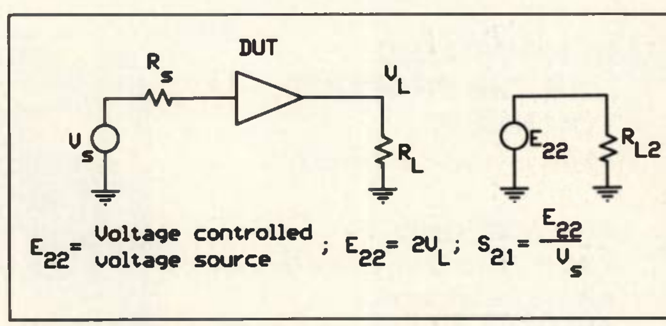

Figure 2. Measuring S21.

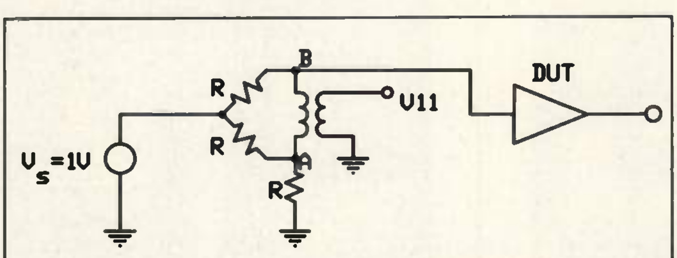

Figure 3. Using an RF bridge to measure S11.

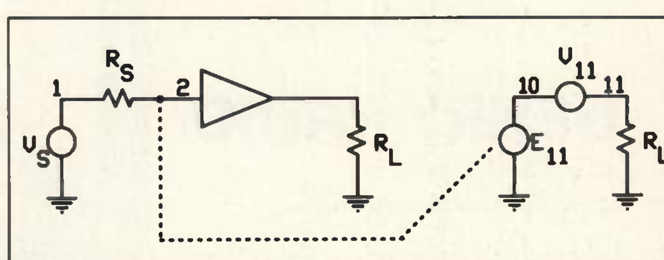

Figure 4. Spice S11 measurement.

```
***                       SOLVES ALL FOUR S PARAMETERS
**                     V11=S11 V21=S21 V12=S12 V22=S22
**
**                      SOLVING FOR  S11  S21
VS1 1 0 AC 1
RSF 1 2 50
L1 2 3 2E-9
L2 5 6 2E-9
RLF 100 4 50
C1 6 0 1
Q1 4 3 5  QP42
I1 6 0 DC 5MA ;               BIAS CURRENT
V1 100 0 5.8      ;           COLLECTOR VOLTAGE
E21 21 0 4 0 2
RL1 11 0 50
RL2 21 0 50
E11 10 0 2 0 2
V11 10 11 AC 1
**                      SOLVING FOR  S12 S22
RLR 7 0 50
RS2 101 9 50
L3 7 8 2E-9
L4 14 15 2E-9
C2 15 0 1
Q2  9 8 14 QP42
I2 15 0 DC 5MA  ;             BIAS CURRENT
VS2 101 0 DC 5.8 AC 1 ;       COLLECTOR VOLTAGE
E12 12 0 7 0 2
RL3 12 0 50
E22 20 0 9 0 2
V22 20 22 AC 1
RL4 22 0 50
.OP
.AC LIN 10 1MEG 901MEG
.PRINT AC VM(11) VP(11) VM(21) VP(21) VM(12) VP(12) VM(22) VP(22)
****  TRANSISTOR MODEL
*
**  THIS IS A NATIONAL SEMICONDUCTOR PROCESS 42 - MPSH10
**           A SMALL SIGNAL VHF AMPLIFIER
.MODEL QP42 NPN (BF=100 IS=2.9E-15 VA=150 IKF=10M RB=12
+CJE=1.8PF CJC=1.4PF TF=.13NS ITF=.3 XTB=2.5 MJC=.33 VJC=.3
+PTF=40 XTF=8 )
.END
```

```
***               SOLVES ALL FOUR S PARAMETERS

****     AC ANALYSIS                    TEMPERATURE =   27.000 DEG C

*******************************************************************
```

FREQ	VM(11)	VP(11)	VM(21)	VP(21)	VM(12)	VP(12)	VM(22)	VP(22)
1.000E+06	7.678E-01	-8.749E-01	1.232E+01	1.794E+02	2.798E-04	8.950E+01	9.968E-01	-1.621E-01
1.010E+08	5.794E-01	-7.401E+01	8.586E+00	1.288E+02	1.989E-02	5.293E+01	8.719E-01	-9.479E+00
2.010E+08	4.394E-01	-1.149E+02	5.417E+00	1.054E+02	2.566E-02	4.314E+01	7.928E-01	-9.141E+00
3.010E+08	3.861E-01	-1.402E+02	3.842E+00	9.215E+01	2.839E-02	4.290E+01	7.661E-01	-8.261E+00
4.010E+08	3.670E-01	-1.579E+02	2.962E+00	8.263E+01	3.063E-02	4.559E+01	7.564E-01	-7.896E+00
5.010E+08	3.628E-01	-1.713E+02	2.411E+00	7.478E+01	3.286E-02	4.917E+01	7.532E-01	-7.913E+00
6.010E+08	3.665E-01	1.778E+02	2.037E+00	6.785E+01	3.515E-02	5.297E+01	7.533E-01	-8.179E+00
7.010E+08	3.750E-01	1.687E+02	1.766E+00	6.147E+01	3.749E-02	5.675E+01	7.553E-01	-8.613E+00
8.010E+08	3.869E-01	1.608E+02	1.563E+00	5.548E+01	3.987E-02	6.049E+01	7.588E-01	-9.168E+00
9.010E+08	4.013E-01	1.538E+02	1.403E+00	4.975E+01	4.226E-02	6.421E+01	7.635E-01	-9.820E+00

P42505 Frequency MHz	Return Input Mag	Loss (S11) ANG	Trans. Forward Mag	Loss (S21) ANG	Trans. Reverse Mag	Loss (S12) ANG	Return Output Mag	Loss (S22) ANG
1.000	.90	1.8	13.94	-178.1	0.00	-20.6	.98	2.7
101.000	.57	-65.4	8.27	124.1	.02	56.8	.86	-7.1
201.000	.38	-96.7	4.91	102.3	.03	58.4	.81	-9.2
301.000	.31	-118.6	3.42	89.6	.04	60.5	.80	-12.0
401.000	.29	-136.9	2.62	80.4	.05	63.2	.79	-15.2
501.000	.30	-153.0	2.12	72.4	.05	64.9	.78	-18.6
601.000	.32	-167.6	1.79	65.4	.06	67.4	.78	-22.5
701.000	.34	-178.9	1.56	58.7	.07	69.0	.77	-27.0
801.000	.36	171.8	1.38	52.6	.07	72.0	.76	-31.5
901.000	.38	162.5	1.23	47.2	.08	74.1	.75	-36.0

Table A. Enhanced HP 8505 S-parameter run.

Appendix 1. Example of a Spice file.

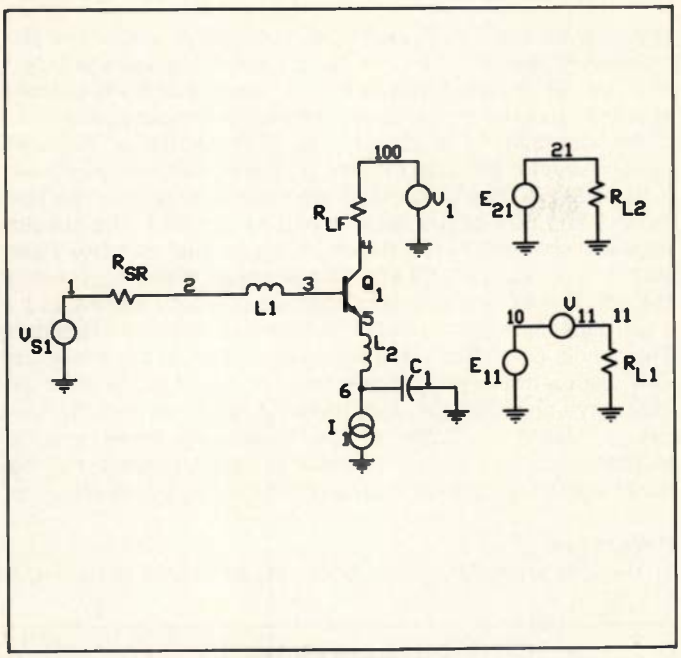

Figure 5(a). S11 and S21 measurement.

this can be done by comparing the output voltage supplied to a load, to two times the generator voltage. The times 2 multiplication factor accounts for the difference between the

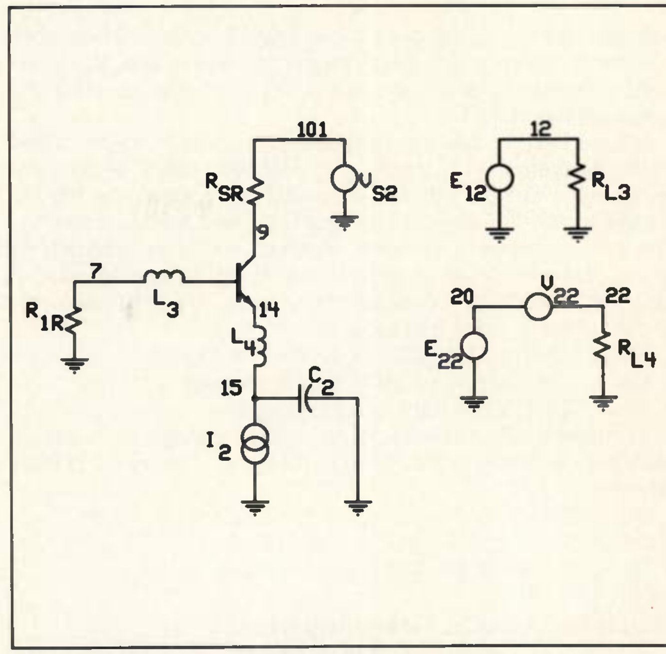

Figure 5(b). S12 and S22 measurement.

open circuit generator voltage and that voltage delivered to the matched load.

A useful component in Spice is the voltage-controlled voltage source. It will produce a scaled voltage of another voltage in the circuit, in both magnitude and phase. It is used here to multiply the circuit output voltage by 2 to simulate the load match factor.

Measuring S11 without a directional coupler (in Spice) poses some problems, but considering methods used in the real world helps to illustrate how it can be done. Consider the RF bridge shown in Figure 3 and how it is used to measure S11. The bridge consists of three resistors and a transformer to obtain the differential voltage between the reference point A and the unknown B. Consider three cases — a short, an open and 50 ohms at point B to ground:

Short: Vb=0; V11= −0.5V or 0.5V −180 degrees
Open: Vb=2; V11= +0.5V or 0.5V 0 degrees
Term: Vb=1; V11= 0.0V or 0 (no phase)

In these measurements, a generator voltage of 1 volt is assumed. Multiplying the above numbers by 2 gives the correct answers for S11:

Short: S11 = −2*0.5V, −180 or 1, −180 or 0 dB, −180
Open: S11 = 2*0.5V, 0 or 1, 0 or 0 dB, 0
Term: S11 = 2*0.0V, 0 or 0, 0 or −(inf) dB

Simulating a Spice Measuring Circuit

The bridge circuit of Figure 3 can be implemented quite nicely in Spice since ideal transformers are readily obtainable. However, a transformer is not necessary; a voltage-controlled voltage source can measure the differential voltage (A−B) and can add the times 2 factor discussed above. A simulation circuit for S11 (and S22) is shown in Figure 4. A fixed AC voltage (in phase with the input excitation voltage) is added in the measuring circuit to account for the reference voltage (point A) in the RF bridge circuit, and is connected with the polarity shown to account for the phase reversal term noted above.

An example of a Spice file to measure a National Semiconductor process 42 VHF amplifier transistor is shown in Appendix 1. Two simulations are done in sequence: the first for S11 and S21, and a second for S12 and S22. The circuits for these simulations are shown in Figures 5(a) and 5(b). Note that inductors L1, L2, L3 and L4 have been added to simulate the bond wires. Package capacitance could be simulated by small capacitors from collector to base and collector to emitter. The results of the Spice simulation are shown in the appendix. The values are in magnitude and not dB. A printout of an accuracy-enhanced HP 8505 network analyzer S-parameter run is shown in Table A. By comparing these results, modifications to the Spice model for the transistor can be made to more accurately approach the measured values. rf

Reference

1. PSpice, MicroSim Corporation, 20 Fairbanks, Irvine, CA 92718.

About the Author

Tom Mills is a member of the technical staff, Hybrid Systems Products at National Semiconductor, 2900 Semiconductor Drive, M/S 11-130, Santa Clara, CA 95052-8090. Tel: (408) 721-3400.

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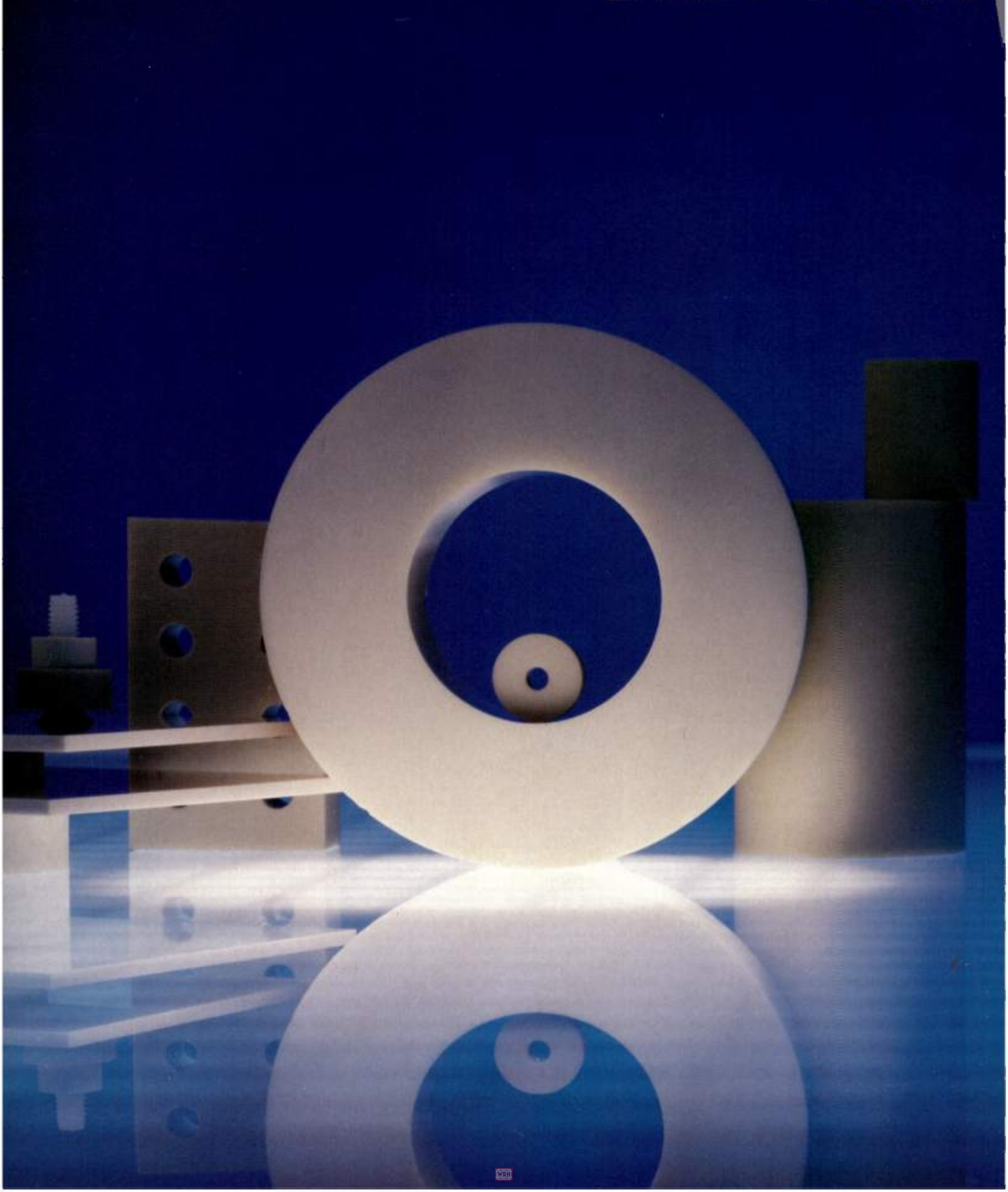

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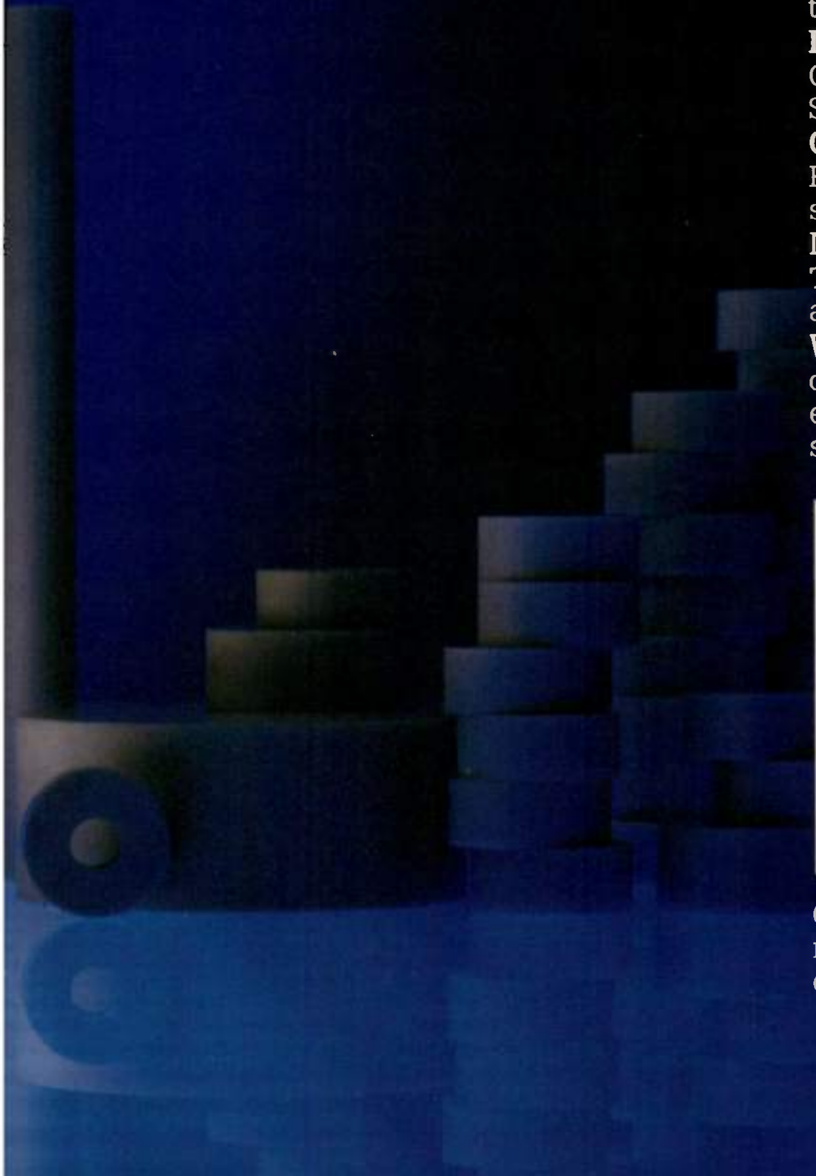

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Interstage Coupling With an Edge-Coupled Line

By H. Paul Shuch
Microcomm

Cascading of active RF devices typically requires the use of a coupling capacitor as a DC block between stages. Unfortunately, this capacitor may exhibit reactive effects detrimental to circuit function. This article, an entry in the 1988 RF Design Awards contest, presents a simple technique for achieving interstage coupling in microstrip assemblies, which passes only the desired signal component and costs nothing but knife-blades. Performance of the proposed coupling circuit is evaluated, and a MMIC amplifier application example is presented.

The conventional method of coupling signals between active stages while blocking any DC bias component which might be present is illustrated in Figure 1. The coupling capacitor mounts to, and becomes part of, the transmission line connecting the stages. The chip capacitor employed is considered a short to RF, an open to DC and, for purposes of analysis, is treated as an extension of the microstripline on which it is installed. For this assumption to hold, it is vital that the installation of the chip cap not alter the characteristic impedance of the microstripline in any way.

The single most critical parameter in determining microstrip characteristic impedance on a given substrate is trace width. If the impedance of the interstage coupling network is to remain constant, the physical width of the chip capacitor must match that of the microstrip on which it is installed. Impedance discontinuities caused by differences in widths will result in reflections, which may degrade stage gain, contort frequency response, increase intermodulation distortion, induce oscillation or, if taken to extremes, damage active devices.

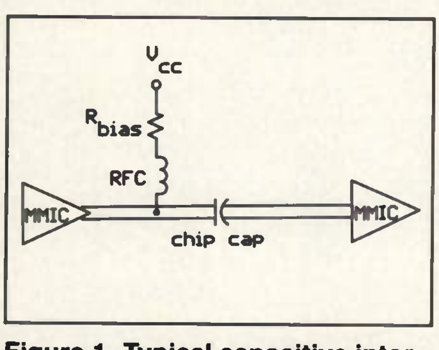

Figure 1. Typical capacitive interstage coupling network.

Even a chip cap of optimal dimensions, however, is not without limitations. A capacitor need not have wire leads to exhibit inductance, and since a transmission line is often modeled as series L, shunt C, it can readily be seen that the additional series L of a chip cap can indeed alter microstrip characteristic impedance. Often, an attempt to minimize this impact is made by selecting the largest practical value of capacitance for a DC block, on the theory that this will swamp out any stray inductance in the chip. Unfortunately, because of the physical constraints of manufacturing multi-layer chip capacitors, the higher the value of capacitance, the higher the residual inductance is likely to be. The process is thus self-defeating.

One solution to the inductance problem is to design for self-resonance. Given the capacitor dimensions required to physically match a given strip, it is possible to calculate the residual inductance of the component. To accomplish this, a capacitance value which will resonate with that particular inductance at the operating frequency is selected.

For example, a 50 ohm microstrip on 1/16 in. fiberglass-epoxy circuit board is roughly a tenth of an inch wide. A chip cap in a 1/10 in. cube should exhibit perhaps 0.5 nH of inductance. At a frequency of 1 GHz, this represents approximately +j3 ohms of reactance. This is not much, but it can be negated by selecting a capacitor with −j3 ohms of reactance, which at 1 GHz works out to about 53 pF. A 50 pF, 0.1 in. cube chip cap is not an atypical choice for 1 GHz interstage coupling.

Even if a chip capacitor of proper dimensions, with negligible inductance, is selected, the fact remains that capacitive reactance varies inversely with frequency. Thus any capacitive interstage coupling network is, unavoidably, a high-pass filter. This can only serve to degrade the harmonic content of any signal being processed. Since nonlinearities in active devices always generate harmonic distortion, it appears that, in the interest of spectral purity, what may actually be desired is not a high-pass but a low-pass coupling network. For narrow-bandwidth applications, a bandpass response would be even better.

Resonator Coupling

Consider the popular edge-coupled microstrip bandpass filter, shown in Figure 2. The circuit, which passes a narrow band of frequencies centered on its resonant frequency, provides significant harmonic suppression and (most important here) affords a DC block between input and output. If properly designed, such a circuit maintains a uniform characteristic impedance across

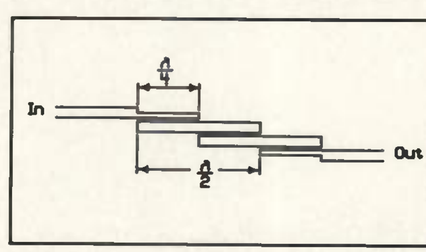

Figure 2. Edge-coupled microstrip bandpass filter.

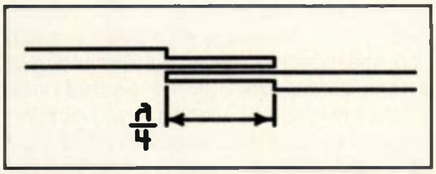

Figure 3. Edge-coupled interstage coupler provides DC blocking, with uniform impedance and low insertion loss over a narrow range of frequencies.

its operating band. Further, it contains no components other than those etched on the substrate; thus its only cost is in circuit board real estate.

That is, however, a significant cost. The individual resonators are each one-half wavelength, and they are overlapped at their midpoints, creating a rather sprawling structure. The number of poles of filtering employed is a function of the required filter Q. For interstage coupling applications, where the coupling network is not depended on for primary control of frequency response, real estate can be conserved by making the number of resonators small, or even zero.

Resonator-Less Coupling

Notice in Figure 2 how coupling into and out of the half-wave resonators was achieved. Edge coupling is accomplished with a quarter-wave matching section, narrower (thus with a higher characteristic impedance) than the input and output lines. This section can be thought of as a quarter-wave matching transformer, with its characteristic impedance the geometric mean of the low impedance of the system and the considerably higher impedance of the resonator.

Why can't two such matching sections couple into each other? They can, of course, as shown in Figure 3. Seen here is an impedance step from the system impedance (say 50 ohms) up to a higher coupling impedance, then back down through an identical section to the system impedance again. Note that the entire coupling circuit occupies only a quarter-wavelength of board space, has a moderate Q response centered on some design frequency, and maintains DC isolation between input and output.

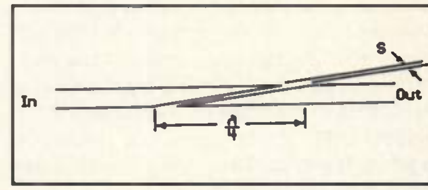

Figure 4. Tapered, edge-coupled resonator provides DC blocking and interstage coupling over a one octave bandwidth.

The Tapered, Edge-Coupled Resonator

The coupling structure described above shares two major drawbacks with all quarter-wave matching transformers. It is effective only for continuous trains of waves (not for pulses), and it functions only over a fairly narrow range of frequencies, centered on the design frequency. For applications requiring wider bandwidths (such as typical interstage coupling), the favored solution has long been the tapered matching section. By gradual transitioning between impedances to be matched, reasonable performance can be achieved over perhaps an octave of bandwidth. And there is no reason not to edge-couple between tapered transformers, just as was done for quarter-wave sections.

The basic topology proposed for interstage coupling is illustrated in Figure 4. Two quarter-wave, tapered, matching transformers are edge-coupled at distance s. The exact spacing is not particularly critical. Loose spacing increases both Q and insertion loss, so for wideband, low-loss coupling, a narrow dimension for s is indicated. For the previously described 50 ohm line on 1/16 in. glass epoxy, the line width is about 2.5 mm, and a spacing of about 0.1 mm is acceptable.

By no coincidence whatever, a tenth of a millimeter is about the thickness of a razor blade cut! This means that once a 50 ohm trace is etched, the coupling network can be fabricated directly on the pc board with a straight edge and an

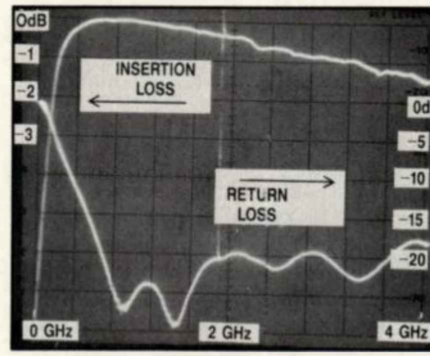

Figure 5. Swept frequency response of a coupling capacitor, self-resonant at 2 GHz.

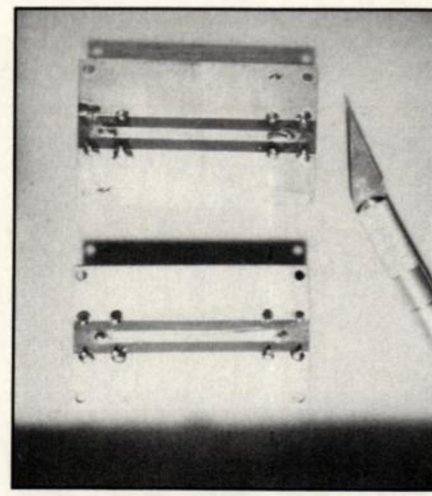

Figure 6. Test substrates before (top) and after (bottom) making the required blade cut.

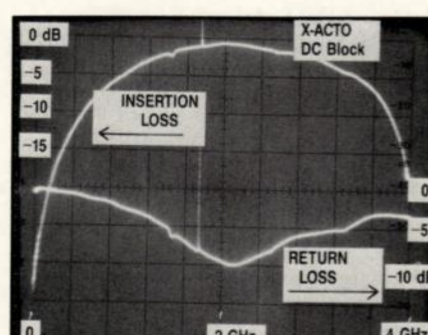

Figure 7. Swept response of the test coupler.

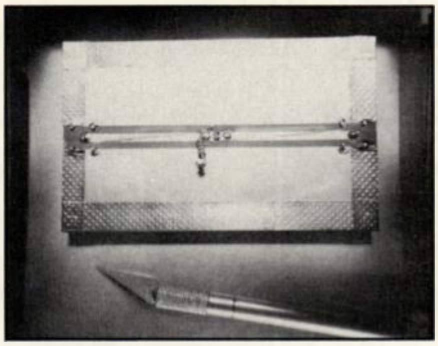

Figure 8. 1.5 GHz MMIC amplifier uses an Avantek MSA-0285.

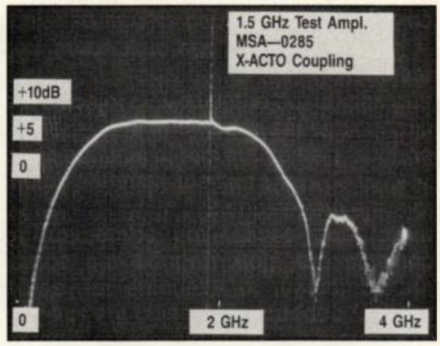

Figure 9. Swept gain response of the MMIC amplifier.

"approxo" knife (there's nothing exact about it).

Even-Harmonic Rejection

The tapered, edge-coupled resonator just described exhibits DC isolation and low insertion loss across a fairly broad band, centered on the frequency at which the tapered sections are a quarter-wave long. But what happens as frequency increases to, say, twice the design frequency? At f times 2, the coupled lines are a half-wave long, and parallel (i.e., not staggered) half-wave coupled lines exhibit a null. Since this null repeats for even multiples of a quarter-wave, it can be seen that the proposed coupling structure actually rejects all even harmonics. Thus, interstage coupling through quarter-wave, edge-coupled resonators has the hidden advantage of improving spectral purity.

Test Results

In order to establish a baseline for comparison, two identical 50 ohm microstriplines, each 3.5 cm long and terminated in SMA connectors at both ends, were fabricated from 0.059 in. thick fiberglass-epoxy printed circuit stock. The residual insertion loss of each was measured as 0.5 dB at 2 GHz. A self-resonant chip capacitor was installed in one microstrip, and swept measurements performed as shown in Figure 5. Note that the additional insertion loss of the capacitor at its resonant frequency is negligible, and that return loss is greatest at resonance.

Next, a knife cut, visible in Figure 6, was made in the other test substrate, to provide a DC block as described above, resonant at 2 GHz. Swept response indicates about 0.5 dB of additional insertion loss, and return loss which indeed optimizes at 2 GHz, although reflections are more pronounced than in the previous case. It is probable that varying the thickness of the knife cut will result in an optimum level of coupling, which should improve the observed return loss. Note the obvious dip at 4 GHz seen in Figure 7, indicating the expected null at twice the design frequency. The edge-coupled resonator performs about as expected.

Design Example

To verify the effectiveness of the proposed coupling device, a MMIC amplifier was built, with input and output coupling by knife cut, a quarter-wave long at 1.5 GHz. The test amplifier is shown in Figure 8, and its swept response in Figure 9. Again, the null at twice the design frequency is quite evident.

Conclusions

A simple knife cut on a microstripline can perform interstage coupling between active devices, afford a DC block, and provide a modicum of selectivity at virtually no cost. Although it is doubtful the technique will ever replace the ubiquitous chip capacitor, it functions as expected, and appears worthy of further study. rf

About the Author

Paul Shuch is founder and chief engineer of Microcomm, 14908 Sandy Lane, San Jose, CA 95124. He heads the Microwave Technology Program at San Jose City College, where he can be reached at (408) 288-3722. He will be spending the 1989-90 academic year as Hertz Fellow in Transportation Engineering at the University of California, Berkeley, where he will further the aviation safety research introduced in the May 1988 issue of *RF Design*.

A General-Purpose Oscillator

By Jonathon Y.C. Cheah
Hughes Network Systems

In a RF laboratory where system concepts are commonly prototyped at very short notice, RF building blocks such as filters, amplifiers, mixers and oscillators are indispensable. Amplifiers and mixers from UHF to L-band are generally available at low cost and broadband specification. Filters and oscillators, on the other hand, pose various problems. Filters at these frequencies are generally designed using passive components and tend to be well-behaved. However, oscillators usually require some effort to realize. The objective of this design note is to construct a reasonably good oscillator very quickly and easily. Design compromises are made with this objective in mind.

The design presented here is a quick and easy realization of an oscillator or a VCO intended for preliminary RF system prototype evaluation. A frequency band of 0.5 to 1.5 GHz has been chosen arbitrarily. This approach can be used for virtually any RF band.

The oscillation conditions for a two-port device are:

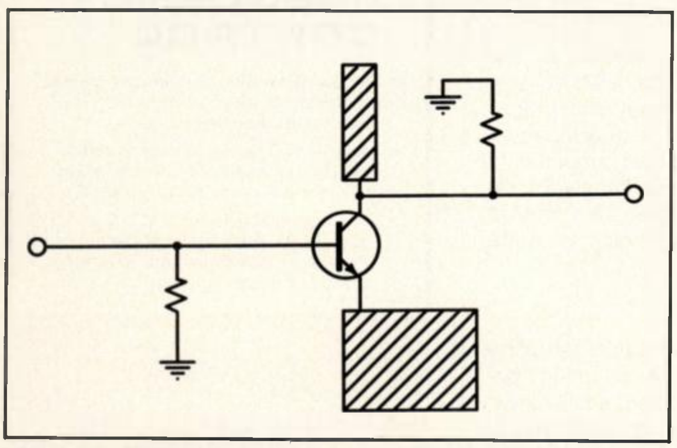

Figure 1. Unstable two-port configuration.

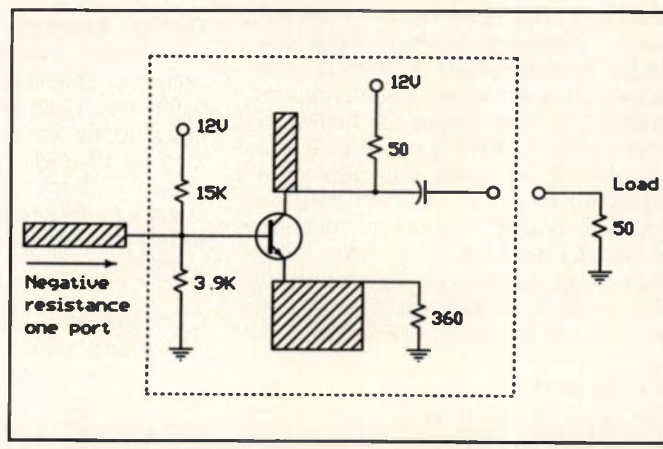

Figure 2. Negative resistance reflection oscillator.

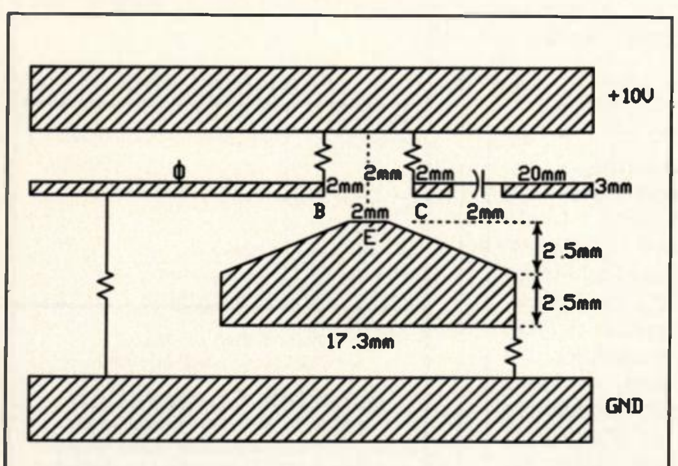

Figure 3. Oscillator printed circuit board. (Not to scale).

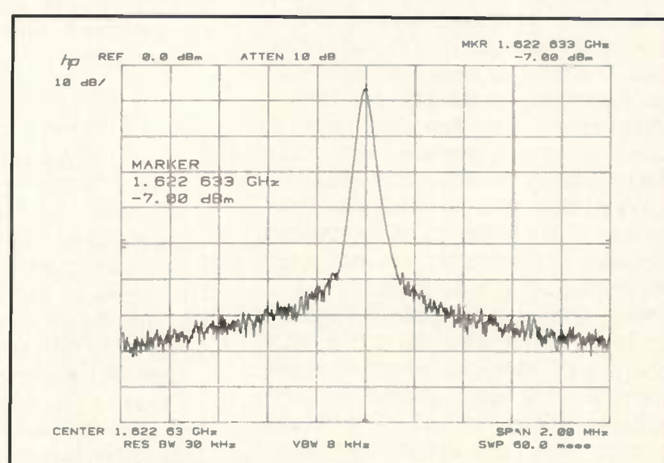

Figure 4. Phase noise plot of the oscillator at 1.68 GHz.

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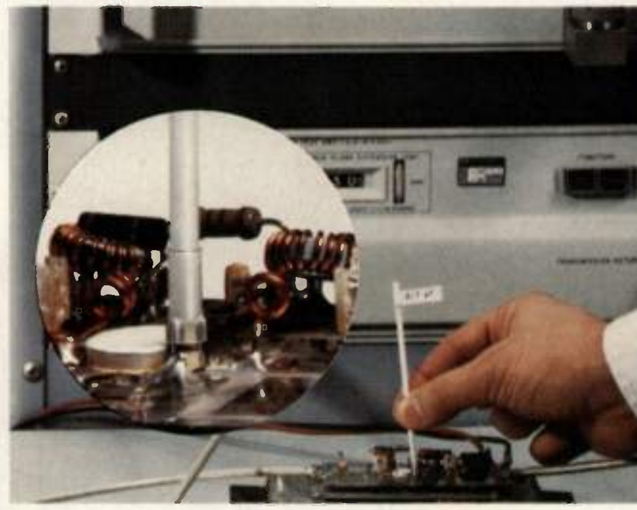

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150 180 220 270 330 390 560 680 820	K

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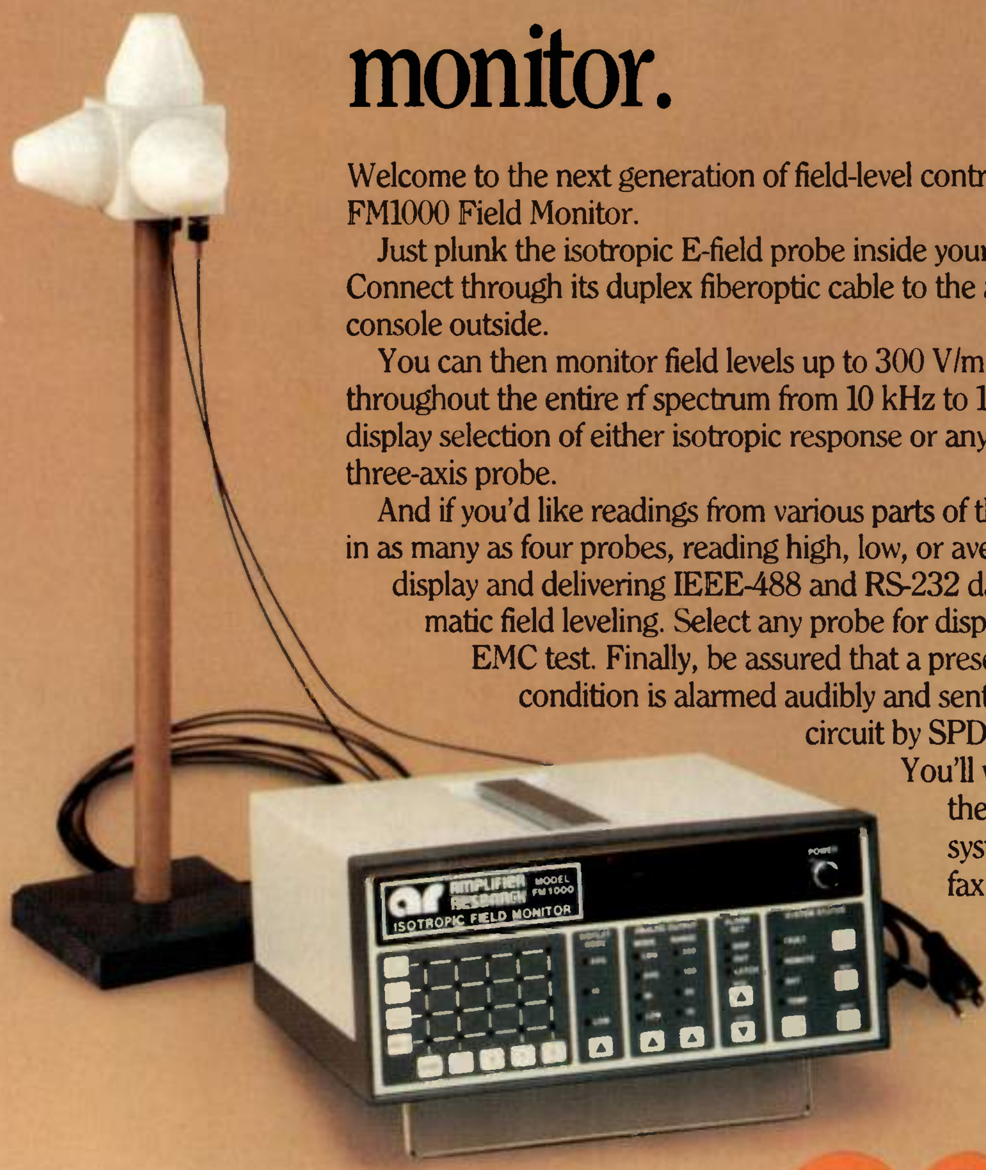

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Frequency	S_{11}	S_{12}	S_{21}	S_{22}	K
0.5 GHz	1.13; −13°	0.20; 81.4°	0.41; −120.2°	1.05; −11°	−0.9
1.0 GHz	1.69; −38°	0.54; 67.5°	1.17; −159.4°	1.29; −29°	−0.7
2.0 GHz	1.66; −162°	0.77; −35.6°	1.77; 76.8°	0.79; −100°	−0.3

Table 1. S parameters for circuit with emitter patch at 15.1 ohms and collector patch at 146 ohms.

Frequency	S_{11}	S_{12}	S_{21}	S_{22}	K
0.5 GHz	1.17; −13°	0.10; 85.9°	0.35; −113.9°	0.09; −75°	−5.1
1.0 GHz	1.98; −43°	0.30; 70.2°	1.10; −153.0°	0.23; −64°	−4.4
2.0 GHz	1.51; −177°	0.28; −41.9°	1.25; 74.6°	0.43; −141°	−2.0

Table 2. S parameters for circuit with emitter patch at 13.6 ohms and collector patch at 158 ohms.

1. Stability constant $K < 1$
2. Product of the input and source reflection coefficients = 1
3. Product of the output and load reflection coefficients = 1

where,

$$K = \frac{1 + |\Delta|^2 - |S_{11}|^2 - |S_{22}|^2}{2\,|S_{12}S_{21}|}$$

$$\Delta = S_{11}S_{22} - S_{12}S_{21}$$

Since conditions 2 and 3 are in fact interrelated, the two-port device can be manipulated as a general case of a one-port oscillator. This approach is used in the design. The MRF901 microwave transistor is chosen for this exercise because it is readily available.

The microstrip layout shown in Figure 1 satisfies the oscillation conditions described above. With the bias point chosen as $I_c = 5$ mA, $V_c = 10$ V; collector patch = 146 ohms, 0.6 degrees at 2 GHz; and emitter patch = 15.1 ohms, 19.4 degrees at 2 GHz, the resultant S parameters are shown in Table 1.

To make the final oscillator more manageable, the output of the two-port device is matched so that it can be buffered for isolation and drive reasons. All that needs to be done to produce an oscillator at the frequency of choice is to match the one-port device created. Figure 1 shows the oscillator circuit. The emitter feedback DC biasing is used here to maintain the accuracy of the S parameters and thus maintain repeatability. It also provides circuit stability.

Under the same DC bias condition and with the emitter patch = 13.6 ohms, 25.9 degrees at 2 GHz; collector patch = 158 ohms, 0.6 degrees at 2 GHz; and a collector 50 ohms matching resistor, the circuit is calculated as shown in Table 2. The maximum output power, P, can be estimated to provide some ideas on the requirement of the buffer amplifier.

$$P = \varrho(1 - 1/|S_{21}|^2 - \ln|S_{21}|^2/|S_{21}|^2)$$

where ϱ is the saturation power of the transistor.

The circuit analysis is provided in Appendix 1. Similar computations can be done for any other transistor of choice. The solutions provided in the appendix agree well with commercially available microwave analysis software results.

To satisfy conditions 2 and 3, an open circuit resonator is used to complete the circuit. Using a 50 ohm line, the electrical length of the resonator can be obtained directly from a Smith chart. When the open circuit resonator length gets too long, there are a number of ways to shorten it. This includes the addition of a shunt capacitor or the use of a short circuit match. These techniques, however, take a little longer tuning time and will not be discussed here.

Construction

The actual preparation of the printed circuit board can be done through photographic processes. Since this is not always the most convenient method, most engineers cut the circuit pattern using surgical scalpels. There is a very simple and efficient way to do this.

First, the wanted microstrip outlines are cut deep enough to penetrate the copper layer accurately. Then, the unwanted copper is carefully peeled off by heating the copper at the edge of the board using a hot soldering iron for a few seconds. A scalpel is then used to lift and peel the copper layer away from the dielectric. The copper in front of the new detached layer must be heated continuously while the peeling process is carried out. With a little practice, a microstrip board such as that shown in Figure 3 can be done very quickly. The layout (Figure 3) is designed to facilitate this construction technique using G10 material of 1.59 mm thickness. All copper strips are straight so that they can be stripped easily.

Frequency (GHz)	Level (dBm)	Resonator Length θ (mm)
0.5	+0.7	135
0.75	+0.0	87
1.0	−2.4	57
1.5	−4.2	33

Table 3. Performance of the oscillator shown in Figure 3.

To transform the microstrip oscillator into a VCO, one can take advantage of the change of S parameters as a function of transistor bias current. This is done by attaching a 20 k ohm resistor to the base of the transistor. The frequency tuning constant can be changed a little by varying the 20 k ohm resistor value.

Results and Conclusions

The performance of an oscillator built using the layout shown in Figure 3 is tabulated in Table 3. The circuit was constructed with 1/8 watt standard resistors and a 90 pF coupling chip capacitor. The circuit performance will improve on the high frequency end if a 50 ohm chip resistor is used. The construction layout and the components used limit the acceptable accuracy of the prediction to below 1 GHz. At about 1.7 GHz, the parasitics of the resistors cause the transistor to re-enter the stable region.

Figure 4 shows the phase noise output of the oscillator at 1.68 GHz.

This simple one-port oscillator circuit design procedure can be adapted to any similar transistor to produce similar results. Higher frequency oscillators can also be built the same way, but one should then worry a little about the loss tangent of the dielectric material used. The refinement of one's cutting skill should also be considered.

References

1. H.B. Gatland, *Electronic Engineering Applications of Two Port Networks*, Pergamon Press, 1976.

About the Author

Dr. Jonathon Y. C. Cheah is principal engineer, VSAT technical manager at Hughes Network Systems, 10790 Roselle St., San Diego, CA 92121. He can be reached by telephone at (619) 453-7007.

Converting S parameters to Z parameters:

$$\begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} = \frac{Z_O}{(1-S_{11})(1-S_{22}) - S_{12}S_{21}} \cdot \begin{bmatrix} (1+S_{11})(1-S_{22}) + S_{12}S_{21} & 2S_{12} \\ 2S_{21} & (1+S_{11})(1-S_{22}) + S_{12}S_{21} \end{bmatrix}$$

Connect the transistor in "Series - Series" with Z_f:

$$\begin{bmatrix} Z'_{11} & Z'_{12} \\ Z'_{21} & Z'_{22} \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} - \begin{bmatrix} \dfrac{jZ_e}{\tan(\beta l_e)} & \dfrac{jZ_e}{\tan(\beta l_e)} \\ \dfrac{jZ_e}{\tan(\beta l_e)} & \dfrac{jZ_e}{\tan(\beta l_e)} \end{bmatrix}$$

where, Z_e is the characteristic impedance of the emitter open circuit line Z_f, and l_e is the electrical length of the line Z_f.

$$\beta = \frac{2\pi}{\lambda}$$

Converting Z parameters to A parameters:

$$\begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} = \begin{bmatrix} Z'_{11} & Z'_{11}Z'_{22} - Z'_{12}Z'_{21} \\ 1 & Z'_{22} \end{bmatrix} \frac{1}{Z'_{21}}$$

Cascading the remaining ladder network:

$$\begin{bmatrix} A'_{11} & A'_{12} \\ A'_{21} & A'_{22} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} 1 & 0 \\ \dfrac{1}{r} & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ \dfrac{-j}{Z_C}\tan(\beta l_c) & 1 \end{bmatrix} \begin{bmatrix} 1 & \dfrac{-j}{\omega_C} \\ 0 & 1 \end{bmatrix}$$

where, Z_C is the characteristic impedance of the collector open circuit line, and l_c is the electrical length of the line.

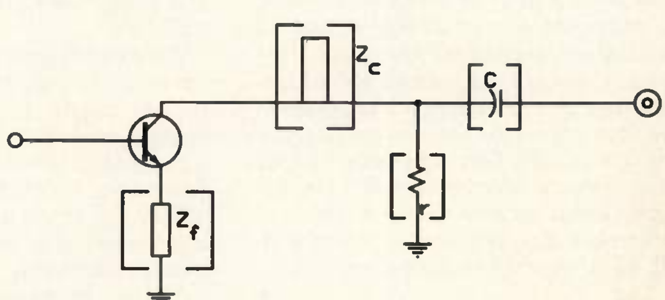
Converting A parameters to S parameters (To avoid lengthy matrix elements, the A parameters are converted to Z parameters):

$$\begin{bmatrix} Z''_{11} & Z''_{12} \\ Z''_{21} & Z''_{22} \end{bmatrix} = \begin{bmatrix} A'_{11} & A'_{11}A'_{22} - A'_{12}A'_{21} \\ 1 & A'_{22} \end{bmatrix} \left[\frac{1}{Z_O A'_{21}} \right]$$

$$\begin{bmatrix} S'_{11} & S'_{12} \\ S'_{21} & S'_{22} \end{bmatrix} = \begin{bmatrix} (Z''_{11}-1)(Z''_{22}+1) - Z''_{12}Z''_{21} & 2Z''_{12} \\ 2Z''_{21} & (Z''_{11}+1)(Z''_{22}-1) - Z''_{12}Z''_{21} \end{bmatrix} \cdot \left[\frac{1}{(Z''_{11}+1)(Z''_{22}-1) - Z''_{12}Z''_{21}} \right]$$

The resultant S′ parameters should agree closely with all the major microwave software packages.

The circuit below aids in the S parameter to Z parameter conversion. Not that Z_e is the characteristic impedance of the emitter open circuit line Z_f, and Z_c is the characteristic impedance of the collector open circuit line.



Appendix 1. S parameter conversions (1).

Designing Facilities for Lightning Protection

By Richard Little
Motorola Cellular Systems Engineering

Each year, lightning inflicts millions of dollars worth of damage to electronic equipment improperly designed or installed. This article presents an examination of the phenomenon and the principles of its control in the design of radio equipment and facilities.

The hundred million volts behind a typical lightning stroke ensure that it will act as a current source. The peak current can exceed 400,000 Amperes (400 kA), while the ionized lightning path's inductance limits its rise time. Most strokes rise to crest in 0.1 to 10 us and fall to half-crest in 20 to 100 us. Most literature on the subject addresses the problem of magnitudes in kA. However, when dealing with radio site grounding networks with at least modestly good bonding (and given the statistical range of magnitudes), inductive voltage drops predominate over resistive drops. Resistive effects may thus safely be ignored. It is appropriate to think in terms of kA per microsecond (kA/us) while tracing the surge through the essentially inductive ground structure.

Small strokes occur more often than large ones, as illustrated in Figure 1. Only about half of all strokes exceeding 10 kA/us will exceed 20 kA/us; just 10 percent will exceed 60 kA/us and only about 1 percent will exceed 100 kA/us. As a way of putting things into perspective, it is helpful to consider the relationship V = L(di/dt). This states that 1 kA/us generates a 1 kV spike across 1 uH, the approximate inductance of a piece of wire one meter in length or of an 8 ft. tall, 19 in. rack full of equipment.

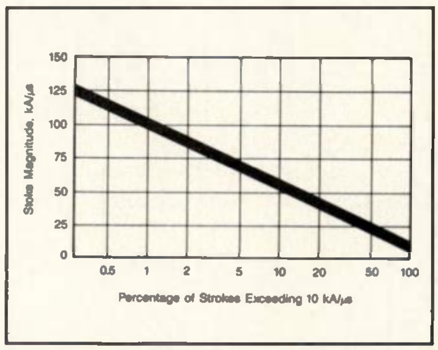


Figure 1. Plot of lightning stroke magnitude versus frequency of occurrence.

The Principles

It is common for the designer getting started in lightning control to worry about the effects of a surge coming down the center conductor of a coaxial cable and wiping out a solid state amplifier's input or output stage. Actually, the sheath carries a higher surge current into the equipment. The following priorities should be kept in mind:

- Protect people!
- Shunt the surge current (to ground) at every opportunity. Design the site and the equipment to attenuate the surge currents that flow through the equipment, and design the equipment to tolerate the residuals.
- Keep the transient voltages within bounds. Design the site to limit the open circuit voltages at equipment interfaces, and design the equipment to tolerate the residuals.

Of these factors, the only areas well covered by established standards relate to the safety of people: equipment design, electrical grounding, cable TV grounding and telephone line protector grounding. Since a radio site, with its tall towers, tends to increase exposure, it is beneficial to review those precepts before proceeding.

Personnel safety dictates tying together everything conductive at a radio site. The essentially inductive network thus created must then be grounded. If not, the full brunt of a tower stroke would find a path (coaxes and cable tray) to the radio room and thence to the power and telephone lines via their protectors, generating potentially lethal voltage differentials all along and around this path. A good ground also reduces the stress on those protectors and increases the reliability of those services.

Outside, free standing towers may appeal aesthetically but guys significantly reduce a tower's inductance. The guys share the surge and distribute the current into ground over a much larger area. Despite this, personnel safety cannot be guaranteed either on or close to a tower or its guys; the current intensity of a large stroke can generate lethal voltage gradients however good the grounding. In addition to tower and guy proximity, step voltage equalization provides electrical protection. Still, a direct strike can blow an antenna asunder, resulting in the hazard of falling debris.

Inside the radio room, "ground" inevitably carries surge current during a stroke. Care must be taken that no two points which a person can touch will expose him or her to danger. However, because of evolution in the telecommunications industry, the magnitudes for people safety and for equipment tolerance have converged. A site that does not expose the equipment tip-ring interfaces any more severely that FCC Part 68 longitudinals (considered in more detail below) also provides reasonable safety for people.

Voltage and Current Considerations

The rapid change in current per unit of time through the various structures and conductors causes damage by generating voltage spikes in and between these objects, both external and internal to the equipment. The equation V = L(di/dt) indicates that unless the voltage is effectively limited by other methods, either the inductance or the current must be reduced, since any reasonably good grounding network

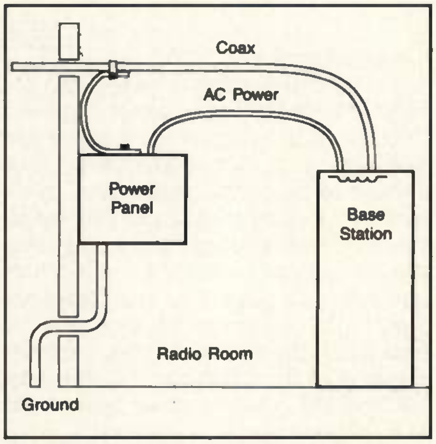


Figure 2(a). A radio site window.

equalizes the rise times in all the conductors irrespective of magnitude. Surge control, and lightning control in particular, therefore combines judicious use of inductance control in surge current attenuation along with selective voltage limiting.

Surge current flowing through a ground structure's inductance can generate voltages within the structure that can disrupt operation and even destroy components. While a discrete solid state analog circuit may tolerate about a 10 V ground differential, many logic families can tolerate only about 1 V, and as little as 0.1 V in a microcomputer's ground can knock it off the rails.

The Window at Radio Room Entry

Figure 2(a) illustrates a simple radio room entry and grounding scheme, revealing the general problems encountered when attempting to shunt antenna coax surge current to ground. The equivalent circuit is given in Figure 2(b). In this entry arrangement, or "window,"

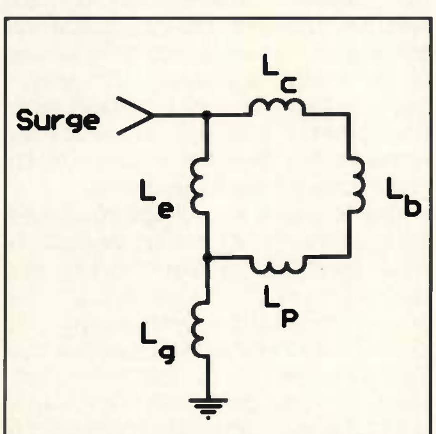


Figure 2(b). Radio site window equivalent circuit.

Attenuation =

$$20 \log [(L_e + L_c + L_b + L_p)/L_e]$$

where L_e is the coax entry bonding strap inductance, L_c is the coax, L_b is the equipment structure between the coax connector and the AC green wire ground tie point, and L_p is the power cord ground wire's inductance. While not rigorously accurate, because of mutual inductance between the power cord ground and the coax, this equation suffices to demonstrate the importance of reducing the shunt inductance at the entry or window. Using a typical bonding strap as shown in Figure 2(a), the arrangement might provide 15 to 20 dB of surge current attenuation. A grounded entry plate may be implemented where the coaxes enter a radio room and the power then distributed from that plate, with all base station connections returned to that plate *and nowhere else*. Under these conditions 30 to 50 dB of attenuation may be achieved (in addition to the attenuation provided by the tower grounding).

Windowing the Base Station

By minimizing L_b, engineers can create another window where external connections attach to a base station. This requires only that these connections attach near one another. Furthermore, since extraneous ground connections result in increased surging through the equipment, a superior design makes it very difficult for an installer to inadvertently provide a ground connection elsewhere, including the floor, adjoining equipment, cable trays and earthquake bracing.

Windowing Within the Base Station

Internal construction offers further opportunities for surge attenuation. Figure 3 illustrates this more generalized case and applies not only to the entry of the base station itself, but to each of the modules within the equipment and even to each subassembly within a module. This arrangement concentrates all the window's surge injecting (outside) connections near one another. In addition, it minimizes the lead lengths of the shunting elements relative to the lengths (inductances) of those grounded connection lead lengths inside the window. Shield or chassis multiple contacts are permitted to either the outside environ-

rfi/emc corner

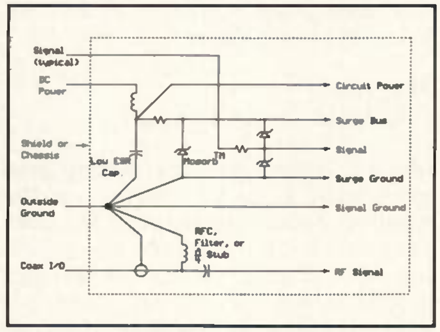


Figure 3. The generalized window.

ment or the inside circuitry, but not to both. AC power connections have been omitted from Figure 3 because normally a transformer would isolate them. Each of these steps can contribute another 15 to 25 dB of surge current attenuation.

Bonding Practices

In implementing windows or trying to reduce inductances within structures, the designer should not depend on the bolts between two painted subassemblies, even with star washers. Equipment assembled in this manner tends to qualify very inconsistently (and, by the way, lights up like a Christmas tree when surge-tested).

To summarize, calculations show that a well-developed site could attenuate a surge by more than 60 dB but that many sites probably offer less than 30 dB of protection. For that reason, every opportunity should be taken to attenuate surges within a base station.

Voltage Control

Voltage control at a site or in the equipment can be implemented by either isolation or limiting. Isolation can effectively remove current surging, while limiting only controls it. Referring again to Figure 2(a), note that during a surge:

- The coaxial cable's center conductor could carry a surge into the equipment unless equipped with a capacitively coupled surge arrester.
- AC hot and AC common, restrained to within surge arrester potential of the power panel, thus impose the drop in L_p on the equipment's power transformer primary insulation. Reducing either L_p or L_e would reduce this stress, but reducing L_p also increases base station surging, again pointing to the necessity of good entry practices.
- If a base station has telephone line connections, mounting and grounding the telephone line surge protectors near the other entry services minimizes the voltage stress on the equipment's isolating transformers.
- The entire surge passes down the conduit from the power panel to ground through an inductance L_g. A surge can generate a potential across L_g high enough to cause the base station to arc over to the (grounded) floor. This inductance can be reduced by cross-bonding the entry plate to outside ground, a halo and the cable trays. The cable trays are then cross-bonded to the halo and the halo to outside ground. But, notwithstanding all the cross-bonding, the base stations are only grounded back to the entry plate.

Voltage Isolation

Transformers and inductors have traditionally provided voltage isolation, but optical couplers and fiber optics offer new opportunities. The capacitance between external wires and the equipment may be ignored as trivial in equipments using only a single power transformer and a couple of audio transformers. However, this capacitance can accumulate to serious proportions in multiport systems. The better transformers exhibit very low *high-frequency* capacitance between the external wires (tip-ring or power) and the other connections (including frame). Ferrite cup-cores for audio offer reduced capacitance, and special winding methods can reduce high-frequency capacitance in power applications. Layout and connectorization offer further opportunities for reducing the capacitance between the external wires and the equipment.

Transformer isolation of RF can completely remove surge current from a radio base station, but few equipments incorporate this method internally. One may obtain a few models of coax lightning arresters that incorporate this full isolation. These do not compensate for a poorly developed site ground because they can only withstand about 5 kV between input and output coaxes. However, they do sometimes solve equipment surge sensitivity problems.

Consider next the voltage breakdown rating of the other isolating devices. To what value can a site constrain the longitudinal stress on tip-rings and the power connections (with respect to ground)? And what about people safety? FCC's Part 68 calls for 2500 V longitudinally on power (protected from people) and 1500 V on tip-rings (which people may inadvertently touch). Equipment designs incorporating these values survive reasonably well in a good installation, but a few improvements can be made.

For tip-rings, it is recommended that the transformers, artwork and connectors be designed to tolerate 2500 V, with an intentional violation of about 2000 V to a low inductance ground so that arc-over follows a controlled path. This ensures Part 68 qualification, with only minute current from capacitive effects. For power, going even higher than Part 68's 2500 V is recommended, but with surge protectors on the site's power distribution box (almost mandatory), the equipment will never experience the 6000 V suggested by IEEE Standard 587 (without surge protection).

Voltage Limiting

Figure 3 illustrates some of the ways to control voltage spikes inside a window. A low ESR capacitor, zener diode or a Mosorb™ (trade name for Motorola's silicon surge protectors) between ground and the outside signal requiring protection will limit the voltage. Series inductors, "soak" resistors or capacitors in series with the signals will limit the current through the limiting devices. If these signals come in from the outside world, however, the limiting devices will inject surge current into internal grounds. Note how these devices are grounded in Figure 3.

On the other hand, limiting the voltage between tip and ring, or power hot and common, on either the transformer's primary or secondary windings offers the opportunity to reduce metallic voltages without injecting surges into the equipment grounds.

Limiting or Isolation?

Inside a piece of equipment, with good windowing practices and if the designer can control the impedances at both ends of a connection, limiting should be considered. Where interfacing to the outside world, alternate methods should be considered. Three such examples are tip-rings, RS-232 ports and coaxial cable center conductors.

For tip-rings, Part 68 longitudinal testing uses 1500 V spikes of both polarities from a source capable of delivering 200 A, to each tip-ring pair while the others just hang there with terminations on them. The designer may isolate or clamp. In a real-world base station, all the tip-rings surge together, often with faster rise times and perhaps even higher net peak current capabilities than Part 68 specifies. Clamping can inject substantial fractions of these enormous surges into the equipment's ground structure; transformers or chokes (with adequate insulation) isolate the equipment from these surges. This explains why experienced designers prefer isolation.

In the case of RS-232 and other ground-referenced connections, even if soaks and clamps protect the signal leads, the signal ground lead in RS-232 connections between a base station and the outside world can introduce substantial surging on an internal ground shared by logic. Often only a few tenths of a volt ground drop in microcomputers and memory will upset operation. It is preferable to converse with base stations through built-in transformer-isolated modems, optical couplers or fiber optics.

Coaxial cables are treated differently. After the implementation of a window of the type in Figure 3 on the receiver front end or the power amplifier, none of the surge current and very little of the residual voltage will reach the solid-state devices via coaxial center conductors in the VHF and UHF equipment. This is because the low inductive impedance to ground in the surge spectrum effectively shunts the surge. In the HF region, diode clamps placed "inside" the capacitor can limit a receiver's input voltage; this usually does not impair performance. At these lower frequencies, protecting transmitter semiconductor devices will challenge the designer. If it must operate during storms, a tube-type amplifier should be considered.

Testing

Surge testing not only offers a valuable way of qualifying the results of the design effort but also provides a useful design tool. Unlike lightning, a good surge generator will inject a known surge through a known path, and permit examination of the resultant voltage transients within and along the path. It permits a gradual increase in the surge magnitude until a failure or an operational anomaly occurs, thus revealing design flaws without massive destruction. A complete surge protection program requires testing. When instituting a surge qualification procedure, it is important to establish values that lend credibility to the practical installation. Criteria should be set for surging any point on the equipment that the installers might improperly ground (between that point and the coax sheath). When the testing program is being implemented, it can be useful to go beyond the specified surge magnitudes. Often a few minor changes will add 10 dB to the tolerance of an equipment.

Summary

The principles of surge protection in the design of radio equipment include: using every opportunity to attenuate the current surging that penetrates the equipment; designing the isolated connections to withstand the residual voltages, with controlled breakdown points; following up to make sure that all participants of the design team understand these precepts and work together; and surge testing the design before putting it into production.

References

1. FCC Part 68, Connecting to the Telephone Network.
2. IEEE Standard 587-1980, Surge Voltages in AC Power Circuits.
3. David Bodle, *Electrical Protection Guide for Land-Based Radio Facilities*, Joslyn Electronic Systems, March 1976.
4. "Fundamental Considerations of Lightning Protection, Grounding, Bonding and Shielding," FAA, July 28, 1978.
5. *Surge Protection Test Handbook*, KeyTek Instrument Corp., 1982.
6. Roger R. Block, *The Grounds for Lightning and EMP Protection*, Polyphaser Corporation, 1987.

About the Author

Richard Little is principal staff engineer with Motorola Cellular Systems Engineering, Cellular Infrastructure Division, 1501 West Shure Drive, Arlington Heights, IL 60004. He can be reached at (312) 632-5032.

Phase Relationships for Maximum Power Transfer

By Robert A. Witte
Hewlett-Packard Company
Colorado Springs Division

Supplying maximum power to a load in a system has always been an important consideration for RF engineers. Ideally, the load impedance is a perfect resistive match (typically 50 ohms). However, the load may or may not present a pure 50 ohm impedance to the generator, so various techniques have been developed to match the load to the generator.

The severity of the mismatch at the load is usually described in terms of the standing wave ratio (SWR) or the return loss. Although the widespread use of SWR and return loss has allowed engineers to make very usable, practical measurements of power transfer, it also tends to obscure some of the basic principles of how electrical energy flows from one device to another. In particular, the phase relationship between voltage and current is important, but cannot be determined from the SWR, since SWR is inherently a scalar quantity. Much insight can be gained by understanding how phase relates to power transfer.

Actually, "power transfer" is a poor choice of terminology, but certainly a common one. Power, p, is defined as the rate of change of energy:

$$p = \Delta E/\Delta t$$

So, what is actually of interest is energy transfer, not power transfer, and power is the measure of how fast energy is being transferred.

Instantaneous Power

The electrical definition of power is voltage times current. More specifically, instantaneous power, p(t), is defined as:

$$p(t) = v(t)i(t)$$

where, p(t), v(t) and i(t) are all time-dependent.

For many RF applications, the voltage and current are sinusoids, so:

$$v(t) = V_0\cos(\omega t + \theta)$$
$$i(t) = I_0 \cos \omega t$$

where, V_0 is the zero-to-peak voltage.
I_0 is the zero-to-peak current.
ω is the angular frequency.
θ is the phase angle between voltage and current.

Note that, in general, there will be a phase difference between the voltage and current waveforms, determined by the complex impedance, Z (Figure 1).

Continuing,

$$p(t) = V_0 \cos(\omega + \theta)\, I_0\cos \omega t$$

$$p(t) = (1/2)V_0I_0[\cos(2\omega t + \theta) + \cos \theta]$$

which states that the instantaneous power has two components:

1. A constant term equal to $(1/2)V_0I_0 \cos\theta$

2. A sinusoid with frequency twice the original frequency

Depending on the value of θ, the instantaneous power can be always positive, always negative, or sometimes positive and sometimes negative.

Usually, the instantaneous power is not as important as the average power, which is found by mathematically averaging the previous equation. The required calculus is shown in Appendix 1. Basically, the sinusoidal term has an average value of zero and all that is left is the constant term, so:

$$\bar{P}_{AV} = (1/2)V_0I_0\cos \theta$$

This shows the relationship between the phase angle θ and the average power. Power engineers have defined

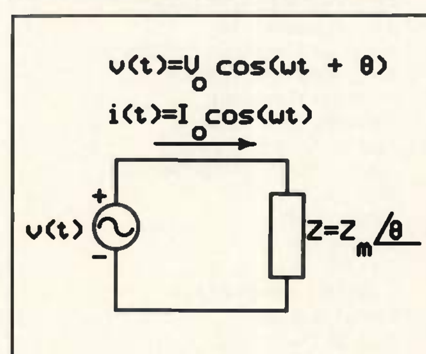


Figure 1(a). Sinusoidal voltage source applied to the load impedance, Z.

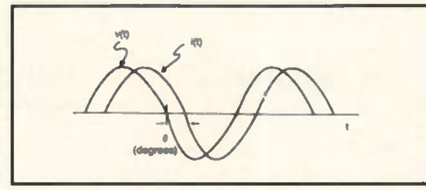


Figure 1(b). Both voltage and current are sinusoidal, but have different phase angles.

the concept of power factor (PF) as:

$$PF = \cos\theta$$

The power factor can vary between −1 and 1 (between 0 and 1 for passive loads), with 1 usually being the most desirable value, since it indicates maximum power transferred. If V_0 and I_0 are considered constant, then θ determines the average power. The voltages and currents can be expressed in terms of their RMS values:

$$P_{AV} = V_{RMS} I_{RMS} \cos\theta = V_{RMS} I_{RMS} PF$$

Also,

$$p(t) = V_{RMS} I_{RMS} [(\cos 2\omega t + 2\theta) + \cos\theta]$$

In order to illustrate the situation better, a few specific cases will be considered.

Resistive Load

First, consider the case where the impedance is just a resistor, R. The voltage and current will be in phase with $\theta = 0$. The resulting instantaneous power, p(t), is always positive and has an average value of $V_{RMS}\, I_{RMS}$ (Figure 2).

$$PF = \cos(0) = 1$$

Reactive Loads

Next, consider a capacitor as the impedance. The phase angle associated with Z is −90 degrees. The voltage, current and power waveforms are shown in Figure 3. The interesting result is that p(t) is positive half of the time and negative the other half. The average power and power factor are both equal to zero.

For sinusoidal waveforms, a capacitor absorbs power when p(t) is positive and supplies power when p(t) is negative. These two actions exactly cancel and the average power is zero.

Similarly, when Z is an inductor, θ equals 90 degrees. The resulting waveforms are shown in Figure 4. Again, p(t) is positive half the time and negative the other half, producing an average power equal to zero. The power factor PF is equal to cos (90) = 0.

Complex Impedances

In general, θ can take on any value between +180 degrees and −180 degrees. Phase angles greater than +90 degrees or less than −90 degrees indicate a negative average power, which means that the device, Z, is supplying the power rather than absorbing it. For passive circuits, this is not the case and θ will have the range +90 degrees to −90 degrees.

As an example, let θ be 45 degrees. This phase angle could result from a Z made up of both a resistor and an inductor. The resulting waveforms (Figure 5) show that p(t) is sometimes positive and sometimes negative, but is positive much longer than it is negative. This results in a net positive value for the average power.

$$P_{AV} = V_{RMS}\, I_{RMS} \cos(45\ \text{deg}) = 0.707\, V_{RMS}\, I_{RMS}$$

$$PF = \cos(45\ \text{deg}) = 0.707$$

Note that the power factor indicates less than maximum power transfer.

A similar case exists when a capacitor and resistor combination are used as Z. Depending on the particular component values and frequency, θ will be between 0 and −90 degrees. The voltage, current and power waveforms for $\theta = -60$ degrees are shown in Figure 6. Once again, p(t) is sometimes positive and sometimes negative, and the average power is a nonzero positive value.

$$P_{AV} = V_{RMS}\, I_{RMS} \cos(-60\ \text{deg}) = 0.5\, V_{RMS}\, I_{RMS}$$

$$PF = \cos(-60\ \text{deg}) = 0.5$$

For other phase angles, the power factor and the average power can be determined using the plot of power factor vs. phase angle (Figure 7).

Zero Phase

The previous analysis and examples show that for the circuit in Figure 1(a), with a given voltage and current, maximum power occurs when θ is zero. This is the same as stating that the impedance Z appears resistive. Z does not actually have to be a pure resistance, but must appear resistive at the frequency of interest.

Source Impedance

The phase between the voltage and current sinusoids is not the only thing that affects the average power. Typically, the voltage sources used (signal generators, radio transmitters, etc.) have a nonzero output impedance (typically 50 ohms). This was not included in Figure 1(a).

Consider a voltage source with a resistive source impedance, R_S, connected to a load, R_L (Figure 8). It is

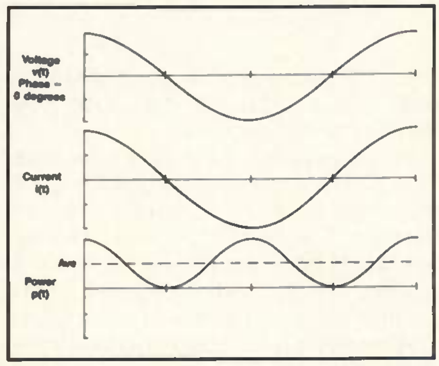


Figure 2. Voltage, current and power waveforms for the case where Z = resistor.

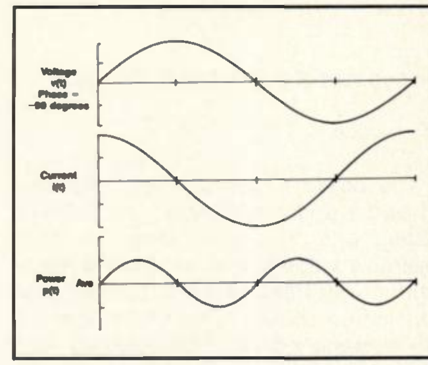


Figure 3. Voltage, current and power waveforms for the case where Z = capacitor.

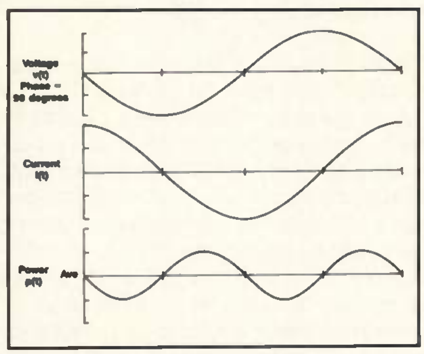


Figure 4. Voltage, current and power waveforms for the case where Z = inductor.

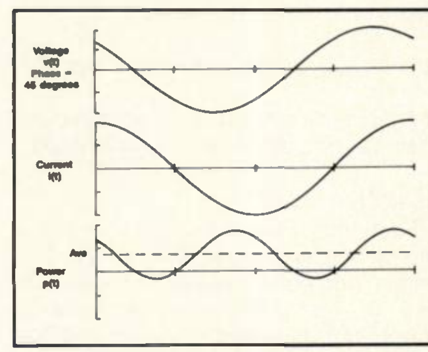


Figure 5. Voltage, current and power waveforms for the case where Z = resistor + inductor.

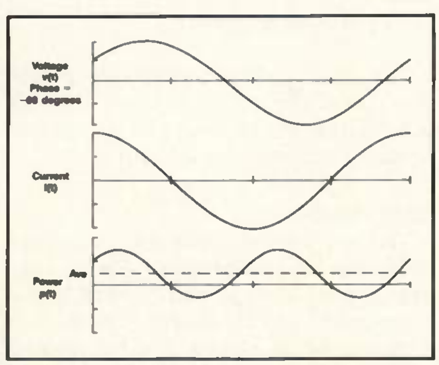


Figure 6. Voltage, current and power waveforms for the case where Z = resistor + capacitor.

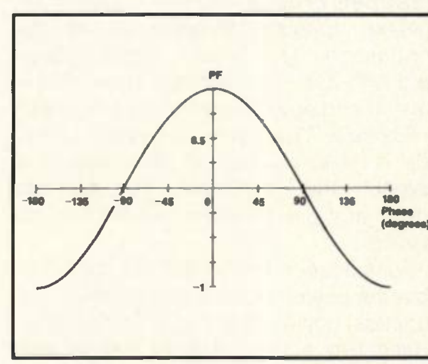


Figure 7. Plot of the power factor as a function of the phase angle.

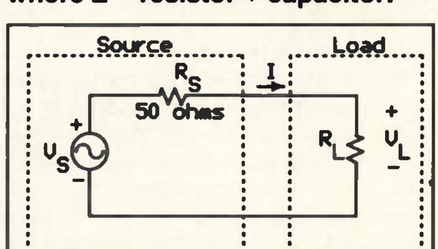


Figure 8. A source with internal resistance, R_S, is connected to the load, R_L.

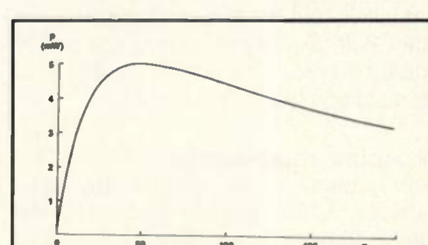


Figure 9. Power to load is plotted assuming V_S=1 volt RMS, R_S= 50 ohms.

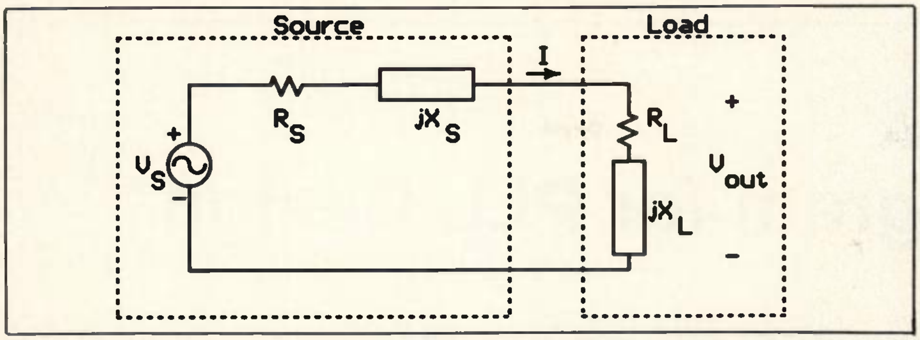


Figure 10. The source and load may be complex impedances (resistance plus reactance).

important to differentiate between the source and load, since the objective is to supply power to the load and not to the source impedance. The well-known principle of impedance matching requires that maximum power to the load will occur when R_L equals R_S. An R_L much larger than R_S will increase the voltage across the load, but will cause the current to decrease. Making R_L smaller than R_S causes the current to increase, but at the expense of a decreased load voltage. Figure 9 shows the power supplied to the load as a function of R_L, assuming R_S = 50 ohms and V_S = 1 volt RMS.

In the general case, the source impedance may not be purely resistive but may also include a reactive component. Figure 10 shows such a source connected to a load which also includes a reactive component. Maximum power occurs for this circuit when the load is the complex conjugate of the source impedance (1). This means:

$$R_L = R_S \text{ and } X_L = -X_S$$

which makes the magnitudes of the source and load impedances the same, but with opposite phase angles.

The voltage source, V_S, sees the equivalent impedance:

$$Z_{EQ} = R_S + jX_S + R_L + jX_L$$

If the load is matched to the source, the two reactances cancel, leaving:

$$Z_{EQ} = R_S + R_L = 2R_S$$

So, again, maximum power occurs when the impedance across the voltage source is purely resistive, producing in-phase voltage and current waveforms (Figure 10).

Summary

There are two parameters involved in obtaining maximum power transfer: the magnitude of the impedances and the phase of the impedances. RF engineers often speak of a load as being "a good 50 ohms," but don't always consider the effect of nonzero phase angle due to reactance in the load. Power factor is not likely to replace SWR in radio frequency systems, but it does provide another way of thinking about power. ∎

References

1. J. David Irwin, *Basic Engineering Circuit Analysis*, Macmillan Publishing Company, 1984.

About the Author

Robert A. Witte is a research and development project manager with Hewlett-Packard's Colorado Springs Division, P.O. Box 2197, Colorado Springs, CO 80919. He can be reached at (719) 590-3230.

$$P_{AV} = \frac{1}{T}\int_0^T p(t)\,dt$$

$$P_{AV} = \frac{1}{T}\int_0^T \frac{V_0 I_0}{2}[\cos(2\omega t + 2\theta) + \cos\theta]\,dt$$

$$P_{AV} = \frac{V_0 I_0}{2T}\left[\int_0^T \cos(2\omega t + 2\theta)\,dt + \int_0^T \cos\theta\,dt\right]$$

$$P_{AV} = \frac{V_0 I_0}{2T}\left[0 + (\cos\theta)\,t\Big|_0^T\right]$$

$$P_{AV} = \frac{V_0 I_0}{2T}(\cos\theta)\,T$$

$$P_{AV} = \frac{V_0 I_0}{2}\cos\theta$$

Appendix A. Average power for sinusoidal voltage and current.

A BASIC Program for PLL Design

By James B. Conn
Naval Avionics Center

The program described in this article is the result of the author's interest in the many phase-lock loop (PLL) articles that have been published over the years, particularly in RF Design. *Rather than discuss PLL theory and design, which is well documented in those articles and other sources, the purpose of this program is to establish a "seed" BASIC program that can be modified by interested individuals. These individuals may then publish their changes in future articles.*

This PLL program provides benchmark references to check against as changes and corrections are made. Some typical additions that could be made to the program are graphics output, divider delay models, phase noise analysis, new benchmark references, and other capabilities that are discussed in Reference 1. Hopefully, the outcome of this effort will be an accurate, easy to use, universal PLL program that all parties can copy and use.

Figure 1 is a listing of the PLL analysis program. The program is based on the work of Andrzej B. Przedpelski, whose models the author considers to be the best and most accurate. References for his work are given in the bibliography. The program, as shown, has two sections. The user has a choice of either using the stability analysis section if the required parameters are known, or calculating his own parameters in the loop parameter calculation section. Table 1 shows the equations and other information used in the program.

Program Operation

The best way to demonstrate the operation of the program is to go through several examples. These examples are considered the benchmark references. Published data from the references will be compared with the PLL program data to

$T_1 = C_1 \times R_1$
$T_2 = C_1 \times R_2$
$T_3 = C_2 \times R_2$

$$T_3 = \frac{\sec\phi - \tan\phi}{\omega_0} \qquad \text{Note: } \sec = \frac{1}{\cos}$$

$$T_2 = \frac{2\tan\phi}{\omega_0}$$

$$T_1 = \frac{K1K2}{N\omega_0^2}\sqrt{\frac{[\omega_0(T_2+T_3)]^2+1}{(\omega_0T_3)^2+1}}$$

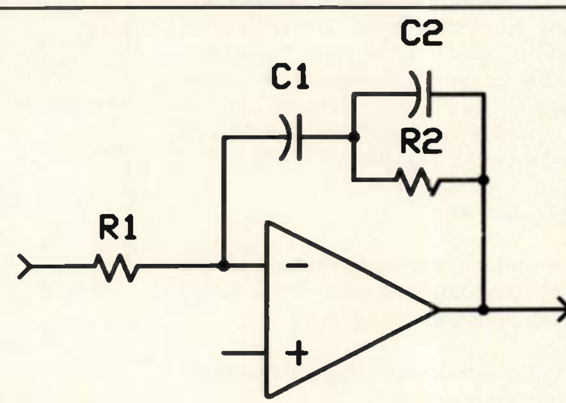
where ϕ = Phase Margin
and ω_0 = Loop Bandwidth

$$G(S)\,H(S) = \frac{K1K2}{N\omega T_1}\cdot\frac{j\omega T_2+1}{j[\omega^2(\omega^2\frac{T_0}{A_0}T_4T_3 - T_3 - T_4) + \frac{1}{A_0T_1}] + \omega(\omega^2T_4T_3-1)}$$

G(S)H(S) = open loop response (DB and DEG.)

$$\frac{G(S)}{1 - G(S)H(S)} = \text{closed loop response (CLR-DB)}$$

$$E/En(DB) = \text{loop response to VCO noise} = \frac{1}{1+G(S)H(S)}$$



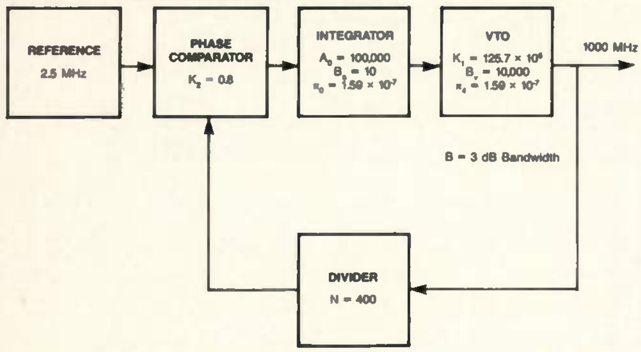
Third Order Loop Integrator

A_0 = DC operational amplifier gain
T_0 = time constant of amplifier's first pole, seconds
T_1, T_2, T_3 = loop filter time constants, seconds
T_4 = VCO tuning input time constant, seconds
ω_0 = cut off frequency (unity frequency), radians per second
N = division ratio
K1 = VCO gain, radians per second per volt
K2 = phase detector gain, volts per radian

Table 1. Summary of the PLL program equations and parameters.

```
10 REM THIS PROGRAM WRITES TO A PRINTER AND SCREEN AT THE
20 REM SAME TIME. A PRINTER SHOULD BE CONNECTED.
30 CLS
40 LPRINT:LPRINT
50 LPRINT DATE$:PRINT "JAMES B. CONN":LPRINT "JAMES B. CONN"
60 PRINT "********************PLL ANALYSIS*************************************"
70 LPRINT "********************PLL ANALYSIS*******************************************"
80 REM ***********LOG SWEEP ONLY******************************************
90 PRINT "PRESS <L> FOR LOOP PARAMETER CAL. OR <S> FOR STAB. ANALYSIS"
100 INPUT A$
110 IF A$="L" THEN GOTO 1130
120 IF A$="S" THEN GOTO 140
130 PRINT "INVALID RESPONSE":GOTO 90
140 CLEAR
150 REM*****************STABILITY ANALYSIS*****************************
160 PRINT "PRESS <T> FOR ENTERING T1,T2,T3 OR <R> FOR R1,R2,C1,C2"
170 INPUT B$
180 IF B$="T" THEN GOTO 220
190 IF B$="R" THEN GOTO 280
200 PRINT "INVALID RESPONSE":GOTO 160
210 IF C$="Y" THEN 220 ELSE 280
220 LPRINT "WHAT IS T1,T2,T3"
230 PRINT "WHAT IS T1,T2,T3";
240 INPUT T1,T2,T3
250 LPRINT T1 T2 T3
260 GOTO 370
270 LPRINT:LPRINT
280 LPRINT "WHAT IS R1,R2,C1,C2"
290 PRINT "WHAT IS R1,R2,C1,C2";
300 INPUT R1,R2,C1,C2
310 LPRINT R1,R2,C1,C2
320 T1=R1*C1
330 T2=R2*C1
340 T3=R2*C2
350 LPRINT "THE VALUES OF T1, T2, T3 ARE"
360 LPRINT T1,T2,T3
370 LPRINT "WHAT IS VCO SENS(K1), PHASE DET GAIN(K2), & N"
380 PRINT "WHAT IS VCO SENS(K1), PHASE DET GAIN(K2), & N";
390 INPUT K1,K2,N
400 LPRINT K1,K2,N
410 LPRINT "WHAT IS OP AMP RESP(T0),VCO RESP(T4),& OP AMP GAIN(A0)"
420 PRINT"WHAT IS OP AMP RESP(T0),VCO RESP(T4),& OP AMP GAIN(A0)";
430 INPUT T0,T4,A0
440 LPRINT T0,T4,A0
450 B#=2.302585093#
460 PRINT"WHAT IS START(B1),STOP(B2),& STEP/DEC(S1) FREQ";
470 REM PRESS CONTROL C TO EXIT PROGRAM
480 INPUT B1,B2,S1
490 LPRINT"*******************************************************************"
500 LPRINT"  FREQ(HZ)"," G(S)H(S)(DB)","    DEGREES","  E/EN(DB)","   CLR(DB)"
510 PRINT"  FREQ(HZ)"," G(S)H(S)(DB)","    DEGREES","  E/EN(DB)","   CLR(DB)"
520 FOR M8=0 TO S1*LOG(B2/B1)*.434295
530 F=B1*(EXP(B#/S1))^M8
540 W=6.2832*F
550 A1=1
560 A2=6.2832*F*T2
570 GOSUB 820
580 P1=P
590 M1=M
600 A1=W*(W*W*T4*T3-1)
610 A2=((W*W*((W*W*(T0*T4*T3/A0))-T3-T4))+(1/A0*T1))
620 GOSUB 820
630 P2=P
640 M2=M
650 G=(((K1*K2)/(N*T1*W))*(M1/M2))
660 A3=P1-P2-180
670 D=20*LOG(G)*.434295
680 GOSUB 1060
690 A1=X
700 A1=A1+1
710 A2=Y
720 GOSUB 820
730 M3=M
740 E=1/M3
750 ER=(N*G)/M3
760 L=20*LOG(E)*.434295
770 LR=20*LOG(ER)*.434295
780 LPRINT F,D,A3,L,LR
790 PRINT F,D,A3,L,LR
800 NEXT M8
810 GOTO 460
820 REM************RECT TO POLAR*************************************
830 IF A1+A2=0 THEN 900
840 IF A1=0 THEN 930
850 IF A2=0 THEN 990
860 P=ATN(A2/A1)
870 P=(P*180)/3.14159
880 M=SQR(A1*A1+A2*A2)
890 GOTO 1050
900 P=0
910 M=0
920 GOTO 1050
930 IF A2>0 THEN 960
940 P=-90
950 GOTO 1050
960 P=90
970 M=A2
980 GOTO 1050
990 IF A1>0 THEN 1030
1000 P=180
1010 M=ABS(A1)
1020 GOTO 1050
1030 P=0
1040 M=A1
1050 RETURN
1060 REM**********************POLAR TO RECT**********************
1070 A=(A3*3.14159)/180
1080 X=G*COS(A)
1090 Y=G*SIN(A)
1100 RETURN
1110 REM*****************LOOP PARAMETER CALCULATIONS**************
1120 CLEAR
1130 LPRINT "WHAT IS K1(R/V-S),K2(V/R),PHASE MARGIN(DEG.),W0(RAD),C1(FARADS),N"
1140 LPRINT
1150 PRINT "WHAT IS K1(R/V-S),K2(V/R),PHASE MARGIN(DEG.),W0(RAD),C1(FARADS),N";
1160 INPUT K1,K2,PM,W0,C1,N
1170 PRINT
1180 LPRINT K1,K2,PM,W0,C1,N
1190 LPRINT:LPRINT
1200 PI=3.141593:RADIANS=PM*PI/180
1210 T3=((1/COS(RADIANS))-(TAN(RADIANS)))/W0
1220 T2=(2*(TAN(RADIANS)))/W0
1230 X1=(K1*K2)/((W0*W0)*N)
1240 X2=((W0*(T2+T3))^2+1)/((W0*T3)^2+1)
1250 T1=X1*SQR(X2)
1260 R1=T1/C1
1270 R2=T2/C1
1280 C2=T3/R2
1290 F=W0/6.2832
1300 LPRINT "T1(SEC)", "T2(SEC)","T3(SEC)", "R1(OHMS)", "R2(OHMS)", "C1","C2"
1310 PRINT "T1(SEC)", "T2(SEC)","T3(SEC)","R1(OHMS)", "R2(OHMS)", "C1","C2"
1320 LPRINT T1,T2,T3,R1,R2,C1,C2
1330 PRINT T1,T2,T3,R1,R2,C1,C2
1340 LPRINT:LPRINT
1350 LPRINT "LOOP BANDWIDTH(HZ) IS"
1360 PRINT
1370 PRINT "LOOP BANDWIDTH(HZ) IS"
1380 LPRINT F
1390 PRINT F
1400 PRINT "PRESS <A> FOR ANOTHER CAL OR <S> FOR STABILITY ANALYSIS"
1410 INPUT C$
1420 IF C$="A" THEN GOTO 1110
1430 IF C$="S" THEN GOTO 140
1440 PRINT "INVALID RESPONSE":GOTO 1400
1450 REM****************LINEAR SWEEP CAPABILITY***************************
1460 REM TO GET LINEAR SWEEP CAPABILITY,
1470 REM OMIT 450(B#=2.302585093#).
1480 REM CHANGE 460,(B1),(B2),STEP/DEC(S1)
1490 REM TO (F1),(F2),INCREMENT(F3).
1500 REM CHANGE 480(INPUT B1,B2,S1)
1510 REM TO INPUT F1,F2,F3.
1520 REM OMIT 520,530(FOR M8=0 TO ETC AND F=B1*ETC).
1530 REM ADD 535,FOR F=F1 TO F2 STEP F3.
1540 REM CHANGE 800(NEXT M8) TO NEXT F.
```

Figure 1. PLL program listing.



ORDER	PHASE MARGIN	T_1	T_2	T_3
3	$\phi = 40°$	1.37×10^{-3}	2.67×10^{-4}	7.42×10^{-9}

Figure 2. Typical PLL example taken from Reference 3.

check program accuracy. Table 1 contains a summary of the PLL program equations and parameters.

Operation of the program begins with prompts asking for a loop parameter calculation or stability analysis. If the loop

Frequency (dB)	Open–Loop Response (dB)	Open–Loop Response /0	Loop Response to VCO Noise
100	116.01	−179.94	−116.01
1,000	76.01	−179.44	−76.01
10,000	36.06	−174.44	−35.92
94,650	0	−139.85	3.27
100,000	−0.71	−138.58	3.30
1,000,000	−26.25	−139.59	0.32
10,000,000	−63.21	−174.68	0.01

Phase margin = 180 − 139.85 = 41.15 degrees

Table 2. Calculated loop response from Reference 2.

parameter calculation is selected, the user can determine the required R and C values for a PLL circuit by inserting the known VCO sensitivity (K1), phase detector gain (K2), a standard starting value of C1 and the required phase margin, loop bandwidth and division ratio. The phase margin is in degrees, usually between 30 and 45 degrees for good stability.

The program will then prompt for another loop parameter calculation or a stability analysis of the determined values. If stability analysis is selected, the program will ask for the appropriate data to be entered. The program has the capability to do a log or linear sweep over the frequency regions of interest. Please note the following items about operation of the program:

1. A printer needs to be connected for proper operation.
2. Press Control-C to exit or restart the program.

```
********************PLL ANALYSIS**********************************
WHAT IS  T1,T2,T3
 .000047    1.706E-06    1.33E-07
WHAT IS VCO SENS(K1), PHASE DET GAIN(K2), & N
 3E+09             .25              64
WHAT IS OP AMP RESP(T0),VCO RESP(T4),& OP AMP GAIN(A0)
 1E-09            1E-09             400000
******************************************************************
  FREQ(HZ)      G(S)H(S)(DB)       DEGREES          E/EN(DB)        CLR(DB)
100             116.0086         -179.9442        -116.0086        36.12365
1000            76.00902         -179.442         -76.00765        36.12502
10000           36.05768         -174.4433        -35.92051        36.26082
100000          -.7102025        -138.6106         3.311661        38.72511
1000000         -26.24788        -139.9321         5.992898E-03   -27.09134
******************************************************************
  FREQ(HZ)      G(S)H(S)(DB)       DEGREES          E/EN(DB)        CLR(DB)
94000           9.037505E-02     -140.0476         3.262065        39.47608

                         Phase margin = 40 degrees
```

Table 3. Program-generated data using Reference 2 parameters.

3. T4 can only be entered as a time constant, in seconds, depending on the R and C values used.

4. T4 can be omitted by making the time constant very small.

5. K1 (VCO sensitivity) is the VCO modulation sensitivity (MHz/volt) multiplied by 2π radians.

6. To obtain phase margin from a stability analysis run, subtract the phase of the open loop response at the unity gain point from 180 degrees (see Table 2).

Examples

Reference 2 gives the following parameters on a 960 MHz transmitter design using a PLL:

N = 64
R1 = 10,000 ohms
C1 = 4700E−12 farads
R2 = 330 ohms
C2 = 470E−12 farads
K1 = 3E9 rad./s-V
K2 = 0.25 V/rad.
T1 = 4.7E−5 sec.
T2 = 1.706E−6 sec.
T3 = 1.551E−7 sec.

The results of the calculator program included in this reference are shown in Table 2. The results from the PLL program are given in the printout of Table 3. The operational amplifier response (T0), VCO response (T4), and operational amplifier gain (A0) were made large to negate their influence. The PLL program also has an additional output parameter which is the PLL closed loop response (CLR). As shown, the data from the PLL program compares very closely with the published data from Reference 2.

Another example (from Reference 3) gives the parameters shown in Figure 2. The variable names have been changed to coincide with the variables used in the PLL program. The data, shown in Table 4, was taken from the graphs provided in the reference. Table 5 is the data generated by the PLL program. The first part of these results uses the loop parameter calculation section of the program to calculate the time constants (T1,T2 and T3) and values of R1 ,R2, C1 and C2. The second part uses the values from Figure 2 to run the

Freq (Hz)	G(S)H(S) (dB)	Degrees	E/EN (dB)	CLR (dB)
100	33	−172	−32	52
1000	0	−148	5	55
10000	−38	—	0	14
Phase margin = 32 degrees				

Table 4. Calculated loop response from Reference 3.

stability analysis section of the program. The PLL program output data shown in Table 5 tracks closely with the data shown in Table 4.

The last example uses the stability analysis section of the PLL program. Table 6 shows the data taken from Reference 4. Table 7 is a printout of the data generated by the PLL program using these parameters.

Conclusions

In this article, a BASIC PLL analysis program has been presented to aid the designer in the development of phase-locked loops. Benchmark references from other published sources have been provided to check the accuracy of the program. The program has been used to design several synthesizers, and the analysis has been found to track very closely with the measured data from the hardware, when closed loop response measurements were made.

This program is available on disk from the RF Design Software Service. See page 47 for details.

```
********************PLL ANALYSIS**********************************
WHAT IS K1(R/V-S),K2(V/R),PHASE MARGIN(DEG.),W0(RAD),C1(FARADS),N

  1.25E+08      .8            40           6280          .000001
  400

T1(SEC)         T2(SEC)        T3(SEC)       R1(OHMS)      R2(OHMS)
C1              C2
 1.359403E-02   2.672293E-04   7.425281E-05  13594.03      267.2293
 .000001        2.778618E-07

LOOP BANDWIDTH(HZ) IS
  999.4908
WHAT IS  T1,T2,T3
  .0137      .000267     .0000742
WHAT IS VCO SENS(K1), PHASE DET GAIN(K2), & N
  1.25E+08      .8            400
WHAT IS OP AMP RESP(T0),VCO RESP(T4),& OP AMP GAIN(A0)
  .0159         .0000159     100000
******************************************************************
  FREQ(HZ)      G(S)H(S)(DB)     DEGREES      E/EN(DB)       CLR(DB)
100              33.45638      -173.7183     -33.27105       52.2266
1000            -1.737207      -151.4971      6.357638       56.6617
10000           -38.66781      -36.49306     -8.123066E-02   13.29222
******************************************************************
  FREQ(HZ)      G(S)H(S)(DB)     DEGREES      E/EN(DB)       CLR(DB)
875             -2.784983E-02  -151.4579      6.156451       58.16987

                   Phase margin = 29.5 degrees
```

Table 5. Data generated by program, using parameters from Reference 3.

References

1. Corinn Fahrenkrug, "CAE Basics for Phase Locked Loops," *RF Design*, May 1988, p. 37.
2. A. B. Przedpelski, "Analyze, Don't Estimate, Phase-Lock-Loop Performance of Type-2, Third-order Systems," *Electronic Design*, May 10, 1978, p. 120.

Frequency (Hz)	G(S)H(S) (dB)	Exact Calculation Degrees	E/E(N) (dB)
0.01	229.59	−141.63	−229.59
0.1	191.67	−175.47	−191.67
1.0	151.70	−179.53	−151.79
10	111.70	−179.75	−111.70
100	71.71	−177.99	−71.71
1,000	32.34	−161.06	−32.14
10,000	3.33	−131.48	−0.82
13,700	0	−136.61	2.64
100,000	−26.33	−253.88	0.11
1,000,000	−108.37	−354.41	0

Phase margin = 43.39 degrees

Table 6. Calculated loop response from Reference 4.

```
********************PLL ANALYSIS**********************************
WHAT IS  T1,T2,T3
  .00201    .0000573    .0000064
WHAT IS VCO SENS(K1), PHASE DET GAIN(K2), & N
  1E+11          .25           8192
WHAT IS OP AMP RESP(T0),VCO RESP(T4),& OP AMP GAIN(A0)
  .016           .0000016      10000
******************************************************************
  FREQ(HZ)       G(S)H(S)(DB)     DEGREES       E/EN(DB)       CLR(DB)
.01              231.7001      -179.9996     -231.7001        78.2679
9.999999E-02     191.7001      -179.9982     -191.7001        78.2679
1                151.7         -179.9822     -151.7           78.2679
10               111.7         -179.8225     -111.7           78.26791
100              71.70548      -178.2261     -71.70323        78.27015
1000             32.22175      -163.0782     -32.01609        78.47356
10000            2.469774      -132.9792      .2042699        80.94194
100000          -27.24924      -74.03706     -.1104506        50.90821
1000000         -109.2883      -174.422       2.978506E-05  -31.02039
******************************************************************
  FREQ(HZ)       G(S)H(S)(DB)     DEGREES       E/EN(DB)       CLR(DB)
12600           -1.359553E-03  -136.1782      2.542067        80.8086

                 Phase margin = 43.84 degrees
```

Table 7. PLL program data using Reference 4 parameters.

3. A. B. Przedpelski, "PLL Primer, Part II," *RF Design*, May/June 1983, p. 12.

4. Ulrich Rohde, *Digital PLL Frequency Synthesizers-Theory and Design*, Prentice-Hall, Inc., NJ, 1983, p. 411.

5. A. B. Przedpelski, "PLL Primer, Part I," *RF Design*, March/April 1983, p. 18.

6. A. B. Przedpelski, "Optimize Phase-Lock Loops to Meet Your Needs," *Electronic Design*, Sept. 13, 1978, p. 134.

About the Author

James Conn is an Electronic Engineer at the Naval Avionics Center, 6000 E. 21st St., Indianapolis, IN 46218 and works in B/815 of the Applied Research Department. He can be reached at (317) 353-7945.

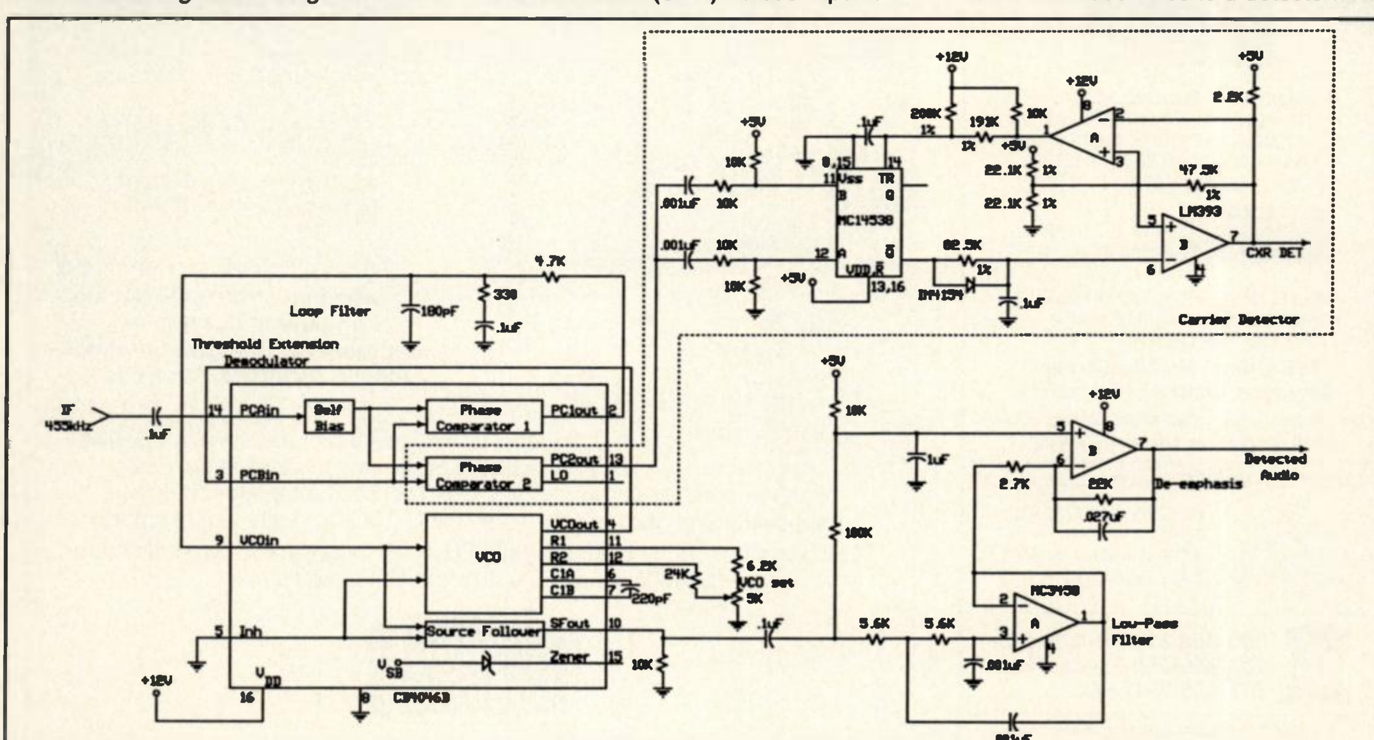
Carrier Detection Utilizing FM Click Characterization

SNR Indication for Satellite Receivers

By Gerald L. Somer
Somersoft

In the demanding world of satellite communication, ground receivers must make use of threshold extension detection (TED) in order to maximize receiver sensitivity and thus reduce the requirement for more expensive, higher power transmitters and power supplies in the satellite. In a balanced system, the ground receiver must contain carrier detector circuits which can accurately indicate the presence of a threshold-level signal; this indicator signal is then used to either gate-on or gate-off the audio or signal path. Described in this article is a simple, fundamentally accurate technique for carrier detection which takes advantage of the FM clicks that are a manifestation of FM threshold. The circuit does not require adjustment, and the signal level range between signal-present and signal-not-present may easily be set by the design to within the specification limit of 5 dB.

A plot of FM detector output signal-to-noise ratio (SNR) versus input carrier-to-noise ratio (CNR) is shown in Figure 1. The solid line is taken as the response of an ideal frequency discriminator against which all other devices are to be compared. The term "ideal" is not meant to imply "optimum." A response very close to ideal would be the result of a well-designed conventional limiter-discriminator circuit. All good discriminators have the same performance at large CNR, but if a discriminator has a lower threshold than ideal it is said to be an extended threshold detector. The



Circuit diagram of TED with carrier detection.

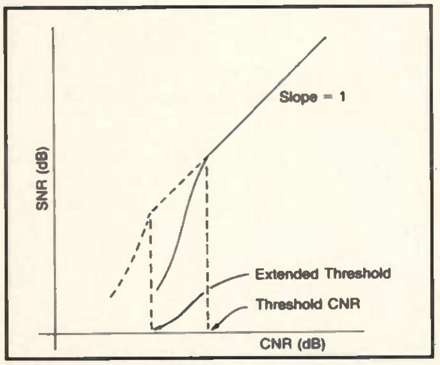


Figure 1. FM threshold effect on SNR.

phase-locked FM detector shown in the circuit diagram is a common implementation of such a device. For proper operation, a phase-locked TED must utilize an EXOR phase detector and the preceding receiver sections must not employ any limiting. It is capable of extending threshold by about 2.5 dB.

Because of the economics of the situation, operation of a satellite system at CNR levels very far above threshold is rare. Therefore, an accurate method of predicting threshold is needed. The output of a below-threshold discriminator can be observed to contain large-amplitude, short-duration spikes or clicks (to use Rice's term). These clicks very rarely appear above threshold and become increasingly frequent as the CNR drops below threshold. In fact, a commonly accepted definition of threshold is the point on the CNR-versus-SNR curve where the added energy of the clicks causes the curve to deviate from linearity by 1 dB. For an illustration of the origin of FM clicks, please refer to Figure 2.

Figure 2(a) is an illustration of the vector sum of a typical carrier signal and a noise component with the reference arbitrarily chosen as a constant-amplitude carrier at zero degrees. For the case when the noise component is less than the carrier component, the vector sum will always exhibit a total phase deviation of less than ±90 degrees. This situation is illustrated by the dashed curves of Figures 2(b) and 2(c). If, on the other hand, the noise component is larger than the carrier component, by even the slightest amount (which is the most common case near threshold), the vector sum will swing a full 360 degrees. The results of this are illustrated by the solid curves of Figures 2(b) and 2(c). With the difference in required noise level being very small, it is clear that the phase velocity of a click can be very high, resulting in a very large spike at the output of a discriminator (since frequency is the time derivative of phase). For this reason, the click rate at threshold is relatively low — on the order of several hundred clicks per minute.

Because an increasing click rate and the onset of threshold are essentially the same thing, a circuit which can detect

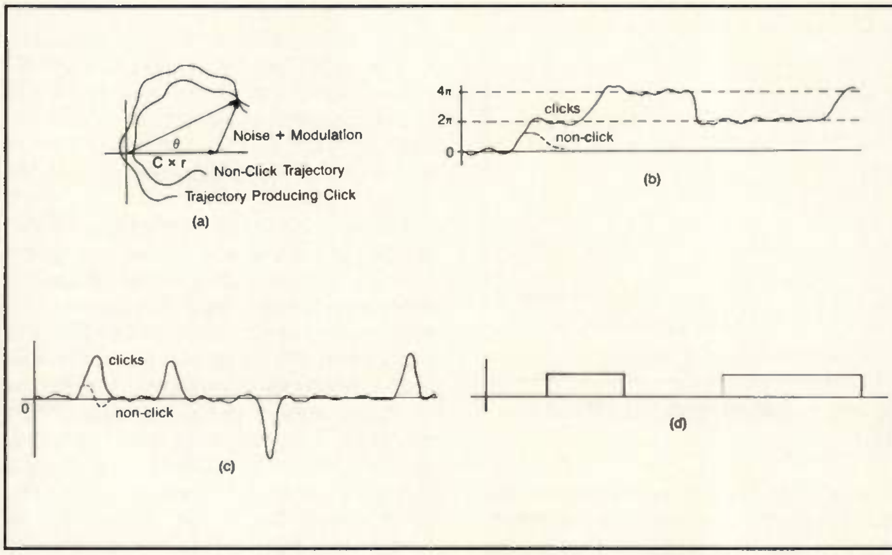


Figure 2. (a) Phasor diagram of click generation; (b) Phase; (c) Frequency; (d) Output of synchronous phase detector.

and characterize the click rate can also be used to accurately indicate the onset of threshold. This is exactly what the circuit presented here can do.

Circuit Description

As stated earlier, the phase-locked FM detector shown in the circuit diagram is a common implementation of a TED. Nothing more will be said about it except that its loop parameters have been optimized for best threshold extension in its particular application (an SCPC receiver with a choice of either 30 kHz or 22.5 kHz channel spacing). The variable resistor is used to set the initial VCO frequency to ensure lockup and may be replaced with fixed resistors if suitable tolerance components are used. The circuitry within the dashed block comprises the carrier detector.

The 4046 synthesizer chip is an ideal component for this type of application, primarily because it contains both an EXOR phase detector (required by the TED) and a synchronous phase detector. A characteristic property of the EXOR phase detector is that when the loop is locked, the nominal condition will be that the two inputs to the phase detector are in quadrature. In contrast, a characteristic of loops using the synchronous phase detector is that the two input signals will be locked with nearly zero degrees phase difference. In the present situation, where the EXOR phase detector is in the loop and the synchronous phase detector is not, yet shares the same input signals, the output of the synchronous phase detector will be saturated either high or low and will only change state if the loop slips a cycle. This will also be the case during a click. This operation is illustrated in Figure 2(d). If one were to trigger a scope on every transition at Pin 13 of U1, a click corresponding to each transition would be observed at Pin 10, and the clicks would be observed to be much larger in amplitude than the surrounding non-click noise.

The signal at Pin 13 of U1 is differentiated and applied to both trigger inputs of the precision retriggerable monostable U2A. In this manner, the monostable will be triggered off both leading and trailing edges of the phase detector's output. The time constant of the monostable is dependent on C12, R18, R19, R20, and the state of U4A —an open-collector comparator used as an inverter. For this application, the time constant in effect when the output of U4A is high (equivalent to carrier not present) is 3 milliseconds. The time constant in effect when U4A is low (equivalent to carrier not present) is 7.5 milliseconds. The reason for this dual time constant will be made clear later. Another delay (or post filter) network is situated at the output of the monostable and is comprised of R17, C13, and CR1. Its components are arranged to charge C13 quickly when the monostable times out, and to discharge C13 slowly when the monostable is set. The discharge time constant of this post filter is set to cause the output comparator, U4B, to change state after 7 milliseconds. The large amount of hysteresis at the output comparator prevents the output from rattling up and down due to ripple on the post filter.

In the case when the carrier is below threshold, the high noise rate at the output of U1 will cause the monostable to be continually reset. As the carrier is slowly increased, there will be a level where the time between two consecutive clicks will reach 7.5 milliseconds and the monostable will time out. This event will quickly charge C13 through CR1 and cause the output of U4B to go low, indicating carrier present. At this instant, the time constant of the monostable is changed from 7.5 milliseconds to 3 milliseconds.

In the case when there is a carrier just above threshold, the low click rate will occasionally trigger the monostable which will produce 3-millisecond pulses at its output. This amount of time is not sufficient to discharge C13, which requires 7 milliseconds, and C13 will quickly recharge at the end of each 3-millisecond period. To discharge C13 to the point where the output comparator will change state requires that the carrier level be reduced to the point where the click rate will provide at least three clicks within a 6-millisecond interval. Because the monostable is retriggerable, this 6 milliseconds plus the 3-millisecond time-out period of the monostable will provide more than the 7 milliseconds that is required to discharge C13.

Summary of Performance

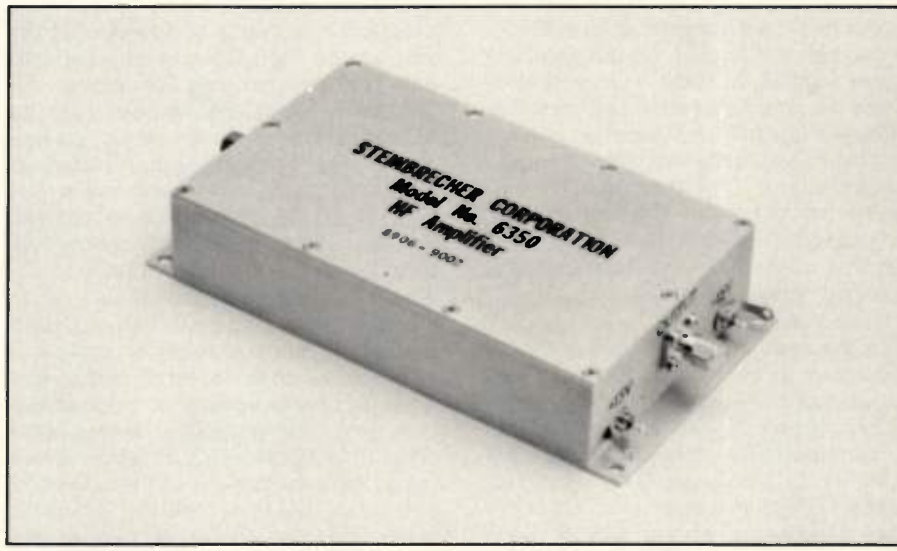
As can be seen from the above discussion, the dynamic switching of the monostable period along with the dual time constant of the post filter provides a sufficient degree of freedom in characterizing the FM click rate to independently set, by changing component values, the two CNR values used to indicate either carrier-present or carrier-not-present. For this particular application, the carrier-present indication has been set at 0.5 dB below threshold and the carrier-not-present indication has been set at 4.5 dB below threshold, for a difference between the two of 4 dB. In the lab, it has also been demonstrated that a difference of 3 dB or smaller is easily obtainable through component changes. For purposes of these measurements, the indication levels were chosen to be those CNR levels which cause false indications at the rate of 12 per minute. Between the two indication levels, the false indications happen at a much higher rate; within a fraction of a dB outside this range, the falsing completely stops. rf

About the Author

Gerald L. Somer is owner of Somersoft, 2939 Burnside Road, Sebastopol, CA 95472. He is currently consulting for Noller Communications and Avantek, Inc. His telephone number is (707) 829-0164.

Steinbrecher Announces New High Dynamic Range Products

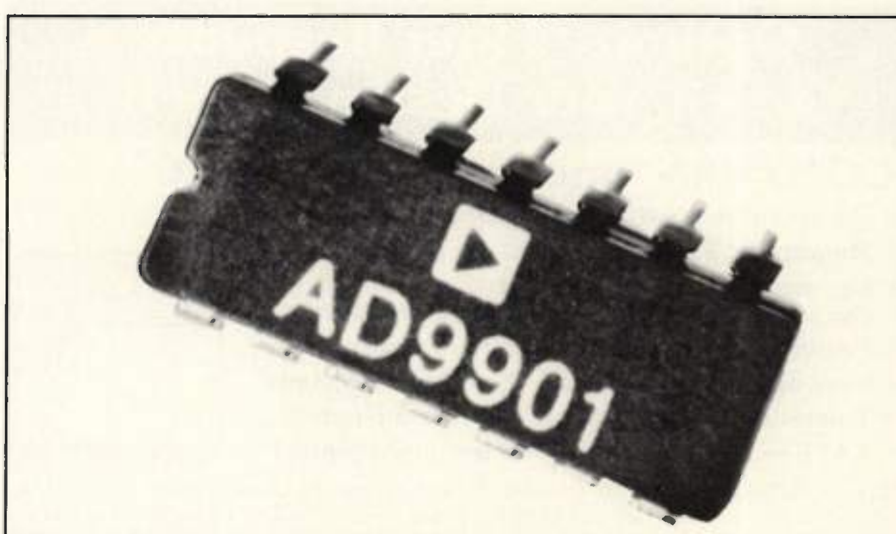
The Accuverter™ RF-to-digital converter is divided into two separate modules. The RF section, with RF to baseband translation, forms a family of tuners with bandwidths up to 8 MHz providing up to 120 dB of spurious-free dynamic range in a 1 kHz bandwidth. The digital converter section of the Accuverter is a linear baseband-to-digital converter, which can be fitted to most receivers and can effectively convert baseband analog signals to digital words with up to 96 dB of spurious free dynamic range.



Also from Steinbrecher is the Model 6350 high frequency amplifier. This push-pull amplifier is designed for use in the front-ends of broadband HF receiving systems. Low noise figure and low intermodulation distortion are featured. The amplifier also demonstrates low input and output VSWR, making it the ideal input amplifier for multi-couplers requiring high output-to-output isolation. Frequency range is 2 to 32 MHz, gain is 11 dB, and third order output intercept is +55 dBm. Second order output intercept is typically +100 dBm and VSWR is 1.15:1. **Steinbrecher Corp., Woburn, MA. INFO/CARD #230.**

Analog Devices Introduces a 200 MHz Phase/Frequency Detector

The AD9901 is a phase/frequency detector that is capable of comparing signals up to 200 MHz. Specifications include a linear phase detection range of 360 degrees, 320 degrees and 270 degrees at 40 kHz, 30 MHz and 70 MHz, respectively. Output current is from 1 to 10 mA with programmable voltage swing up to 1.8 volts peak-to-peak.



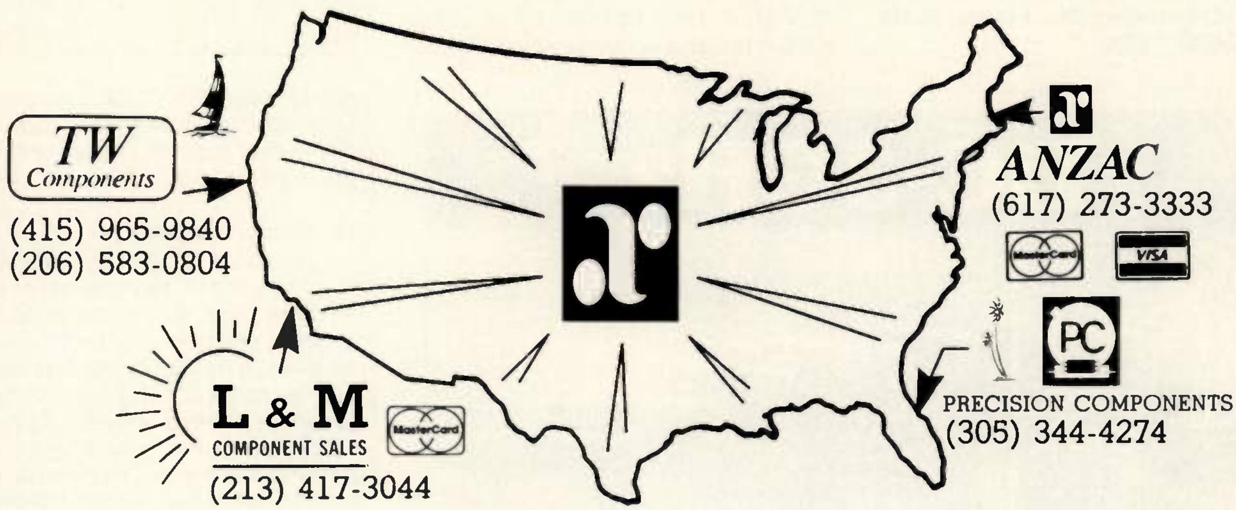
Phase/frequency detectors are used in a wide range of phase-locked loop applications, including frequency synthesizers, frequency multipliers, oscillators and demodulators. This device produces a variable pulse-width output signal, whose width varies according to the phase/frequency difference between two input signals. Constant phase gain through the middle of its phase detection range eliminates the "dead zone" from the device's transfer characteristics.

Specific operating temperature ranges for the AD9901 are 0 to +70°C for KQ grades and −55 to +125°C for TQ/TE versions. Packaging options include a 14-pin ceramic DIP or 20-terminal LCCF. Nominal power dissipation is 215 mW.

In 100s, the AD9901KQ costs $8.00. TQ and TE grades are available at $24 and $33, respectively. **Analog Devices, Inc., Norwood, MA. INFO/CARD #229.**

RF & MICROWAVE NEWS

ANZAC Announces Coast to Coast Distributors



Burlington, Ma. The *ANZAC* division of Adams-Russell recently announced the opening of three distributors in the United States. The introduction of one distributorship in Florida, two on the West Coast, and *ANZAC*'s own standard product distribution center in Massachusetts now makes local procurement of *ANZAC* catalog components easier than ever.

A spokesperson for *ANZAC* expounded on the advantages design engineers and procurement agents are receiving by dealing with their local *ANZAC* distributor. "By opening regional distributors, we now offer 2 distinct advantages to our customers. The first is local delivery. Each distributor is fully stocked with *ANZAC* components and can provide off-the-shelf delivery in 24 hours or less. The second advantage is service. *ANZAC* distributors have years of technical experience in the RF & Microwave industry and are already familiar with the *ANZAC* product line. They can offer technical assistance to design problems and provide the devices to solve those problems right away."

Future plans for *ANZAC* distributors include the sale of components from other Adams-Russell Components Group companies such as RHG Electronics and SDI Microwave. *ANZAC* distributors are presently fully stocked. For more information, interested parties in these areas should call their local distributor direct.

No. California, Washington, Oregon:
TW Components
625 Ellis Street, Suite 101
Mountain View, CA 94043
(415) 965-9840
(206) 583-0804 - IN SEATTLE

So. California:
L&M Component Sales
8939 So. Sepulveda Blvd.
Suite 104
Los Angeles, CA 90045
(213) 417-3044

Southeast United States:
Precision Components
12020 N.W. 40th Street # 203
Coral Springs, FL 33065
(305) 344-4274

All Other Domestic:
Adams-Russell
ANZAC Division
80 Cambridge Street
Burlington, MA 01803
(617) 273-3333

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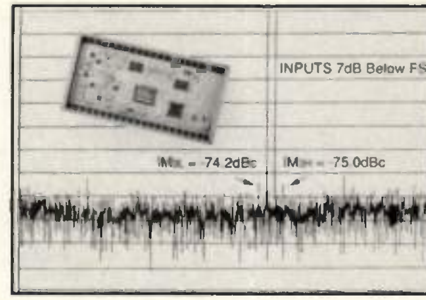
Fixed Frequency Receiver

Cyclo-Comm Division's Model R500 fixed frequency receivers provide AM, FM and/or AGC outputs from signals in the 136-520 MHz or 1435-2500 MHz bands. Six IF bandwidths are available. The 1435-2500 MHz unit is supplied with a remote filter-preamplifier. **Cyclo-Comm Div., Techtrol Cyclonetics, Inc., New Cumberland, PA. Please circle INFO/CARD #228.**

12-Bit A/D Converter

The CLC926 is a 12-bit analog-to-digital converter subsystem. It includes a 12-bit quantizer, internal track-and-hold, reference circuitry, and error-correction circuits. Specifications include an SFSR of 67.2 dB at 4.996 MHz (66 dB min) and 75.8 dB at 404 kHz (69 dB min). This is coupled with an SNR of 66.7 dB at 4.996 MHz (65 dB min). The device features a 10 megasamples/sec



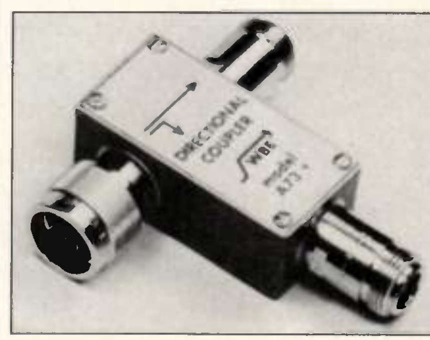
update rate. The CLC926AI is a 40-pin DIP that is priced at $925 in the 100-piece quantity. **Comlinear Corp. Fort Collins, CO. INFO/CARD #227.**

HF Radio System

The Harris RF-950 system includes four receivers, two high-speed data modems, two 1 kW transmitters, two antenna couplers and four new switch matrices. A frequency management system is optional. The switch matrices include a receive antenna matrix, data matrix, audio matrix and high/low-level transmit RF matrix. The matrix panels can be controlled via an RS-422 bus. **Harris RF Communications, Rochester, NY. INFO/CARD #226.**

Directional Coupler

Wide Band Engineering introduces a 1-1000 MHz directional coupler that features 20 dB coupling. In-line power is 2 watts CW, minimum directivity is 30 dB and flatness of the coupled port is ±0.25 dB. VSWR for the 10-1000 MHz



range is 1.1:1 and 1.5:1 for the 1 to 10 MHz range. This 50-ohm unit comes with BNC-type connectors. Price is $300. Other connectors are available at additional cost. **Wide Band Engineering Company, Inc., Phoenix, AZ. Please circle INFO/CARD #225.**

RF Power Amplifier

Model A1010 from Amplitech provides a minimum of 10 watts of linear RF output between 10 and 1000 MHz with typical gain flatness of ±1.0 dB.

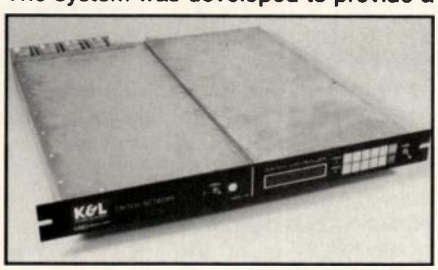
Associated IM distortion is measured at −25 dBc typical, input VSWR is 2:1 max, output VSWR is 3:1 max, and harmonic output at 10 watts output is −22 dBc max. **Amplitech, Inc., Fairfield, NJ. Please circle INFO/CARD #224.**

Programmable Filter/Amplifier

This 2 MHz programmable filter/amplifier offers an attenuation slope of 80 dB/octave. Series 6611A can provide 16 anti-alias filter/amplifiers or eight bandpass filter/amplifiers with differential input, pre-filter and post-filter gain, calibration and monitoring. Choice of filter characteristics includes 6 pole, 6 zero elliptic high-pass and low-pass filters; 6 pole, 6 zero constant time delay filters (linear phase); and 6 pole, 6 zero, user selectable, high-pass or low-pass filters, set by an on-card switch. The filters offer channel-to-channel match with ±2 degrees typical phase match to 2 MHz. **Precision Filters Inc., Ithaca, NY. INFO/CARD #223.**

Modular Switching System

K & L introduces the Model 115 modular switching system which provides an interface to coaxial switches. The system was developed to provide a



means of controlling the various coaxial switches, used in applications such as automated test stations, scanners and multiplexers, from a remote computer or manually from the front panel. This unit comes with 4-1P8T or 3-1P10T coaxial switches mounted on the rear panel. **K & L Microwave Inc., Salisbury, MD. INFO/CARD #222.**

N-Type Female Connector

This N-type female connector is designed for use with microstrip, stripline and coplanar-waveguide applications. The center conductor pin has a 30 mil diameter, which approximately equals the width of the transmission line conductor. It is flange-mounted with good electrical characteristics through 12.4 GHz, and is completely mode-free past 18 GHz. The standard connector includes an electroless nickel plating on a stainless steel body, gold plated inner conductor and a PTFE insulator. The mechanical and environmental specifications meet MIL-STD-39012 requirements. **Shason Microwave Corp., Houston, TX. INFO/CARD #221.**

Peak Reading Wattmeter

Bird introduces the Model 4314B portable peak reading wattmeter designed for the measurement of air navigational aids and other pulsed RF

systems such as telemetry, radar, television, and command and control, as well as peak envelope power (PEP) measurements of SSB and AM signals. A CW/peak switch on the front panels of the unit allows quick selection of operational mode. Power and frequency range are 100 mW to 10 kW and 0.45 MHz to 2300 MHz using Bird plug-in elements. The unit is rated at a maximum insertion VSWR of 1.05:1 to 1000 MHz and 1.1:1 to 2300 MHz. Accuracy is ±5 percent of full-scale CW and ±8 percent of full-scale peak. **Bird Electronic Corp., Cleveland, OH. INFO/CARD #220.**

Sampling Phase Detector

The MSPD 1000 Series sampling phase detector is useful to phase lock DROs and VCOs up to 20 GHz to reference oscillators. It provides a fast step recovery diode and high Q coupling capacitors which drive a matched Schottky pair to sample the microwave signal. In the 10 to 24 piece quantity, it is priced at $36. **Metelics Corp., Sunnyvale, CA. INFO/CARD #219.**

Sub-D Interface

AMP introduces an interface that uses 2.8 mm blindmate coaxial contacts assembled with AMPLIMITE MIL-C-24308 style blindmate connectors. The 2.8 mm fixed plug contacts terminate RG-405 semirigid cable and provide low VSWR performance to 40 GHz. They exhibit a maximum engagement force of 3 pounds, and offer a durability of 500 mating cycles. **AMP Inc., Harrisburg, PA. INFO/CARD #218.**

GaAs Switch Family

These GaAs switches are available in surface-mount, connectorized, TO-8, DIP and flatpack packaging. Options include built-in 50 ohm terminations for the unselected ports and hi-rel screening. The devices feature integral TTL or CMOS drivers. **Daico Industries, Inc., Compton, CA. INFO/CARD #217.**

High Power Tees

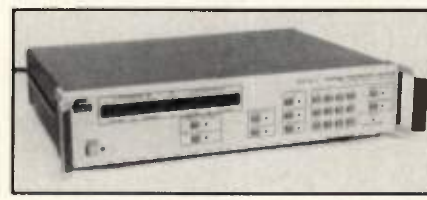
Model 9460 is a high power tee that features an SWR of 1.2 or lower. Model 9460-.08-XX has a frequency range of 0.4 to 1.3 GHz and Model 9460-1.0-XX has a 0.5 to 1.6 GHz frequency range. **Alford Manufacturing Company, Woburn, MA. INFO/CARD #216.**

200 MHz TCXO

KS Electronics introduces a line of TCXOs featuring frequencies up to 200 MHz. Temperature stability is ± 2 ppm from −55°C to +105°C and ± 1 ppm from −30°C to +85 °C. Harmonics are down to −20 dBc and spurious is down to −70 dBc. Output in 50 ohms is +10 dBm and SSB phase noise at 1 kHz offset from the carrier is −125 dBc/Hz. **KS Electronics, Phoenix, AZ. INFO/CARD #215.**

Programmable Attenuator Controller

Flann Microwave unveils a line of control processors for use in conjunction with their line of programmable attenu-



ators and phase shifters. Settling times are 1.2 seconds from 0 to 60 dB and 70 ms from 50 to 60 dB. Phase shifters can be repositioned from 0 to 360 degrees in 320 ms. **Flann Microwave Instruments Ltd., Bodmin, Cornwall, UK. Please circle INFO/CARD #214.**

Water-Cooled Power Triode

The 7835 is a water-cooled large power triode for use in long-range search radar, pulse transmission in communication service, and particle

accelerator applications. When used as a plate-pulsed amplifier in Class B service, the Burle 7835 has a pulse power output of 5000 kW at 250 MHz.

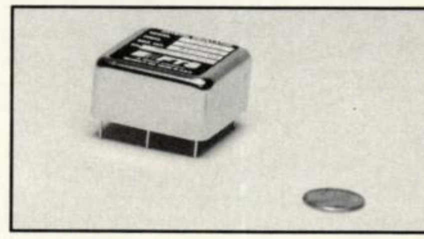
Also from Burle is the 4648 power tube. It is rated as an RF power amplifier in Class C telegraphy service, as a plate

modulated amplifier in Class C telephony service, and as a power amplifier in Class B plate-pulsed service. The tube delivers up to 350 kW of CW power and a pulsed output up to 1000 kW, operating with a power gain up to 28 dB. It is a liquid-cooled, beam power tube of ceramic and metal construction.

The Burle 4616 ceramic and metal water-cooled power tetrode provides 275 kW at 425 MHz at a pulse duration of 2000 us. Frequency range is 195 to 600 MHz and typical applications include search radar and particle acceleration applications. **Burle Tube Products Div., Lancaster, PA. Please circle INFO/CARD #213.**

Ovenized Crystal Oscillator

Model FTS 2510-AT is an ovenized crystal oscillator that features sine or TTL outputs in the 4 to 16 MHz range. Typical specifications for a 10 MHz unit include phase noise of −95 dBc at 10 Hz and a floor of −150 dBc. Thermal stability is ± 2.5 X 10^{-8}, while aging is 3 X 10^{-9}/day and 5 X 10^{-7}/year. In the 1 to



10 second interval, short-term stability is 5 X 10^{-11}. In small quantities, prices range from $250 to $350. **Frequency and Time Systems, Inc., Beverly, MA. Please circle INFO/CARD #212.**

SP5T Switch Module

The TCSWM-13-45 is an SP5T switch module that is usable up to 3 GHz. It is housed in a TC-45 20-lead glass beaded metal package that measures 0.625 in. X 0.625 in. X 0.146 in. Typical insertion loss is 1.8 dB at 2 GHz with associated VSWR of 1.4:1. Isolation is typically 70 dB at 50 MHz and 45 dB at 2 GHz. Power handling is 30 dBm for 1 dB insertion loss compression and switching time is typically 70 ns. **Tachonics Corp., Plainsboro, NJ. INFO/CARD #211.**

SMA Launchers

M/A-COM Omni Spectra introduces SMA field replaceable jack launchers in various flange designs. These include 0.500 in. 4-hole, 0.375 in. 4-hole, 0.625 in. 2-hole, and 0.550 in. 2-hole. Frequency range is DC to 18 GHz and VSWR is 1.04 + 0.006F GHz. **M/A-COM Omni Spectra, Inc., Merrimack, NH. INFO/CARD #210.**

Coaxial Adapter

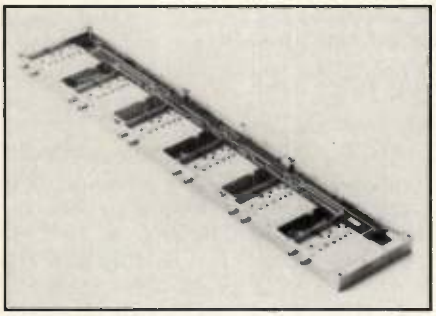
This 50 ohm coaxial adapter is a type SC male to type N female with a brass nickel plated body, PTFE insulation and silver plated contact. It features low loss over the DC to 11 GHz frequency range. The adapter will mate any type N male and SC female connectors that meet the MIL-39012 interface requirements. **Pasternack Enterprises, Irvine, CA. Please circle INFO/CARD #207.**

Microwave Spectrum Analyzer

Tektronix unveils the 2782 microwave spectrum analyzer which has a 100 Hz to 33 GHz frequency range with direct fundamental mixing to 28 GHz. The resolution bandwidth is 3 Hz to 10 MHz and the instrument exhibits a 100 dB display dynamic range. Features include two GPIB ports, simultaneous digital and analog display, and a built-in microwave frequency counter. **Tektronix, Inc., Beaverton, OR. Please circle INFO/CARD #209.**

6-Channel Power Combiner

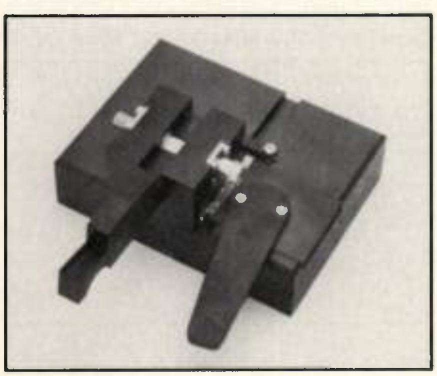
Model MIC-B30 provides up to six channels of power combining and operates from 1.7 to 2.1 GHz. It contains in-phase balanced three-way Wilkinson



power dividers. Independent phase control is achieved with phase shifters adjusted with 6-bit CMOS driver logic in each channel. It has a typical insertion loss of 15 dB and maximum VSWR of 2:1 **KDI/triangle Electronics, Whippany, NJ. INFO/CARD #208.**

Adjustable Microstrip Test Fixture

Design Technique announces the availability of its microstrip test fixture



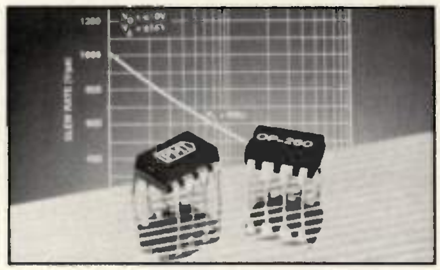
designed for testing MICs, MMICs and individual devices up to 26.5 GHz. The fixture, designated the 3.5-AD2-1P, has a sliding carrier loader which allows the user to quickly and accurately place the test circuit into contact with the microstrip launch. It is priced at $4,000. **Design Technique International Inc., Chatsworth, CA. INFO/CARD #206.**

SMB Termination

A 1 watt plug-in termination for microwave circuit packages has been introduced by EMC Technology. Model 3001P measures 0.56 in. long by 0.25 in. wide and operates from DC to 12.4 GHz, with maximum VSWR of 1.5 from DC to 1.0 GHz, 1.15 from 1.0 to 2.0 GHz, and 1.3 from 2.0 to 12.4 GHz. Impedance is typically 50 ohms. **EMC Technology, Inc., Cherry Hill, NJ. Please circle INFO/CARD #205.**

Current Feedback Op Amp

The OP-260 is a dual high-speed



current feedback operational amplifier that features a slew rate of 1000 V/us at unity gain and slew rate of 550 V/us at a gain of 10. Gain bandwidth product exceeds 400 MHz, and the amplifier bandwidth does not change with closed-loop gain. **Precision Monolithics, Inc., Santa Clara, CA. INFO/CARD #204.**

7 mm to 3.5 mm Adapters

Midisco introduces a line of precision adapters between 7 mm (APC-7) and 3.5 mm type connectors. The 3.5 mm connector mates with SMA type connectors. VSWR over the DC to 18 GHz range is 1.01 + 0.006F, where F is the frequency in GHz. In small quantities, the adapter is priced at $155. Both male and female 3.5 mm connectors are available. Also available are adapters between SSMA, SMA, Type N, BNC, TNC, SMB, SMC, and 7 mm. **Midisco, Commack, NY. INFO/CARD #203.**

1000 W Class AB Amplifier

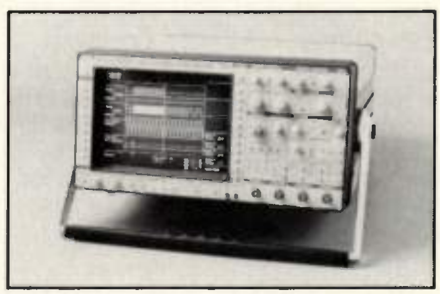
Model BHE 1858-1000 delivers 1000 W CW from 100 to 500 MHz. Instantaneous bandwidth is 400 MHz and RF input is 0 dBm for full power output. Class AB linear operation allows the amplifier to accept CW, AM, pulse, FM or phase modulated signals. The amplifier is available with optional IEEE bus interface for remote operation and monitoring. Even harmonics are −20 dBc max, and odd harmonics are −12 dBc max. Spurious signals are measured at −60 dBc max, pulse rise/fall time is typically 150 ns, and AC to DC efficiency is typically 16 percent. **Power Systems Technology, Inc., Hauppauge, NY. Please circle INFO/CARD #202.**

High Speed Op Amp

Comlinear introduces the CLC404 monolithic op amp which features a 2600 V/us slew rate and full-power bandwidth (5 V p-p) of 165 MHz. The differential gain is 0.07 percent and the differential phase is 0.03 degrees. Settling time to 0.05 percent is typically 10 ns. **Comlinear Corp., Fort Collins, CO. Please circle INFO/CARD #201.**

350 MHz Digital Oscilloscope

Model 9424 is a portable four-channel digital oscilloscope that features 350 MHz of bandwidth, individual 8-bit flash ADCs and 50K of memory. It digitizes repetitive signals up to 10 gigasamples/sec and single-shot phenomena at up to 100 megasamples/sec. For television and video development, the 9424 includes a TV trigger facility. Suitable for



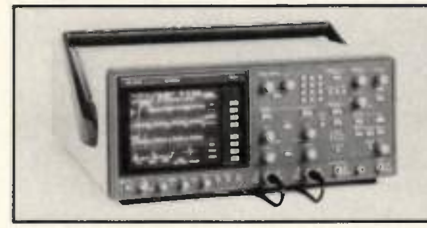
use on NTSC, PAL and SECAM systems, the mode allows line or field selection for jitter-free waveform viewing. For situations that require noise reduction or improved sensitivity (up to 500 uV/div), the 9424 includes summation averaging (up to 1000 waveforms) simultaneously on all channels. The instrument is priced at $20,400. **LeCroy Corp., Chestnut Ridge, NY. Please circle INFO/CARD #200.**

Super Power Isolator

This super power isolator is designed for HDTV use. It will stabilize impedance, absorb antenna reflection and can be used as a "hot" switch. During a test, the klystron saw a constant impedance with no change in the output power with VSWRs on the antenna line of 1.1, 1.2, 1.5 and infinity. **Micro Communications, Inc., Manchester, NH. Circle INFO/CARD #199.**

10-Bit Dual Channel DSO

The PM 3323 is a dual-channel storage oscilloscope that offers a 300 MHz bandwidth, with a 500 megasamples/sec synchronous sampling rate on both channels for 2 ns single-shot resolution. Features include a 10-bit vertical resolution on each channel and four memories. An optional FFT facility that performs a 4000-point FFT in 13 seconds



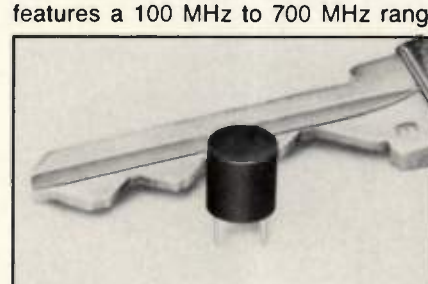
is available. The price of the DSO starts at $10,900. **John Fluke Mfg. Co., Inc., Everett, WA. INFO/CARD #198.**

Microwave Tuner

The TU123/WJ-8969 is a high stability microwave tuner that is a fully synthesized multi-octave frequency counter and covers the 0.5 GHz to 18 GHz frequency range. The IF output is 160 MHz, 140 MHz or 70 MHz (operator selectable) and it can provide up to 100 MHz of instantaneous RF/IF bandwidth. It is compatible with the WJ-8969 receiving system or can be independently operated via IEEE-488, RS-422 or MIL-STD 1553B interfaces. **Watkins-Johnson Company, San Jose, CA. Please circle INFO/CARD #197.**

Miniature Fixed Inductor

Toko introduces an ultra-miniature fixed inductor designed for DC line noise filter and choke applications. The 6RA features a 100 MHz to 700 MHz range



and is available for the 0.18 uH to 1.1 uH inductance range. **Toko America, Inc., Mt. Prospect, IL. Please circle INFO/CARD #196.**

TEM Cell

The Model TC1510 TEM cell holds test items up to 15 cm wide and operates from DC to 750 MHz. Input power capability is 500 watts. When terminated in 50 ohms, the cell produces a uniform high-impedance TEM field approaching that of free space around the test object. The cell is priced at $5,300. **Amplifier Research, Souderton, PA. Please circle INFO/CARD #195.**

Dual-Output Amplifiers

Miteq's Model AFSPD32-00011200-60-20P-42 is a dual-output amplifier that covers from 10 MHz to 12 GHz with 23

dB gain and +20 dBm output power. Output port-to-port isolation is 35 dB. **Miteq Inc., Hauppauge, NY. Please circle INFO/CARD #194.**

Gasket Test System

The EMPS-3000 gasket test system is comprised of the EMPS-3001 pulse generator and GTF-501 test fixture and meets MIL-G-83528 specifications. The 3001 produces a 1.0 to 1.5 MHz pulse with a peak to peak amplitude of 9000 amps. The test fixture measures the diameter of the gasket cross section, compresses the gasket to test conditions, accesses the gasket for resistance measurements, and injects the test pulse into the gasket. **R & B Enterprises, W. Conshohocken, PA. Please circle INFO/CARD #193.**

20 GHz Microwave Counter

The Model 2440 microwave counter has a 10 Hz to 20 GHz frequency range. It is designed for complex signals with high FM and AM tolerance and amplitude discrimination. A GPIB is included. **Marconi Instruments, Allendale, NJ. INFO/CARD #192.**

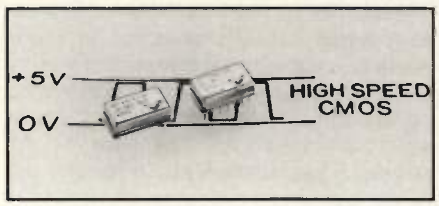
Surface-Mount Clock Oscillator

Champion Technologies introduces the MSO Series surface-mountable inductors, available from 1.25 to 35 MHz with frequency stability of ±0.01 percent. Dimensions are 0.560 in. X 0.360 in. X 0.160 in. **Champion Technologies,**

Inc., Franklin Park, IL. Please circle INFO/CARD #191.

ACMOS Clock Oscillator

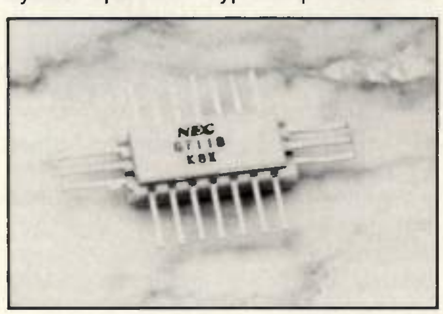
Vectron introduces the CO-440 Series of high-speed CMOS clock oscillators which are available up to 125 MHz using ACMOS technology. Stability is ±25 ppm over the 0°C to +70°C range, with a MIL-option of ±50 ppm over −55°C to +125°C and an improved stability option of ±5 ppm from 0° to 50°C. It operates from 5 V, and drives Schottky TTL as



well as ACMOS. Packaging options include 4-pin DIP, 14-pin DIP, surface-mount and flat pack. In the 10-piece quantity, unit price starts at $91. **Vectron Laboratories, Inc., Norwalk, CT. Please circle INFO/CARD #190.**

8-Bit Shift Register

The NEC UPG711B is a GaAs digital 8-bit shift register. The features include ECL-compatible logic levels and 50-ohm system operation. Typical specifications



include a clock frequency of 2.5 Gb/s and propagation delay of 750 ps. It is available in both chip form and a hermetic package. Prices start at $275 in quantities of 100. **California Eastern Laboratories, Inc., Santa Clara, CA. INFO/CARD #189.**

Fiber Optic Link

Ortel introduces the Model 5601A Broadband Link™. This AM VSB format, multi-channel link can transmit up to 20 AM video channels through a single optic fiber over distances in excess of 10 km. Fiber loss is measured at under 0.4 dB/km, frequency range is 50 to 550 MHz, typical CNR value is 49 dB for 20 channels at 10 km, and typical link loss is 22 dB. The input signal per channel

rf products *Continued*

is 42 dBmV. **Ortel Corp., Alhambra, CA. INFO/CARD #188.**

Parallel Seam Welder

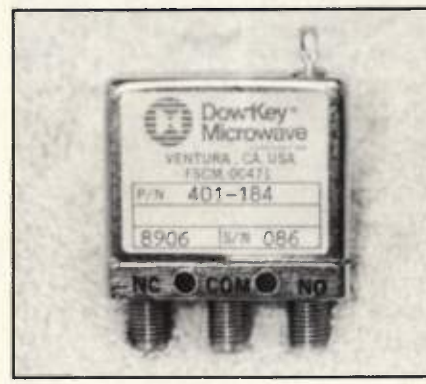
Accu-Weld 3100 from Polaris hermetically seals ceramic or glass to metal packages without complicated programming. Weld schedules are programmed by entering an identification number which is etched on the front of the carrier. The number automatically establishes current, pressure, speed and package dimensions. In addition, an adjustable heat pulse provides a different temperature profile for each axis welded. The welder seals or solder reflows microelectronic packaging of various materials, shapes, and sizes up to six inches. **Polaris Corp., Olathe, KS. INFO/CARD #187.**

Turns Counter

Model TC-48 turns counter dial is designed to drive roller inductors, but it may be used with any device requiring multi-turn counting like variable capacitors and potentiometers. One revolution of the drive knob indicates one turn on the TC-48 zero to 48 scale. It is designed for panel mounting, and for use with 1/4 inch drive shafts. The price is $25.50 each. **Kilo-Tec, Oak View, CA. Please circle INFO/CARD #186.**

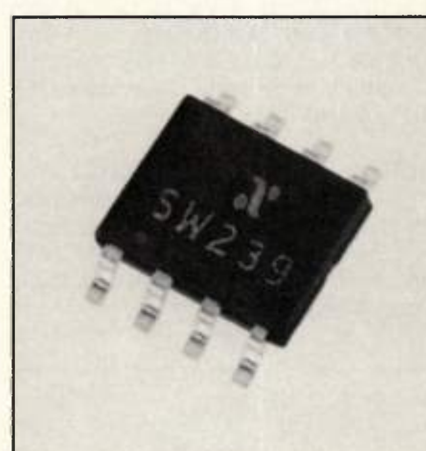
SPDT Coaxial Switch

Dow-Key introduces the 401-184 SPDT electromechanical switch that features a 5 ms switching time. Insertion loss is 0.35 dB from DC to 18.5 GHz, and 0.5 dB from 18 to 26.5 GHz. Isolation is 50 dB min and VSWR is 1.5:1 max at 26.5 GHz. **Dow-Key Microwave Corp., Ventura, CA. INFO/CARD #185.**



GaAs SPDT Switch

Model SW-239 is a GaAs SPDT RF switch that features a typical switching time of 4 ns and frequency range of DC to 1000 MHz. Specifications over this range include a maximum insertion loss of 0.8 dB, VSWR of 1.2:1 and isolation of 30 dB min. It is packaged in an 8-lead SOIC. **Anzac Div., Adams-Russell Components Group, Burlington, MA. Please circle INFO/CARD #184.**



rf software

RF Design Software Subscriptions Available

Annual subscriptions are now available for the RF Design Software Service. The subscriptions will include 13 disks, including programs from the 12 monthly issues of *RF Design*, plus the "Design Guide" section of the fall Directory issue. The cost is $90.00 (5 1/4 in.) or $100.00 (3 1/2 in.), a 23 percent savings over single disk prices. (Subscriptions outside the U.S. and Canada are an additional $50.00.) Computer programs published in *RF Design* have been available on disk since February 1989, with collections of programs from previous issues also being developed. **RF Design Software Service, Littleton, CO. INFO/CARD #169.**

Curve-Fitting Program

Tatum Labs introduces an interactive curve-fitting program. Curve-F is designed for creating models of circuit components. It produces polynomial equations that can be used to approximate the input data. The output can be represented either in graphical or tabular form. The software runs on IBM PC/XT/AT/PS-2 and compatibles, and costs $120. **Tatum Labs, Inc., Ann Arbor, MI. INFO/CARD #168.**

Nonlinear Simulator

This microwave CAE simulator is designed to analyze nonlinear circuits. It is used to design circuits such as amplifiers, mixers, limiters, multipliers, and oscillators. The simulator is an integrated part of the HP 85150B microwave design system used by designers of MMICs and hybrid-microwave integrated circuits. It integrates numerical algorithms which enhance the capabilities of the harmonic balance analysis technique, and is capable of analyzing circuits operating at medium or high levels of compression. The HP 85155A nonlinear simulator is priced at $15,000. **Hewlett-Packard Company, Palo Alto, CA. INFO/CARD #167.**

RF Circuit Analysis and Optimization Program

ingSOFT introduces Version 1.1 of RFDesigner™, a small circuit analysis program for the Apple Macintosh II, SE, Plus and XL computers. The updated program features an enhanced user interface, more component models, an expanded S-parameter library, and optional software modules. The enhancements to the user interface include frequency response graphs of unlimited complexity and size that can be saved to disk as PICT files and accessed by other Macintosh applications for editing and plotting. The new component models include a voltage-controlled current source, physical stripline, physical microstrip, and coupled microstrip. In addition to the present S-parameters for devices from Avantek, Hewlett-Packard, Motorola and NEC, the expanded library includes cascadable monolithic amplifiers from Mini-Circuits, M/A-COM discrete devices and Matcom-Toshiba GaAs microwave devices. This version is priced at $1,500. **ingSOFT Limited, Willowdale, Ontario, Canada. Circle INFO/CARD #166.**

Software Adds Spurious Analysis

SysCad 4.0 adds the capability for spurious analysis of up to three simultaneous frequency conversions. In addition, the new analysis mode allows local oscillator signals to be generated by a mixing process. The program performs analysis of receiver and exciter frequency conversion schemes, with the versatility of frequency arrangement. It requires an IBM PC/XT/AT or PS-2 or compatible with 640K of RAM. Price is $995 and SysCad 3.0 users will receive the new release at no cost. **Webb Laboratories, Hartland, WI. Please circle INFO/CARD #165.**

3D-Finite Element Software for Electromagnetic Analysis

Ansoft Corp. introduces a set of software tools for three-dimensional low-and high-frequency electromagnetic analysis. The programs can simulate the electromagnetic performance of products such as microwave integrated circuits and solenoids. It is designed for various workstation platforms and 386 PCs. **Ansoft Corp., Pittsburgh, PA. INFO/CARD #164.**

Spice Schematic Entry Program

Intusoft introduces an interactive schematic program dedicated to Spice that allows circuit designers to use PCs to draw or edit circuit diagrams. SpiceNet 2.0 produces a Spice netlist that is compatible with Spice simulation programs. It offers improved viewing, panning, zooming, multiple pages and 14-E sizes in landscape or portrait mode. Features include the display of post processor waveforms and node voltages, automatic subcircuit symbols. It supports IBM PC, XT, AT, 386, PS-2 and is priced at $295. **Intusoft, San Pedro, CA. INFO/CARD #163.**

Substrate and IC Brochure

This brochure from Harris Farinon Components Operation covers standard and jumbo thin film metallized substrates and microwave integrated circuits. It details specifications, coatings, artwork and design, resistor and circuit tolerances, processing, and assembly services. **Harris Farinon Components Operation, San Carlos, CA. Please circle INFO/CARD #183.**

Bulletin Describes Suppression Filters

Bulletin 14 describes a line of high power FM harmonic suppression filters from Microwave Filter Company. It contains electrical specifications, frequency drawings, mechanical specifications and dimension drawings for each of the units. Included is a brief summary of products for other broadcast areas such as ITFS, MDS, ENG, VHF and UHF. The back panel serves as an order form or request card for additional literature. **Microwave Filter Company, East Syracuse, NY. INFO/CARD #182.**

Test Instrumentation Catalog

RAG Electronics announces the availability of a catalog featuring new and used test instrumentation. The used equipment section features instruments manufactured by Tektronix, Hewlett-Packard, Lambda, Sorenson, Wavetek, Tenney and others. The product categories listed include spectrum analyzers, AC and DC power sources, environmental chambers, signal sources and oscilloscopes. The manufacturers featured include Fluke, Leader and Hitachi. **RAG Electronics, Inc., Canoga Park, CA. INFO/CARD #181.**

Coaxial Connector Catalog

This catalog highlights a line of connectors available from Connectronics. Descriptions are given for BNC, SMA, TNC, SMC, N, twinax and triax connectors and between series adapters. General specifications are also featured. **Connectronics, Inc., Franklin, IN. Please circle INFO/CARD #180.**

Capabilities Brochure

The sections in this brochure describe the variety of telecommunications, military, FCC/commercial, and associated testing services provided by Retlif. These include FCC testing of consumer, industrial, medical and scientific devices; telecom testing to Part 68 and Canadian DOC standards; ESD testing; EMP testing; shielded effectiveness and EMI/RFI testing including 200 V/m susceptibility testing. **Retlif Testing Laboratories, Ronkonkoma, NY. INFO/CARD #179.**

High Power Combiners/Dividers Brochures

Werlatone introduces two brochures that cover a line of two- and four-way power dividers/combiners. The two-way units feature various frequency ranges in the 0.1 to 1000 MHz band at power levels up to 12 kW. The four-way devices are available for various ranges in the 1 to 1000 MHz band with power levels from 15 W to 20 kW. Specifications together with isolation and insertion loss graphs are provided. **Werlatone, Inc., Brewster, NY. INFO/CARD #178.**

EMC Design Guide

R&B Enterprises announces the publication of the 1989 edition of *ITEM, The International Journal of EMC*™. This guide and directory is devoted to the reduction and control of all forms of electromagnetic interference and to environmental effects. Subjects include shielding, filters, TEMPEST, EMP, lightning, ESD, shielded cabinetry, product safety, radiation hazards, and power line conditioning. Additional coverage is devoted to various local and international commercial and military EMI standards. It is available free of charge to qualified subscribers. **R & B Enterprises, West Conshohocken, PA. Please circle INFO/CARD #177.**

Telemetry Microwave Components Catalog

This catalog describes a range of telemetry microwave components from AML. The products described include circular and linear polarizers, low-noise amplifiers, monopulse comparators, scan converters, filters and other passive components. Specifications and outline drawings are included. **Advanced Milliwave Laboratories, Inc., Camarillo, CA. INFO/CARD #176.**

VXIbus Newsletter

A publication called *VXIbus Newsletter* is available for manufacturers and users of this standard for instruments-on-a-card. It covers new products, show reports, user reports, adoptions, IEEE-P1155, consortium action and market analysis. Published once a month, the newsletter has an annual subscription fee of $195. Additional information can be obtained by circling the reader service number. **Bode Enterprises, La Mesa, CA. INFO/CARD #171.**

EMI Window Selection Brochure

Selecting Shielding Windows for Effective EMI Control explains design considerations and performance characteristics necessary for product selection. Factors of optical performance, glare reduction and substance material evaluation are among the subjects covered. **Teknit, Cranford, NJ. Please circle INFO/CARD #175.**

Book Describes LAN Filters

Applications for radio frequency filters in Local Area Networks (LANs) are described in this book from Microwave Filter Company. It describes nine different filter categories and examples of 12 custom filters designed for LANs. Included are two appendices that list split frequency schemes, TV channel allocations used in the U.S. and Canada, and some additional LAN channel designations. **Microwave Filter Company, Inc., East Syracuse, NY. INFO/CARD #174.**

Microwave Switch Distributor Kit

A distributor kit which contains 12 data sheets on microwave switches is available from K & L. Descriptions together with photographs, specifications and performance graphs are included. **K & L Microwave, Inc., Salisbury, MD. INFO/CARD #172.**

Test and Measurement Instruments Catalog

LeCroy introduces its Spring 1989 catalog that describes digital oscilloscopes, waveform capture and replay systems, arbitrary function generators, software tools, and service and extended warranty options. Complete specifications are included. **LeCroy Corp., Chestnut Ridge, NY. Please circle INFO/CARD #173.**

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RF Design Editorial Calendar
July-December 1989

Month	Featured Technology	Industry Insight	Special Coverage/ Extra Distribution	Advertising Closing Date	Advertising Materials Deadline
July	RF Design Awards Contest Winners, Electromagnetic Compatibility (EMC)	Update on the Filter Industry	EMC Expo	June 6	June 9
August	Crystal Oscillators and Filters	RF Attenuators and Switches	EIA Quartz Devices Conference, Antenna Measurement Techniques Assn. (AMTA)	July 6	July 12
September	Test and Measurement Techniques	Ferrite and Iron Powder Materials, Inductors	Coil Winding Show	July 31	August 9
Directory Issue	The Directory issue features product listings by category, vendor information, plus useful Design Guide reference data.			August 7	August 14
October	System Design: Build-or-Buy Decision Making	SAW Update	Society of Old Crows, Ultrasonics Symposium	September 6	September 12
November	Using Passive Components	RF Software	RF Expo East: Official Show Issue	September 26	October 2
December	Mixers, Modulators, Demodulators	Cables and Connectors	1988-1989 Index of Articles	November 7	November 13

Advertiser Index

MONICOR

ELECTRONIC CORP.

The Monicor IC-15ME is a portable radio modem designed to easily interface RS-232 devices to a computer. Up to 27 of these devices within a mile radius can be polled by the IC-210A Base Network Modem on a single simplex 12.5 kHz 450-470 MHz radio channel. Proprietary firmware transfers CRC corrected variable length packets over the radio at 2400 or 4800 baud. Due to synchronous transmission, packet error correction and extremely fast receiver response time, IC-15ME data throughput often exceeds that of other modems boasting 9600 baud radio transfer rates. The unit responds to X.3 Packet Assembly/Disassembly commands for a simple software interface simple and requires no special languages or site licenses. Rates from 50 to 19200 baud and all other parameters including the powerup configuration can be set through the serial port. The metal enclosure's mounting flanges and standard DB-9 RS-232 connector allow easy mechanical and electrical connection for most OEM applications. The unit accepts 12-24 VDC, battery or AC power. Prices start at $1195 for the portable and $1495 for the base. Monicor Electronic Corp., Ft. Lauderdale, FL

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