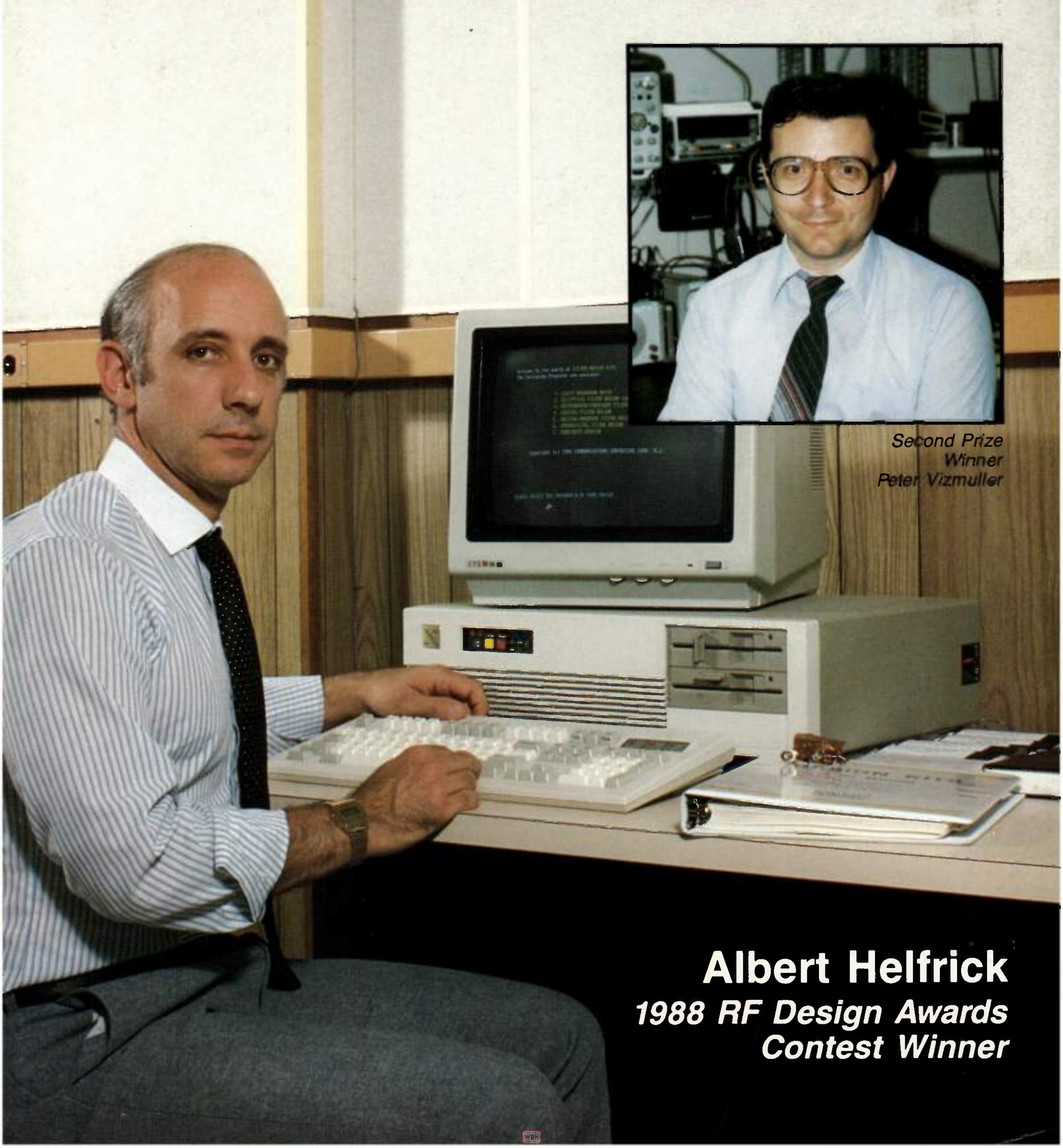
rf design

engineering principles and practices

1978–1988 10th ANNIVERSARY

July 1988



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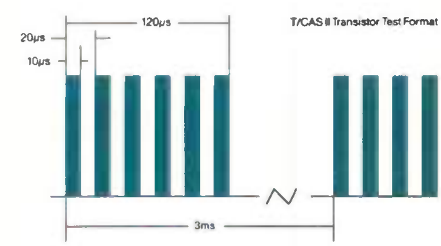

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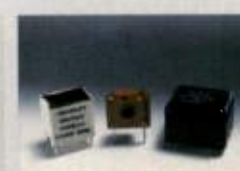

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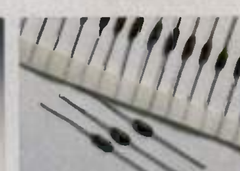

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rf design

July 1988

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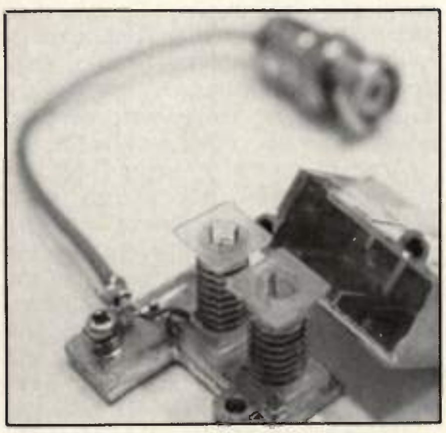
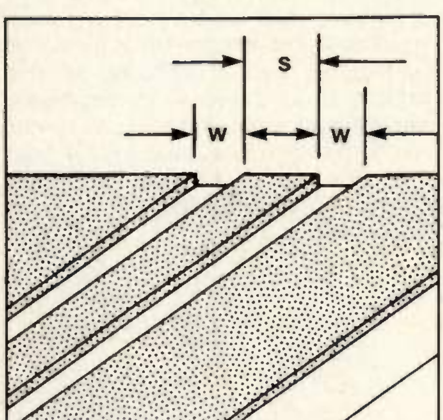


Page 31 — Absorptive Notch Filter



Page 52 — Coplanar Waveguide Primer

Cover Story

Featured Technology Section

Departments

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rf editorial

Thanks for Taking Part

By Gary A. Breed
Editor

This issue includes two important reports that involve our readers: the results of our Third Annual RF Design Awards Contest, and a summary of our latest Reader Profile Survey. The information from the survey will help us do a better job serving your needs, and our advertisers certainly want us to take good care of you. Interested, informed and involved engineers are high quality customers.

The contest serves two additional purposes: it lets us recognize the unique achievements of at least a few RF engineers; plus, it offers insight into the types of projects you find interesting and challenging.

Both the contest and the survey required enthusiastic participation from all of you who read *RF Design*. Thanks!

Next Month

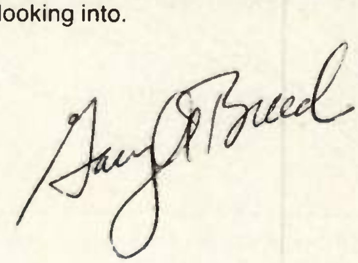
Now, let me look ahead to the August issue. We will have a "first" for *RF Design:* a special section of the magazine devoted to quartz technology, honoring the 10th anniversary of the Quartz Devices Conference in Kansas City (August 30-September 1).

We readily accepted when Howard Wolk, chairman of the conference committee, invited us to take part. Quartz technology (oscillators, filters, SAWs) is one of the oldest and most important parts of RF. Plus, our own 10th anniversary comes just two months later in October, an interesting coincidence.

The technical program at the conference is one reason for you to consider attending. First, there is a collection of technical papers emphasizing applications, to inform users of quartz devices. There will be basic materials and processing papers, to help young engineers within the quartz industry improve their skills; and to educate customers' engineers, to better utilize and specify components. Articles in the August issue will parallel these areas, covering quartz materials, oscillators and filters.

Another group of papers will be targeted to the quartz industry itself, covering latest developments in materials, manufacturing, quality control and packaging. Highlighting this part of the conference is an excellent presentation on statistical process control (SPC), the most advanced method for analysis and improvement of manufacturing processes in *any* industry.

One more reason for our cooperation with the Electronic Industries Association (EIA) in promoting this conference is the emphasis on practical engineering. This is not an esoteric or academic conference, but a gathering of one industry's companies and engineers, with the purpose of educating customers and improving their products. If your work includes quartz technology, the Quartz Devices Conference is worth looking into.



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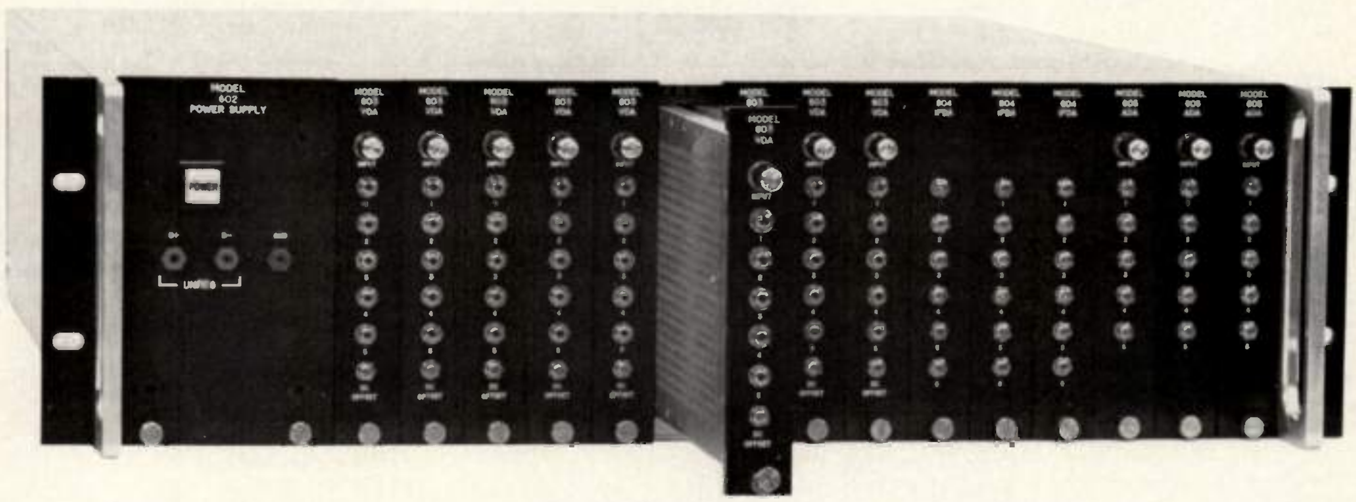

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INFO/CARD 5

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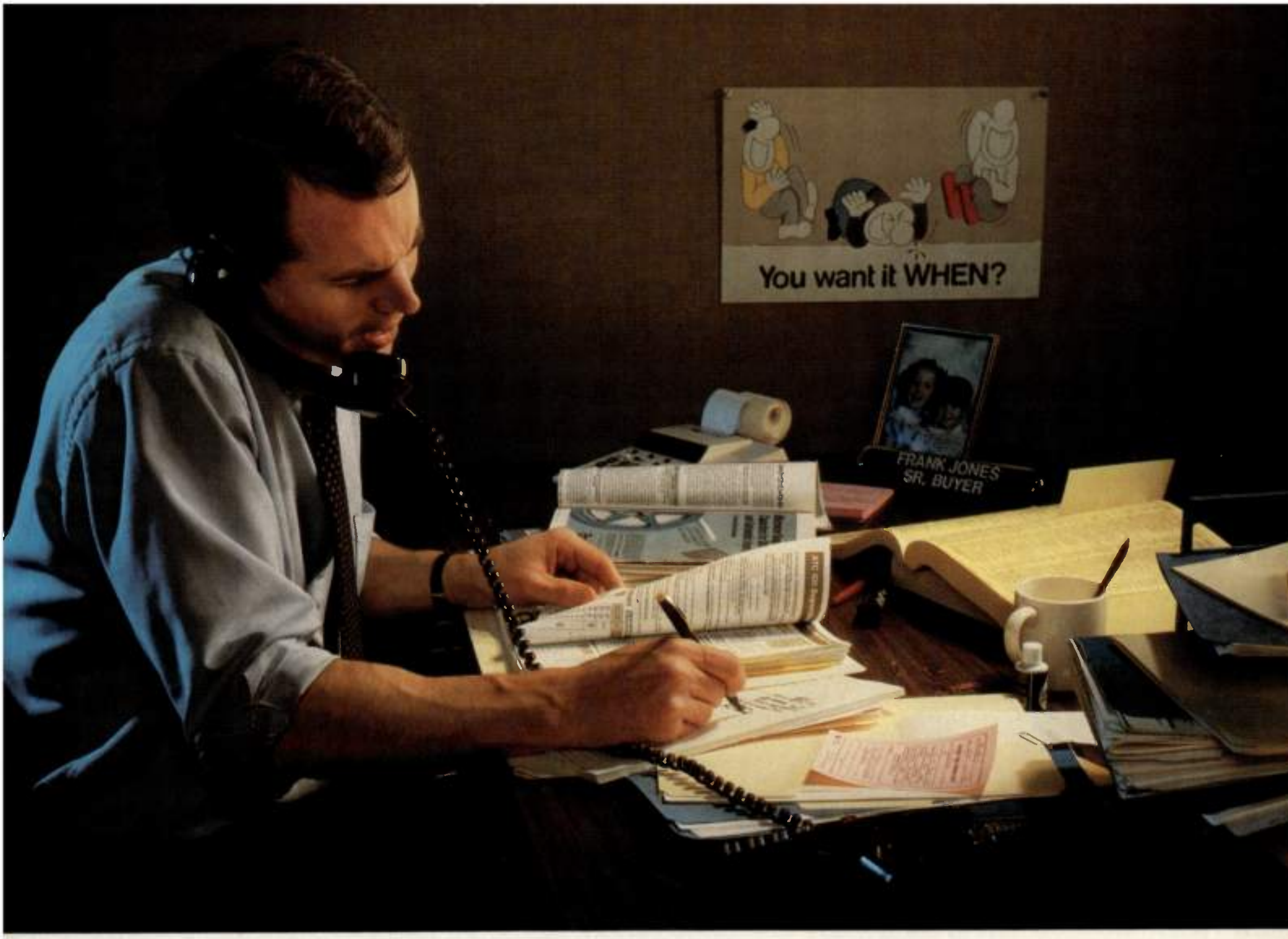

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rf letters

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Feedback on RF Education

Editor:

I read your editorial on RF education and I agree with you 100 percent. I am a graduate of Villanova and did not receive an RF education. Discussing this with my peers who graduated from other institutions, I found the same was true. I think the additional classroom time [at RF Expo] is a great idea and look forward to attending. Please have your office forward registration information for the Expo and the classes to me.

R. Slegelmilch
GE RESD
Philadelphia, PA

More on Microprocessor RFI

Editor:

I certainly did enjoy Daryl Gerke's article ("Microprocessor Interference to VHF Radios," March 1988, *RF Design*) and wanted to add the following observation:

In this situation, several receivers are operated in HF, VHF and UHF bands. About 10 meters away, there is a Macintosh Plus with a Rodime 20 megabyte hard disk and an Apple Imagewriter II. The Imagewriter had a 32 Kbyte memory expansion card.

Interference increased dramatically each time the printer finished a job. The computer itself didn't seem to cause any interference, and when interference did occur, turning off the computer did not help. When the 32K expansion card was removed from the printer, the interference stopped. (It didn't work with the Macintosh anyway). Our experience led us to believe that the memory refresh cycle was a big cause of the problem.

In a related and perhaps more important area, handheld emergency radios are often interfered with by computers as the radio user moves about. This perhaps can be critical enough to warrant some investigation. Retail check-out cash register terminals are a notorious culprit.

Eugene B. Simmons, Jr.
Harvest, AL

Choosing RF Components for Better Selectivity

Editor:

The figure-of-merit (Q factor) of RF components reaches a peak value at some frequency, and the magnitude of that value depends on the materials used for their construction.

The inductance and Q of a coil are determined by the wire's conductivity and insulation dielectric constant, the wire and core permeabilities, the frequency and geometry of the winding, etc.

I wish to get information on manufacturers, and then ask them for data sheets with such information. I am looking for coils, leadless varactors and capacitors which have their peak Q at about 235.25 MHz. From such data (providing there is any choice), I will select the parts that have the highest available peak Q.

Regarding coils, I considered making my own with solid platinum wires, since this metal has superior conductivity. I wonder if even better performance can be obtained with metals of the same family, like iridium, palladium or rhodium. It would be interesting to get a table of their characteristics: resistivity at room temperature, magnetic permeability, linear dilatation temperature coefficient and solderability.

This problem has preoccupied me for months, I hope someone is able to provide appropriate information.

Michel Samson
1001 Petit-Bois
Louiseville, QC
Canada J5V 2V1

Correction

Editor:

I very much appreciate the new product announcement you published in your May issue, for the Oscilloquartz D-TCXO model 8500. We have received several responses from your readers.

I have made a mistake, though. There are two rep firms involved here. One is Tauber-Dreyer Corporation, involved primarily in offering milspec parts from such domestic companies as Q-Tech and Electronic Research Corporation. The other company name is B&J Marketing, which serves as both rep and distributor for the Oscilloquartz line alone. My mistake was in referring to the wrong business name in the letter accompanying the press release.

My apologies for the misinformation. Would you please print this correction stating that B&J Marketing is, in fact, the right contact name. I offer my sincere apologies for any inconvenience this has caused.

Jim Rue
B&J Marketing
Tustin, CA

rf courses

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Tactical High Frequency Radio Communications System Planning and Engineering
September 19-23, 1988, Washington, DC

Radiowave Propagation for Communications System Engineering
September 19-23, 1988, Washington, DC
November 7-11, 1988, Orlando, FL

Microwave Radio Systems
September 22-23, 1988, Washington, DC

Introduction to Digital and Analog Modulation
October 3-7, 1988, Washington, DC

Satellite Communications Engineering Priciples
October 5-7, 1988, Washington, DC

Modern Communications and Signal Processing
October 10-14, 1988, Washington, DC

New HF Communications Technology: Advanced Techniques
October 17-21, 1988, San Diego, CA

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

Besser Associates

Microwave Circuit Design I: Linear Circuits
August 15-19, 1988, Baltimore, MD

Microwave Circuit Design II: Non-linear Circuits
August 22-26, 1988, Baltimore, MD

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

EEsof, Inc.

Introduction to Microwave Computer Aided Engineering
September 6-7, 1988, Westlake Village, CA
November 7-8, 1988, Westlake Village, CA

Introduction to Microwave Computer Aided Layout and Design
September 8, 1988, Westlake Village, CA
November 9, 1988, Westlake Village, CA

Advanced CAE
September 12-13, 1988, Westlake Village, CA
November 14-15, 1988, Westlake Village, CA

Advanced Microwave Computer Aided Layout and Design
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November 16, 1988, Westlake Village, CA

Nonlinear Circuit Design
September 19-20, 1988, Westlake Village, CA
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Information: Sandra Scoredos, EEsof, Inc., 5795 Lindero Canyon Road, Westlake Village, CA 91362. Tel: (818) 991-7530

Interference Control Technologies, Inc.

Grounding and Shielding
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September 12-16, 1988, San Diego, CA
September 26-30, Philadelphia, PA
October 24-28, Atlanta, GA

TEMPEST Facilities Design
August 15-19, 1988, Washington, DC

EMC Design and Measurement
August 9-12, 1988, Washington, DC

Intro to EMI/RFI/EMC
August 9-11, 1988, Ottawa, Canada
August 16-18, 1988, Palo Alto, CA

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

Bloom Associates

Modern Power Conversion Design and Analysis Methods
September 19-23, 1988, San Francisco, CA

Information: Bloom Associates, Inc., 115 Duran Drive, San Rafael, CA 94903-2317. Tel: (415) 492-8443

Integrated Computer Systems

Digital Signal Processing: Techniques and Applications
August 30-September 2, 1988, Washington, DC
September 13-16, 1988, San Diego, CA
October 4-7, 1988, Boston, MA
October 4-7, 1988, Toronto, Canada
October 18-21, 1988, Los Angeles, CA
November 1-4, 1988, Washington, DC

Image Processing and Machine Vision
August 30-September 2, 1988, Boston, MA
September 20-23, 1988, Washington, DC
October 4-7, 1988, San Francisco, CA
November 1-4, 1988, Los Angeles, CA

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

Southeastern Center for Electrical Engineering Education

Antennas: Principles, Design, and Measurements
August 2-5, 1988, San Diego, CA

Information: Ann Beekman, SCEEE, 1101 Massachusetts Ave., St. Cloud, FL 32796. Tel: (305) 892-6146

University Consortium for Continuing Education

Modern Microwave Techniques
September 26-29, 1988, Washington, DC

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

Compliance Engineering

EMI
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Safety
October 19, 1988, Boston, MA

ESD
October 20, 1988, Boston, MA

Telecom
October 21, 1988, Boston, MA

Information: Compliance Engineering, 271 Great Road, Acton, MA 01720. Tel: (617) 264-4208.

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Westin Crown Center, Kansas City, MO
Information: Peter Walsh, Components Group, EIA 2001 Eye St., N.W., Washington, DC 20006. Tel: (202) 457-4930

August 30-September 1, 1988
Midcon '88
Dallas Convention Center, Dallas, TX
Information: Electronic Conventions Management, 8110 Airport Boulevard, Los Angeles, CA. Tel: (213) 772-2965

September 12-16, 1988
10th Annual Antenna Measurements Techniques Association Meeting
Atlanta Hilton and Tower Hotel
Information: Becky Clark, 1988 AMTA Symposium, c/o Scientific-Atlanta, Inc., Mail Station ATL 28-I, P.O. Box 105027, Atlanta, GA 30348.

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September 21, 1988, Indianapolis, IN
September 23, 1988, Chicago, IL
October 4,5, 1988, Baltimore, MD
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September 14-15, 1988
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September 27-29, 1988
20th International SAMPE Technical Conference
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Information: Marge Smith, P.O. Box 2459, Covina, CA 91722. Tel: (818) 331-0616

September 30, 1988
5th David Sarnoff Symposium on New Trends in Microwave, Millimeter Wave and Photonic Device Technologies
David Sarnoff Research Center, Princeton, NJ
Information: Judy Hohman, David Sarnoff Research Center, CN5300, Princeton, NJ 08543-5300. Tel: (609) 734-2037

October 4-6, 1988
Northcon '88
Seattle Center Colliseum, Seattle, WA
Information: Electronic Conventions Management, 8110 Airport Boulevard, Los Angeles, CA. Tel: (213) 772-2965

October 9-11, 1988
ASYST '88
University of Rochester, Rochester, NY
Information: Kristen Bartles, Asyst Software Technologies, Inc., 100 Corporate Woods, Rochester, NY 14623. Tel: (716) 272-0070

October 25-27, 1988
RF Expo East 88
Philadelphia Civic Center, Philadelphia, PA
Information: Linda Fortunato, Cardiff Publishing, 6300 S.Syracuse Way, Suite 650, Englewood, CO 80110. Tel: (303) 220-0600; (800) 525-9154

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Minneapolis Hilton Inn, Minneapolis, MN
Information: Diane Swenson, Tel: (612) 462-7001

November 8-12, 1988
Electronica '88
Munich Trade Fair Centre, Munich, W. Germany
Information: Gerald Kallman, Kallman Associates, 5 Maple Ct., Ridgewood, NJ 07450-4431. Tel: (201) 652-3898

November 15-17, 1988
Wescon '88
Anaheim Convention Center, Anaheim, CA
Information: Electronic Conventions Management, 8110 Airport Boulevard, Los Angeles, CA. Tel: (213) 772-2965

February 5-10, 1989
1989 Aerospace Applications Conference
Breckenridge, CO
Information: Leo Mallette, Hughes Aircraft, MS: Bldg R-10, A9026, P.O. Box 92919, Los Angeles, CA 90009. Tel: (213) 334-2909

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

Acrian Celebrates 10th Anniversary

On April 13, 1988, Acrian, Inc. officially celebrated 10 years of business supplying power solutions for the RF and microwave market. Following this occasion, 36 employees were honored for ten years of service to the company with certificates and 10-year pins.

Acrian is an independent supplier of application specific power amplifiers and semiconductor devices for military and commercial applications. Applications include ground, air and sea-based military and commercial radar, avionics and communications, mobile/cellular communications, microwave communications, and broadcast communications.

After posting a loss in FY 1987, the company earned a profit in FY 1988 (ending March 29, 1988). According to Gary Irvine, President and CEO, Acrian is forecasting a strong, steady growth over the next five years.

Advanced Ceramics: A Key to Future Technologies

According to a National Bureau of Standards report, worldwide production of advance ceramics is growing rapidly, providing stiff competition for the U.S. industry, with Japan controlling 50 percent of the $30 billion world market. In accordance with that, the NBS advanced ceramics program is tailored as a measurement-oriented research effort. The program provides information for the U.S industry and helps them to compete effectively in the race towards the next generation of materials and technologies.

Advanced ceramics are a new generation of high-performance materials. They have high strength and dimensional stability, are chemically inert and wear resistant, and retain most of these properties at high temperatures. Their electrical and optical properties can be tailored to provide otherwise difficult-to-reach performance.

The recent discovery of superconductivity at temperatures greater than 90 degrees kelvin in ceramic materials has generated a lot of interest. A few possible applications for the advanced ceramics are the transmission of electricity over long distances without power losses, economical storage of electrical energy, more efficient electric motors, and more practical magnetic resonance imaging devices for medical and other applications.

Tracor and GIE in Merger

General Image Engineering Corporation (GIE), headquartered in Provo, Utah, recently announced its acquisition by Tracor. GIE specializes in camouflage concepts and technologies and is a manufacturer of countermeasures coating materials, as well as systems and components for the protection of land-based and airborne military systems.

Ford Succeeds with GaAs-on-Silicon Technology

Ford Microelectronics, Inc. and Ford Aerospace have demonstrated fully functional LSI digital circuits and mercury-cadmium-tellurium (HgCdTe) photovoltaic detectors fabricated on GaAs-on-silicon material. The digital LSI circuit is a 504-gate array with approximately 6,600 transistors and wafer yields as high as 10.8 percent. The HgCdTe medium wavelength infrared photovoltaic detectors have a resistance area product greater than 100,000 ohm-cm^2 at 80 K.

In this process, an epitaxial layer of single crystal GaAs is grown on 3-inch diameter silicon substrates using metal organic chemical vapor deposition. The integrated circuits are fabricated in the GaAs layer using a depletion mode, realigned gate field effect transistor process. The detectors are fabricated through the epitaxial growth of HgCdTe on an intermediate cadmium-tellurium layer on a GaAs-on-silicon substrate.

Applications for this technology include high-speed data processors, tactical missile systems, radar navigation and avionics, microwave systems, communications, and supercomputers.

Datum and Austron in Merger Agreement

Datum and Austron have announced that they have entered into a definitive agreement that allows Datum to purchase 100 percent of outstanding shares (3,599,927) of Austron common stock at $3.25 per share in cash. Consummation of the acquisition is subject to the satisfaction of various conditions including approval by the Austron shareholders.

Hughes Buys Westar Satellite

Hughes Aircraft Company has announced that it has signed a definitive agreement to purchase the Westar satellite system from Western Union. The Westar system includes C-band communication satellites in orbit and a fourth on the ground that is scheduled to be launched in 1989. The satellites will be operated with three Hughes owned and operated C-band Galaxy satellites. The purchase will not include the Westar earth stations, which will be sold separately by Western Union.

Epsco Acquires M/A Com Division

Epsco has announced the acquisition of MA Electronics Canada, a division of M/A Com, Inc. for $2 million. MA Electronics Canada is a manufacturer of broadband microwave amplifiers and subsystems. Sales conducted by this division for the fiscal year ending October 3, 1987 were approximately $4.3 million.

TriQuint/Compact Software Alliance

TriQuint Semiconductor and Compact Software, Inc. have announced that they are incorporating TriQuint's MMIC library of foundry design models into Super-Compact. TriQuint's MMIC library models are algorithmic expressions that represent the electrical behavior of MMIC elements (FETs, diodes, resistors, capacitors and inductors) over a range of bias conditions and frequencies. By providing access to these models from within the software, a designer can simulate the operation of a MMIC to be built in the TriQuint foundry before incurring the expense of fabrication, packaging and evaluation of the actual device.

US West Awards $1.8M to Research Programs

US West, Inc. has announced the selection of 18 universities to share research support funds totalling $1.8 million for telecommunication technologies. Detailed proposals were solicited from 50 entries. Technologies specifically targeted by US West were system architecture and standards, artificial intelligence, software engineering, user interface, transmission technology, modeling, and simulation. The selected projects have been offered one-year contracts ranging from $30,000 to $200,000.

Tracor/Elsin Takeover

Elsin Corporation has disclosed that its interests, including those held by Whittaker Corporation, have been acquired by Tracor. This deal expands Tracor's elec-

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Certain members of our RF family have had problems finding work. Bad news for us but good news for you. Should you need the services of any of these hard-working, well-maintained instruments, now is the time to act. We'll warranty their performance for 120 days, even give you five days to review their performance, and if you don't like them, you can send them home.

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HP8620C*	$21,795	$11,000
HP8660C**	$34,230	$2,550
HP8663A	$48,700	$29,000

*with 86290B/4 **with 86603A, 86632B

ANALYZERS	LIST PRICE	SALE PRICE
HP8566B	$57,650	$45,000
TEK494P	$49,000	$28,000
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INFO/CARD 19

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Toko has what you need, so you won't need to compromise... subminiature adjustable coils and transformers, molded coils, radial fixed coils and fixed coils with axial leads. Toko high-Q coils are engineered in sizes from 5mm to 15mm, and inductance ranges from .02 µH to 500 mH.

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Need to reduce the size of your products or automate production? Toko solves these problems with a wide range of surface mountable coils and LC, ceramic and helical filters in fixed and adjustable configurations. Packaged for automatic insertion and available for reflow or solder dipping.

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Toko hybrid modules are a great way to simplify design and production tasks. With short lead time, Toko can develop compact custom modules utilizing a variety of components, surface mounted on a ceramic substrate. One module replaces dozens of components.

FILTERS

For i-f or tuned rf circuitry, Toko filters simplify attenuation of out-of-band signals, while cleanly passing your desired signal. Ultra-miniature ceramic and LC filters at popular i-f frequencies fit tight spaces and tight budgets. With frequencies up to 1.2 GHz Toko helical filters are the right choice for communications transceivers.

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For more information on:
Subminiatures, INFO/CARD 99
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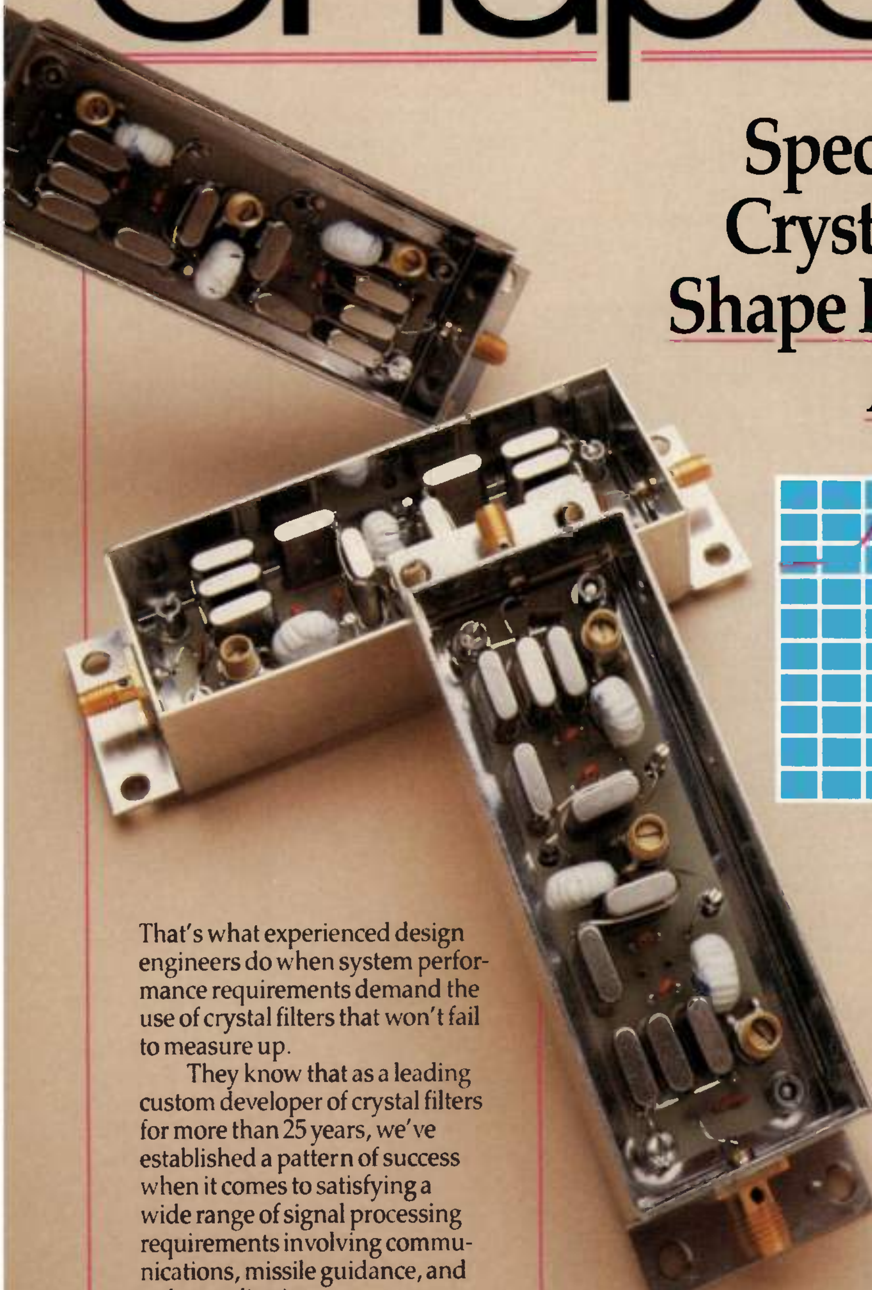
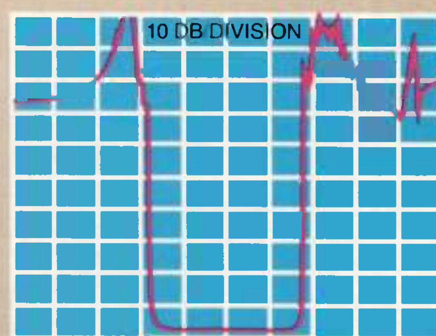
RF & I-F Filters, INFO/CARD 103
Active Filters, INFO/CARD 101
Sample Kit, INFO/CARD 104

Shape Up!



Specify DAMON Crystal Filters with Shape Factors As Steep As 1.05:1.



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As a system designer it means that you can optimize incoming signal processing, thus assuring better selectivity at the front end.

All of which adds up to increased design flexibility in terms of both performance and packaging, as well as improved reliability at the overall system level.

Behind this claim is Damon's continuing commitment to the latest in manufacturing resources, which includes a facility that's equipped with the latest in CAD and CAE technology, as well as provisions for in-house environmental testing (MIL-Std-202), crystal fabrication (MIL-C-3098), and soldering (WS-6536E). And that's only the beginning.

For more information, call us today to discuss your application (1-800-348-0028). And send for our complete catalog.

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INFO/CARD 12

tronic combat system capabilities. Elsin specializes in the development of receivers and digital signal processing equipment which exploit communication and radar signals in military applications.

Electro-Metrics Completes Facility Expansion

Electro-Metrics, a supplier of automated EMI test equipment, has expanded its Amsterdam, N.Y., facility by 30 percent with the recent completion of a renovation project. In addition to creating more than 10,000 square feet of engineering space, the company has expanded the size of its R&D, production and administrative departments.

Raytheon/TI Venture Wins $68.6M Contract

The team lead by Raytheon Company and Texas Instruments, Inc. is one of four selected by the Department of Defense to develop and produce GaAs micro-circuits under Phase 1 of the tri-service Microwave/Millimeter Wave Monolithic Integrated Circuits (MIMIC) program. The contract, awarded by the Naval Air Systems Command, has a value of $68.6 millions.

It will enable the Raytheon/TI joint venture to implement a plan for developing design techniques and manufacturing technologies for the production of large quantities of affordable, reliable, high performance components. Based on this plan, the cost of GaAs microcircuits will be reduced from the current figure of $20 per square millimeter to 80 cents per square millimeter by 1994.

Harris Announces MIMIC Team Affiliations

Harris Microwave Semiconductor has announced its participation in Phase 1 of the Defense Advanced Research Projects Agency's MIMIC program as a member of the Hughes Aircraft Company and General Electric Company team. Harris Microwave will serve as a GaAs monolithic integrated circuit foundry and also provide development work.

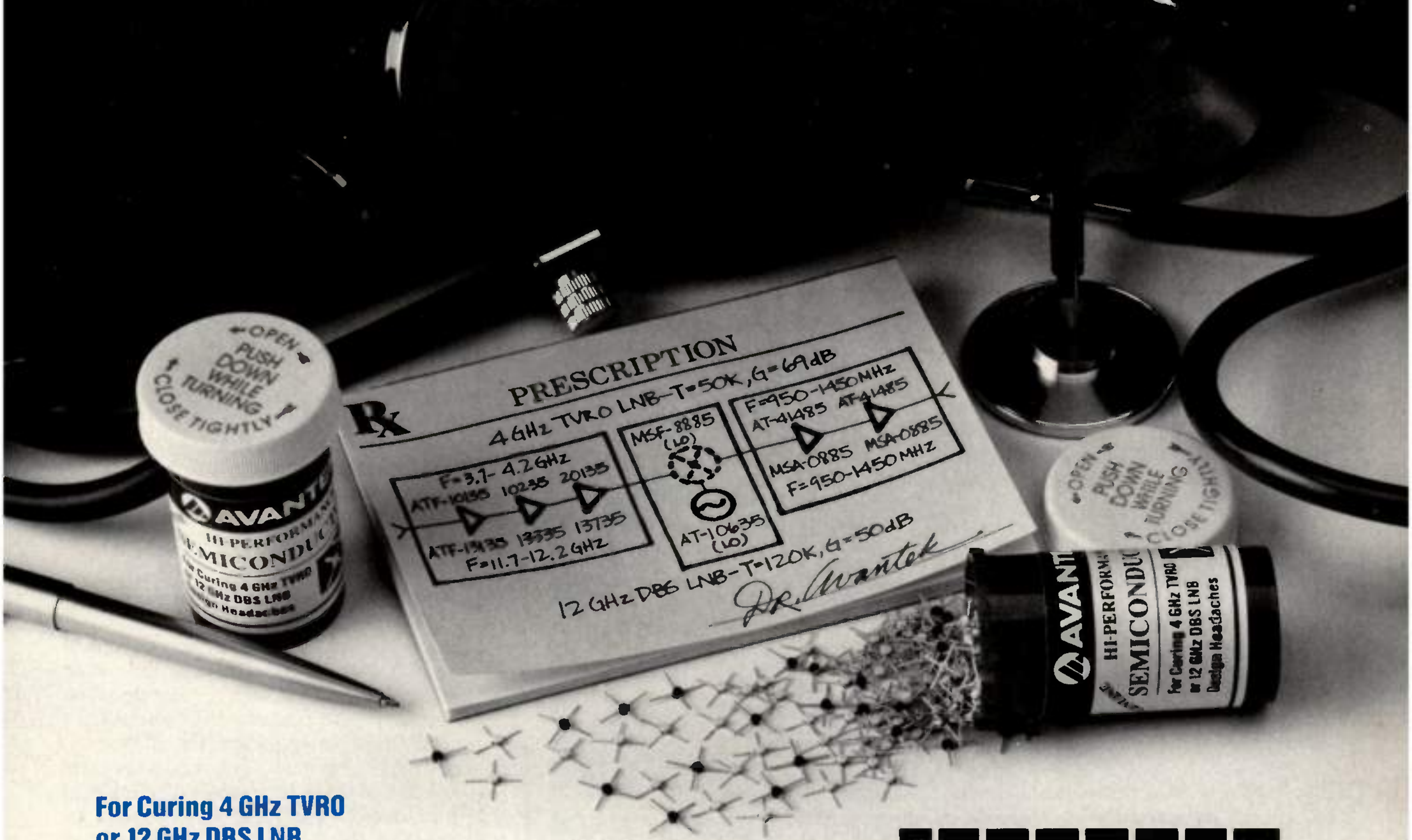
Team Led By TRW Awarded $57M Contract

A team of four contractors led by TRW's Electronic Systems Group has been awarded a $57 million contract under Phase 1 of the MIMIC program. The cost plus fixed fee contract calls for the development of advanced GaAs microelectronic integrated circuits which measure less than 20 millionths of an inch in size. The 36-month Phase 1 contract follows the completion of the TRW team's work on a $1 million, 12 month MIMIC (Phase 0) definition contract completed in February 1988.

AS Solves RF Coverage Problem

The Antenna Specialists Company recently solved a constant problem at the Telocator Network of America meetings of poor RF coverage. The problem led to the point where exhibitors were unable to demonstrate cellular products and services to attendees. Antenna Specialists solved the problem at the St. Louis meeting by driving their mobile laboratory onto the convention floor and donating the use of their extend-a-cell cellular booster system. The low power broadband booster provided Telocator's exhibitors and attendees with cellular service by amplifying and rebroadcasting signals between equipment inside the building and a donor cell site about six miles away.

Just What The Doctor Ordered



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Avantek high performance microwave semiconductors are available from local Avantek distributors in the quantities needed to support your program. For the location of your nearest Avantek distributor call (408) 970-2834.

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ATF-10135	4.0	0.5	13.0
ATF-13135	12.0	1.2	9.5
AT-41485	1.0	1.4	20.0
MSA-0885	1.0	3.3	22.5

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We'd like you to design your next 4 GHz or 12 GHz LNB with Avantek semiconductors. Our free *LNB Design Kits* make it easy. Each kit contains the GaAs and silicon devices in this ad. Only a limited number of design kits are available. The first 500 qualified respondents will receive both 4 GHz and 12 GHz design kits. The completed coupon below must be accompanied by business card or company letterhead.

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Electrospace Receives S2.8M From Boeing

Electrospace Systems, Inc., of Richardson, Texas, has received contracts totalling $2,841,437 from Boeing Aerospace, Seattle, Wash. The contract calls for the production of communications antenna systems aboard the E-6A TACAMO aircraft. Deliveries will extend through early 1990.

Navy Contract Awarded to Eaton

Eaton Corporation's AIL Division has been awarded $45 million by the U.S. Navy to provide components to improve the effectiveness of the service's EA-6B electronic warfare aircraft. Eaton will provide the Navy with 96 universal exciters — an electronic package designed to boost the flexibility of the aircraft's onboard ALQ-99 tactical jamming system. The exciters have a programmable techniques generator which provide a versatile jamming capability over a wide range of operating frequencies. The $45 million FY 1988 option contract for the devices, exercised under an existing production contract the Navy holds with Eaton, will be managed by the Naval Air Systems Command, Arlington, Va.

Tracor Awarded Contract for Navy ASW Program

Tracor Applied Sciences, Inc., a subsidiary of Tracor, Inc., has received a contract from the Naval Sea Systems Command to provide technical and management support for the AN/SQQ-89 program. The AN/SQQ-89 is an integrated anti-submarine warfare (ASW) combat system that provides detections, classifications, localizations and fire control for the U.S. Navy surface ASW combat ships. The contract includes four option years with a total value of $95.2 million.

Anadigics to Develop Analysis Model for Navy

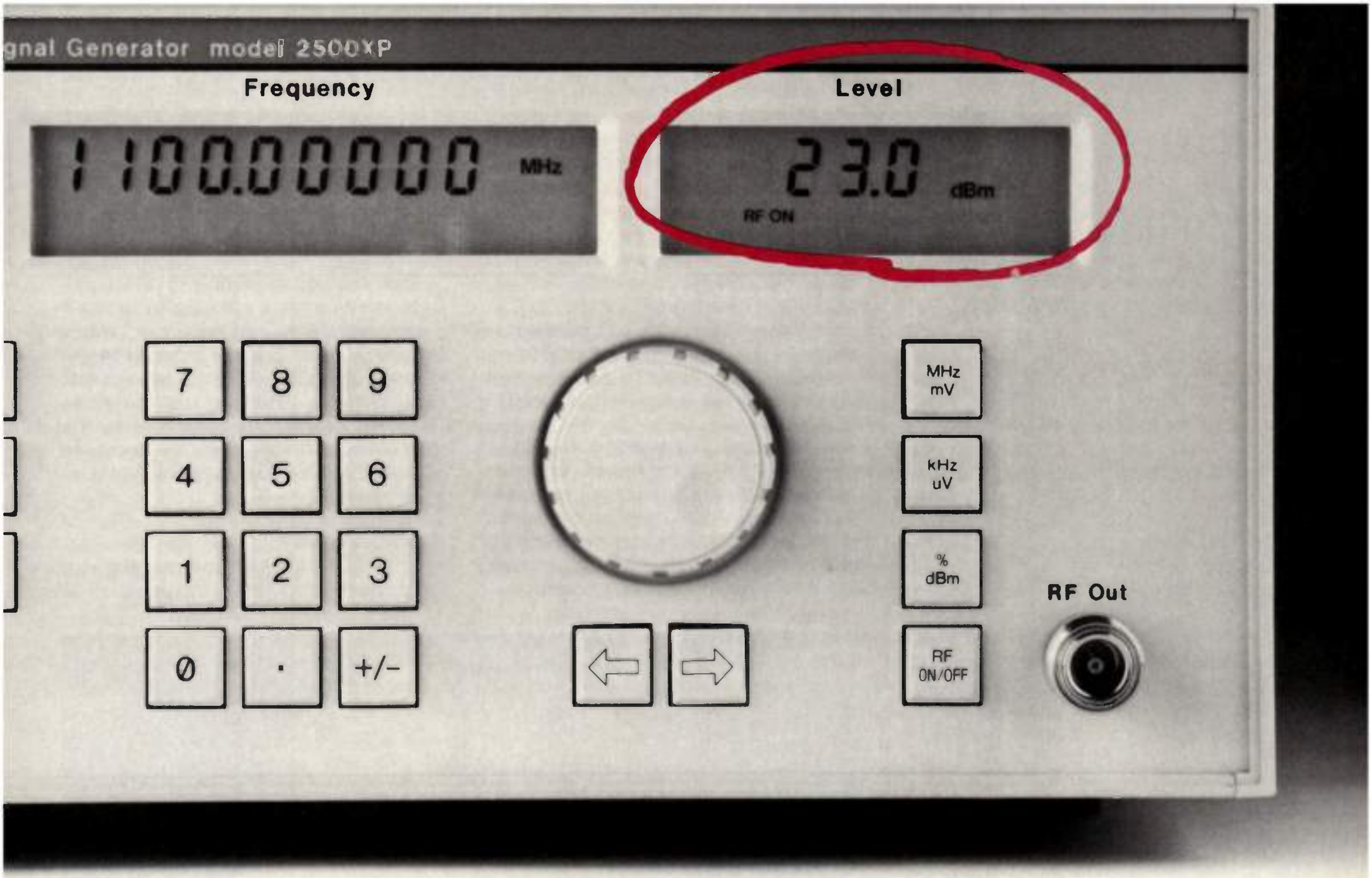
A contract, valued at approximately $500,000 to develop a cost and yield analysis model for X-band radar transmit/receive (T/R) modules has been awarded by the Navy to Anadigics, Inc. of Warren, N.J. The model will be used to evaluate the use of GaAs microwave ICs (MMICs) on radar T/R modules. The baseline for the modules will be custom-designed X-band chips such as phase shifters and amplifiers.

W-J Wins $1M Order

Watkins-Johnson Company has announced that is has received an order valued in excess of $1 million from the Singer Company's Dalmo Victor Division, Belmont, Calif. The order calls for the delivery of microwave filters and includes an option for additional deliveries totalling more than $300,000.

$27M Army Contract to Wiltron

Wiltron Company has been awarded a five year contract worth more than $27 million by the United States Army Procurement Center at Fort Monmouth, N.J. The contract calls for the supply of an estimated 1,800 Wiltron Series 6600B microwave sweep frequency generators and replacement parts. The award was made as part of the Army's electronic instrumentation modernization program for the 1990s. The sweep generators cover from 10 MHz to 40 GHz and will be used to monitor the Army's microwave and satellite communications systems.



Power full.

The new Wavetek 2500XP High Power Signal Generator delivers the highest standard output power of any modern signal generator.

With a maximum RF output of +23 dBm from 1 MHz to 1100 MHz, the 2500XP outperforms the +13 to +18 dBm output of low power generators, without compromising flatness, accuracy and signal purity.

It offers excellent output performance for high level mixer or receiver saturation testing. And test system builders can now easily split signals without reducing signal levels or using additional amplifiers.

The 2500XP makes the conventional combination of signal generator and output booster amplifier obsolete. It automatically corrects any power inaccuracy or flatness variations caused by the output amplifier and registers the true RF output delivered to a device under test. No more calculations are needed for outboard amplifier gain and flatness. Even stray radiation is kept to less than 1.0 μV.

All this power, all this ease of use, all for the price of the typical +13 dBm generator: $5750.

For a free 2500XP demonstration and data sheet, call or write Wavetek RF Products, Inc., 5808 Churchman Bypass, Indianapolis, IN 46203-6109, 317-788-5965.

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INFO/CARD 23

The Winning Designs

Results of the Third Annual RF Design Awards Contest

By Gary A. Breed
Editor

Twenty-seven entries were submitted for this year's contest, each one a worthy representative of the RF engineering profession: amplifiers, oscillators, test instruments, modulators, filters and couplers. If only we could award a prize to every engineer who entered the Third Annual RF Design Awards Contest...

This collection of entries was a challenge to the judges, despite the fact that there were no more entries than last year. The task of evaluating such a diverse collection was somewhat frustrating for each individual judge, but with the variety of interests and expertise represented by all four judges, we have confidence in the results.

Consulting Editors Andy Przedpelski and Bob Zavrel commented on the difficulty of making side-by-side comparison of dissimilar ideas. Together with Charles Wenzel (last year's winner), they also noted the problem of judging entries outside their primary areas of expertise, making it necessary to spend a lot of time on research. Despite these things, all judges agreed that the entries represented 'a lot of good ideas.'

Another item of note is the length and thorough preparation of the entries. While there were some that presented a circuit with a minimal amount of analysis and explanation, most were well-documented presentations. Readers will have a chance to see all of the prize winners, plus another five or six entries, during the next year.

The Grand Prize Winner

Albert Helfrick of Dowty RFL Industries in Boonton, New Jersey is the 1988 First Prize winner, receiving the Design Kit software collection from Compact Software. His entry, "An Optically Coupled VCO," was judged to be the cream of this year's crop. The circuit describes an interesting way of eliminating load pulling of a VCO, while also eliminating the last unfiltered connection to a shielded oscillator — the output cable.

When Al was called to inform him of his success, he was naturally surprised, noting, "Just this morning I told one of my co-workers that the third rejection letter was due from the RF Design contest." The third entry really was a charm! He will deliver a paper on his VCO circuit design at RF Expo East in October, and if his schedule permits, at the RF Technology Expo at Santa Clara in February. His winning entry is featured in this issue, following this report.

Second Prize: A Repeat Winner

The winner of the IFR A-7550 Spectrum Analyzer is Peter Vizmuller of Motorola Canada, North York, Ontario. In 1987 Peter also finished second, making him the first engineer to win a prize in more than one contest. His entry, also featured in this issue, describes a UHF notch filter to improve spectrum analyzer measurements, using a helical filter and a circulator to maintain a low VSWR without degrading notch performance.

It is interesting to note that the top prize winners were not lengthy or complex entries. They may not be absolutely unique or novel circuits, but they represented elegant solutions to specific engineering problems. Over the three years the contest has been held, with a total of six different judges, the top prize winners have all been relatively uncomplicated designs.

Runners-up

Four more entries win inductor kits from Coilcraft. Taking them in alphabetical

David Pacholok's microwave oven-to-amateur television transmission conversion.

Grand Prize winner Al Helfrick explains his prototype VCO to technical editor Mark Gomez.

order, we begin with Dan Baker, another repeat winner. Dan, an engineer at Tektronix in Beaverton, Oregon, won the first contest, and is back among the leaders with his entry, "A Simple 70 MHz FM Demodulator." While working on a cost effective modulator, this linear demodulator design was developed to evaluate modulator performance.

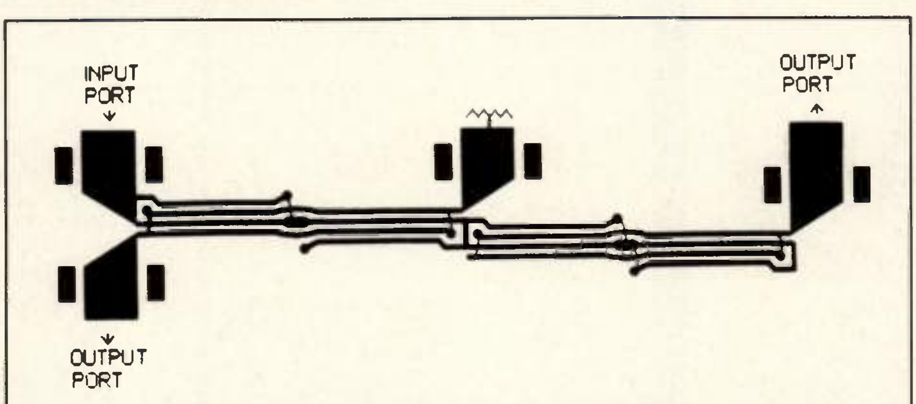
Derek Fitzgerald, a Principal Engineer at Raytheon in Bedford, Massachusetts is another winner. "Designing With a Double Lange" is the title of his successful entry, describing variations on the basic quadrature Lange interdigitated coupler. This paper presents designs for in-phase and 180-degree couplers, offering a good example of the time saving application of computer simulation of microstrip circuitry.

Thomas Mathews takes one of the runner-up prizes with his voltage-controlled phase shifter design. Mathews is a Senior Engineer at Wavetek RF Products in Indianapolis, Indiana, His design was developed to perform the task of controlling phase, a necessary function in many of today's high performance instruments. Along with the other runners-up, this design will be published in an upcoming issue of *RF Design*.

David Pacholok of Creative Electronics Consultants in Sleepy Hollow, Illinois will receive the final prize. His entry was a report on his conversion of a microwave oven to an amateur television transmitter. His work in tuning and modulation methods for consumer-grade magnetrons may be the first of its kind. David's entry demonstrates an application not covered in the manufacturer's data sheet.

In total, the entries once again represented the best side of the RF profession: creative design, using both theoretical principles and practical innovation. The above six entries were prize winners, but there were several more which deserve attention. Over the next nine months, all winning designs will be published in *RF Design*, plus some of the entries which just barely missed the top six.

Be watching for the announcement of the Fourth Annual RF Design Awards Contest in the November 1988 issue. Most of the prizes have been determined, and are guaranteed to be every bit as good as those awarded so far. Also, we plan to make minor adjustments to the rules to make it both easier to enter and easier to judge. Let us find your design among the next group of winners! rf



Derek Fitzgerald's entry covered the design of interdigitated Lange couplers.

Peter Vizmuller's bench gets a new IFR A-7550 Spectrum Analyzer.

The Prizes

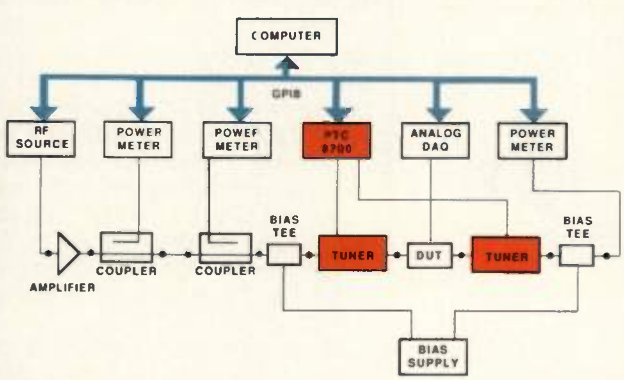
The Grand Prize, won by Albert Helfrick, is the "Design Kits" package from Compact Software. This is a collection of four RF design aids: The RF Design Kit for optimization, transformer and oscillator design; the Communications Design Kit for transmission, reception, antenna and path evaluation; the PLL Design Kit for complete synthesizer design; and the Filter Design Kit which includes LC, crystal, helical and interdigital designs.

Second prize was sought by many entrants even more than the Grand Prize, Peter Vizmuller receives the A-7550 Spectrum Analyzer provided by IFR, Inc. This 100 kHz to 1 GHz unit is microprocessor controlled, with automatically optimized control of resolution bandwidth, span and sweep rate. A built-in demodulator lets the operator monitor the signal displayed, and its battery power capability makes it an excellent choice for field service as well as bench use.

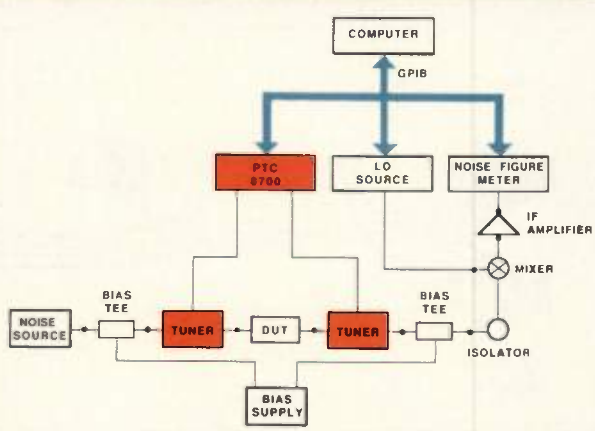
The four runners-up receive two variable inductor kits from Coilcraft. The "Slot Ten" kit includes 108 coils with values ranging from 0.7 to 1143 uH, while the "Unicoil" kit has 196 single-layer slug tuned coils over the 0.0435 to 1.5 uH range.

RF Design wishes to thank the companies who have supplied these prizes. They have contributed significantly to the success of the RF Design Awards Contest!

DISCOVER LARGE SIGNAL



A typical configuration for performing load and source-pull characterization with respect to power and/or efficiency.



A typical configuration for performing noise figure characterization.

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An Optically Coupled VCO

Contest Winner Uses Novel Approach for Load Isolation and Shielding

By Albert Helfrick
Dowty RFL Industries

Voltage controlled oscillators for frequency synthesizers must be well isolated to prevent the VCO from being frequency modulated by external fields, or from the effects of varying loads. The amount and effectiveness of the isolation is dependent on: the frequency pulling that can be tolerated; the frequency and tuning range of the oscillator; the ability of the phase-locked loop to remove frequency pulling; the intensity of the electromagnetic field in the vicinity of the oscillator; and the amount of variation of the load.

A particularly troublesome situation is a VCO that generates the output frequency for a pulse- or amplitude-modulated transmitter. The modulator must be well isolated from the oscillator, as the input impedance of many modulators is a function of the modulating waveform.

Although any external electromagnetic field can cause frequency modulation, the situation is particularly difficult when the external field is phase coherent with the oscillator. Even small amounts of energy finding its way from the transmitter output to the VCO can cause serious frequency modulation of the VCO. The situation is also difficult, but not quite as bad, when the external field is close to the oscillator frequency.

Shielding techniques are well known. A highly conductive enclosure is provided around the entire oscillator. The enclosure must be completely sealed against RF signals which involves seam soldering, overlapping joints and finger stock on removable parts of the enclosure. RF ingress through the electrical connections is prevented by the use of feedthrough capacitors and filters. There must be, however, one "hole" for RF and that is for the RF output of the oscillator. This RF port provides a point of ingress for RF energy. Typically, buffer amplifiers and attenuators are provided with additional enclosures for isolation as well as shielding. This shielding and isolation can be quite extensive if the VCO is sensitive and the ultimate power output of the system is quite high (500-1000 watts), such as aircraft transponders and distance measuring equipment (DME).

Isolation, rather than shielding, is required to prevent frequency pulling due to changes in the load seen by the oscillator. This is particularly true when the stages driven by the oscillator are modulated or the oscillator feeds a mixer, which is also a form of modulator. Another, often overlooked, variable load presented to an oscillator in a phase-locked loop system is a dual modulus prescaler. There is often a slightly different input impedance between the two modes of the prescaler.

An attenuator is one popular method of providing isolation. However, the attenuator reduces the level of the oscillator output which must be compensated for by amplification. Luckily, the amplifier provides additional isolation, since the isolation of the amplifier is at least equal to its amplification. As an example, when 10 dB of attenuation is followed by a 10 dB amplifier the isolation is 20 dB, minimum.

A technique that provides superb shielding and isolation is to couple the RF energy out of the shielded enclosure with an optical coupler. Thus, the oscillator is completely enclosed with the exception of a very small hole to allow the light energy

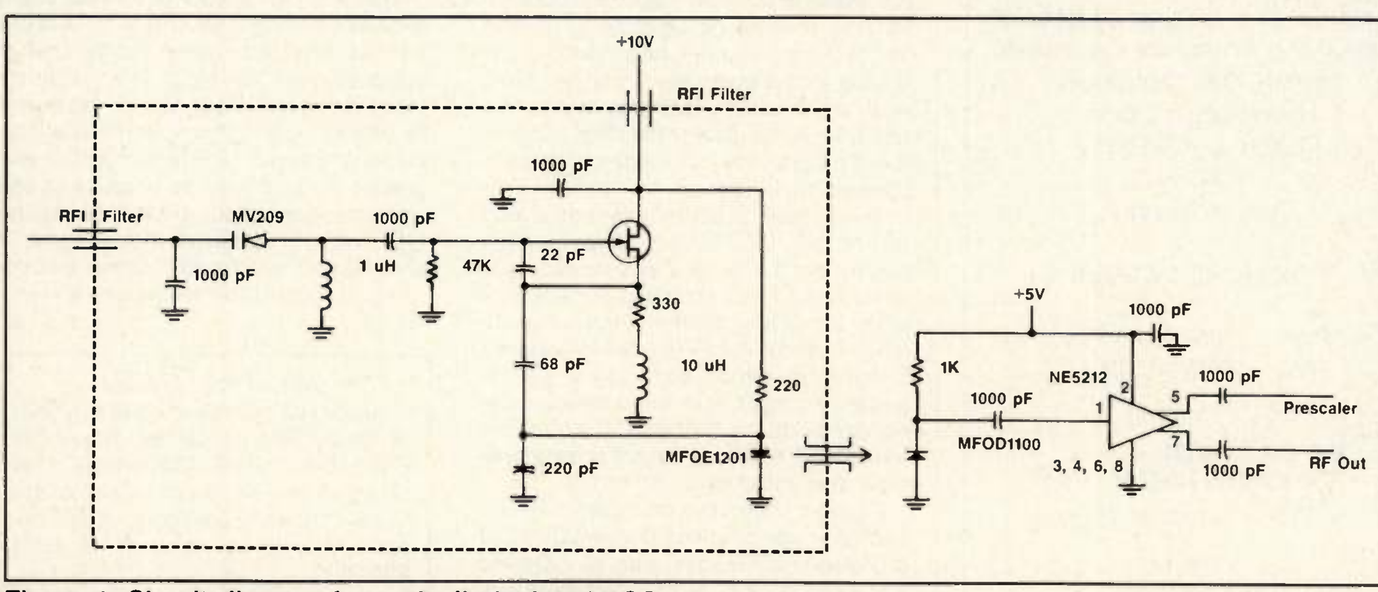
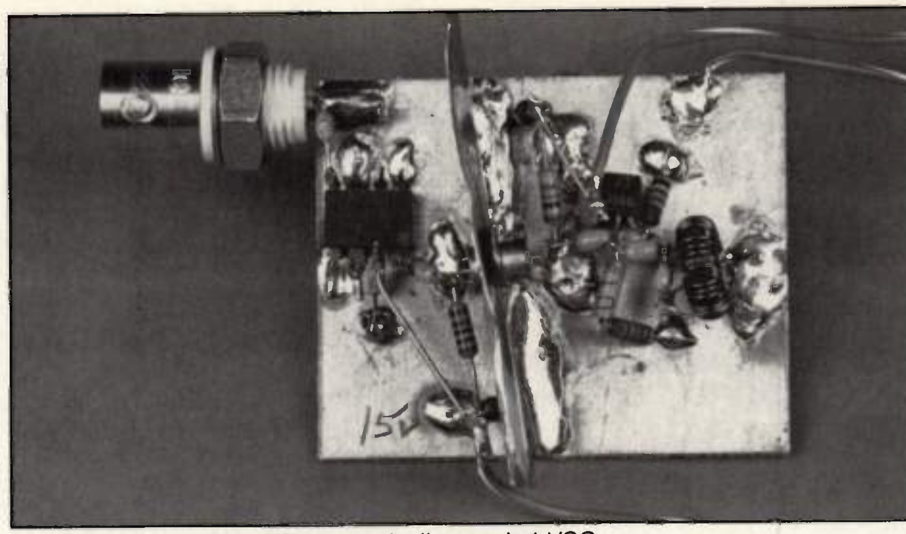


Figure 1. Circuit diagram for optically isolated VCO.



Close-up view of the prototype optically coupled VCO.

to pass through. There is absolutely no "hole" for RF from the shield enclosure.

Although the technique is possible in theory, there are no available optical couplers that can provide signal passage into the VHF region, or can straddle an RF shield. For this example oscillator, an optical coupler was constructed using a very fast light emitting diode and an equally fast PIN diode photodetector. A Motorola MFOD1100 PIN diode and a MFOE1201 aluminum gallium arsenide LED were used. The bandwidth of the emitter diode is 100 MHz, while the response time of the detector diode is less than 1.5 ns. Therefore, the frequency response of the system is limited by the LED. The application was a 40 MHz VCO for a frequency synthesizer where very low phase noise was required but a second phase-locked loop was present and the frequency of the two VCOs would differ by only a few hundred Hz.

The VHF opto-isolator was created by mounting two diodes "head to head" without an intervening fiber. The diodes are made to fit into a fiber optic connector and it would be possible to provide connectors and fiber and connect the diodes in the convention manner. However, the coupling loss due to the two fibers would be greater than that encountered by coupling the diodes in this unconventional manner.

The biggest problem associated with driving the LED is the rather low impedance of the diode. The dynamic resistance of the forward biased diode is only a few ohms and there is a large capacitance of about 70 pF. This low impedance is driven by simply providing a low impedance output from the oscillator. The emitter diode is provided with a bias current so the resultant output is an amplitude modulated light carrier.

Figure 1 shows the example VCO. The oscillator was operated and evaluated at two frequency ranges, one at 100 MHz and a second at 40 MHz by simply changing the inductor. The output levels and frequency pulling characteristics were quite similar for the two oscillator versions. The PIN photodiode feeds a transimpedance amplifier which provides a +5 dBm output. Unlike more conventional designs, the transimpedance amplifier provides an increase of signal, is not required for isolation and does not require shielding.

The test data for the optically isolated oscillator shows, essentially, no frequency pulling for load variations extending from open circuit to a short. The test was done using a frequency counter after the oscillator had been on for a long period of time. The oscillator was placed in a simple insulated container and allowed to operate for several hours. An output cable equal to a wavelength of electrical length was provided so that known mismatches could be applied to the oscillator within the insulated container.

There would be no sense in tabulating the data as, within the error of the measurements (10 Hz) there was *no* frequency pulling due to the load mismatch.

The limiting factors of the example oscillator are the 3 dB frequencies of the transimpedance amplifier and the emitter diode of about 120 MHz. The frequency limits of this technique can be increased by employing a higher speed PIN photodiode, a wideband RF-style amplifier and a laser diode. It may be possible to use an inexpensive laser diode such as the type used in compact disk players. It should be possible with these components to extend the technique above 1 GHz. rf

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An Absorptive Notch Filter

Contest Runner-up Combines Helical Filter and Circulator for High Performance

By Peter Vizmuller
Motorola Canada

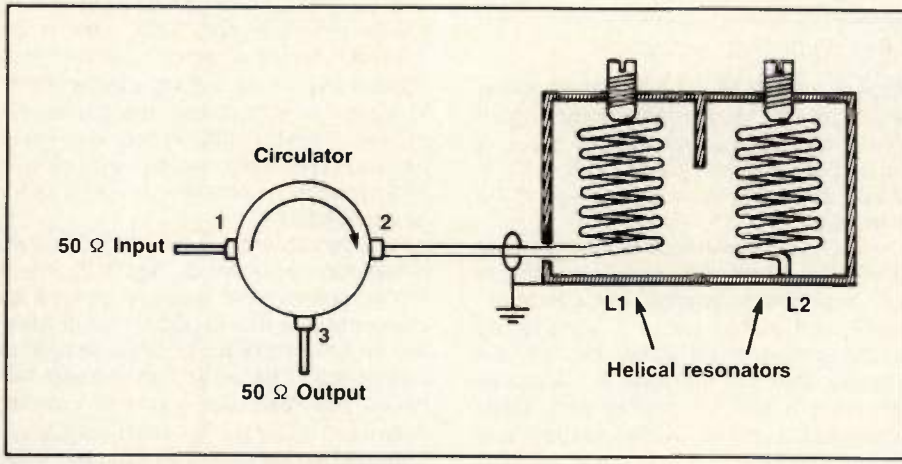


Figure 1. Absorptive filter topology.

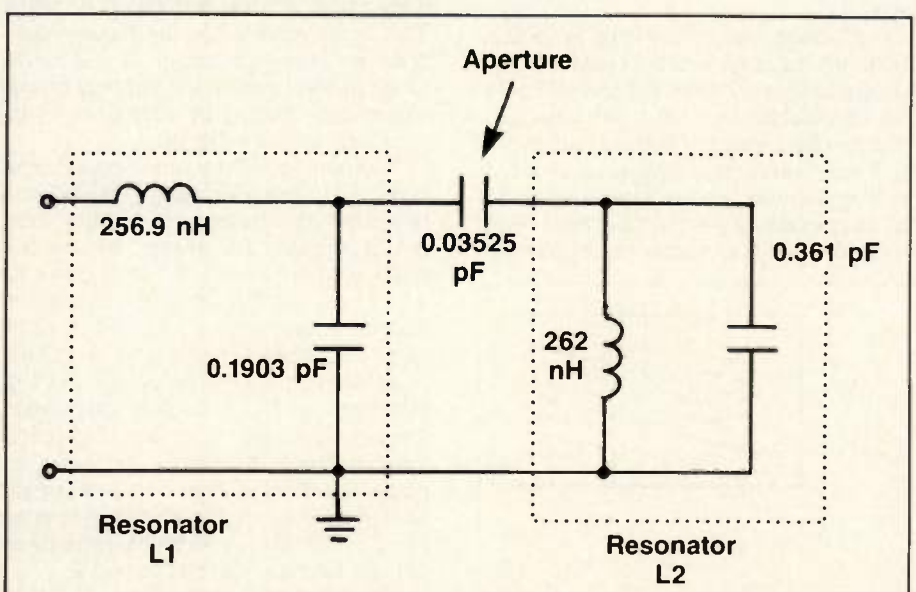


Figure 2. Equivalent circuit of helical filter.

The design of high performance frequency synthesizers presents many challenges, one of which is the reduction of spurious outputs. Most of these spurious outputs are generated by digital signals and show up as sidebands on the desired carrier, from several kilohertz to few megahertz away. This article describes a miniature, tunable UHF notch filter which can be used to reduce the level of the fundamental carrier, allowing observation of the sidebands on a spectrum analyzer.

Measurement of these spurious outputs depends on their characteristics. For discrete signals up to 100 kHz away from carrier, the best method is to mix the desired carrier down to DC and examine the spurious outputs with an audio spectrum analyzer. Other discrete spurious outputs can be measured directly on an RF spectrum analyzer, narrowing the resolution bandwidth as much as necessary to obtain the required dynamic range.

There is another class of spurious output, which is difficult to measure because the spurious outputs are not discrete, but are pseudo-random or noise-like in nature. Examined by a spectrum analyzer, they look like 'noise humps' and their apparent spectral properties can be altered by changing the spectrum analyzer's sweep time. Because these signals are pseudo-random, narrowing the spectrum analyzer's resolution bandwidth in an effort to improve the measurement dynamic range reduces their amplitude as well, and an accurate measurement cannot be taken. The only reliable method of measuring such signals is to leave the

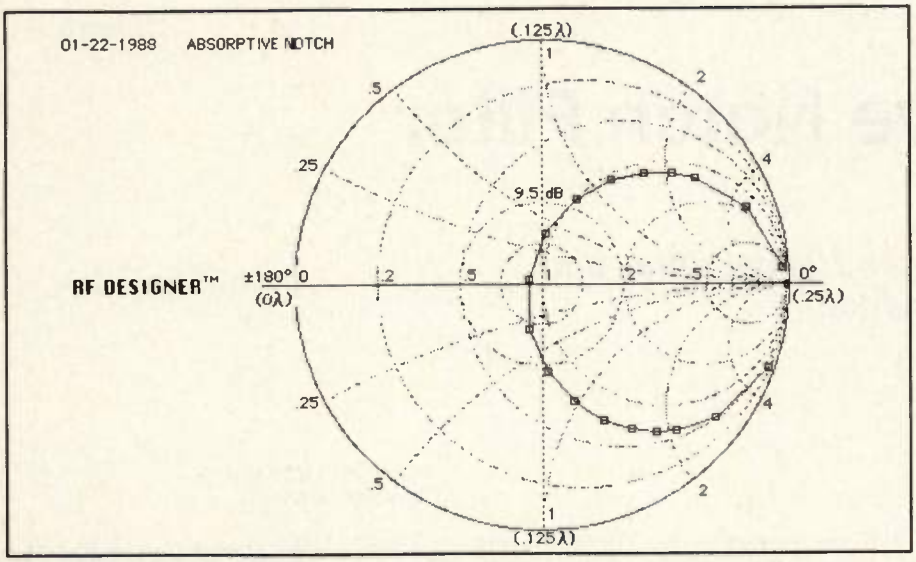


Figure 3. Input impedance of helical filter excluding circulator.

resolution and video bandwidths wide open and use a very narrow notch filter to remove the carrier, so that all RF attenuation ahead of the analyzer's mixer can be removed. This measurement technique is of course well known and widely used, but can be improved in several important areas, as will be shown.

The Need For A New Type of Filter

Conventional band-reject filters are reflective — their stopband attenuation is obtained by reflecting the signal from the filter input. As a consequence, their input impedance in the stop-band is highly reactive. Therefore, a synthesizer under test cannot be directly connected to such a filter since it would be highly mismatched exactly at its operating frequency. An attenuator has to be used between the synthesizer and notch filter to minimize this impedance mismatch. A 10 dB attenuator will provide a good 20 dB return loss termination, but at the expense of 10 dB of dynamic range! It would be nice to have a filter which could notch out the carrier without creating an impedance mismatch, and without introducing excessive attenuation in the passband.

Notch filters with less than 1 per cent 3 dB bandwidth are usually expensive and their characteristics — notch depth, width and tuning range — cannot be easily changed (at least not without voiding the manufacturer's warranty). An inexpensive notch filter with easily controllable notch width, depth and tuning range and which could be built in less than a day could be considered useful.

An absorptive notch filter is usually built using a large tunable coaxial cavity, an adjustable sliding short and a circulator connected together in an ingenious manner by a maze of coaxial cables and a T-connector, resulting in a piece of test equipment whose size is an order of magnitude larger than the item being measured. It is possible to obtain comparable performance in a smaller size, with less touchy tuning and with greater tuning range by substituting helical resonators for both the sliding short and the coaxial cavity, using aperture coupling instead of the T-connector and coaxial cables.

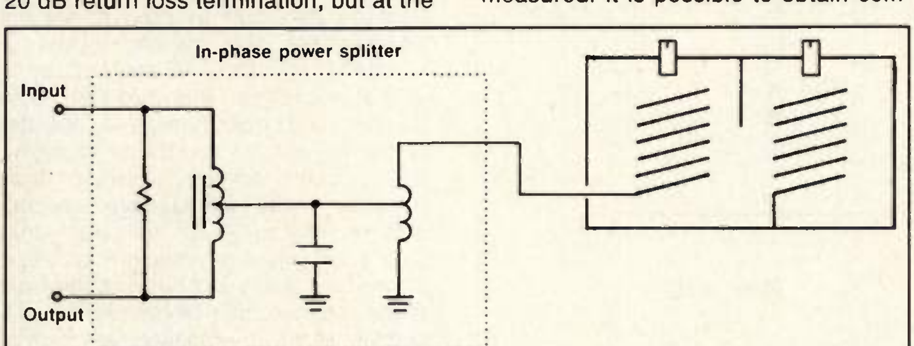


Figure 4. Notch filter using power splitter.

Absorptive Filter Topology

Figure 1 shows a filter which has very good return loss in both passband and stopband, is inexpensive to build, relatively easy to design for the desired response, and is much smaller and more versatile than a conventional absorptive filter.

The filter's operation can be intuitively described as follows: Helical resonator L2 has a high but finite Q-factor which can be modelled as a small resistor in series with the coil. This very small resistor is transformed by L2 and L1 into 50 ohms. Because the impedance transformation is so extreme, the bandwidth of the transforming network is very narrow. The input return loss of this two-resonator network shows a very sharp notch.

An equivalent circuit for the two resonators is shown in Figure 2, where the component values were derived by computer simulation. Both helical resonators are modelled as large inductors with a small parasitic capacitance between the resonator top and ground. Aperture coupling is modelled as a small capacitance between the resonator tops. Figure 3 shows the theoretical input impedance of this equivalent network. This figure shows that the input impedance crosses the center of the Smith Chart in a very narrow frequency range, elsewhere the input impedance approaches an open circuit.

The purpose of the broad-band circulator is to convert loss, which is a reflection parameter into insertion loss, a transmission parameter. At the frequency where the helical filter presents a 50 ohm load, the circulator is matched and no output appears at port 3. At all other frequencies, port 2 is mismatched, input signal is fully reflected and appears at port 3 only slightly attenuated. Thus transmission from port 1 to port 3 exhibits band-reject behavior. Since no power is reflected from port 3 to appear at port 1, the input impedance looking into port 1 is always 50 ohms, regardless of impedance conditions at port 2.

There are many other circuits which can perform the same function as the circulator, but all of them exhibit greater

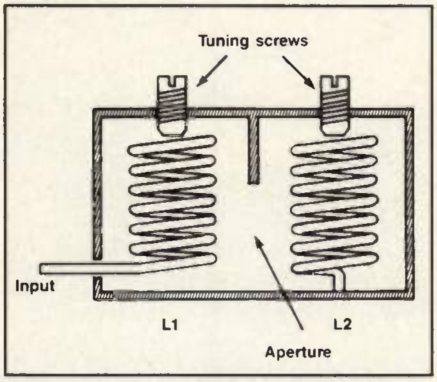


Figure 5. Helical filter definitions.

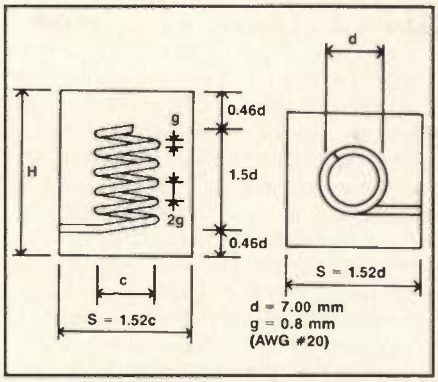


Figure 6. Resonator dimensions.

insertion loss. Figure 4 shows an in-phase power splitter to obtain the same frequency response as using a circulator, except for passband insertion loss which will be about 7 dB.Other circuits, such as directional couplers and VSWR bridges can also be used to build an absorptive notch filter.

Design Procedure

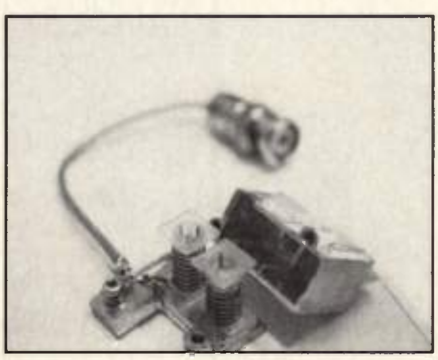
Referring to Figure 5, the Q-factor of helical resonator L2 determines the notch width, the aperture size determines the ultimate notch depth obtainable by tuning L1 and the overall helical resonator design determines the frequency range. Once the filter is built and connected to a circulator, tuning of L2 helical resonator tuning screw sets the notch frequency, tuning the first resonator screw determines the notch depth. Thus, the notch frequency and depth can be independently adjusted.

The unloaded Q and aperture capacitance required for a given desired response can be easily obtained from computer simulation. These parameters then have to be translated to physical dimensions. Relating unloaded Q to physical size or wire gauge is fairly straightforward (1), (2), while obtaining the correct aperture dimensions is best done empirically, by constructing the filter with a smaller aperture to begin with and gradually increasing it until the desired performance is obtained. The number of turns on L1 may also have to be trimmed empirically for optimal frequency response.

Helical resonators show another advantage over the conventional coaxial cavity and sliding short approach. For a given setting of the L1 tuning screw, which corresponds to a notch depth of about 20 dB, the only coil which needs to be tuned to change frequency is L2. Figure 8 shows that this 20 dB notch depth is maintained over 50 MHz of tuning range by tuning of L2 only. This is due to the fact that the Q of a helical resonator changes with tuning, and in our case the Q-variation is just right to produce a 50 ohm match at the frequency to which L2 is tuned. For greater than 20 dB notch depth, both resonators have to be tuned.

Figures 6 and 7 show the dimensions of helical resonators and aperture size used to build an absorptive filter. This filter can easily allow measurement of synthesizer spurs about 75 dB down 1.5 MHz away from a UHF carrier.

The above physical dimensions produce a resonator Q of about 500, tuning range from 430 MHz to 520 MHz (using 8-32 x 1/2' brass tuning screws), notch



Internal view of filter.

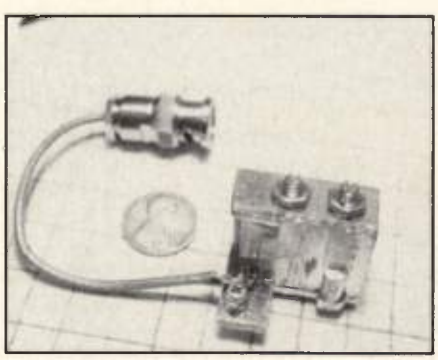


Photo of helical filter assembly.

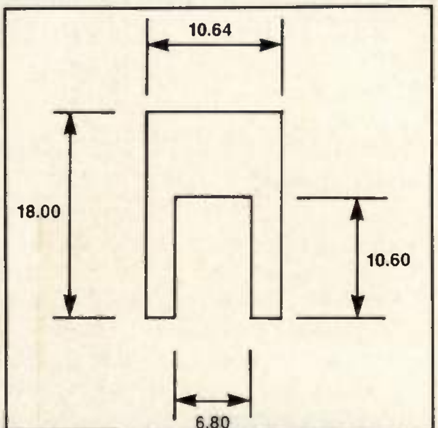


Figure 7. Aperture dimensions in mm.

depth greater than 50 dB anywhere in this frequency range, and a 3 dB notch bandwidth of less than 0.4 per cent. Figure 9 shows the filter response at 400 kHz per division, with the 3 dB bandwidth of 1.528 MHz (0.31%) identified by markers. Insertion loss in the passband is less than 1 dB. Figure 10 shows the filter input return loss over 80 MHz of bandwidth. It is better than 20 dB and is only limited by the circulator characteristics. In this figure the reference 0 dB return loss is at the top of the graph. Figure 11 is a close-up of the stopband to make sure that the return loss is well-behaved in this region: it is greater than 23 dB, with no sudden changes near the notch frequency.

The output of a synthesizer under test is shown in Figure 12, where the carrier at 474 MHz was notched out (top of graph is -30 dBc), showing pseudo-random spurious outputs 70 to 80 dB down anywhere from 1.5 to 5 MHz away from the carrier. The "noise" sidebands are not symmetrical about the carrier, indicating that the spurious outputs are either added to the output signal or that a combination of amplitude and phase modulation of the carrier is taking place. Asymmetry in the sidebands can also be caused by a mis-tuning of the notch filter, which is not the case in Figure 12, since our filter is much too narrow to affect sidebands more than 2 MHz away form the carrier.

Also, because the impedance of an absorptive notch filter is purely resistive, any number of them can be easily cascaded with the responses simply adding without interaction. Figure 13 shows two cascaded absorptive notch filters. The two notches are tuned approximately 130 kHz apart, giving a 50 dB notch bandwidth of only 150 kHz.

Conclusion

An absorptive notch filter of small size and good electrical performance can be built with helical resonators and a

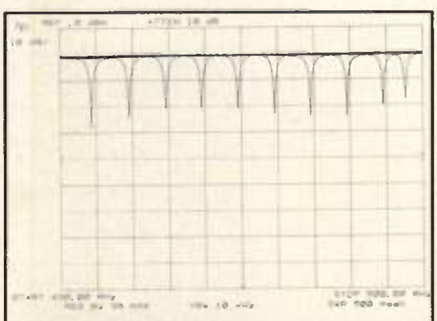


Figure 8. Notch performance tuning L2 only.

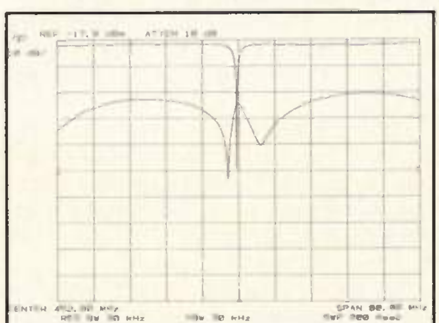


Figure 10. Shows return loss in stopband.

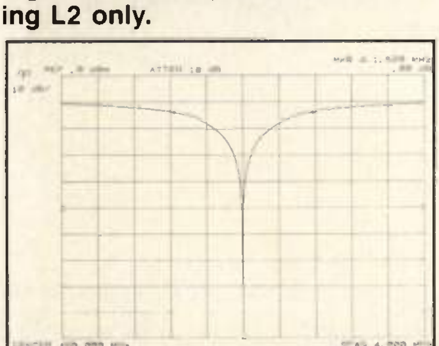


Figure 9. 400 kHz/div. filter response.

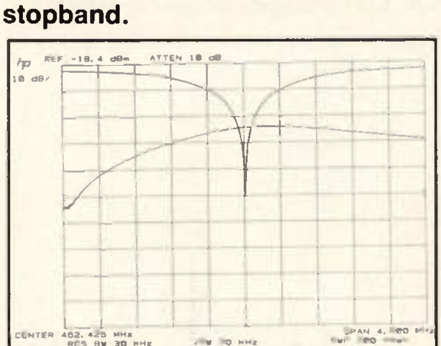


Figure 11. Close-up of stopband return loss.

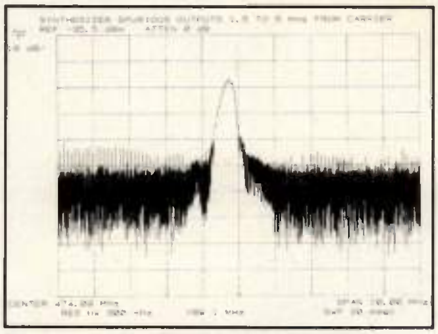


Figure 12. Synthesizer spurious output measurement.

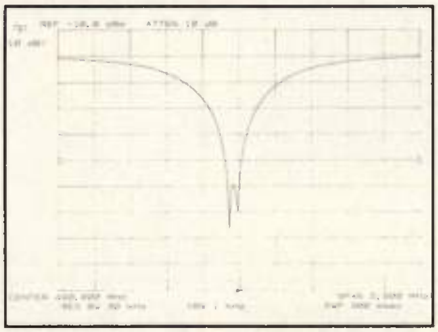


Figure 13. Response of cascaded notch filters.

circulator. This filter can be used when a very narrow notch with resistive input impedance is required, such as in the measurement of high-performance frequency synthesizers.

Acknowledgement

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Profile of an RF Engineer

The 1988 RF Design Reader Survey

by Gary A. Breed
Editor

This Spring, we mailed surveys to our readers to determine the current status of the RF engineering profession. The responses have now been tabulated, with the results showing interesting statistics about RF engineers. Many areas turned out as we expected, but there are also seem to be some unexpected trends. We will be watching closely to see how they continue to develop.

The survey was mailed to 3000 names at random from our list of subscribers in an "every nth" sequence. 308 readers returned completed questionnaires. This return rate is considered a good statistical sample, and should be an accurate representation of the entire corps of *RF Design* subscribers. Much of the data included in this summary can be compared to a similar survey conducted in 1986, indicating trends within the RF engineering profession.

Age (Figure 1)

A typical RF engineer is about the same age as two years ago. The median age today is about 38 years old, almost exactly the same as in 1986. As can be seen in the graph, there are some changes in age distribution: a small drop in the under-30 group, a noticable increase at 30-39, another small decrease in the number of 40-59 year olds, and a few more over 60. These results show no clear trend in age, but the shifting in age groups is something we will watch.

Salary (Figure 2)

RF engineers are relatively well-paid, with half the responding engineers earning $45,000 or more. Less than two per cent reported salaries under $25,000, while more than 26 per cent make $55,000. This area has another statistic to watch: The number of engineers making over $45,000 was slightly larger in 1986. Figure 2 also shows some shifting in the distribution of salaries, much like the variation in the age category.

Experience

Although the median age of RF engineers is unchanged from two years ago, the level of experience has increased by about two years. Overall engineering experience has risen from 12 years to 15 years, and RF experience is up from 6 years to 8 years. The greater increase in overall experience indicates that engineers are coming to RF from other areas of engineering.

Education (Figure 3)

We are pleased to note that *RF Design* readers are very well educated! We tabulated the education levels of our questionnaire responses according to the highest level achieved, and found that only 10 per cent had no baccalaureate degree. Most of this group had two-year degrees or specific technical training. This non-degreed group is smaller than it was two years ago.

Nearly 31 per cent of our readers have graduate degrees, with the majority being MSEEs. The rest are MS degrees in the sciences, a handful of PhDs, plus a few MBAs. 54 per cent have BSEE degrees, with the remaining 5 per cent having BS or BA degrees in

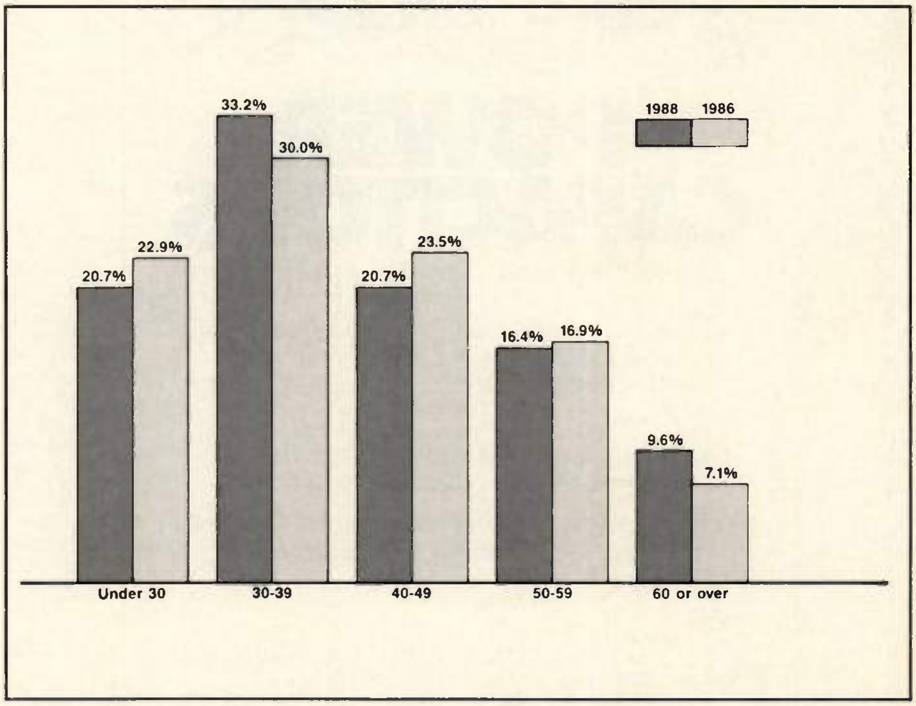


Figure 1. "What is your age range?"

other fields. A significant number of surveys noted that some graduate course work has been completed.

Industry Classifications

We asked readers to categorize their work in four broad categories: consumer, military/aerospace, non-military aerospace and industrial/commercial. 55 per cent work on military projects, with 10 per cent involved in other aerospace work. Taken as a group, this is a larger percentage than in 1986, even though the non-military aerospace

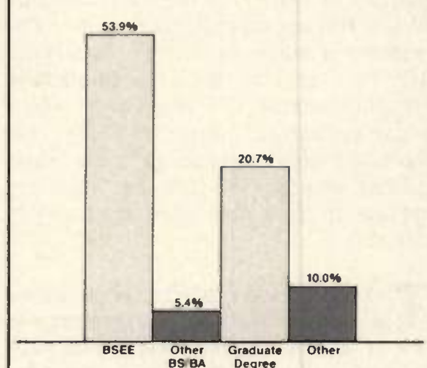


Figure 3. Highest degree.

category is down slightly. The industrial/commercial category is also up slightly, with one-third involved in this type of work.

This leaves consumer applications as the loser, down by over three percentage points in the last two years. Any recent improvement in the condition of the U.S. consumer industry has bypassed the RF community.

Frequency Range of Work (Fig. 4)

Our readers are truly RF engineers. Some work at low frequencies (9 per cent working under 100 kHz), and some are involved in microwave projects (27 per cent do at least part of their work over 3 GHz). The vast majority work in the VHF/UHF frequency range, with 38 and 41 per cent indicating work in 30-200 MHz and 200 MHz-1 GHz ranges, respectively. Another 27 per cent mark is given to 100 kHz-30 MHz, and 25 per cent to the RF/microwave transition area of 1-3 GHz.

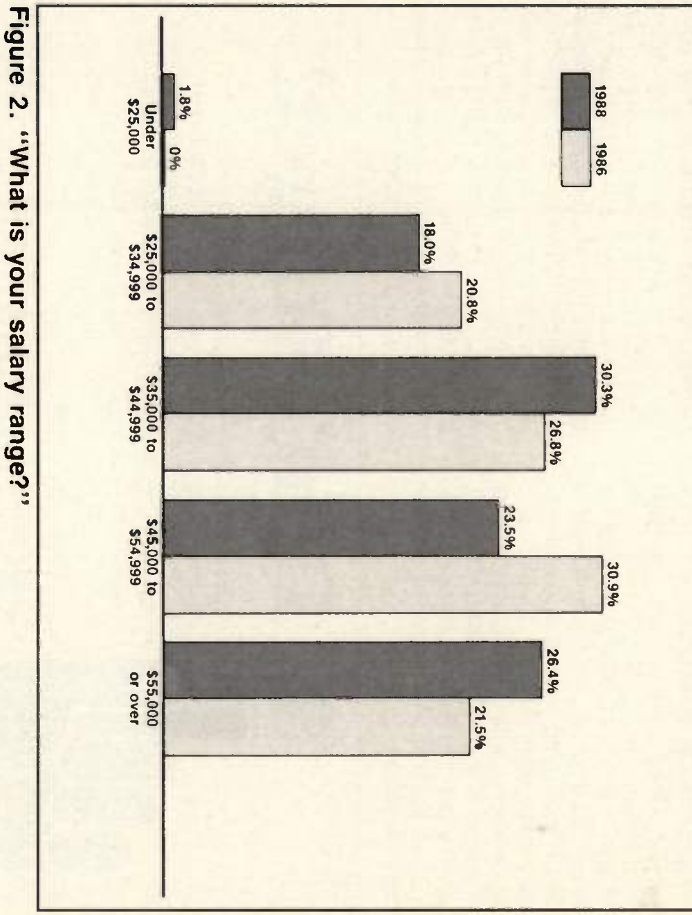


Figure 2. "What is your salary range?"

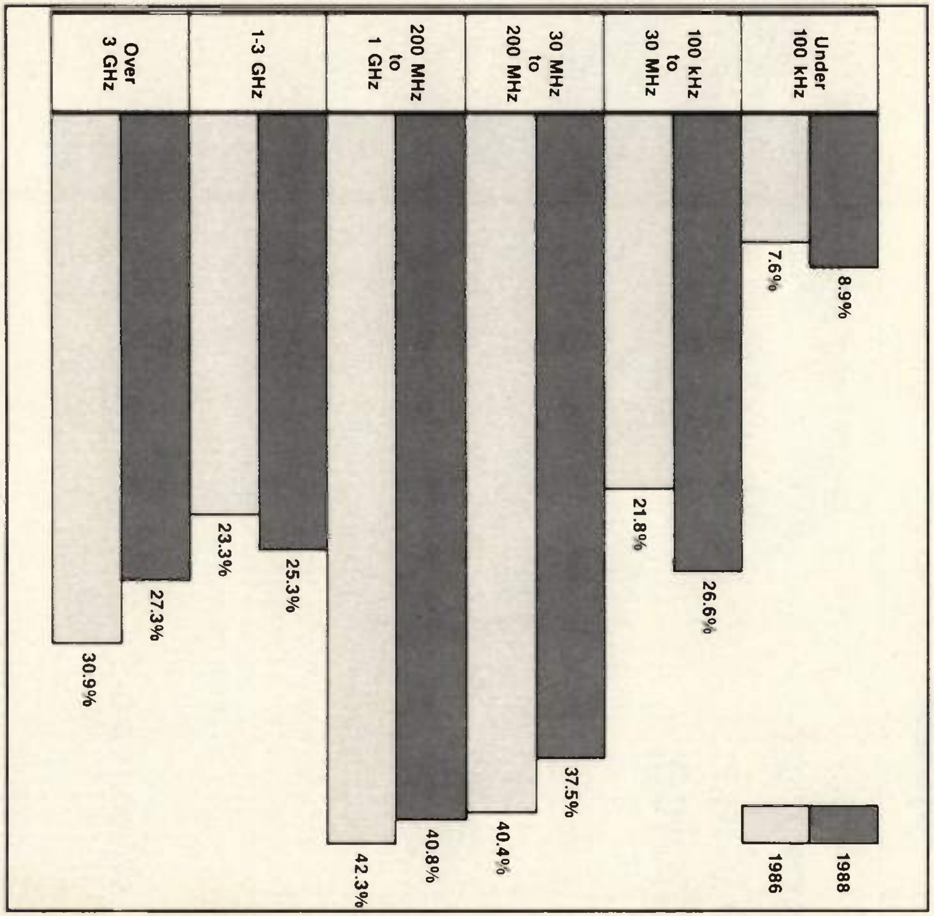


Figure 4. "Indicate the one or two frequency ranges in which you mainly work."

Compared to 1986, engineers reading *RF Design* are working at lower frequencies. The prime RF territory of 30 MHz-1 GHz is still the largest, but the over-3 GHz group is down almost 4 percentage points, and the under-30 MHz categories are up a total of 6 percentage points. The biggest change was seen in the 100 kHz-30 MHz range, which was up by five percentage points, a 22 per cent increase in activity over the past two years.

Company and Plant Size (Fig. 5)

This is a category with virtually no change from the previous survey. The median company size is 5040, and the engineer's own location has a median size of 500 employees. Only 16 per cent of our readers work for companies with 100 or fewer employees. Almost a third work for companies that employ more than 10,000 workers.

The particular office or plant where our readers work is more modest. Half are 500 persons or less and only 10 per cent are home to 5000 workers. 21 per cent are locations with 50 employees or less.

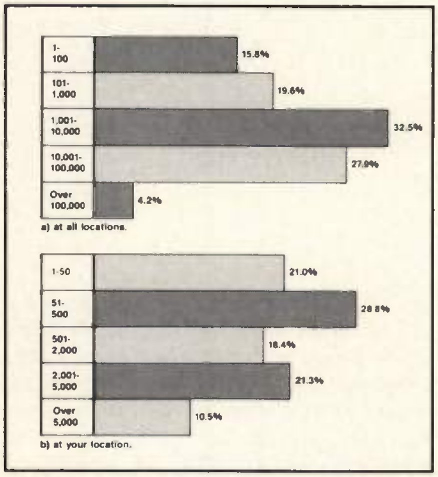


Figure 5. "Approximately how many people are employed by your company or institution?"

Conclusions

A few significant observations can be made from this survey. First, RF does not seem to be a beginner's industry. The typical RF engineer has spent only half of his or her professional career working in RF. The salary levels reflect this same maturity, with half making over $45,000, and more than a quarter making over $55,000. Our readers' level of education is also noteworthy. 31 per cent have a Master's Degree or higher, and only 10 per cent are non-degreed, fewer than two years ago. These statistics indicate a high level of competence among RF engineers.

Although there are several apparent changes from the 1986 survey, few represent more than a couple percentage points and are, therefore, within the range of uncertainty of both surveys. Besides the smaller number of non-degreed engineers just noted, there are two other trends we feel are significant: increased activity in lower frequencies; and the reduction in consumer-related RF engineering. The first is positive, since any area of increased activity is a sign of vitality. However, the further erosion of U.S. consumer electronics is not good news.

Be assured that these topics will get a keen examination when the next RF engineer survey is completed. rf

Shielding — An Overview

By Mark Gomez
Technical Editor

Shielding can be defined as a method of suppressing interference which is radiated directly from a source. It is a barrier that separates two regions of space — one containing electromagnetic emissions and the other relatively free of those emissions due to the shielding action. In other words, a perfect shield does not allow the passage of electrostatic, inductive or electromagnetic energy.

In order to control or eliminate electromagnetic interference (EMI) to maintain compliance of a product, the designer has to eliminate the source, deflect the EMI field from areas it is not wanted or absorb its energy into a lossy material.

Eliminating the source is usually a step that cannot be performed since interference is usually a by-product of a desired operation. Reflection and absorption are criteria that are dependent on frequency. Reflection is the result of impedance mismatch similar to the reflection that occurs at a discontinuity in a transmission line.

When an electromagnetic wave hits a shield, it induces currents which create magnetic (H) and electric (E) fields. This phenomena reinforces the wave on the incident side while opposing the incident wave on the other side of the shield. This results in substantially reduced field strength that is transmitted through the field.

The external flux fields of eddy currents, created as a result of induced voltages by a variation in magnetic flux, can usually cancel the impinging magnetic or induction fields. This cancellation, measured as attenuation, is determined by the conductivity of the material. The attenuation characteristics of a shield are illustrated in Figure 1. As shown in Equation 1, attenuation of a mono-metal is also related to the penetration depth, δ.

$$\delta = \frac{\sqrt{2}}{2\pi f \sigma \mu} \qquad (1)$$

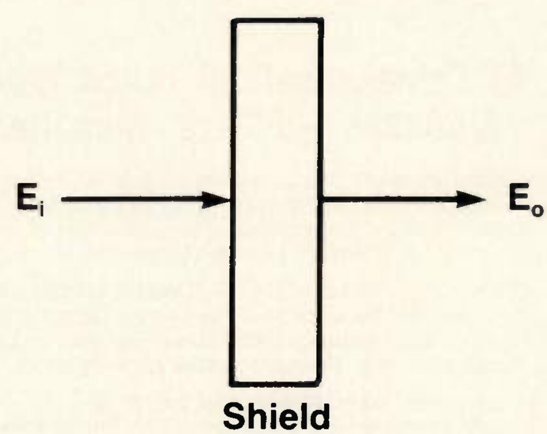
Where f is the frequency, σ is conductivity and μ is permeability. The attenuation is related to thickness of the shield by the following equation:

$$t = \frac{A}{3.338 \times 10^3 \sqrt{f \sigma \mu}} \qquad (2)$$

A is required absorption loss in dB and t is thickness of shield in mils. The value for frequency used in the equation should be the lowest frequency associated with the equipment being shielded.

Permeability of a material also determines attenuation. Materials with low permeability, when configured as a flat plane, allow good shielding efficiency against high impedance or electric fields. However, low permeability shielding materials do not attenuate low impedance magnetic or induction fields unless the shielding configuration is altered to create eddy currents in the material.

Since most metals and alloys have low impedance, they are effective in reflecting high impedance waves, either far-field or near field of the source. In this case, eddy currents induced in the metal reflect the interference energy away from the protected area and oppose the transmission of the wave through shields.



$$\text{Attenuation} = \frac{E_o}{E_i}$$

$$\text{dB} = -20 \log_{10} \frac{E_o}{E_i}$$

Figure 1. Attenuation measurement.

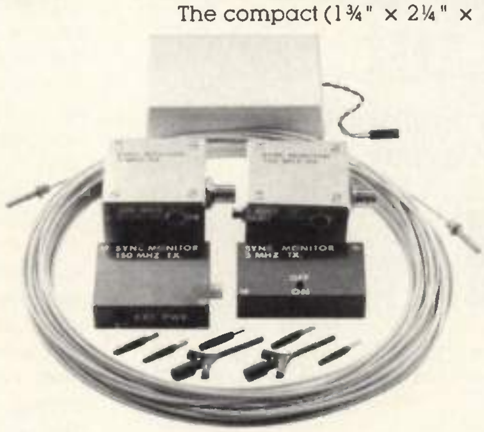
EMCO UPDATE

New Diagnostic Aid Offers Non-Intrusive Testing

Sync Monitor Kits Use Fiber Optic Technology

A new diagnostic aid from EMCO offers a non-intrusive tool for identifying the source of EMI emissions. The Model 4000 series of sync monitor kits include small transmitters, receivers and fiber optic links. Using minimal length input jacks for attachment to the targeted circuit, and non-radiating fiber optic links for for signal output, the transmitters are almost electrically invisible during testing.

In typical use, a transmitter is placed inside the EUT and attached to a targeted circuit where it will monitor machine functions during emissions testing. The transmitter (via the fiber optic link) sends its signal output to the matched receiver included with the kit. The signal output is converted and passed on to an oscilloscope. Simultaneously, radiated emissions from the EUT are received by a spectrum analyzer equipped with an antenna. By comparing the signal traces of the emissions on the display of the two signal analyzing devices, the probable source of emissions can be easily located.



The compact (1¾" × 2¼" × ½") size of the transmitters means that several units can usually be placed inside of an EUT at once. The thin diameter of the fiber optic link permits routing through the EUT's air This combination of features make the kits ideal for emissions testing of multiple circuits when the EUT's enclosure must remain sealed.

Two sync monitor kits are offered. The Model 4100 kit measures low frequency digital signals of up to 5 MBs and the model 4200 measures high frequency digital and analog signals up to 180 MHz. Both kits consist of a transmitter, receiver, fiber optic link, pins, sockets, clips, and carrying case. The kits can be used to test for both radiated and conducted emissions. Both kits are covered by EMCO's two year parts and labor warranty.

Call or write for a product description and pricing.

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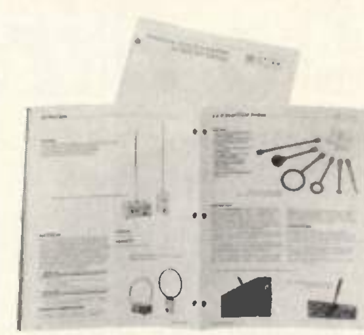
Engineers have found that this set offers a surprising amount of flexibility in solving a wide variety of emissions problems. For example, circuit designers use the probe set to detect and reduce radiated emissions in the early design stages of a new product.

Mechanical designers find the probe set valuable for checking shielding effectiveness of prototype enclosure designs. While it's true that final compliance testing requires more elaborate equipment, you can accomplish much of your preliminary detective work with these probes before bringing out the heavy artillery.

The Model 7405 Probe Set consists of three directional H-field loops, each with varying sensitivity according to loop size. The two E-field probes are omni-directional and identify signals over a broad frequency range. An extension handle and a carrying case are included. A preamp with 19dB gain is optional. The set is covered by EMCO's two year parts and labor warranty.

For an excellent discussion of how the probes are used, call or write for a twelve page reprint of a published article.

New Catalog Available



EMCO's new 80 page catalog is here! It's packed with helpful product info on more than 100 different antennas and accessories for EMI/RFI compliance testing.
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Types of Shielding

To maintain EMC, various types of shielding are available. Materials that provide shielding range from fabrics to metal filled plastics and various coatings. The following is a partial list of shielding materials.

The most basic form of shielding is a metallic box. Cabinets made of silver, copper, aluminum and zinc generally provide some form of shielding. Silver, copper, aluminum, zinc and nickel form the hierarchy of shielding metals with silver being the best. Despite its apparently good shielding qualities, silver is not used due to cost reasons. Copper, which is used fairly often, provides the next best shielding effectiveness but costs more and is heavier than aluminum. Copper is superior to aluminum at lower frequencies, but this gap diminishes at high frequencies. In general, absorption losses are low at low frequencies and generally rise to high levels at high frequencies. Factors such as soldering ease also make copper more desirable. With the greater use of plastics and other synthetic materials that do not perform as well as metals, other methods have been and are being developed.

Metallic Alloys — A metallic shield should have both high conductivity and high magnetic permeability for maximum absorption. The most conductive metals such as copper and aluminum are no more permeable than free space while materials with low permeability have high conductivity and vice-versa. However, when copper and a ferromagnetic alloy are combined in a clad metal, the absorption properties generally rise. The combination of copper with high permeability alloys provide maximum reflection at low frequencies where energy absorption is small for both low and high impedance waves. This new material also has an increase in absorption properties at high frequencies.

Foil Laminates — Flexible laminated shielding materials are composed of metal foil, usually aluminum or copper, combined with a reinforcing substrate such as plastic films or specialty papers. Insulation and mechanical reinforcement is provided by the substrate while the metal foil provides attenuation. At 100 MHz, a laminate of 1 ounce copper foil with 0.75 mm polyester film has a shielding effectiveness of 58 dB. This value rises to 60 dB at 1 GHz.

Metallic Fabric — This material is usually lightweight, washable, ductile, breathable and flexible. It is a woven fiber coated with a microthin membrane of metal. The protection provided by this fabric is not only against RF and microwave radiation but it also reduces static build-up. The fabric materials that can be used include polyester, polyamide, polyurethane, polyacrylate, rayon, cotton, glass and cotton fibers. The metals for coating the fabric are copper, nickel, cobalt, chrome, gold, and silver. These metals can be used either in the pure stage or as alloys. The shielding effectiveness of a single layer metallic fabric is typically 53 dB at 100 MHz and 55 dB at 1 GHz.

Electroplating and Selective Brush-Plated Deposits — Selective electroplating is an electrolytic process used to deposit metal on conductive substrates. It does not require the use of tanks to immerse the part to be plated. Brush plating can be used to deposit 19 different metals and several alloys on selected areas metal parts without extensive masking. It can be applied to non conductive surfaces by first applying a conductive paint or epoxy. The shielding effectiveness for a 0.002 inch thick deposit of nickel would range from 40 dB to 400 dB over a 100 kHz to 100 MHz range at a distance of five inches from the source.Tin, tested at the same thickness and frequency range, had attenuation ranging from 36 dB to 100 dB.

Electroless Coating — Multilayer electroless coating on a dielectric plastic, with no shielding ability, can be described as an initial shielding coating of electroless copper that is subsequently top coated with electroless nickel. The electroless copper is used due to its high conductivity. The thickness of this layer is determined by the immersion time in the electroless plating bath. Since electroless plating is used, the deposit is uniform and consistent. Multilayer coatings normally have a protective electroless nickel coating applied on top of the electroless copper film. Tests for electroless copper/nickel at 15 micro-inches per side of nickel and 26 micro-inches per side of copper at 100 MHz revealed a shielding effectiveness of 75 dB for near field and 88 dB for far field.

Spray Coating — Spray coatings use paints that contain conductive metal particles. The best metals are those that do not lose conductivity due to oxidation. These metals are gold, platinum, palladium, iridium, silver and osmium. The least expensive of which is silver. Conductivity in coatings are achieved by touching and forming vast networks of conductive chains. Since ferrite is a strong absorber of RF energy, it can be added to the paint to enhance the shielding without creating magnetic attraction. Coatings are generally insufficient below 1 MHz due to skin depth and component magnetic contribution. For low frequency shielding of 40 to 60 dB, a thickness on the order of 1 cm is required. The effectiveness increases rapidly around 100 MHz since skin depth approaches that of the coating thickness.

Zinc Arc Spray — This process involves electrically isolated wires which are continuously fed into a gun so that only ends of wires come into contact. As the ends reach a critical distance, an intense arc melts the ends and the surface to be shielded is hit by an air jet carrying minute particles of pure molten metal. As the molten zinc hits the surface to be shielded, it solidifies and forms a dense metallic film. This method is expensive, toxic, has poor adhesion and cracks but it offers high dB attenuation, good conductivity and a continuous coating.

Conductive Plastics — Conductive plastic composites are a blend of electrically conductive additives in polymer resins. The additives are usually spherical, particulate or fibrous. High performance resins are easy to process and provide uniform and consistent inherent shielding without the need for secondary operations. A common material used in plastics is nickel coated graphite fibers. Fiber bundles, up to 12,000 quarter-inch long fibers, and pellets of resin are melted together to achieve the desired shielding material. Varying the levels of the resin and nickel coated fibers can yield the desired shielding levels with costs and conductivity requirements taken into consideration. A seven percent loading of nickel coated fiber yields an attenuation of 47 dB.

Conclusion

The need for proper shielding is constantly growing. With increase in demand for RF shielding with wider frequency ranges and higher attenuation needs, this field continues to expand. The reduction of EMI to achieve EMC is an increasing challenge with the more stringent regulations and consumer needs. rf

A Coplanar Waveguide Primer

This Transmission Line Structure is used for RF Semiconductor and MMIC Probes

By Peter S. Bachert
Motorola Semiconductor Products Sector

Coplanar waveguide (CPW) is a quasi-TEM transmission medium of planar construction which is more closely related to microstrip than to true waveguide. Like microstrip, CPW allows signal transmission to DC. However, at a sufficiently high frequency, CPW exhibits some dispersion — a phenomena that occurs in microstrip as well. This article deals with pure CPW transmission structures.

A comparison of coplanar waveguide to microstrip is shown in Figure 1. If a microstrip ground plane is moved to the upper surface of the substrate and the ground plane is split so that the two resulting pieces straddle the signal track, a CPW is the result. CPW yields reasonable physical dimensions when the bulk dielectric constant of the substrate is greater than or equal to that of alumina. There is also a version of CPW with a microstrip-like lower ground plane in addition to the upper ground plane. This medium, sometimes referred to as CPWG, has a propagation mode which is a hybrid of CPW and microstrip.

One major reason for considering CPW is that the top-side ground allows very low inductance shunt ground paths without the need for plated-through holes. For applications such as semiconductor device characterization this feature is important since common lead inductance will effect the performance of the device under test. The second reason is more subtle — the signal track may be tapered in width without changing the characteristic impedance of the transmission line. This is also important for semiconductor device characterization because a typical device die has much smaller dimensions than the launch tab of commonly used RF connectors.

A practical application of CPW is the 50 ohm RF wafer probe used in MMIC characterization. This application makes use of the ability of CPW to be tapered while maintaining a constant characteristic impedance.

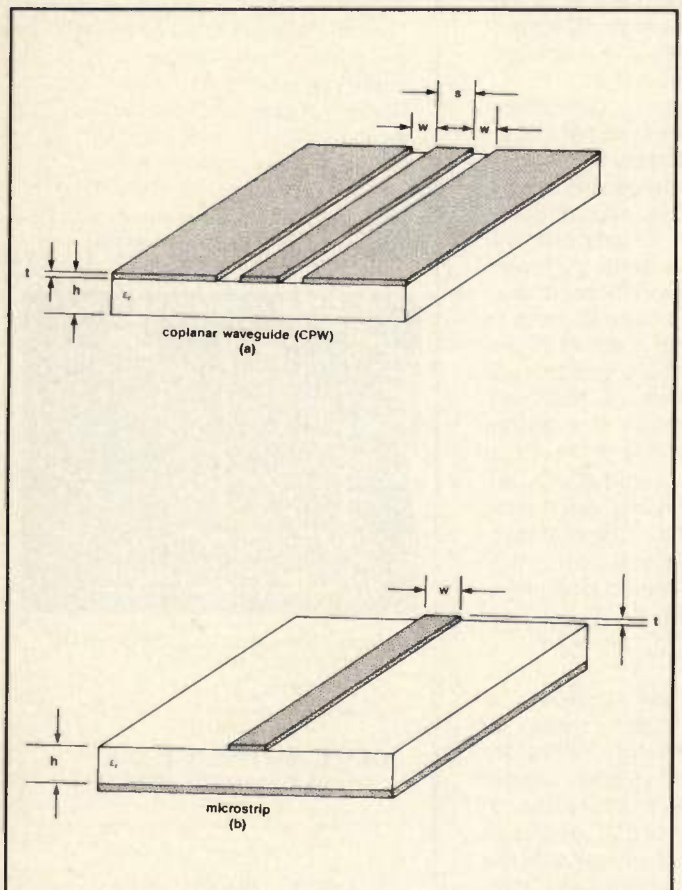


Figure 1. Comparison of physical constructions.

A Qualitative Description of CPW

Over the frequency range for which CPW's fundamental propagation mode is quasi-TEM, up to several GHz for most reasonable physical dimensions, the characteristic impedance

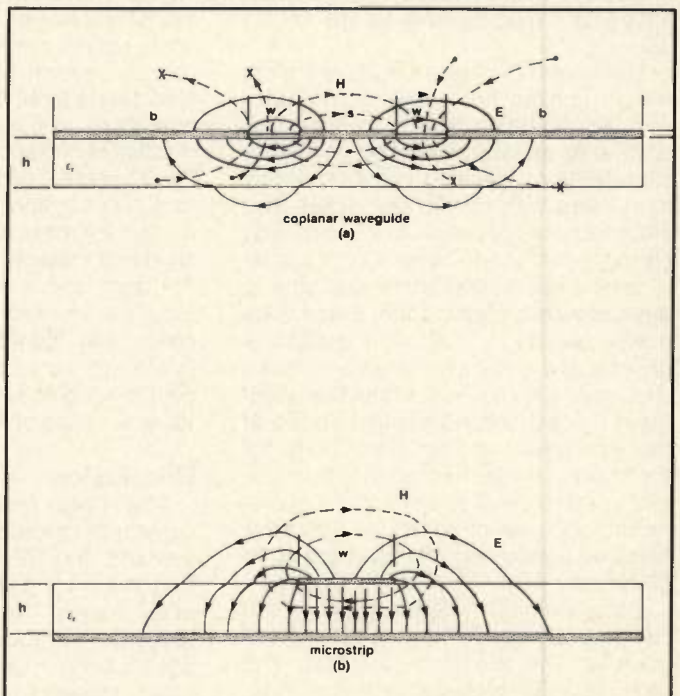


Figure 2. Quasi-static transverse field lines.

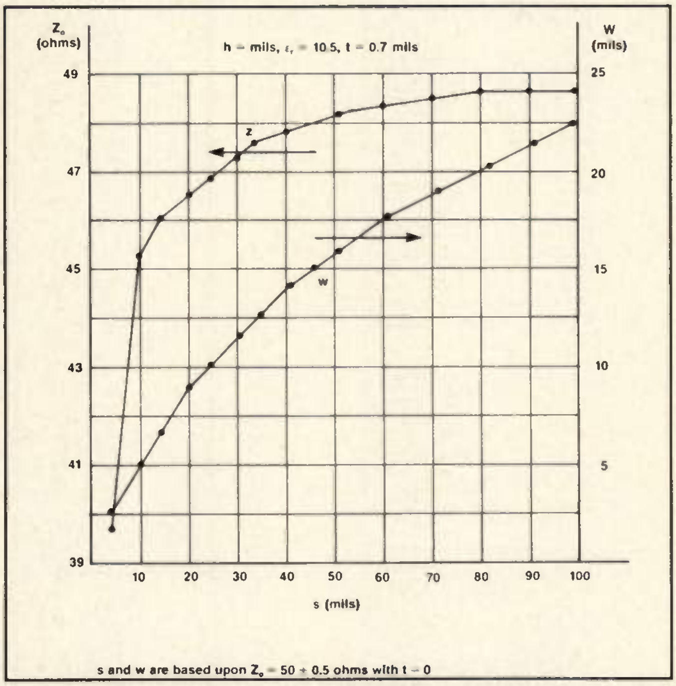


Figure 3. Effect of neglecting metal thickness, t, on the computed values of Z_o.

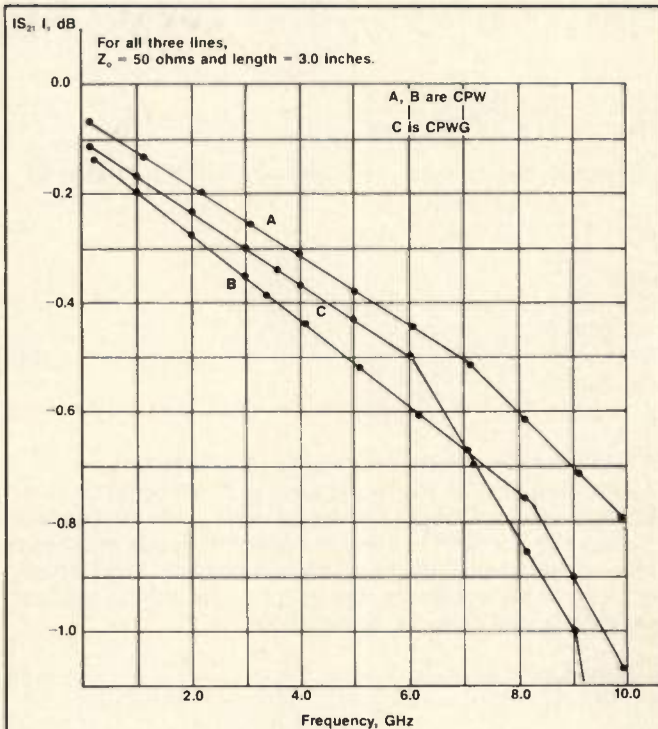
of CPW may be expressed as

$$Z_o = \sqrt{\frac{L}{C}} \tag{1}$$

where L is the inductance per unit length and C is the capacitance per unit length. As with microstrip, the incremental inductance is determined by the physical dimensions of the signal track. However, unlike microstrip the incremental capacitance is primarily a function of the gap width, w, and to a lesser-degree, the substrate characteristics. Decreasing the track width will increase the incremental inductance, but if the gap width is also decreased by an appropriate amount, the incremental capacitance will increase in direct proportion to the inductance and the characteristic impedance will remain unchanged. This is the principal that allows constant impedance tapering.

There is a dual structure to CPW called coplanar strips (CPS) which shares both the tapering capability and ease of shunt component attachment with CPW. CPS has conductor material wherever CPW has a gap, and vice-versa, on the top surface of the substrate. One conductor is considered the signal track and the other is considered ground although both tracks carry equal currents in opposite directions. Although this article will not consider CPS, many references listed in this article for CPW also deal with CPS.

A comparison of the quasi-static transverse field patterns between CPW and microstrip is shown in Figure 2. Note that the electric field in CPW is comprised almost entirely of fringing fields, whereas microstrip may have a considerable amount of parallel plate capacitor electric field flux, depending upon the track width, w. CPW does have a small amount of parallel plate capacitor electric field flux in the gaps between the signal track and ground planes. This extra capacitance is due to the sidewalls of the metal on each side of the gap. Consequently, failure to take the metal thickness, t, into account in CPW



Curve	Dielectric	h(mils)	t(mils)	s(mils)	w(mils)
A	RT/Duroid 6010.5™	25	0.7	50	18
B	RT/Duroid 6010.5™	25	0.7	20	10.5
C	G-10 (CPWG)	31	1.4	73	28

RT/Duroid is a trademark of Rogers Corp.

Figure 4. Measured losses of CPW/CPWG test lines.

designs will yield an error in the calculated value of Z.sub O). This error can be quite large in CPW structures with narrow gaps, as shown in Figure 3.

The thickness correction equations used in calculating the data for Figure 3, and described in the next section, slightly overestimate the added capacitance caused by the metal thickness. This is the reason why Z.sub 0) in Figure 3 asymptotically approaches 49 ohms instead of 50 ohms for large values of gap width, w.

CPW Design Equations

Over the frequency range for which CPW is non-dispersive, the characteristic impedance is given by

$$Z_o = \frac{30\pi}{\sqrt{\epsilon_{eff}}} \; \frac{K'(k)}{K(k)} \tag{2}$$

where K(k) is the complete elliptic integral of the first kind, and K'(k) is its complimentary function, defined by

$$K'(k) = K(k') \tag{3}$$

$$k' = \sqrt{1 - k^2} \tag{4}$$

The argument k is called the shape factor of the CPW (see Figure 1) and is defined as:

$$k = s/(s + 2w) \tag{5}$$

The function K(k)/K'(k) may be approximated by the following expressions:

$$\frac{K(k)}{K'(k)} = \left\{ \left(\frac{1}{\pi}\right) \ln\left[2\left(\frac{1+\sqrt{k'}}{1-\sqrt{k'}}\right)\right]\right\}^{-1} \quad \text{for } 0 \leqslant k \leqslant 0.7 \tag{6}$$

$$\frac{K(k)}{K'(k)} = \left(\frac{1}{\pi}\right) \ln\left[2\left(\frac{1+\sqrt{k}}{1-\sqrt{k}}\right)\right] \text{for } 0.7 \leqslant k \leqslant 1.0 \tag{7}$$

The effective dielectric constant, . epsilon sub eff), is given by

$$\varepsilon_{eff} = 1 + \frac{\varepsilon_r - 1}{2} \frac{K'(k)}{K(k)} \frac{K(k_1)}{K'(k_1)} \tag{8}$$

where,

$$k_1 = \frac{\sinh\left[\left(\frac{\pi}{4}\right)\left(\frac{s}{h}\right)\right]}{\sinh\left[\left(\frac{\pi}{4}\right)\left(\frac{s+2w}{h}\right)\right]} \tag{9}$$

and ε_r is the bulk dielectric constant of the substrate.

As discussed earlier, significant error in Z_o will occur for CPW structures with narrow gaps (w small) if the metal thickness is not taken into account. In order to correct for metal thickness, t, new values for the effective dielectric constant, signal track width, gap width and hence, the shape factor, will be defined. First, a correction factor, Δ, is defined as

$$\Delta = (1.25t/\pi)[1 + \ln(4\pi s/t)] \tag{10}$$

Then,

$$S_e = S + \Delta \tag{11}$$

and,

$$W_e = W - \Delta \tag{12}$$

The correct shape factor is then:

$$k_e = \frac{S_e}{S_e + 2W_e} \tag{13}$$

and the corrected effective dielectric constant is defined as:

$$\varepsilon_{eff}t = \varepsilon_{eff} - \frac{(\varepsilon_{ff} - 1)}{w(0.7t)[K(k)/K'(k)] + 1} \tag{14}$$

Finally, the corrected expression for the characteristic impedance is:

$$Z_o = \frac{30\pi}{\sqrt{\varepsilon_{eff}t}} \frac{K'(k_e)}{K(k_e)} \tag{15}$$

Losses, Dispersion and Higher-Order Modes

An expression for conductor loss is given in reference (1), along with an expression for dielectric loss. Unfortunately, radiation loss is not considered in the above reference. For a 25 mil thick substrate with bulk dielectric constant 13.0, and (s + 2w) 47 mils, reference (4) gives Q-factors of 150 for Z_o 50 ohms, 130 for 33 ohms and 100 for 95 ohms. However, it does not mention the conductor thickness used, but 0.2 mils would be a reasonable number for thin film.

Reference (2) compares microstrip to CPW at 10 GHz, using 25 mil thick alumina substrates for both structures. The losses for CPW, where the gap width, w, is 12.5 mils, are 0.08 dB/cm for 50 ohm line and 0.28 dB/cm for 100 ohm line. For reference, these numbers are double what the losses are for comparable microstrip lines.

Some measured losses versus frequency for three different 50 ohm test lines are shown in Figure 4. Two of the lines are pure CPW and the third is CPWG. The reason for the change in loss slope for the CPW lines is that the coax to CPW transition has not been optimized, and the VSWR is beginning to increase above 7 GHz. The CPWG line loss slope increases because the z-straps connecting the top and bottom ground planes are spaced such that above 6 GHz, the circuit structure will support moding between the ground planes.

Both dispersion and higher-order modes are calculated (or measured) by placing the CPW test piece into an enclosure and calculating (or measuring) the phase constant, β, of the

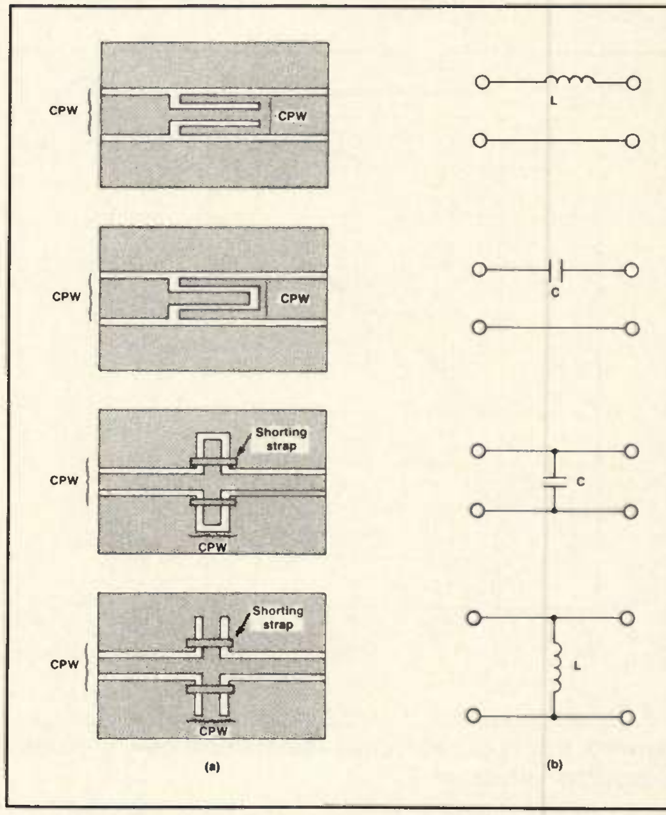


Figure 5. Circuit elements in CPW configuration (2): (a) CPW circuit realization; (b) equivalent circuit (first order approximate).

Figure 6. Semiconductor chip characterization fixture using CPW.

Step	Entry	Comments
01	LBL ^{T}CPW	
02	LBL 05	input data entry
03	^{T}LINEWIDTH?	
04	PROMPT	
05	STO 10	s
06	^{T}GAP WIDTH?	
07	PROMPT	
08	STO 11	w
09	^{T}METAL THK?	
10	PROMPT	
11	X=0?	
12	SF 01	zero thickness case flag
13	STO 12	t
14	^{T}SUBST HT?	
15	PROMPT	
16	X=0?	
17	GTO 10	if 0 entered, execute using existing h and ε_r values
18	STO 13	h
19	^{T}DIEL CON?	
20	PROMPT	
21	X=0?	
22	GTO 10	if 0 entered, execute using existing ε_r value
23	STO 14	ε_r
24	LBL 10	begin execution
25	RCL 11	
26	2	
27	*	
28	RCL 10	
29	+	
30	RCL 10	
31	X<>Y	
32	/	
33	STO 15	k
34	X↑2	
35	CHS	
36	1	
37	+	
38	SQRT	
39	STO 16	k'
40	RCL 15	
41	XEQ 20	calculate elliptic integral
42	GTO 26	branch around e. i. subroutine after completion
43	LBL 20	elliptic integral subroutine
44	.7	
45	X>Y?	
46	GTO 25	retrieve k' from stack
47	SF 02	
48	X<>Y	
49	LBL 24	elliptic integral equation
50	ENTER↑	
51	SQRT	
52	1	
53	+	
54	X<>Y	
55	SQRT	
56	CHS	
57	1	
58	+	
59	/	
60	2	
61	*	
62	LN	
63	PI	
64	/	
65	FC?C 02	
66	1/X	
67	RTN	return to main program
68	LBL 25	k' retrieval subroutine
69	RDN	
70	RDN	
71	GTO 24	
72	LBL 26	resume program after e. i. subroutine
73	STO 18	K(k)/K'(k)
74	PI	
75	4	
76	/	
77	RCL 10	
78	RCL 13	
79	/	
80	*	
81	XROM ^{T}SINH	see Appendix 1 if you don't have MATH1 ROM
82	RCL 10	
83	RCL 11	
84	2	
85	*	
86	+	
87	RCL 13	
88	/	
89	PI	
90	4	
91	/	
92	*	
93	XROM ^{T}SINH	see step 81 comment
94	/	
95	STO 26	k_1
96	X↑2	
97	CHS	
98	1	
99	+	
100	SQRT	(k_1')
101	RCL 26	
102	XEQ 20	calculate elliptic integral
103	RCL 18	
104	1/X	
105	*	
106	RCL 14	
107	1	
108	-	
109	2	
110	/	
111	*	
112	1	
113	+	
114	STO 17	ε_{eff}
115	FS?C 01	
116	GTO 30	bypass thickness correction routine
117	4	begin thickness correction routine
118	PI	
119	RCL 10	
120	*	
121	*	
122	RCL 12	
123	/	
124	LN	
125	1	
126	+	
127	1.25	
128	*	
129	RCL 12	
130	*	
131	PI	
132	/	
133	STO 19	Δ
134	RCL 10	
135	+	
136	STO 20	s_e
137	RCL 11	
138	RCL 19	
139	-	
140	STO 21	w_e
141	2	
142	*	
143	RCL 20	
144	+	
145	RCL 20	
146	X<>Y	
147	/	
148	STO 22	k_e
149	RCL 18	
150	RCL 11	
151	*	
152	.7	
153	/	
154	RCL 12	
155	/	
156	1	
157	+	
158	RCL 17	
159	1	
160	-	
161	X<>Y	
162	/	
163	CHS	
164	RCL 17	
165	+	
166	STO 23	ε_{eff}^{t}
167	RCL 22	
168	X↑2	
169	CHS	
170	1	
171	+	
172	SQRT	
173	STO 24	k'_e
174	RCL 22	
175	XEQ 20	calculate elliptic integral
176	1/X	
177	STO 25	$K'(k_e)/K(k_e)$
178	GTO 40	bypass zero thickness routine
179	LBL 30	zero thickness routine
180	RCL 17	
181	STO 23	$\varepsilon_{eff}^{t} = \varepsilon_{eff}$
182	RCL 18	
183	1/X	
184	STO 25	$K'(k_e)/K(k_e) = K'(k)/K(k)$
185	LBL 40	calculate Z_0
186	30	
187	*	
188	PI	
189	*	
190	RCL 23	
191	SQRT	
192	/	
193	^{T}Z0 IS:	
194	PROMPT	
195	STOP	
196	GTO 05	interrogate user for new input data
197	END	

Test Trial Cases

1. $s=18.5$, $w=10.0$, $t=0.7$, $h=25.0$, $\varepsilon_r=10.5$ yields $Z_0=50.1258$
2. $s=18.5$, $w=10.0$, $t=0.0$, $h=25.0$, $\varepsilon_r=10.5$ yields $Z_0=53.3967$
3. $s=60.0$, $w=10.0$, $t=0.5$, $h=25.0$, $\varepsilon_r=10.1$ yields $Z_0=40.4763$
4. $s=60.0$, $w=10.0$, $t=0.0$, $h=25.0$, $\varepsilon_r=10.1$ yields $Z_0=42.1634$

Table 1. Coplanar waveguide analysis HP-41 program.

resulting structure versus frequency.

Dispersion may be described qualitatively as the condition which occurs when the longitudinal component of the magnetic field, H_z, becomes large enough compared to the transverse field that propagation is no longer quasi-TEM. This condition manifests itself as an increase in the phase constant and effective dielectric constant and, consequently, a decrease in the characteristic impedance. Because the characteristic impedance is inversely proportional to the square root of the effective dielectric constant, the effect of dispersion on the characteristic impedance is relatively subtle. Dispersive CPW will still allow signal propagation, but it will no longer follow the characteristics described by equations (14) and (15).

Higher-order modes are non-TEM propagation modes which exhibit a lower cut-off frequency and highly dispersive propagation. A similar condition will also occur in microstrip. Through numerical field calculations, CPW on 40 mil alumina with 50 mil gap widths (approximately 100 ohm line) will be free of higher-order modes up to 20 GHz (5). The quasi-TEM propagation mode for this structure is relatively non-dispersive up to 10 GHz. If the substrate height is doubled, the higher-order mode cutoff frequency is halved.

Mueller (6) performed CPW quasi-TEM mode dispersion measurements on 25 mil alumina substrates and found several interesting results. First, 70 ohm CPW with w/h 1.0 is non-dispersive up to 5.0 GHz and only mildly dispersive up to 11.0 GHz. Second, the ground plane width (dimension b in in Figure 2) has no effect on CPW dispersion for $b > 8$ h, provided that the dimensions of s and w are reasonable. Third, for s/h and w/h both less than 1.5, the resulting CPW will be at worst, only mildly dispersive up to 11.0 GHz.

CPW Design Guidelines

The above discussion on dispersion and higher-order modes may be condensed, along with some other construction considerations, into a few handy rules-of-thumb used to design CPW circuits which exhibit quasi-TEM propagation:

1. For 50 ohm lines, use a substrate with a bulk dielectric

1. For 50 ohm lines, use a substrate with a bulk dielectric constant near that of alumina $\varepsilon_r = 10$. Lower dielectric constant material makes low impedance lines, including 50 ohm lines, difficult to build in CPW because of the extremely small gap widths required. Higher dielectic constants lower the frequencies at which dispersion and higher-order modes appear.

2. Use of thin substrate is practical for the application under consideration. The frequencies at which dispersion and higher-order modes appear decrease with increasing substrate height.

3. Do not use too thin of a substrate, or the CPW will become dispersive for high impedances, or for any other CPW structure where the gap width, w, becomes more than 1.5 - 2.0 times the substrate height, h. For 50 ohm line, 25 mil alumina works well for most applications up to 10 GHz.

4. For installations where a bottom ground plane is necessary, CPWG will result. This will allow low impedance lines to be built on low dielectric constant substrate. Reference (7) has closed-form expressions for ε_{eff} and Z_0 for CPWG.

5. For enclosed CPW, through numerical field calculations the effect of the enclosure cover on Z_0 calculations may be neglected for cover heights in excess of 2.5s, for $0.5 \leqslant k \leqslant 0.9$ (ref. 8). The proximity of sidewalls to the CPW will have no effect on Z_0 if the sidewall-to-sidewall dimension is at least 1.75 (s + 2w).

6. Due to the symmetry of the ground plane about the signal track, any components to be connected in shunt to ground on CPW must be tied to both ground planes.

7. For electrically long CPW structures, it may be necessary to periodically jumper the two ground planes together with a conductor bridging the signal track. This will suppress moding between the two ground plane tracks.

CPW Circuit Elements

Many of the same distributed elements used in microstrip design, such as shunt open-and short-circuited stubs may be realized by CPW. The ground plane continuity required in the series signal path will require the use of jumper conductors over the shunt branch CPW lines. As mentioned earlier, the CPW ground plane symmetry will require that two stubs be used in parallel, one on each side of the series signal path.

Series reactive elements may also be realized using re-entrant lines where the signal track from one CPW section 'dove-tails' into the signal track of the second, co-linear, CPW section in series. Both sections share a common set of ground planes. This, and other CPW structures are depicted in reference (2). Four of these structures are also shown here in Figure 5. Reference (9) shows a CPW bandpass filter using such structures, together with empirical design data for the series capacitive structures used.

A Semiconductor Chip Fixture CPW Application

As previously mentioned in the introduction, it is highly desirable to be able to mount a semiconductor die onto a 50 ohm transmission line and have very low common lead inductance to ground. A CPW transmission system is able to satisfy both of these conditions. Figure 6 shows a photo of such a bare chip thin-film CPW fixture. The substrate is a 0.5" square by 25 mil thick piece of 96 percent alumina. The CPW line is 50 mils wide (stripwidth s) at each end to contact an SMA launch tab at each edge of the substrate. The CPW line then tapers down to 20 mils wide in the middle of the substrate in order to accommodate 16 x 19 mil dice. The 20 mil track has a 10 mil transverse gap in the middle of the substrate which separates the input and output transmission lines. The rate of taper is not particularly critical, although if it is made too abrupt, excess shunt capacitance to ground will result.

By tapering down to a narrow track width, the common lead bond wires are kept short, and hence, will have low inductance. This is critical in semiconductor die characterization because common lead inductance can't be tuned out of the circuit from either the input or output port. Common lead inductance results in series feedback which effectively becomes part of the device under test. Note that in a microstrip fixture, the emitter wire bonds would be longer (50 ohm microstrip track on 25 mil alumina would be approximately 25 mils wide), and

INFO/CARD 59

If you do not have the MATH1 ROM pack for your HP-41 calculator, the hyperbolic sine function may be generated by using an additional subroutine.

1. Substitute "XEQ 50" for "XROM ᵀSINH" on lines 81 and 93.

2. After line 196, insert the following:

```
197 LBL 50      sinh subroutine
198 ENTER↑
199 E↑X
200 X<>Y
201 CHS
202 E↑X
203 -
204 2
205 /
206 RTN
```

The final "END" statement of the program will then be line 207.

Appendix 1. Subroutine for hyperbolic sine function.

there would be additional series inductance in contacting the bottom ground plane through the substrate.

The author wishes to thank Carey Johnson for fabricating and characterizing the 50 ohm test lines described in Figure 4.

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Storage Register Contents

Register No.	Contents		
10	s	18	K(k)/K'(k)
11	w	19	Δ
12	t	20	s_e
13	h	21	w_e
14	ε_r	22	k_e
15	k	23	$\varepsilon_{eff}{}^t$
16	k'	24	k'_e
17	ε_{eff}	25	$K'(k_e)/K(k_e)$
		26	k_1

Appendix 2. Store register contents.

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Lumped Element Phase Shifting and Matching Networks

By Andre Boulouard
CNET-LANNION B

For engineers involved in MMIC design, synthesis equations for matched phase shifters and impedance transformers are needed as a good starting point for computer optimization. In this article, the author presents three-element reactive phase shifters and three and four-element reactive matching networks. The equations needed are presented in compact form and should lead to simple programming tasks if so desired.

As can be seen from Figures 1 and 2, matched phase shifters are 3-reactance tee or 3-susceptance pi networks perfectly matched at ω_0. These reactances and susceptances may be positive or negative, leading to low-pass, high-pass or band-pass networks. Figure 3 shows a 7 GHz, +90° tee phase shifter designed from the preceding formulas.

Three-Element Matching Networks

A three element matching network provides the opportunity of matching any resistance R_G (or conductance G_G) to any other resistance R_L (or conductance G_L) while providing complete bandwidth control by a third parameter R (or G) (3) as shown in Figures 4 and 5. A good value for R is 5 percent over the maximum of either R_L or R_G for resistance and G_G or G_L for conductance. Figure 6 shows a 7 GHz, 50 to 100 Ohm tee matching network designed from the preceding formulas.

Four-Element Matching Networks

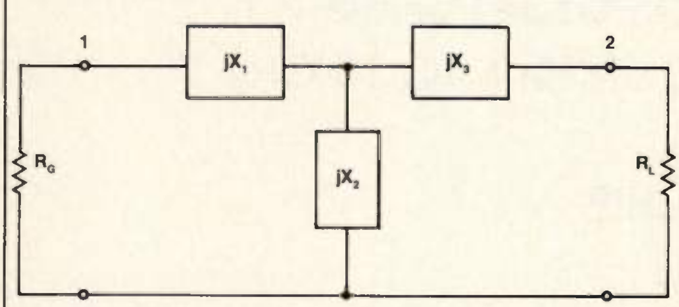
More than three elements may be used when a good match is required over a very wide bandwidth or when complex impedances, such as GaAs FET input or output impedances, must be matched over more than 20 percent bandwidth. The design methodology presented here is restricted to GaAs FET input match but should be widely applicable to other cases as well.

Because the input impedance of a GaAs FET can generally be simulated by a series RC circuit, the designer should try to match a low value load resistance R_L to a higher value generator resistance R_G. As can be seen from Figure 7, the design methodology is described as follows: First, a prototype low pass filter is built from a given insertion loss $L(\omega)$. Then the corresponding bandpass filter is obtained from lowpass to bandpass transformation followed by the addition of a transformer at the input to match generator and load resistances. Finally, the transformer is replaced by a self inductance tee or pi network (5).

The design equations are shown in Figure 8 and a 4-element matching network designed at 7 GHz is shown in Figure 9, for a maximum 0.2 dB insertion loss and 0.1 dB in-band ripple.

Conclusion

Design equations for synthesizing 3-element reactive phase shifters and 3- to 4-element reactive matching networks have been presented. The necessary equations together with corresponding figures are included to aid the designer in constructing lumped phase shifting and matching networks.



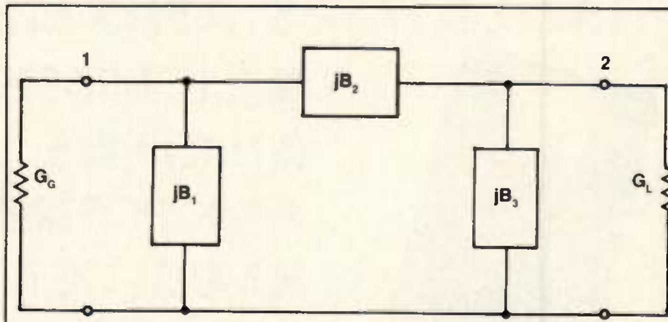
$$X_2 = \frac{\sqrt{R_G R_L}}{\sin\psi}$$

$$X_1 = R_G \cot\psi - X_2$$

$$X_3 = R_L \cot\psi - X_2$$

$$\psi = \angle S_{21}$$

Figure 1. Three-reactance tee phase shifter.



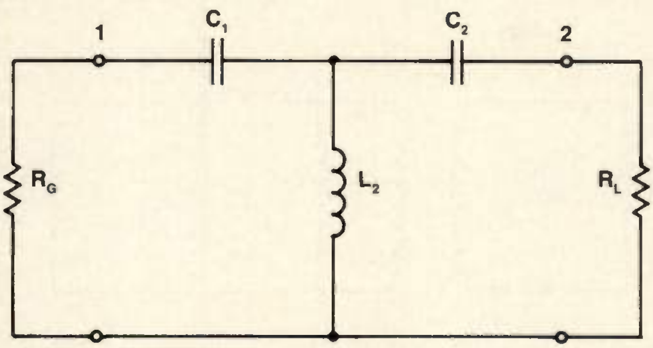
$$B_2 = \frac{\sqrt{G_G G_L}}{\sin\psi}$$

$$B_1 = G_G \cot\psi - B_2$$

$$B_3 = G_L \cot\psi - B_2$$

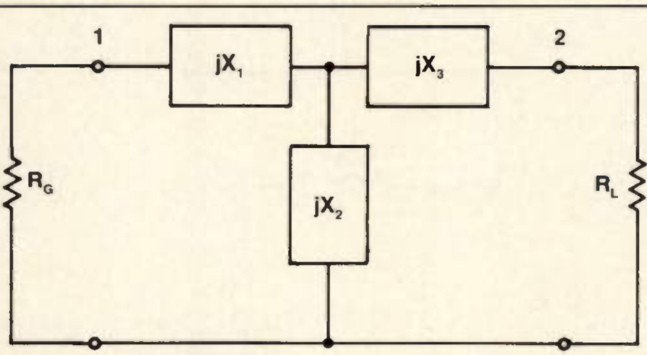
$$\psi = \angle S_{21}$$

Figure 2. Three-susceptance pi phase shifter.



$R_G = 50\Omega$ $C_1 = 0.455$ pF
$R_L = 50\Omega$ $L_2 = 1.137$ nH
$\psi = +90°$ $C_3 = 0.455$ pF

Figure 3. A 7 GHz, +90° phase shifter.

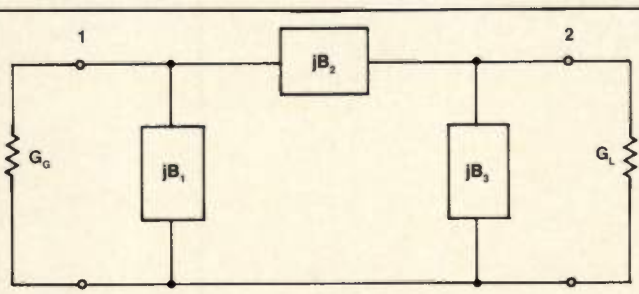


$$X_1 = \pm R_G \sqrt{\left(\frac{R}{R_G} - 1\right)} \quad \text{if } R > R_G$$

$$X_2 = -\frac{R}{\left(\frac{X_1}{R_G} + \frac{X_3}{R_L}\right)}$$

$$X_3 = \pm R_L \sqrt{\left(\frac{R}{R_L} - 1\right)} \quad \text{if } R > R_L$$

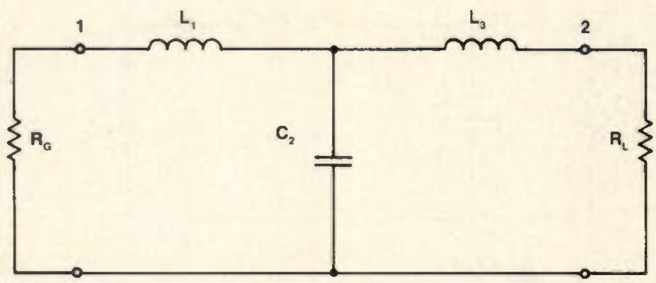
Figure 4. Three-reactance tee matching network.



$$B_1 = \pm G_G \sqrt{\left(\frac{G}{G_G} - 1\right)} \quad \text{if } G > G_G \qquad B_2 = -\frac{G}{\left(\frac{B_1}{G_G} + \frac{B_3}{G_L}\right)}$$

$$B_3 = \pm G_L \sqrt{\left(\frac{G}{G_L} - 1\right)} \quad \text{if } G > G_L$$

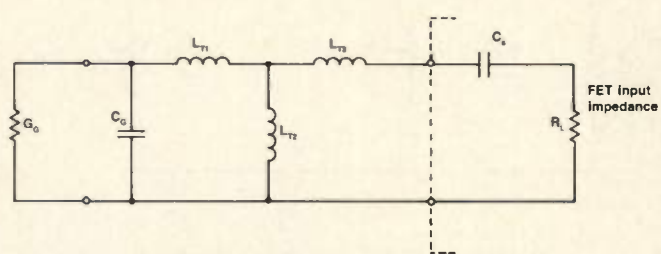
Figure 5. Three-susceptance pi matching network.



$R_G = 50\Omega$ $L_1 = 1.192$ nH
$R_L = 100\Omega$ $C_2 = 0.275$ pF
$R = 105\Omega$ $L_3 = 0.508$ nH

To control bandwidth, R should be about 5 percent over R_G or R_L, whichever is greater.

Figure 6. A 7 GHz, 50 to 100 ohm tee matching network.



Insertion loss: $Lo_{dB} = 0.2$ dB $G_G = 20$ mS $R_L = 10$ Ohm
In-band Ripple: $\delta_{dB} = 0.1$ dB $C_s = 0.200$ pF $f_o = 7$ GHz
$C_G = .2979$ pF $L_{T1} = 0.077$ nH $L_{T2} = 0.096$ nH
$L_{T2} = 2.541$ nH

Figure 9. Four-element reactive matching network at 7 GHz.

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About the Author

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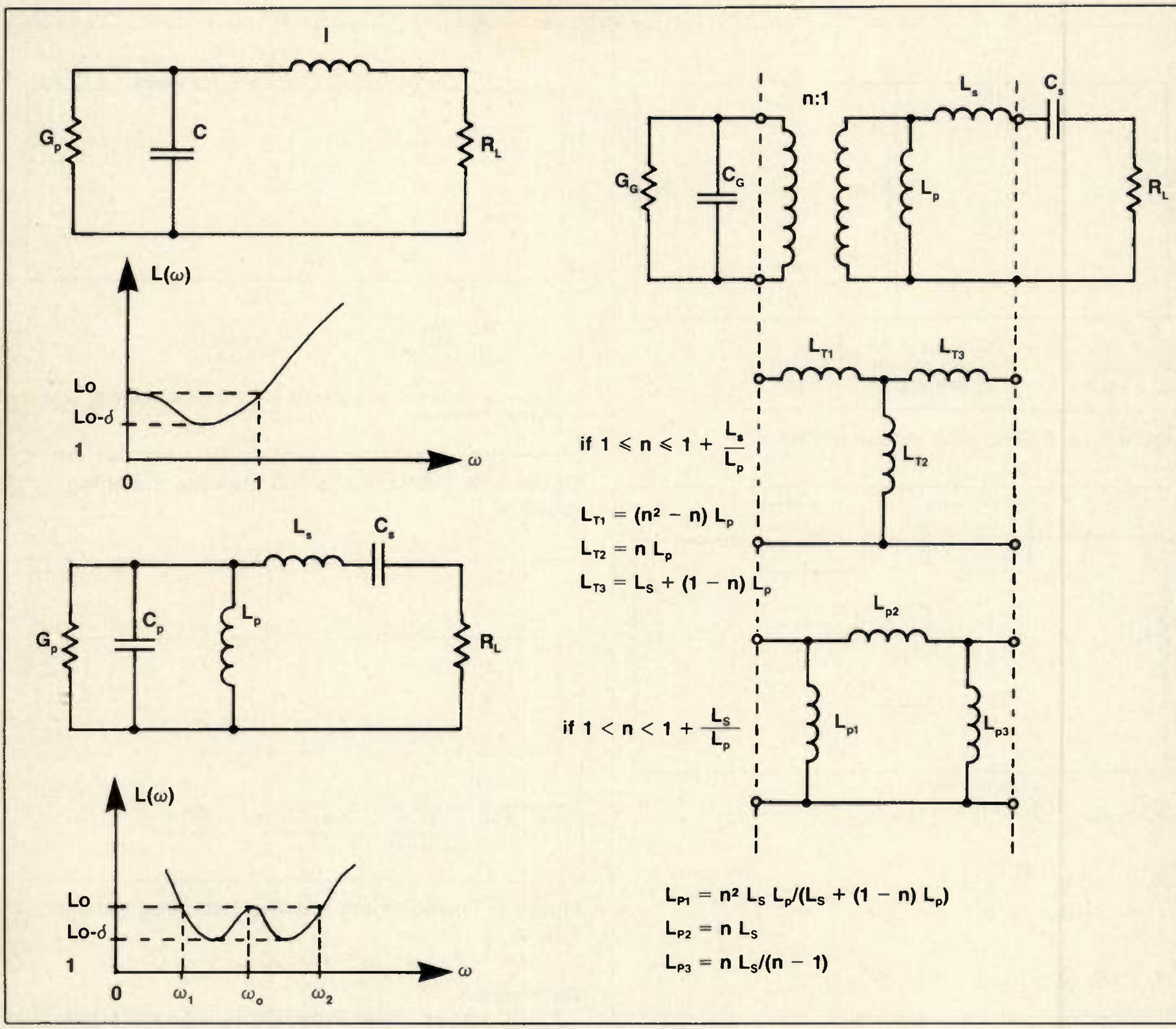


Figure 7. Low pass to band pass transformation.

input data: Lo_{dB}, δ_{dB}, G_G, C_S, R_L, ω_o

$$Lo = +10^{\left(\frac{Lo_{dB}}{10}\right)}$$

$$\delta = -10^{\left(\frac{\delta_{dB}}{10}\right)} + Lo \qquad \text{if } o < \delta_{dB} < Lo_{dB}$$

$$g = (2Lo - 1) \pm 2\sqrt{Lo(Lo - 1)}$$

$$q = 4\sqrt{g\delta}$$

$$s = q(2 - q)$$

$$p = (gq)^2$$

$$r = \sqrt{(s^2 - 4p)}$$

$$c = \frac{1}{R_L}\sqrt{\frac{s \pm r}{2}}$$

$$l = \frac{q}{c}$$

$$b = l\omega_o^2 C_S$$

$$L_S = \frac{1}{C_S\omega_o^2}$$

$$C_p = \frac{c}{b}$$

$$L_p = \frac{1}{C_p\omega_o^2}$$

$$G_p = \frac{g}{R_L}$$

$$n = \sqrt{\frac{G_p}{G_G}} \qquad \text{if } 1 \leqslant n$$

$$C_G = \frac{C_p}{n^2}$$

output data: C_G, n, L_p, L_S

Figure 8. Four-element matching network design equations.

Single-Sideband Systems and Circuits

Edited by William E. Sabin and Edgar O. Schoenike.
Written by members of the Engineering Staff, Collins Divisions, Rockwell International Corporation.
Published by McGraw-Hill Book Company, New York, 1987.
List price: $49.95.

Many *RF Design* readers will remember the 1964 book with a similar title. That classic text, also written by Collins engineers, has been brought up to date with the introduction of this new book. Its 17 chapters and 594 pages are devoted to single-sideband (SSB) communications at both the system and circuit design levels, primarily in the high frequency (HF) range.

The technical level of the material is directed to the practicing engineer. However, an engineer new to SSB or even an advanced amateur can benefit from the background and overview information. Although the book covers everything from the antenna to the speaker, and from the microphone back to the antenna, there are a few areas that deserve special note, presenting state-of-the-art engineering data or other information not previously gathered in one place.

Chapter 2, "System Design Considerations" introduces the reader to the theory of SSB modulation, defining and explaining the characteristics of this mode of transmission. This chapter also presents considerable information on speech intelligibility, a subject rarely covered in depth in engineering literature. When this data is combined with Chapter 6, "Speech Processing, Squelch, and Noise Blanking," the result is an excellent, in-depth analysis of voice communications. Particularly interesting are the analyses of the effects of various modulating waveforms and types of speech processing on the transmitted SSB envelope.

The introduction of digital techniques is an obvious change from the earlier book. A chapter is devoted to digital signal processing, presented in system and concept rather than circuit design. Plenty of fundamental information is provided to start an analog engineer toward understanding of DSP. Enough material is offered to guide a more advanced digital designer through concepts specific to SSB. A later short chapter is devoted to the concepts of digital remote control of SSB equipment (or other communications gear).

"Solid-State Power Amplifiers" is the title of Chapter 12, where as much information as possible has been squeezed into 54 pages. Of special interest are the sections on transformers and combiners, offering up-to-date information on materials and configurations. The following two chapters also address the subject of power amplifiers, with Chapter 13 discussing low distortion design, very important in military systems and any other system with multiple co-located facilities. Chapter 14 follows, covering high power tube amplifiers, still an essential essential topic for systems requiring power above 1 kW.

The chapter on synthesizers offers a good look at options available to the RF designer. A valuable feature of this chapter is the graphical representation of a number of important synthesizer performance characteristics, giving a visual representation of concepts that may be nebulous if only described in the text. Although the emphasis is almost exclusively on PLLs, this chapter includes a short introduction to direct digital synthesis (DDS).

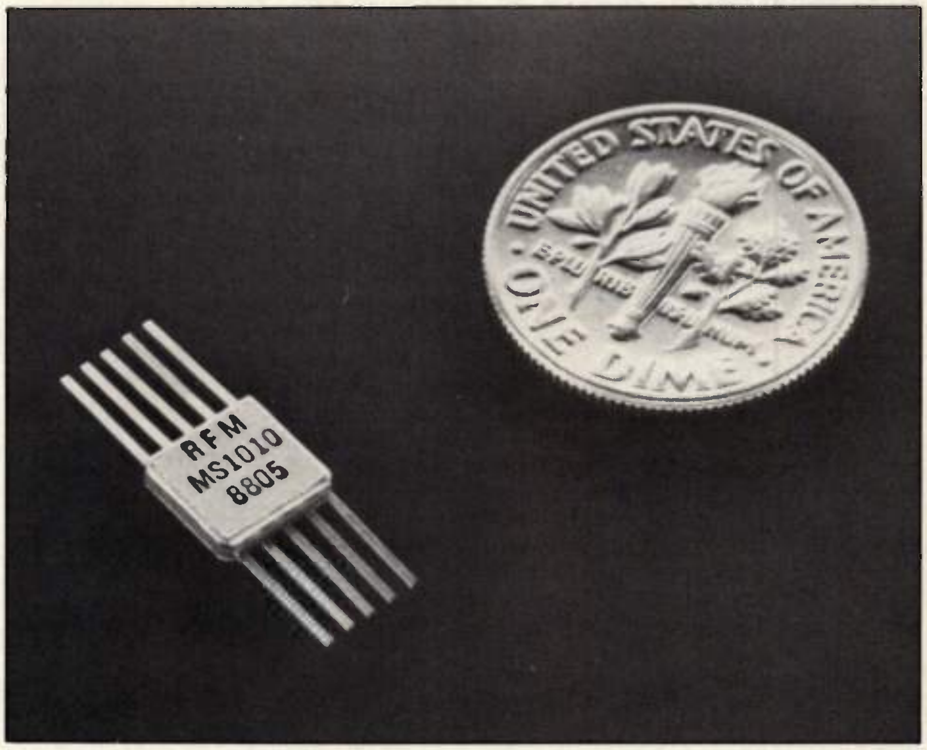
The only criticism is that the book cannot cover all topics in depth. The Rockwell-Collins group has made a tremendous effort to include as much material as possible in a normal-sized book, but the reader should be prepared to use the references provided at the end of each chapter. After all, entire books have been written on the subjects that are covered here in one chapter. *Single-Sideband Systems and Circuits* would be a fine addition to the reference library of any RF engineer working not only with SSB, but in any type of voice communications or HF systems. For more information, circle INFO/CARD #185.

-- Reviewed by Gary A. Breed.

RF Monolithics Introduces UHF Frequency Sources

A new line of SAW signal sources is introduced by RF Monolithics, Inc. Referred to as "microsources," the products are supplied in a hermetic flatpack package with an external volume of less than 0.01 cubic inch. The line covers the frequency range of 250 to 850 MHz, with output power ranging from +3 dBm to +7 dBm. The quartz SAW resonator provides a nominal frequency stability of 200 ppm over the −35°C to +85°C operating temperature range. Internal power supply regulation allows operation from +6V to +10 VDC. Pulse AM modulation capability and power adjustment provisions are also included.

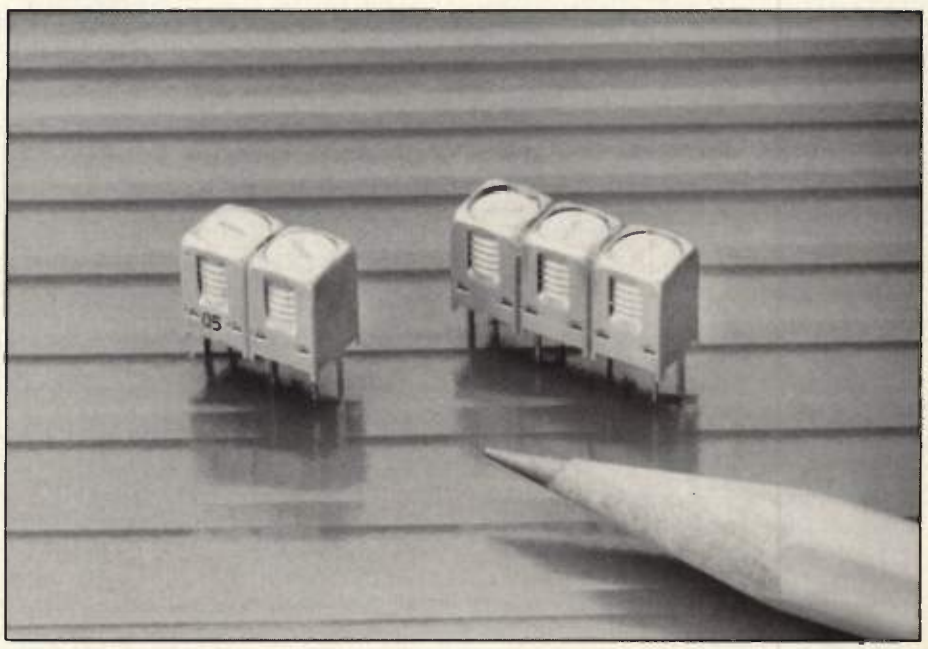
The MS1010 500 MHz microsource, a representative model of the product line, has the following specifications: second harmonic, −15 dBc; third harmonic, −20 dBc; nonharmonic spurious outputs, −65 dBc; SSB phase noise, −92 dBc/Hz at 1 kHz offset, and −120 dBc at 10 kHz offset. Power output is typically +8 dBm, with 8 dB adjustment range. Pulse modulation (AM) has a minimum on/off ratio of 40 dB, with a maximum rise/fall time of 1.0 us. At maximum supply voltage of +10 VDC, the supply current is 25 mA, with lower supply voltages drawing less current.



Pricing of the microsource oscillator line is under $250 (100s); varies with quantity and specifications. **RF Monolithics, Inc., Dallas, TX. Please circle INFO/CARD #220.**

Helical Filters From Toko

These adjustable 5HW double-tuned and 5HT triple-tuned helical filters are designed for applications between 350 MHz and 1.5 GHz. Features include an adjustable, screw-type core for tuning with wide tuning ranges made possible through the use of oversized ceramic cup cores.



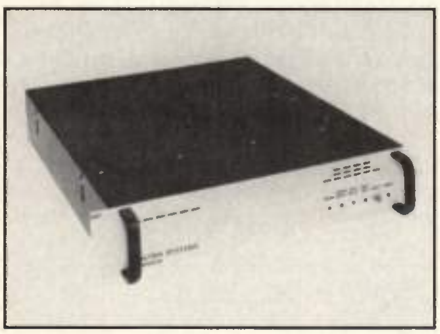
The filters have a length of 11.2 mm for the 5HW and 16.8 mm for the 5HT while width is 6.0 mm and height is 9.5 mm. A plated brass case is used to provide high Q and low insertion loss. For consistent spacing in the windings, molds which create equal spacing between grooves and constant winding pitch are used during fabrication. The coil bobbins and bases are formulated from a compounded material which promotes low insertion loss together with temperature and humidity stability. Prices range from $6 for the 5HW to $7.75 for the 5HT. **Toko America, Inc., Mt. Prospect, IL. Please circle INFO/CARD#219.**

Synthesized Signal Generator

Model 2500XP from Wavetek has a maximum RF output of +23 dBm with a frequency range of 1 MHz to 1100 MHz. Features include GPIB, spin knob, extensive self diagnostics and an instrument prompted calibration system. The instrument is ideal for high level mixer or receiver saturation testing where high level drive signals are required. It is priced at $5,750. **Wavetek RF Products, Inc., Indianapolis, IN. INFO/CARD #218.**

Audio Switching System

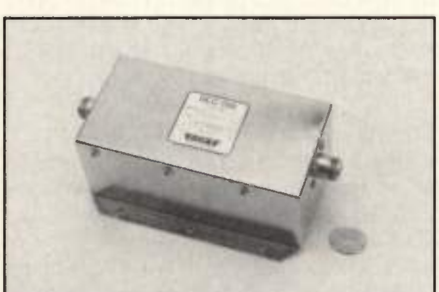
Matrix Systems introduces an audio relay matrix which operates from 30 Hz to 200 kHz. Model 8836 features a 96 × 15 × 2-wire balanced configuration and



can be randomly addressed via an IEEE-488 interface bus. Also, multiple outputs can be provided from a single input. Specifications include unity gain and −60 dB isolation. **Matrix Systems Corp., Calabasas, CA. INFO/CARD #217.**

1 kW Lowpass Filter

This line of filters from Eagle feature cutoff frequencies from 3 MHz to 500 MHz. The passband insertion loss is less than 0.3 dB while stopband is greater than 50 dB to 10 times F_c or 2 GHz whichever



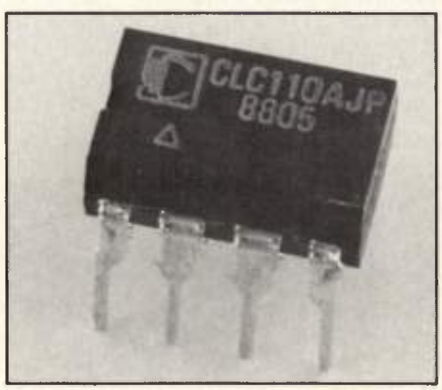
is lower — stopband occurs at 140 percent of cutoff. The filters handle up to 1 kW into a 1.5:1 VSWR. Prices start at $495 when purchased in quantities of 5 and up. **Eagle, Fallbrook, CA. INFO/CARD #216.**

LCR Meter

HP introduces an LCR meter with a 20 Hz to 1 MHz range and accuracy of 0.05 percent. This instrument, designated the HP 4284A, has six digits of resolution with a constant test-signal-level feature which controls the applied test signal at the device for military tests. Available are 1-, 2-, and 4-meter HP cable lengths that do not alter the normal specifications of the meter. For high volume testing, an optional handler interface and built-in comparator can be combined with component-handling equipment. Also available are test fixtures for axial, radial and chip components. The 4284A is priced at $9,400 without options. **Hewlett-Packard Company, Palo Alto, CA. Please circle INFO/CARD #215.**

80 MHz Op Amp

Comlinear introduces the CLC501 clamping op amp with −3 dB bandwidth of 80 MHz and settling time of 12 ns to 0.05 percent. The device has the ability to clamp the output voltage to within user specified values. This feature allows downstream circuitry to be protected from overloading input signals which would otherwise cause damage or saturation. The packaging options are either plastic or ceramic 8-pin DIP. Prices vary depen-

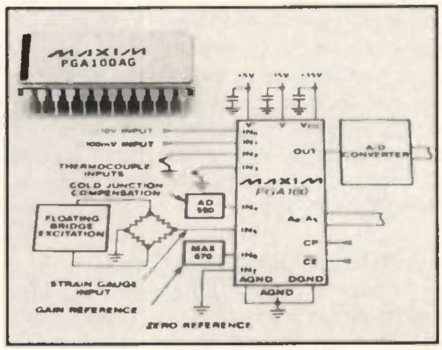


ding on packaging and quantity. The plastic package is priced at $17.10 when purchased in 100-piece quantities.

A unity-gain monolithic buffer, Model CLC110, featuring a bandwidth of 730 MHz, rise times as fast as 400 ps, 2 mV offset voltage and 20 uV/°C drift is also available. At 20 MHz, harmonic distortion is −65 dB and gain flatness from DC to 200 MHz is typically 0 dB. The packaging options for this device are the same as the CLC501 with the price of the 8-pin plastic DIP at $15.50 when purchased in 100-piece quantities. **Comlinear Corporation, Fort Collins, CO. INFO/CARD #214.**

Programmable Gain Amplifier

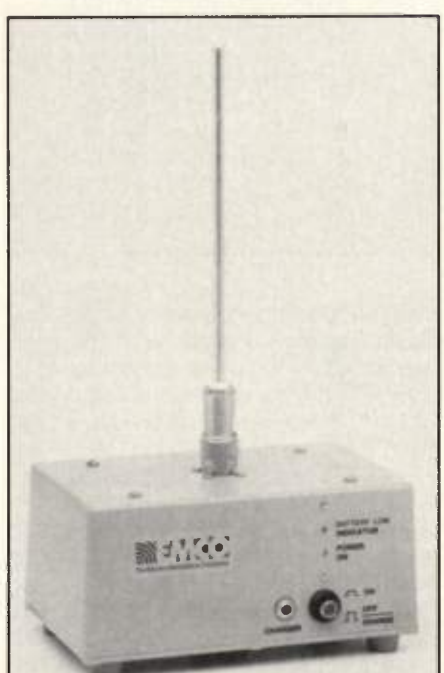
The PGA100 programmable gain amplifier is a precision digitally programmable gain 8-channel multiplexed input amplifier. Any one of eight analog input channels can be selected with any one of eight non-inverting binary weighted gains (1, 2, 4, 8, 16, 32, 64, 128). It settles to within 0.01 percent in 5 us max. making it suitable for rapid channel selection in data



acquisition systems. Initial offset is 0.05 mV, high gain accuracy is ±0.02 percent max. and non-linearity is ±0.005 percent. Gain bandwidth product is 5 MHz, power bandwidth is 220 kHz, slew rate is measured at 14 V/us, overload recovery is 2 us and output crosstalk is ±0.003 percent. **Maxim Integrated Products, Sunnyvale, CA. INFO/CARD #213.**

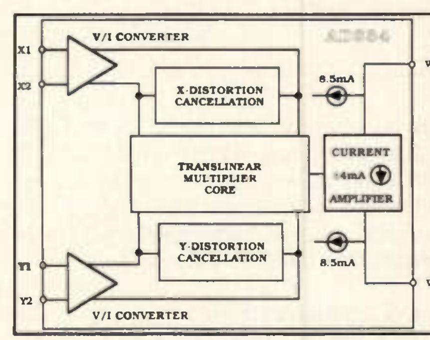
Emissions Generator

EMCO introduces the 4610 Royce field site source. This portable unit is a self-contained emissions generator that creates a reference standard for test site measurement. To create a reference standard, the instrument is placed on the test site in the area normally occupied by the equipment under test. When power is applied, the unit radiates a comb of signal between 10 MHz and 600 MHz spaced in 10 MHz increments. Using an antenna and spectrum analyzer or receiver, the frequency and amplitude of each signal point is measured and recorded. This initial measurement becomes the reference point for future site measurements. The 4610 costs $1,695. **Electro-Mechanics Company, Austin, TX. Please circle INFO/CARD #211.**



Four Quadrant Multiplier

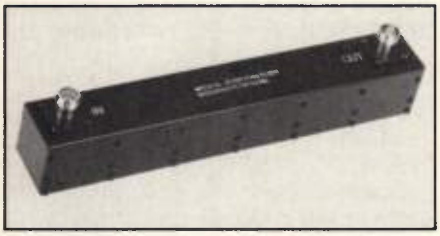
This laser trimmed four quadrant analog multiplier has a large signal bandwidth of 500 MHz and operates from a supply voltage range of ±4 V to ±9 V. For 10 dBm inputs, the output distortion is less than 0.05 percent with power consumption of 290 mW at ±5 V supplies. It is designed for applications in wideband modulation



and gain control, signal correlation and power measurement, and voltage-controlled filters and oscillators. In multiplier modes, the total full-scale error can be held below 0.5 percent, depending on the application mode and external circuitry. **Analog Devices, Norwood, MA. INFO/CARD #212.**

Lowpass and Bandpass Filters

The 6116 lowpass and 6117 bandpass filters are designed for use in high power VHF transmitters. Passbands for series 6116 fall within 30 to 230 MHz with minimum rejection of 40 dB for frequencies between the passband second harmonic and 1 GHz. Passband insertion loss is 0.3 dB. The 6117 has passbands between 52 and 110 MHz, rejection of 20 dB to 30 MHz and insertion loss of 0.6 dB maximum. VSWR is 1.25:1 and passband power is 1300 watts CW into a 2:1 load for



both devices. The 6116 costs $750 and 6117 costs $1,800. **Microwave Filter Company, East Syracuse, NY. Please circle INFO/CARD #210.**

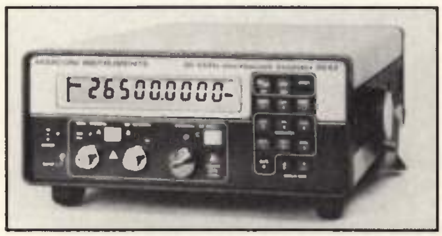
Chip Capacitors

AVX introduces the TAZ Series chip capacitor that features fully molded construction. The flat top surface allows

marking the polarity, capacitance and voltage. The capacitance values of these chips extend up to 2.2 uF at 4 V. Packaging is available in bulk or in tape and reel format in accordance with EIA RS-481. **AVX Corporation, Biddeford, ME. Please circle INFO/CARD #209.**

Microwave Counter

Model 2442 is a 10 Hz to 26.5 GHz frequency counter with 0.1 Hz resolution. Wide tolerance of frequency modulation (up to 30 MHz) ensures that carrier fre-



quencies are measured accurately with AM tolerance up to 40 percent modulation depth. Frequency sensitivity is -25 dBm from 600 MHz to 10 GHz and −20 dBm at 18 GHz. It is equipped with a MPC

rf products Continued

3.5 mm connector and GPIB is standard. **Marconi Instruments, Allendale, NJ. INFO/CARD #208.**

Synthesized Signal Generators

Leader Instruments introduces the Model 3220 AM/FM synthesized RF signal generator with frequency range of 100 kHz to 1.3 GHz with ±1 ppm accuracy and resolution of 10 Hz below 650 MHz and 20 Hz to 1.3 GHz. For in-channel measurements such as sensitivity, distortion, hum and noise, the 3220 offers residual FM signal to noise ratio of 60 dB or better. Modulation modes are AM, FM, and DC to FM.

The 3215, also from Leader, is a similar signal generator with frequency range of 100 kHz to 140 MHz and resolution of 100 Hz for frequencies below 30 MHz and 1 kHz to 140 MHz. A phase-locked loop synthesizer ensures stable carrier frequency outputs to within 50 ppm accuracy. The RF output range is −20 to 126 dBμ in 0.1 dB steps. Internal modulation is provided at 400 Hz and 1 kHz with an external modulation range of 20 Hz to 100 kHz (FM) or 20 Hz to 10 kHz (AM). Price is $2,850.

Model 3216 is an AM/FM stereo synthesized RF signal generator with frequency range of 100 kHz to 140 MHz. Resolution is 100 Hz for frequencies below 30 MHz and 1 kHz to 140 MHz. A phase-locked loop synthesizer ensures stable frequency outputs to within 50 ppm accuracy. RF output range is −20 to 126 dBμ in 0.1 dB steps. Internal modulation is provided at 400 Hz and 1 kHz. External modulation range may be from 20 Hz to 100 kHz (FM) or 20 Hz to 10 kHz (AM). This stereo generator is $2,995. **Leader Instruments Corp., Hauppauge, NY. INFO/CARD #207.**

FFT Based Analyzer

HP introduces a two channel fast fourier transform based analyzer with test and automation features. The HP 35660A performs network analysis from DC to 51.2 kHz and spectrum analyses from DC to 102.4 kHz with 440 lines of resolution in both one- and two-channel modes provided by the FFT. The two input channels have a 70 dB dynamic range and a source that provides signals for stimulus-response testing. It measures linear spectrum, power spectrum, frequency response gain/phase, group delay, time history and power spectral density. A built-in 3.5 inch disc drive, compatible with HP 9000 Series 200/300 workstations, stores traces, tables and HP instrument BASIC programs. **Hewlett-Packard Company, Palo Alto, CA. INFO/CARD #206.**

SMD Oscillator

NEL unveils the SA-100(TTL) and SA-350(CMOS) series of quartz crystal clock oscillators. The available frequencies range from 0.5 MHz to 63 MHz with user specified tolerances from ±0.0025 percent. The oscillator is hermetically sealed in a 0.515" square metal package. **NEL Frequency Controls, Inc., Burlington, WI. INFO/CARD #205.**

Synthesized Signal Generator

The Eaton 5162 synthesized signal generator operates from 10 to 2560 MHz with less than 1 us switching speed and phase noise less than −123 dBc at 1 kHz offset at a carrier frequency of 2560 MHz. Spurious noise is measured at −95 dBc and modulation capabilities include AM, FM, phase, pulse, FSK, and BPSK. **Eaton Corporation, Electronic Instrumentation Division, Los Angeles, CA. Please circle INFO/CARD #204.**

L-Band Delay Line

LV 300 Series bulk acoustic wave delay lines are centered at 1.5 GHz with bandwidth of 900 MHz. Delays of 0.4 to 7.7 μs are available for memory/calibration processing. Insertion loss is less than 35 dB. **Phonon Corporation, Simsbury, CT. INFO/CARD #203.**

Coaxial Cable Assemblies

Micro-coax introduces semi-rigid coaxial assemblies that feature a low-density PTFE dielectric to ensure low dielectric constant and low insertion loss. The assemblies are available in unplated copper and can be silver or tin plated. A choice of SMA male or female connectors is available with minimum bend radius of 3/4". **Micro-Coax Components, Inc., Collegeville, PA. INFO/CARD #202.**

EMI Test System

The EP-6 EMI test system from Rohde & Schwarz conforms to MIL-STD 461/462, FCC, and VDE as well as other standards. The instrument uses a crystal-based synthesized receiver to meet the exacting VDE receiver specifications. Features include softkeys, audio and visual interference identification, color monitor capability, IEEE-488 capability and printer and plotter outputs. The price for this test system is $82,000. **Rohde & Schwarz, Inc., Lanham, MD. INFO/CARD #201.**

Measurement and Parameter Extraction Software

FetFitter™ is a measurement and parameter extraction software package optimized for use in characterizing statistically significant quantities of GaAs MESFETs, MODFETs and JFETs in manufacturing and engineering environments. FetFitter 1.2 runs on the HP 9000 Series 200 and 300 computers and controls a variety of microwave measurement equipment including a vector network analyzer, an autoprober and various types of bias supplies, printers and plotters. A main use of the software is to measure and rapidly extract the microwave linear equivalent circuits of test FETs on a GaAs wafer. It uses an equivalent circuit topology with up to 14 lumped elements, and is designed for maximum accuracy and throughput. The software can generate a large database of RF parameters of basic elements for statistical process control, yield enhancement and for MMIC design libraries. **Cascade Microtech, Inc., Beaverton, OR. INFO/CARD #200.**

Analog Circuit Simulator

IS_SPICE/386 is a high performance SPICE based analog circuit simulator for personal computers. The software contains runtime enhancements that access the features of the 80386 processor while running under DOS. One of the features is that it automatically switches the user from the real mode into the protected mode of the 80386. This gives access to 16 Mbytes of address space. The enlarged memory usage means that circuits 10 times larger than previously simulatable with current PC versions can now be simulated with 2 Mbytes of extended memory. The package costs $386. **Intusoft, San Pedro, CA. INFO/CARD #199.**

Schematic Capture Package

CAECO introduces a schematic capture package which includes a symbol library for capturing MIMIC and other microwave circuits. The package includes a bidirectional interface to Super-Compact™ and Microwave Harmonica™. This interface supports back annotation of optimized programs for Super-Compact into CAECO's database, allowing designers to view circuit values before and after optimization. Features include bidirectional linkage to other software packages. **CAECO, Inc., Santa Clara, CA. INFO/CARD #198.**

Signal Processing Program

Version 2 of this signal processing program (SSP) is written for PC/MSDOS and Macintosh computers. SSP analyzes linear and non-linear systems described by Laplace transfer functions. FFT and its inverse form the basis of the program with utility enhanced by the program's ability to switch rapidly between time domain signals and their frequency domain spectra. The program is completely menu driven and is interactive. SSP costs $125. **BV Engineering Professional Software, Riverside, CA. INFO/CARD #197.**

Optimization Software

NETMATCHs 1 is a program that optimizes L-C and microstrip line (Wheeler) ladder matching type networks over a user specified range of frequencies. It minimizes VSWR for a user defined ladder network which is used to match both source and load impedance. **KASK Labs, Mesa, AZ. INFO/CARD #196.**

Linear and Interface IC Databook

This databook from Motorola lists amplifiers and comparators, power circuits, power/motor control circuits, voltage references, data conversion ICs, RF and other communication circuits, consumer electronic circuits and automotive electronic circuits. A cross reference section, together with sections detailing packaging information and quality assurance, are included. Also listed is application literature available from Motorola. **Motorola, Inc., Phoenix, AZ. INFO/CARD #179.**

Rental Catalog

This catalog lists analyzers, meters, generators, oscilloscopes, desktop computers and various other equipment. Manufacturers represented include Hewlett-Packard, Tektronix, Intel and Fluke. Also included are rental terms and conditions. **Genstar Rental Electronics, Inc., Woodland Hills, CA. Please circle INFO/CARD #194.**

Power Solution Application Note

Extending the Useful Bandwidth of Your Power Resistors is an application note from Acrian that discusses a compensation circuit to extend the frequency range significantly. The note first evaluates the parasitic capacitance of the resistor. This is followed by the derivation of the compensating circuit. The final section of this note highlights further improvements. An example follows each step discussed. **Acrian, Inc., San Jose, CA. INFO/CARD #193.**

Brochure Discusses Solving FM Interference Problems

This bulletin describes how to eliminate interference FM stations may cause to other broadcasters. Overload, harmonic interference and intermodulation are forms of interference very strong FM stations may cause to other FM stations, TV and VHF radio. The bulletin details these three types of interference, the symptoms and types of filters to correct the problem. Among the solutions offered are installing a filter into the receiver system to help overload. When the desired channel and interfering channel are close in frequency, a phasing method must be used. This procedure can be used in cases of harmonic reception and overload. Certain types of intermodulation can be solved by installing a filter between transmitter and antenna. **Microwave Filter Company, East Syracuse, NY. INFO/CARD #192.**

Note Describes LPF with Programmable Cutoffs

This note depicts the design of a low-pass analog filter with software programmable cutoff frequencies from 100 Hz to 50 kHz. It explains the use of the AD7537 CMOS dual 12-bit digital to analog converter in this filter function. The sections highlighted are filter function, digital control of cutoff frequency, gain bandwidth product, tradeoffs and practical limitations. **Analog Devices, Norwood, MA. INFO/CARD #191.**

Powder Cores Catalog

This Hi-Flux power cores catalog describes the characteristics of Hi-Flux products, their applications, and a master part number. Electrical properties as well as typical core loss curves are provided. **Core Products, Arnold Engineering Company, Marengo, IL. Please circle INFO/CARD #190.**

Coaxial Cable Connectors Catalog

This catalog from AMP covers 3.5 mm blindmate connectors for semi-rigid cable and SMA connectors for semi-rigid and flexible cable. It highlights the features, and electrical, environmental and mechanical characteristics of preassembled SMA connectors that terminate RG-405/U and RG-402/U semi-rigid cable with frequencies of 0 to 18 GHz or 0 to 26 GHz. Also covered are features and performance characteristics of 3.5 mm blindmate connectors for semi-rigid cable and a wide range of SMA plugs and jacks for flexible cable. Detailed treatment of each connector includes product drawings, materials information and part numbers. **AMP Incorporated, Harrisburg, PA. INFO/CARD #188.**

GaAs IC Data Book

GigaBit Logic announces the availability of a GaAs IC data book and designer's guide. It provides information on the PicologicTM, NanoRamTM, NanoRomTM and telecom families; standard workstation-based cell ASIC library; foundry services; prototyping and production supports; testing methods; and reliability and quality assurance. The information covers standard, semi-custom and full custom ICs. **GigaBit Logic, Newbury Park, CA. INFO/CARD #195.**

Laminate Selector Guide

A product selector guide from Rogers Corporation is intended to help design engineers select the proper grade of RT/duriod® laminate or R02800TM circuit material for microwave circuit board applications. It provides electrical and mechanical properties of seven grades of RT/duroid material and two grades of R02800 material. Also provided are physical properties of a range of copper cladding materials used with Rogers' dielectric substrate and data on OHMEGA-PLY® planar resistor conductors. **Rogers Corporation, Microwave Materials Division, Chandler, AZ. INFO/CARD #187.**

Used Equipment Catalog

Genstar REI introduces a catalog that includes like-new analyzers, oscilloscopes, generators and desktop computers from major manufacturers. **Genstar REI Sales Company, Woodland Hills, CA. INFO/CARD #182.**

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