rf design

engineering principles and practices

February 1988

1978 1988 10th ANNIVERSARY

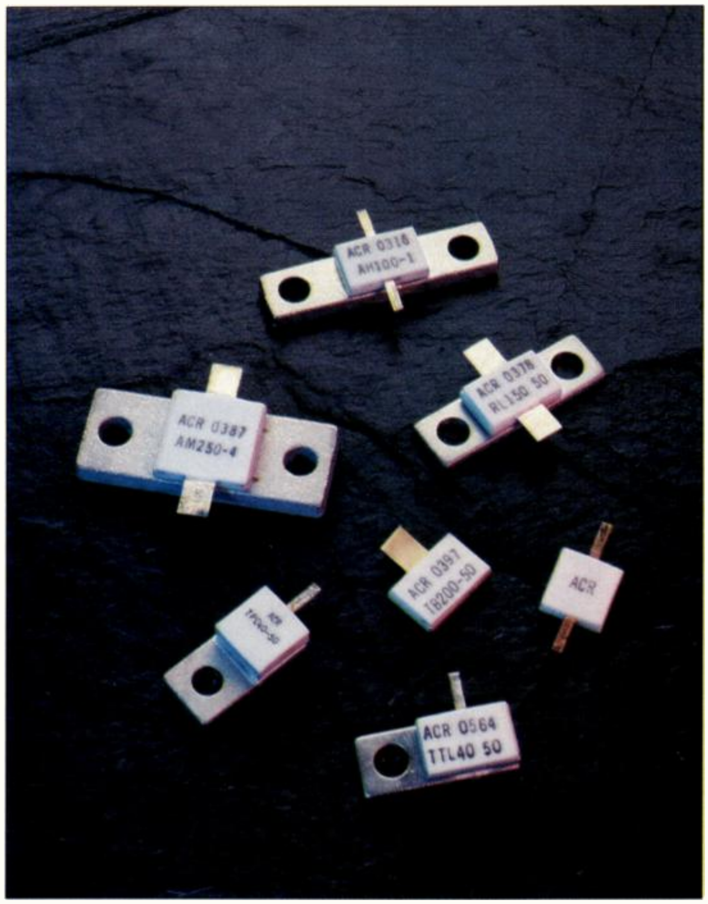
Catalog-on-a-Disk Finds RF Devices *Fast*

******************** 5-DIGIT 33309
736 01020404 41 31
ALAN VICTOR
VP DIR
INTELLICOM
2964 NW 60TH ST
FORT LAUDERDALE FL 33309

Show Issue — RF Technology Expo 88

Featuring RF Power Techniques

RESISTORS ATTENUATORS TERMINATIONS SERVICE



ACRIAN
POWER SOLUTIONS

Richardson
Electronics, Ltd.

OFF-THE-SHELF FROM RICHARDSON ELECTRONICS

When you are designing with high power transistors, you need a RAT!

The fact is, if the output stage of your amplifier has more than one transistor, you need at least two RATS (Resistors, Attenuators, and Terminations). And with power ranges of today's technology well into the mulitkilowatt levels, the selection of high power passive products is more critical than ever. Acrian introduced high power RATS to the world more than 10 years ago, and we still manufacture the best resistors, attenuators and teminations on the market.

Richardson has more than twenty standard package styles for microstrip applications, both flanged and unflanged.

ACRIAN
POWER SOLUTIONS

ACRIAN RATS feature:

- **More watts/sqare inch dissipated**
- **Lowest VSWR (1.25:1)**
- **Standard resistor values at 50 and 100 Ohms**
- **High-temperature brazing**
- **Lowest thermal resistance**
- **Hi-Rel screening available**

For the most reliable high power passive products call for Acrian RATS today at:

Richardson Electronics, Ltd.

40W267 Keslinger Rd., LaFox, IL 60147
(312) 232-6400 **Toll Free** (800) 323-1770
East (800) 645-2322 **West** (800) 348-5580
Northeast (617) 871-5162 **Southeast** (800) 348-5580
Canada (800) 387-2280

INFO/CARD 1

See us at the RF Technology Expo, Booth #323.

Motorola RF Design News

TMOS transmits better performance in RF.

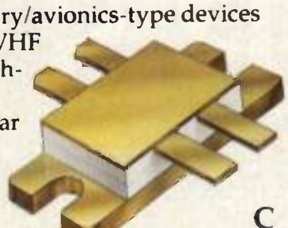
Higher gain and input impedance, enhanced thermal stability and lower noise keynote a broad lineup of TMOS RF powerFETs. With P_O to 600 W and frequency ranges to 500 MHz, these rugged, leading-edge amplifiers offer easy-to-match capabilities for broadbanding. The newest series, MRF141G/151G,/175G/176G offer push-pull packages to aid in implementation of broadband, high-power circuits in SSB and VHF AM/FM designs. The N-channel units are fabricated with an oxide-insulated gate which controls vertical current flow.

Talk to anybody, anywhere with Motorola land-mobile.

You'll find the industry's widest variety of 7.5 V and 12.5 V discrete transistors and amplifiers for mobile 2-way here. We offer package options; high-gain, high-power, rugged devices for low-band, VHF, UHF and 900 MHz; complete, economical lineups of discrete parts in every frequency band; thorough applications support, modules for portables and for mobiles where increased circuit demands make complete amplifiers a logical, economical choice and high-volume, quality-production capabilities. We even have the highest-power (MRF898) and lowest-priced (MRF557) units for 900 MHz applications.

Keep control with hermetic RF power.

The first of several 28 V, military/avionics-type devices to provide complete lineups at VHF and UHF are the 2N6985-86 push-pull transistors in case 382-01. A hermetic version of the popular MRF392-393, the new gold metallized, internally-matched, 2N6985 operates from 225 to 400 MHz, delivers 125 W P_O at a nominal 10 dB gain, Class C. Operate it in Class AB and gain improves to 11 dB. Frequency extends to 500 MHz for the 2N6986, output power is 100 W and gain 8.5 dB, Class C; 9.5 dB, Class AB.



L-band RF devices keep control in air traffic.

The MRF10120 (120 W) and MRF10030 (30W) help provide the right answers to Mode "S" air-traffic-control transponder questions about location and altitude of planes so collison is avoided. Capable of handling 10 μs pulses at 50% duty cycle for up to 3.5 ms, the units have guaranteed performance including ruggedness. Used at 960 to 1,215 MHz, they have an overall duty cycle of 25% and incorporate input matching for broadbanding, gold metallization, nitride passivation and low thermal resistance for heat dissipation. They are also available for JTIDS use.

One-on-one design-in help.

Anywhere in the U.S. or Canada, get an engineer-to-engineer update on the latest in Motorola RF technologies.

1-800-521-6274

Call toll-free any weekday, from 8:00 A.M. to 4:30 P.M., M.S.T. If the call can't cover your applications, we'll have an applications engineer contact you.

And help you to market faster.

We're on your design-in team.

MOTOROLA

To: Motorola Semiconductor Products, Inc. **351 RFD 020088**
P.O. Box 20912, Phoenix, AZ 85036

Please send me the latest information on these Motorola RF Semiconductors:

A ☐ MRF1416/1516/1756/1766 TMOS RF C ☐ 2N6985/86 Hermetic RF
B ☐ Land-Mobile RF D ☐ MRF10126/10030 L-Band RF

Name ____________________

Title ____________________

Company ____________________

Address ____________________

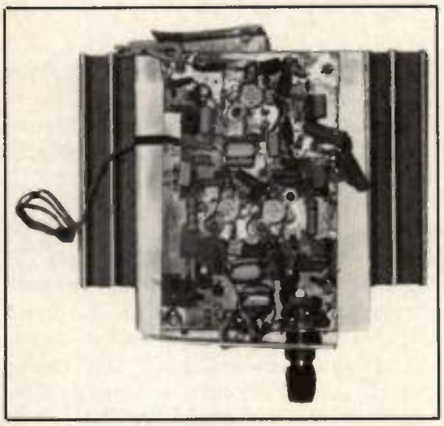
City ____________ State ________ Zip ________

Call me (______) ____________________

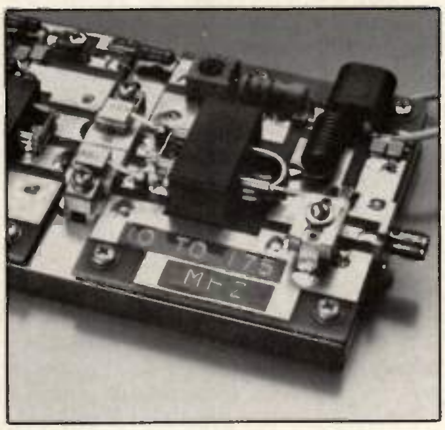
See us at the RF Technology Expo, Booths #324-330 & 423-429.

rfdesign

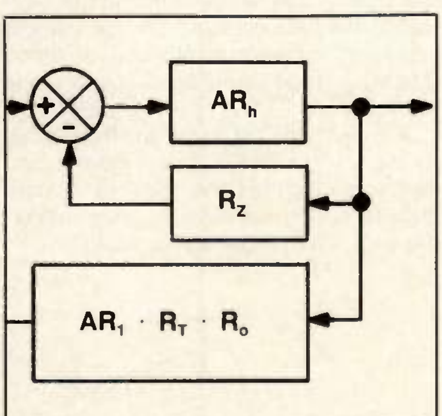
February 1988



Page 32 — 60 Watt Amplifier



Page 53 — 10-150 MHz Amplifier



Page 85 — Improved DC Performance

Cover Story

Featured Technology Section

Departments

R.F. DESIGN (ISSN: 0163-321X USPS: 453-490) is published monthly plus one extra issue in September. February 1988, Vol. 11, No. 2. Copyright 1988 by Cardiff Publishing Company, a subsidiary of Argus Press Holdings, Inc., 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111 (303) 220-0600. Contents may not be reproduced in any form without written permission. Second-Class Postage paid at Englewood, CO and at additional mailing offices. Subscription office: 1 East First Street, Duluth, MN 55802, (218-723-9355). Domestic subscriptions are sent free to qualified individuals responsible for the design and development of communications equipment. Other subscriptions are: $33 per year in the United States; $41 per year in Canada and Mexico; $45 (surface mail) per year for foreign countries. Additional cost for first class mailing. Payment must be made in U.S. funds and accompany request. If available, single copies and back issues are $5.50 each (in the U.S.). This publication is available on microfilm/fiche from University Microfilms International, 300 N. Zeeb Road, Ann Arbor, MI 48106 USA (313) 761-4700.
POSTMASTER & SUBSCRIBERS: Please send address changes to: R.F. Design, P.O. Box 6317, Duluth, MN 55806.

rf editorial

It's Contest Time Again!

By Gary Breed
Editor

Although we have only held the RF Design Awards contest twice, it seems like it has been around for many years. The fun, the challenge and the reward of developing a circuit for the contest is infectious. The judges, the readers and the entrants all seem to be cheering each other on.

Now it is time to get this year's entry completed, tested and written up. The Design Kits from Compact Software, the A-7550 Spectrum Analyzer from IFR, and the Coilcraft inductor kits are waiting to be awarded. (The entry rules are outlined in the announcement on pages 90-91 in this issue.) Entries are already arriving — make sure yours is among them.

Sometimes, the prospect of putting something in writing prevents an engineer from presenting his ideas. As you review the contest rules, please note that it is creative and engineering ability that is judged, not writing talent. The contest entries are treated just like our contributed articles: we want *information*, not fancy phrases. Don't worry about the literary quality of your entry, just make sure it contains complete data on your project.

A Word About the Judges

As has become our tradition, the previous winner will be part of our panel of judges. Charles Wenzel, President of Wenzel Associates, won in 1987 with a novel frequency multiplier circuit. He is especially knowledgeable in frequency control circuitry and measurement techniques.

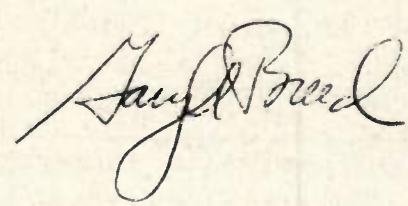
Another new judge is Bob Zavrel, recently added to the *RF Design* family as a Consulting Editor. His work at Digital RF Solutions involves developing and promoting applications for their NCMO direct digital synthesizers. Bob has a strong background in design using audio, digital and RF integrated circuits. Long-time involvement in ham radio (W7SX) is evidence of his enthusiasm for RF technology.

Andy Przedpelski, our well-known Consulting Editor, will again serve as a judge. As Vice President for Development at A.R.F. Products, he has experience in almost every area of RF design. His articles on PLLs, filters, and other aspects of circuit design are legendary. Andy's technical acumen and realistic approach to RF design make him an ideal contest judge.

Finally, I get to enjoy the entries, too. My own experience is in broadcast engineering, with particular emphasis on transmitters and antenna systems, plus plenty of work in audio, video, and control circuitry. As a 26-year radio amateur (K9AY), I have designed and built transmitters, receivers and test instruments.

Although difficult, the contest is fascinating to judge. As we examine the wide range of ideas contained in the entries, our own thinking is stimulated. Once again, we urge you to be as tough on us as you can.

Even with the big prizes and the publicity, the spirit of the RF Design Awards contest is not competition. Charles Wenzel said it best in his winning entry (*before* he won), "What great fun this is!"



rf viewpoint

Use It Or Lose It

By Robert J. Zavrel Jr.
Consulting Editor

When contrasted against other professions, engineers seem to have a dwarfish voice in persuading public policies. Other vocations have powerful lobbies at local and federal levels, but the various engineering societies cannot operate from a position of strength without strong participation from the engineering ranks.

The evolution of technology is the driving force of change in society. But, too often problems involving technical issues are decided without consulting technical people. The creative minds that typify engineers have a rightful place in vital decision-making processes. Ironically, intelligent, creative people tend to be dissuaded from the stupidity and bureaucracy of the modern political process. Also, the instinct for independence common in the engineer's psyche spawns a certain disdain for labor unions or union-like activities. There is a fine distinction, however, between the concepts of "union" and "lobby." We, as engineers, must learn this distinction.

For example, the technology of broadcasting has changed political reality. Today, more than ever, the set of talents and skills needed to win an election does not coincide with the talents and skills needed to function in the office. In the process, technical terms like *radiation, energy,* and *nuclear* have lost any semblance of accuracy in a quagmire of emotional apprehension. Worse yet, some politicians prey on this general fear for personal profit. Where are the voices of reason at these critical moments? Where are our voices?

In a corporate environment, upper management's chief concern is with red and black ink. Sales, marketing, finance and accounting are usually associated with black ink. Engineering, manufacturing, service and quality assurance are usually associated with red ink. This psychological trap is very difficult to avoid by the most enlightened managers even in "engineering" companies. Within the corporate environment, engineers should get involved with "bottom line" calculations. If you start using the same vocabulary as accountants, management will start treating you like a "black ink" person. Engineers are often astonished to find an accountant who knows ohm's law. Similarly, accountants are often astonished to find an engineer who is comfortable with terms like "ledger" or "cost accounting."

How can engineers raise the stature of their profession? They key to political influence is organization and the ability to articulate your stand. The key to corporate influence is being associated with "black ink." Join and *participate* in your professional societies, publications and meetings. Get support from other engineers. *Communicate* with your colleagues and others about various issues. Organized ignorance is a growing force in the world. We can and should challenge it when we encounter it. Freedom of speech is a valuable right. Use it or lose it!

rf letters

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

To Certify or Not to Certify?

Editor:

I don't think that having people who operate EMC test stations pass examinations is going to do much good, for the following reasons:

1. Technical ability is not correlated with honesty. Even intelligence organizations who do thorough background investigations of people who get security clearances are unable to consistently identify dishonest people.

2. People responsible for the manufacturing of equipment which has passed EMC testing are usually not skilled in knowing which minor production variations are acceptable and which are not. Most of them don't know that they don't know.

3. The variety of ATE is rapidly expanding. Passing an examination on one model does not guarantee that a person will know the idiosyncrasies of any other model.

James Long
Sunnyvale, CA

Editor:

The idea of certification of engineers by examination, while having an initial attractiveness, becomes much less attractive under scrutiny.

This is most apparent in military compliance. The regulations change almost constantly, and all regulations do not apply to all programs. In addition, testing creates a large and inflexible bureaucracy to support the test program, which would further slow down needed changes in technology to deliver more efficient and cost effective products.

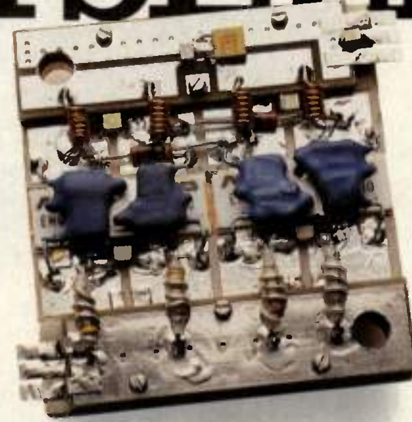
Electromagnetic compatibility is more adaptable to testing of engineers. However, this is an emerging field and test methodology is likely to be fluid for several years hence, hampering efforts to produce meaningful tests.

Finally, certification is no guarantee of performance, only a demonstration that a person can answer questions on a test. (A practical examination is impractical, due the high cost of test equipment and facilities that would be required.)

James A. Grahart
Chicago, IL

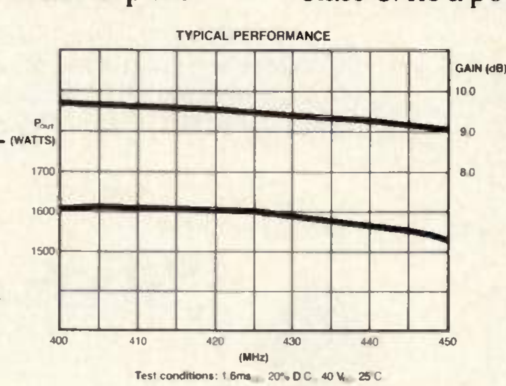
Help celebrate the 10th Anniversary of *RF Design* during 1988 — send us your observations, recollections, or philosophical musings about the past ten years of RF technology. We will print as many letters as we can.

OUR MOST POWERFUL ADVANTAGE IS POWER ITSELF.



You're looking at the highest power density long pulse UHF amplifier we've ever built. And as far as we know, no one else has even come close.

To do so, MMD had to develop the world's highest power long pulse UHF transistor, engineer an innovative flatpack transformer/balun, and devise a sophisticated thermal/mechanical package for maximum heat transfer.



The result is a module capable of 1600 Watts of output power at a pulse width of 1.6 milliseconds (20% duty cycle) with over 9db of gain, operating Class C. It's a powerful reason why you should call MMD for your amplifier needs.

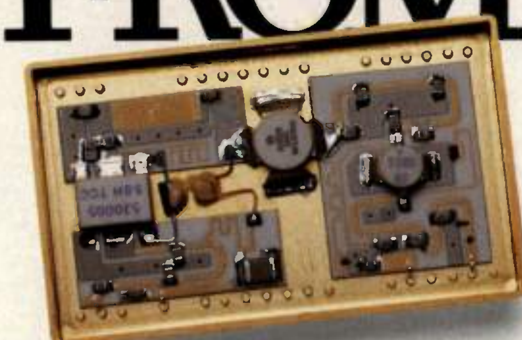
Phone us at (415) 961-1473, or write to Microwave Modules and Devices Inc., 550 Ellis St., Mountain View, CA 94043, Telex 508 746.

MMD®

We Deliver Power.

INFO/CARD 7 **Literature**
INFO/CARD 8 **Demo**

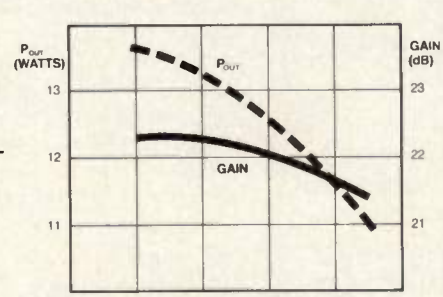
THERE'S HUNDREDS MORE WHERE THIS CAME FROM.



Two hundred and fifty a month, that's the number of this custom amplifier that MMD currently ships to Hughes.

Which is no small feat because when Hughes Aircraft approached MMD, they had the knotty problem of producing this sophisticated amplifier in volume.

MMD took a unique approach to solve this challenge. Our high degree of integration enabled us to respond with precisely what Hughes needed for its PLRS system: a thick film UHF pulsed amplifier with 10 watts of output power (– 55 to + 85 degrees C) at + 19dBm input, with consistent lot to lot performance through production.



10 WATT HYBRID: P_{IN} = + 19dBm, F = 420 – 455 MHz
V_{cc} = 12.5 Volts, I_c = 2.6A Peak

While this success story might not apply specifically to your needs, MMD's unique problem-solving capabilities probably do, because like this custom hybrid amplifier, there are hundreds more success stories where this one came from.

MMD®

We Deliver Power.

INFO/CARD 10 **Literature**
INFO/CARD 9 **Demo**

Come see us at the RF Technology Expo '88, Booths #340, 342, 439, 441.

Unprecedented Performers!

The **A-8000** Spectrum Analyzer. A step beyond the A-7550.

Now 2.6 GHz frequency coverage!

Fully synthesized. Tracking generator.* Quasi-peak detector.* Truly portable. And again, an exceptional value!

The new A-8000, quite simply put, is our response to industry's demand for a higher frequency, yet still economical, Spectrum Analyzer.

Now, with two models and seven options to select from, you can custom configure the unit that meets your specific testing requirements.

The commonality of the A-8000 and A-7550 offer you many benefits. Two powerful microprocessors, menu driven display modes and single function keyboard entry aid the user in the operation of all analyzer functions. To further increase the operational simplicity of the A-8000 and A-7550, the microprocessor systems automatically select and optimize the analyzer's bandwidth, sweep rate and center frequency display resolution, with manual override if desired.

Increased flexibility...added features...and exceptional value continue to make IFR the logical choice when considering your next Spectrum Analyzer.

Contact your IFR distributor or representative for a demonstration.

A-8000 and A-7550 Features — All Standard:

▪ Fully synthesized (**A-8000**) 10 kHz to 2.6 GHz (**A-7550**) 10 kHz to 1 GHz ▪ VRS™ (Vertical Raster Scan) CRT display ▪ Single function keyboard entry ▪ Menu driven display modes ▪ Automatic amplitude calibration ▪ Selectable linear / log display modes ▪ Digital storage of all displayed parameters ▪ 70 dB dynamic range ▪ 300 Hz resolution bandwidth ▪ Selectable scan widths, 1-2-5 sequence + 0 and full scan ▪ Accurate center frequency readout ▪ Direct center frequency entry ▪ Automatically scaled electronic graticule ▪ Variable top scale reference (+30 to −95 in 1 dB steps) ▪ IF gain in 1 dB steps ▪ Line, bar, average, compare and peak hold display modes ▪ 300 Hz and 30 kHz video filters ▪ 106 to 266 VAC operation without switching ▪ 12 to 30 VDC operation

***Optional Features Include:** ▪ Internal rechargeable 5 APH battery for truly portable operation ▪ Internal tracking generator with 1 dB step attenuator ▪ FM / AM / SSB receiver ▪ IEEE-488 interface bus ▪ RS-232 interface bus ▪ 75Ω adapter ▪ Internal quasi-peak detector

IFR SYSTEMS, INC.
10200 West York Street / Wichita, Kansas 67215-8935 U.S.A.
316 / 522-4981 / TWX 910-741-6952

See us at the RF Technology Expo, Booth #240.

Electronic Industry to Grow in '88

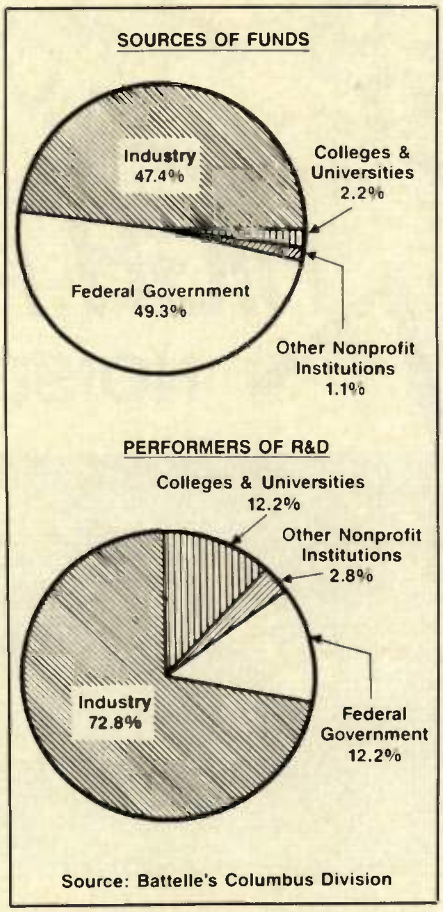
Electronic industry forecasts predict significant growth in 1988. Despite the bleak outlook on Wall Street, the annual *Electronics* market survey indicates that an overall growth of almost 11 percent to more than $170 billion can be expected. This is probably due to the late surge in 1987 that boosted the industry growth by 12 percent. According to a U.S. Department of Commerce Bureau of Economic Analysis survey conducted in October and November 1987, a 7.3 percent increase in spending for new plants and equipment is expected in 1988. This is good news since it is targeted towards electronic automation and productivity.

The *Electronics* survey also points out that the test and measurement market will show a gain of 10 percent. However, specific sectors like digital oscilloscopes, combinational board testers and timers will soar in 1988. Computer aided design and engineering hardware and software should grow by 29 percent. This follows a 1987 gain of 32 percent. In 1987 the U.S. consumed $13 billion worth of semiconductors and this market is expected to rise by 12 percent for 1988.

In the U.S., expenditure for research and development for 1988 is expected to reach $131.5 billion according to the annual Battelle forecast. This represents an increase of $8.5 billion (6.9 percent) over the $123 billion the National Science Foundation estimates was spent for R&D in 1987.

While part of the increase will be absorbed by continued inflation (estimated at 4.5 percent for R&D in 1988), Battelle forecasts a real increase of 2.28 percent for R&D expenditure. This is slightly lower than the 10-year average rate of 3.81 percent experienced since 1977.

Industrial funding for R&D will account for 47.4 percent of the total. Industrial support is forecast to be $62.3 billion, up 6.4 percent from 1987. Battelle sees an increase of 7.3 percent in federal support with funding expected to be $64.8 billion. This constitutes 49.3 percent of total expenditures for 1988. Funding by academic institutions is expected to be $2.93 billion (2.2 percent of total) and other nonprofit organizations will provide nearly $1.52 billion (1.1 percent).



R&D expenditures in the U.S. for the 1988 calendar year.

TIW Awarded Japanese Contract

TIW Systems, Inc., of Sunnyvale, California has received a $9 million contract for the design and construction of a 34-meter radio telescope to be installed in Japan. This is the one of the first purchases by the Japanese Government under the Nakasone Initiative, which establishes a program to improve the trade imbalance between the U.S. and Japan. Rikei Corporation purchased the telescope for Japan's Ministry of Posts and Telecommunications.

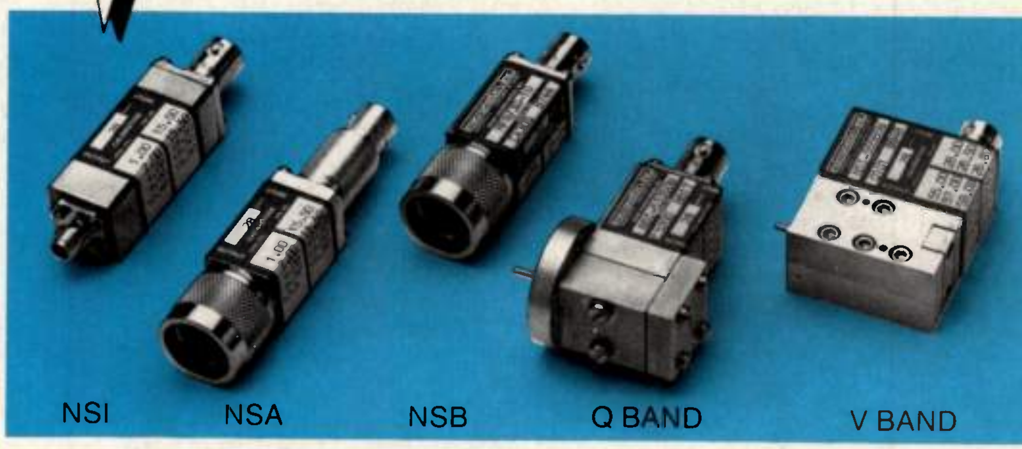
The Radio Research Laboratory (RRL) of Japan will operate the telescope at Kashima, Japan. The principal use of the telescope will be to conduct joint U.S./Japan very long baseline interferometer (VLBI) experiments designed to measure the movements of the earths' crust for earthquake prediction purposes. In addition to VLBI experiments, the telescope

PRICE BREAKTHROUGH

PRICED FROM **$269.00**

THE LOWEST COST EVER FROM STOCK

HIGH FREQUENCY
NOISE MODULES...



- Input Power 28v, 20 MA Max.
- Noise Output Variation With Voltage .1 dB/% V
- Noise Output Variation with Temp .01 dB/°C
- Calibration Sheets Supplied With Each Unit
- Certificates Of Conformance Supplied With Each Unit
- Calibration Points Are Marked On Each Unit
- Noise Diode Hermetically Sealed
- High ENR Output
- BNC (f) DC In; N (m) RF Out

Model Number	Freq. (GHz)	ENR (dB)	Flatness	Package	Calibration Points
RFN/30-10	.010- 1.0	30 Min	±1	N	.010,.500,1.00
RFN/25L	1.0 - 2.0	30 Min	±1	N	1.0,1.5,2.0
RFN/25S	2.0 - 4.0	30 Min	±1	S	1.0 GHz STEPS
RFN/25C	4.0 - 8.0	30 Min	±1	S	1.0 GHz STEPS
RFN/25X	8.0 -12.0	25 Min	±1	B	1.0 GHz STEPS
RFN/25Kμ	12.0 -18.0	25 Min	±1	NSA	1.0 GHz STEPS

*Other packages, frequency ranges, outputs, inputs available.
*Consult factory for more information.

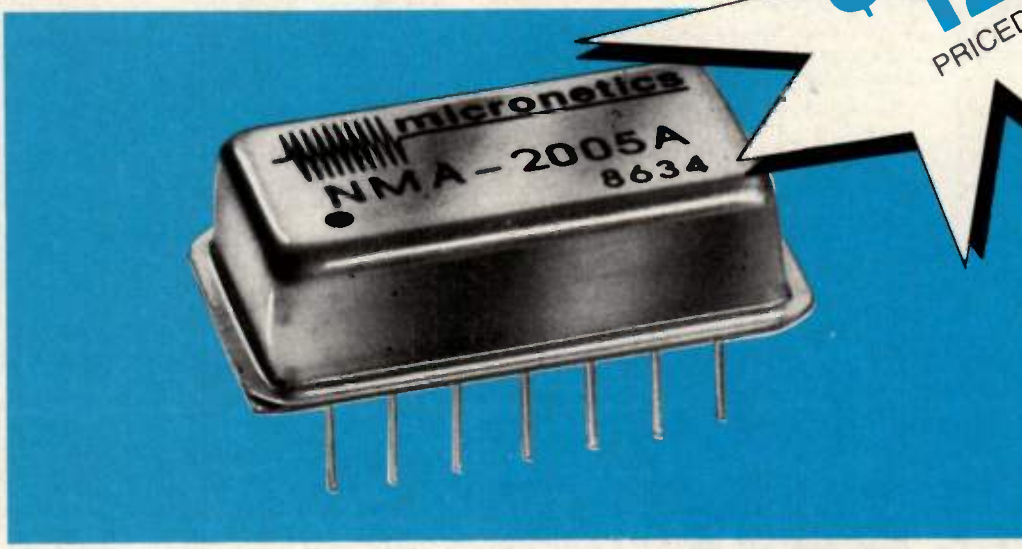
- Call today for these and other products with similar savings...
- Custom designs welcome

micronetics inc. DC-95 GHz

36 Oak Street • Norwood, NJ 07648 • (201) 767-1320
TWX: 710-991-9603 • FAX: 201-767-6551

DELIVERY FROM STOCK

PRICED FROM $129.00



INCREDIBLE

HIGH PERFORMANCE—LOW COST

LOW FREQUENCY
NOISE MODULES

- True White Symmetrical Gaussian Noise
- 5:1 Peak Factor (Voltage) 14 dB
- Ultra Compact Size .875" × .5" × .24"
- High Level Noise Output To 500 MHz
- Optional Supply Voltages Available
- Noise Symmetry 95% Typ, 90% Min
- Peak Factor 5:1 Min (Voltage)
- Operating Temperature −55°C to 85°C
- Temp. Coefficient .025 dB/°C Typ.
- Voltage Supply Sensitivity .4 dB/100 mV
- Maximum Storage Temperature −62°C to 150°C
- 15 Volt Operation

OUTPUT CHARACTERISTICS-50 OHM LOAD

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

Other Output Loads Available.

- Call today for these and other products with similar savings...
- Custom designs welcome

micronetics inc. DC-95 GHz

36 Oak Street • Norwood, NJ 07648 • (201) 767-1320
TWX: 710-991-9603 • FAX: 201-767-6551

See us at the RF Technology Expo, Booth #529.

INFO/CARD 13

will be used to perform a number of scientific studies and investigations.

To achieve this multipurpose role, the instrument operates over a range of frequencies. Any one of eleven frequency bands can be selected by RRL using a computer touch screen. Once commanded, the control system automatically moves the proper frequency feed and receiver system into position. The telescope will be equipped with feeds and cryogenically cooled receiver systems in the 300 to 600 MHz and 1.5, 2/8, 5, 10, 14, 22, 43, 49 GHz bands.

The lower frequencies are provided by feeds mounted in the focal point of the telescope. Cassegrain feeds and a five degree of freedom subreflector provide the higher frequencies. To support operations up to 49 GHz, the telescope is equipped with reflector panels with a surface tolerance of 0.005 inches rms.

Philips/Picker Joint Venture Approved

The United States Department of Justice has completed its review and decided not to oppose a joint venture of the medical divisions of N.V. Philips' Gloeilampenfabrieken of the Netherlands and the General Electric Company, p.l.c., (GEC) of the United Kingdom. The German Cartel office has also decided not to oppose the joint venture.

The new company, Philips and Picker Medical Systems, is a combination of Philips Medical Systems Division and GEC's U.S. medical subsidiary, Picker International. It will be one of the world's largest producers of medical imaging equipment, with $2 billion in sales, 17,000 employees, and a worldwide distribution and service network.

LTI Becomes Gennum Corp.

Gennum Corporation is the new name for the integrated circuit operations of Linear Technology, Incorporated. Gennum will become a wholly owned subsidiary of LTI in the corporate restructuring. This will separate it from the LTI subsidiary Anatek Microcircuits Inc. The company's address is P. O. Box 489, Station A, Burlington, Ontario, Canada.

Protecting Engineering Ideas and Inventions

Protecting Engineering Ideas & Inventions is a guide written for engineers and scientists on patents, copyrights, trademarks, trade secrets and secrecy agreements. It also talks about how engineers and scientists should deal with outside consultants and handle outsiders' ideas. Written in non-legal language by a patent attorney, Ramon Foltz, and an engineering manager, Thomas Penn, it covers every legal issue of importance in engineering and is organized specifically for R & D activities. The guide is designed to assist technical personnel in making correct decisions, to know for sure when an attorney's advice is needed to help prevent loss of legal rights and improve a company's chances of getting a patent or other form of legal protection. The book is priced at $39.00 + $3.00 postage and can be obtained by contacting Penn Institute Inc., P. O. Box 41016, Cleveland, OH 44141. Tel: (216) 237-2345.

New Company to Pursue RF Power Market

Power Systems Technology, Inc., has been formed to design, develop and manufacture RF/microwave high power solid state amplifiers. The company will pursue amplifier products and systems in the 1 MHz to 2 GHz range with power outputs of 1 W to 1 kW. The company is located at 63 Oser Avenue, Hauppauge, NY 11788. Tel: (516) 435-8597/8480.

Physicist Wins Research Award

The New York Academy of Sciences' Minoru and Ethel Tsutsui Distinguished Graduate Research Award in Science has been awarded to Dr. Robert Edward Thorne, a physicist at Cornell University. The plaque and $1,500 was presented by Dr. Fleur L. Strand, President, at the Academy's 170th annual meeting on December 7 in New York City. Dr. Thorne was awarded for his research on charge-density wave transport that showed that when a voltage is applied to a nearly one-dimensional crystal, an oscillatory motion of the crystal atoms and the translation motion of the electrons is produced, resulting in an electric current. The new electrical-conduction mechanism is similar to peristalsis, where the walls of one's intestines contract and expand so as to push the contents along.

The electrical properties of these crystals are mainly determined by the interaction between the charge-density wave and impurities. Dr. Thorne demonstrated the crucial importance of other types of defects. By measuring nearly defect-free crystals, he established many features fundamental to the charge-density wave impurity interaction and many of his results contradicted results in interpretations which had previously been widely accepted.

RF/LSI GaAs Foundry Service

TriQuint Semiconductor announces a radio frequency/large scale integration (RF/LSI) gallium arsenide IC foundry service: the QED/A process. The process allows mixing of low-power digital LSI circuits and precision analog circuits on a single die. This flexibility extends into the microwave domain enabling the analog designer to do conventional microwave designs up to 18 GHz at a fraction of the power previously required for bipolar silicon and GaAs technology.

The QED/A process is an extension of TriQuint's Q-ED process that integrates both enhancement and depletion-mode transistors used to fabricate low-power, high-speed LSI circuits. Also included are analog elements such as MIM capacitors, precision NiCr resistors, and inductors. A low noise medium power FET is also provided for higher current drive and conventional depletion MMIC applications.

Further information can be obtained by contacting Louis Pengue at (503) 629-4227.

Hughes Awarded $58 M Contract

Hughes Aircraft Company, a subsidiary of GM Hughes Electronics, has been awarded a $58 million development and production options contract by Rockwell International for the AC-130U gunship fire control radar system. The AC-130U, based on the C-130H, will be an air-to-ground firing platform equipped with a 105 mm howitzer and 25 mm and 40 mm cannon. It will be operated by the U.S. Air Force's Special Operations Forces.

Hughes Radar Systems Group will provide a modified version of the APG-70 radar, operational in the Air Force's F-15C/D air superiority fighter and currently in flight test for the F-15E Eagle multimission aircraft. The new modes will include fixed target track, ground moving target indication and track, projectile impact point position, beacon track, and a weather mode. In addition, the existing APG-70 antenna and analog signal processors will be modified and a new digital scan converter will be added to complete the system. Delivery of the first system, which is already in production, is scheduled for December 1988, with flight tests a year later. Production is scheduled through 1991.

Ericsson Wins $50 M Contract

Ericsson has received orders totalling $50 million for cellular radio system equipment from Macao, Cyprus, and United Arab Emirates. The United Arab Emirates and Macao have selected the TACS cellular radio system which is currently in operation in the United Kingdom, Ireland, and in the People's Republic of China. Cyprus has chosen the (Nordic Mobile Telephone) NMT 900 cellular system, which is operating in the Nordic countries and in Switzerland. The NMT 450 and NMT 900 systems are used in 15 countries.

New US West Research Facility Site Selected

US West Advanced Technologies, a subsidiary of US West, Inc. announced that it has selected a site in the University of Colorado Research Park in Boulder for its research and development facility. The company will build the facility to house existing employees, with the capability to expand in the future.

Martin Marietta and ITT Form Joint Venture

Martin Marietta Corp. and ITT Corp. have formed a joint venture to compete for the development and production of gallium arsenide integrated circuits for defense electronic systems. These ICs will be developed for a Department of Defense program called by the acronym MMIC, which stands for Microwave/Millimeter Wave Monolithic Integrated Circuits. The program will develop gallium arsenide integrated circuits that could be mass-produced and used to reduce the size, weight and cost of a variety of defense systems.

The ITT/Martin Marietta team also will include Harris Corporation and Alpha Industries. In early 1988, up to six industry teams are expected to be awarded contracts for development and pilot line production of gallium arsenide integrated circuits.

Electrospace Systems Receives Contract

Electrospace Systems, Inc., a Chrysler Company, has been awarded a $2,024,000 contract from Triad Microsystems, Inc. of Winter Park, Florida. The contract calls for engineering, design, manufacture and installation of flight data systems, automatic pilot, fuel saving systems, INS and other

Band/Low/High Pass · Notch · SSB · Wide/Narrow Band

Crystal Filters

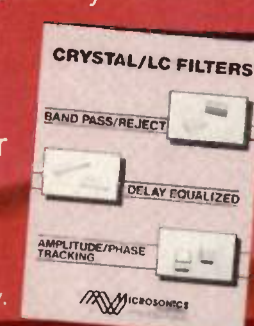
For 25 years, Microsonics has designed, developed, and produced thousands of custom crystal filters, lumped-constant filters, and discriminators to fulfill thousands of space, military, and commercial requirements from dc to 200 MHz. Now we're the largest discrete filter manufacturer in the U.S.

We carefully control each step of the process from the quartz crystal, which we fabricate ourselves, through coil fabrication to the final tested filter. Assembly and inspection employees are each trained and certified to WS6536D. Proprietary computer analysis, modeling, and optimization programs are routinely used. And our engineers work closely with you to ensure you get exactly **what** you want, **when** you want it.

Our new Crystal/LC Filter catalog describes many typical models and their specifications that have been selected for their unique features, and as a class, represent our capabilities.

The next step is yours.

Send for your copy.



MICROSONICS
INCORPORATED
A Subsidiary of Signal Technology Corp.
60 WINTER ST. WEYMOUTH, MA 02188-3336
(617) 337-4200 TWX 710-388-6833

INFO/CARD 17

wiring controls in ten C-141 maintenance trainers to be used by the U.S. Air Force. The engineering, design and manufacturing process will be conducted at Electrospace's Richardson facility and the installation will take place at Triad's facility in Florida. Duration of the contract extends to late 1990.

M/A-Com Receives $23 M

The Electronic Systems division of the Air Force Systems Command has awarded a $23 million contract to M/A-Com Inc. to produce 861 upgrade kits for a satellite communications modem. The kits will provide extended signal processing and enhanced operator control functions and will be capable of transmitting on any one of the four time-division multiplexed channels of the Milstar UHF communications subsystem. The upgrade will allow the existing dual modem to receive downlink signals for the Air Force's AFSATCOM I and II satellites.

rf design

a Cardiff publication Established 1978
Main Office:
6300 S. Syracuse Way, Suite 650
Englewood, CO 80111 • (303) 220-0600

Publisher
Robert A. Searle

Editor
Gary A. Breed

Technical Editor
Mark Gomez

Consulting Editors
Andy Przedpelski
Robert J. Zavrel, Jr.

National Sales Manager
Kate Walsh

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

Midwestern States
Kate Walsh
Main Office

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

Advertising Services
Mary Brussell

Editorial Review Board
Alex Burwasser
Doug DeMaw
Dave Krautheimer
James W. Mize, Jr.
Robert J. Zavrel, Jr.
Ed Oxner
Andy Przedpelski
Jeff Schoenwald
Raymond Sicotte

Circulation Director
Pam Greenberg

Circulation Manager
Patricia Shapiro

Circulation Assistant
Michelle Schwinghammer

Production Manager
Madeline Price

Assistant Production Manager
Mary Barr Felker

Artists
Maurice Lydick
Mary Modeer
Matt Park
Bill Pettit
Bill Schmitt

Composition
Jay Jarrett
Ellen Wilson

Published by

CARDIFF
PUBLISHING COMPANY, INC.

BPA

President
Robert A. Searle

Vice President
Judy L. Rudrud

Controller
Marvin Laut

Operations Manager
Cherryl Greenman

Member of Business Publications Audit of Circulations, Inc.

Please address subscription inquiries to: RF Design, Cardiff Publishing Company, P.O. Box 6317, Duluth, MN 55806
Postmaster: send form 3579 to the above address.

rf calendar

March 3-4, 1988
Bay Area Symposium on Strategic Management of Research and Development
Double Tree Inn, Santa Clara, CA
Information: Carolynn Sherby, Manager, Public Affairs, Acurex; Tel: (415) 964-3200 Ext. 2122

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

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

March 22-23, 1988
IEEE VSLI Test Workshop
Bally's Park Place Casino Hotel, Atlantic City, NJ
Information: Wesley E. Radcliffe, IBM East Fishkill, Dept. 277, Bldg. 321-5E1, Hopewell Junction, NY 12533. Tel: (914) 894-4346

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

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

May 10-12, 1988
Electro '88
Bayside Exposition Center, Boston World Trade Center, Boston, MA
Information: Electronic Conventions Management, 8110 Airport Boulevard, Los Angeles, CA; Tel: (213) 772-2965

May 10-12, 1988
EMC Expo 88
Washington Hilton, Washington, DC
Information: Karen Smith, EMC Expo 88, P.O. Box D, Gainesville, VA 22065; Tel: (703) 347-0030

May 25-27, 1988
1988 IEEE MTT-S International Microwave Symposium
Javits Auditorium, New York City, NY
Information: Charles Buntschuh, Narda Microwave Corp., 435 Moreland Road, Hauppauge, NY 11788; Tel: (516) 231-1700

June 1-3, 1988
42nd Annual Frequency Control Symposium
Stouffer Harborplace Hotel, Baltimore, MD
Information: Raymond L. Filler, Frequency Control and Timing Branch, Department of the Army, Electronics Technology and Devices Laboratory, Fort Monmouth, NJ 07703-5000

rf courses

Besser Associates

Principle of RF and Microwave Circuit Design: Theory and Application
March 21-23, 1988, Los Angeles, CA
March 23-25, 1988, Santa Clara, CA

Microwave Circuit Design I: Linear Circuits
June 20-24, 1988, Los Angeles, CA
August 15-19, 1988, Baltimore, MD

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

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

The George Washington University

Microwave Radio Systems
March 7-8, 1988, Washington, DC

Hazardous RF Electromagnetic Radiation
March 16-18, 1988, Washington, DC

Frequency-Hopping Signals and Systems
March 21-23, 1988, Washington, DC

Elements of Optical Warfare
March 30-April 1, 1988, Washington, DC

Spread-Spectrum Communications Systems
April 4-8, 1988, Washington, DC

Grounding, Bonding, and Shielding
April 7-8, 1988, Washington, DC

Modern Communications and Signal Processing
April 18-22, 1988, Washington, DC

Introduction to Receivers
April 18-19, 1988, Washington, DC

Modern Receiver Design
April 20-22, 1988, Washington, DC

Monopulse Radar Principles and Techniques
May 2-5, 1988, Washington, DC

Modern Spectrum Estimation, Array Processing, and Digital Filtering
May 16-20, 1988, Washington, DC

Spectrum Management
June 20-24, 1988, Washington, DC

Fiber Optics Technology for Communications
June 28-30, 1988, Washington, DC

Antennas and Arrays: Analysis, Synthesis and Applications
July 18-22, 1988, Washington, DC

Electromagnetic Interference and Control
August 1-5, 1988, Washington, DC

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

UCLA Extension

Modern Microwave Techniques
April 25-28, 1988, Los Angeles, CA

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

10 Great Reasons to Choose a Wavecom Coaxial Switch for Your Important System

A BETTER GUARANTEE

1 Every Wavecom switch is guaranteed — in writing — to operate for a minimum of 1,000,000 cycles ***per switch position*** without noticeable performance degradation. What that means to you is (a) no intermittent contacts in either RF or indicator circuits, (b) less than 0.1 dB increase to insertion loss, and (c) less than 50 milliohms increase to indicator circuit resistance.

2 One aerospace customer* hammered an SP6T DC-18.5 GHz Wavecom switch with an 82g environment, but reported that ***"switching speed did not degrade during vibration,"*** and also that ***"chatter was not at all evident during even the most severe of the vibration test levels."*** Another buyer* found resistance of a 6-position Wavecom switch to be only 10 milliohms per position after 1,000,000 cycles of operation.

MORE MODELS/MORE OPTIONS AT OFF-THE-SHELF PRICES

3 Wavecom offers more models and more options than any other switch manufacturer. Choose from multiposition units up to SP12T, transfer switches, matrix switches and switches fully qualified for deep-space application.

4 Standard options include four actuation modes, all popular RF connectors, all common operating voltages, frequencies up to 26.5 GHz, built-in 50-ohm open-circuit terminations (patent pending), self de-energizing circuits, indicator circuits, TTL logic circuits, MOSFET drivers, BCD decoders, manual override and others. If that's not enough, custom designs are just a phone call away.

5 With Wavecom's wider range of high-performance models, you can multiply RF performance and simplify packaging by using a single switch (e.g., SP8T) where you'd need two or more units (e.g., two SP4T's) from other suppliers. Compare the maximum insertion loss of a Wavecom 8-position switch (approx. 0.55 dB at 18 GHz) to two competitive 4-position switches (two times approx. 1.5 dB at 18 GHz).

TYPICAL RF PERFORMANCE (Series 020)

FREQUENCY	VSWR (Max)	ISOLATION (Min. dB)	INSERTION LOSS (dB)
DC-3 GHz	1.2:1	80	0.2
3-8 GHz	1.3:1	70	0.3
8-12.4 GHz	1.4:1	60	0.4
12.4-18 GHz	1.5:1	60	0.5
18-26.5 GHz	1.6:1	50	0.6

A SUPERIOR DESIGN

6 From Wavecom, you'll get more exclusive design features. Included are (a) a self-lubrication provision that never quits, (b) a proprietary termination method good to 5 watts, but with fewer moving parts and no added RF cavity, and (c) a floating solenoid that features high-temp coil wire plus a gold-plated low-friction armature.

7 You'll also get (a) special temperature-compensated bobbins, (b) contacts that offer exceptional indentation hardness, corrosion resistance and high fatigue strength, (c) miniature solenoids that produce nearly double the linear closing force of ordinary switches, and (d) contact springs that hold rated tension from -100°C to +300°C.

HIGHEST MANUFACTURING & STANDARDS

8 Every switch model is designed to meet Mil-S-3928, Mil-E-5400, Mil-Std-810 and Mil-Std-202. Every single unit is manufactured, inspected and tested under conditions and procedures refined for 20 years. Components are periodically tested by independent laboratories.

9 After assembly, every Wavecom switch lot is tested for VSWR (100%), insertion loss (20%), and isolation (20%). Each switch is then cycled at least 50,000 times per position, forging RF contacts, rockers, solenoids and indicators. Solenoid override is then reset to 0.003″-0.004″, yielding a 3:1 safety margin and assuring you that the switch's cumulative dimensions will not vary more than 0.001″ in 1,000,000 cycles.

YOU'LL GET ACTION

10 We move quickly, whether it's a quote for off-the-shelf units, proposal for a customized design, a sample switch for evaluation purposes or a production delivery (just a few weeks from go-ahead, usually). Just call Wavecom Switch Marketing at (818) 882-3010.

WAVECOM
A SUBSIDIARY OF LORAL CORPORATION
9036 Winnetka Ave., Northridge, CA 91324
(818) 882-3010 • TLX-6502408147-MCI
FAX-818-709-8204

FREE SWITCH CATALOG

For Wavecom's new 100-page fully illustrated switch catalog call Wavecom Switch Marketing at (818) 882-3010.

* *Details on request.*

INFO/CARD 22

rf courses *Continued*

Technology Service Corporation
Missile Guidance
March 7-9, 1988, Bethesda, MD

Radar Receiver Design: Principles and Techniques
March 8-10, 1988, Arlington, TX

Radar Signal Processing and Clutter
March 22-25, 1988, Atlanta, GA

Information: Lynda S. Epstein, Technology Service Corp., 962 Wayne Ave. — Suite 600, Silver Spring, MD 20901. Tel: (800) 638-2628 or (301) 565-2970

Design & Evaluation, Inc.
The Worst Case Circuit Analysis Training Seminar
April 4-6, 1988, Orlando, FL
April 18-20, 1988, San Diego, CA
May 9-11, 1988, Washington, DC
July 11-13, 1988, Honolulu, HI
September 12-14, 1988, Boston, MA
October 17-19, 1988, San Francisco, CA

Information: Design & Evaluation, Inc., 1000 White Horse Road — Suite 304, Voorhees, NJ 08043. Tel: (609) 770-0800

R & B Enterprises
Worst Case Circuit Analysis
March 14-16, 1988, Philadelphia, PA
June 20-22, 1988, Philadelphia, PA

Grounding, Bonding & Shielding
March 24-25, 1988, Washington, DC
June 16-17, 1988, Philadelphia, PA

MIL-STD-461C/462 Test Workshop
March 30-April 1, 1988, Philadelphia, PA
April 27-28, 1988, Los Angeles, CA

Understanding & Applying MIL-STD-461C
March 28-29, 1988, Philadelphia, PA
April 25-26, 1988, Los Angeles, CA
June 7-8, 1988, Washington, DC

Electromagnetic Pulse (EMP) Design & Test
April 11-12, 1988, Washington, DC
June 6-7, 1988, Philadelphia, PA

Identification & Control of Microwave/RF Hazards
May 11-13, 1988, Philadelphia, PA

TEMPEST-A Detailed Design Course
May 16-20, 1988, Philadelphia, PA

EMI Suppression Methods
June 28-30, 1988, Philadelphia, PA

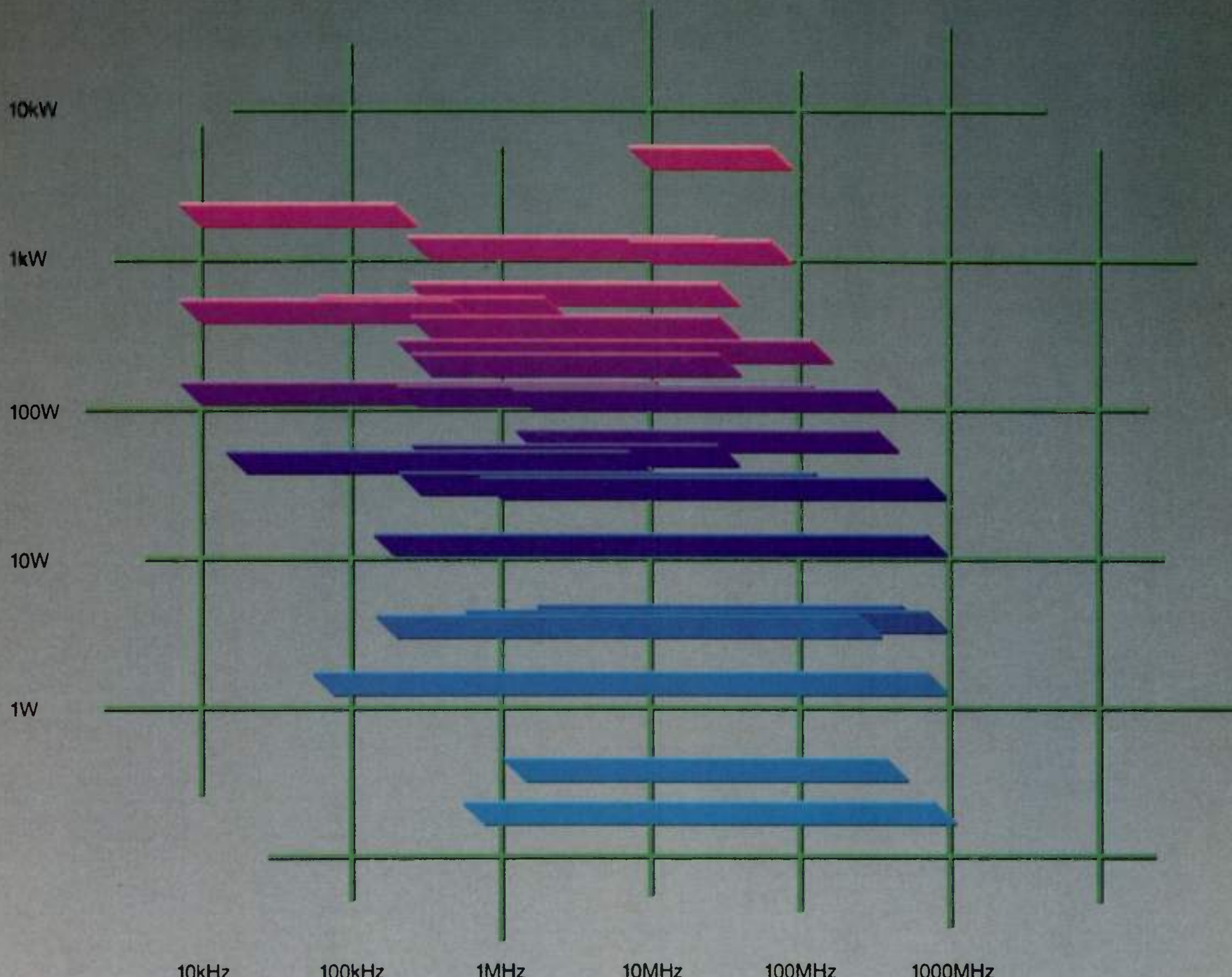
Information: Greg Gore, R & B Enterprises, 20 Clipper Road, West Conshohocken, PA 19428. Tel: (215) 825-1684

Interference Control Technologies, Inc
Intro to EMI/RFI/EMC
May 11-13, 1988, Washington, DC

Grounding and Shielding
March 21-25, 1988, Hilton Head, SC
April 11-15, 1988, San Diego, CA

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

RF POWER
As You Like It.



All solid state. Unconditionally stable. Compact. Tremendously versatile. Whatever your need for RF Power, ENI offers you a choice of Class A power amplifiers unsurpassed in quality. Our wide line spans a frequency spectrum from 10kHz to 1GHz with power outputs that range from 300 milliwatts to over 4000 watts.

These units can be driven by virtually any signal source. They're completely broadband and untuned, amplifying inputs of AM, FM, TV, SSB, and pulse modulations with minimum distortion. Their unconditional stability and fail-safe design make them impervious to severe mismatch conditions, and capable of delivering rated power to any load impedance from an open to a closed circuit.

The design excellence of ENI amplifiers is symbolized by the perfect geometry of the design elements we use with our logo. For our latest catalog, please contact us at any of the offices listed below.

ENI

The advanced design line of RF power amplifiers

UNITED STATES HEADQUARTERS: ENI, INC., 100 Highpower Road, Rochester, NY 14623-3498 USA, Tel: (716) 427-8300, Tlx: 671 1542 ENI UW, Telfax: 716-4277839
WEST COAST: ENI, INC., 2318C Walsh Avenue, Santa Clara, CA 95051, Tel (408) 727-0993, Telfax: 4087271352
EUROPE: ENI EUROPE LTD., Mundells Court, Welwyn Garden City, Hertfordshire AL7 1EN England, Tel: (0707) 371558, Tlx: 24849 ENI UK G, Telfax: 707339286
JAPAN: ENI-JAPAN, 10-20, Shibasaki-cho 3 Chome Tachikawa City, Tokyo, Tel: (81) 0425 229011, Fax: (81) 0425 222636

INFO/CARD 24

See us at the RF Technology Expo, Booth #305.

Touchstone/RF™

gets you out of the lab— to make the most of your talent, boost your productivity

Touchstone/RF is the most advanced program there is for computer-aided RF design. You use it in your own office, on your own PC.

It's much like EEsof's regular Touchstone™ – the microwave industry's standard of CAE. But we have adapted Touchstone/RF specially for your RF design needs.

First, we've eliminated expensive microwave models that are unnecessary for even complex RF circuit designs. So Touchstone/RF is less than half the price of Touchstone.

Just as important, we've added some things specifically for the RF engineer. With Touchstone/RF you have everything you need for circuit design, simulation and analysis:

- **toroidal transformers**
- **lumped elements**
- **transformers**
- **ferrite core inductors**
- **ideal transmission lines**
- **device models**
- **g-, h-, y-, z- and s-parameters**

...and much more.

You build your circuit with Touchstone/RF, predict performance, tune, change elements and retune, optimize. All, with just a few keystrokes. In short, you perfect your circuit – right at your own desk. Quickly, easily, accurately.

Touchstone frees you from the lab, from the breadboard-bashing and component-crunching that can sap so much of your time and talent. With Touchstone/RF, you'll work on elegant, completed, well-running circuits. You won't spend your time tweaking trash. Think what this new freedom will do for your output, for your engineering creativity!

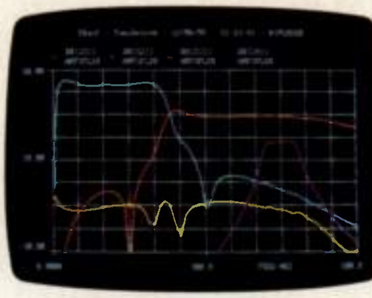
One look at Touchstone/RF will convince you. Call or write EEsof and we'll prove it.

A. Touchstone analysis of an active triplexer circuit with sampled output.

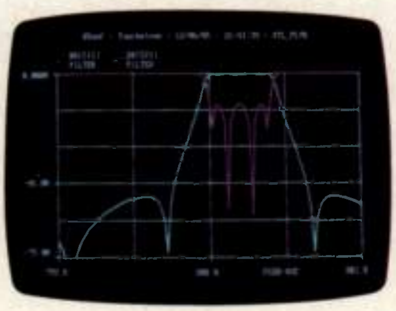
B. Insertion loss and return loss of crystal filter analyzed over its narrow pass band.

C. Schematic diagram of the active triplexer analyzed above.

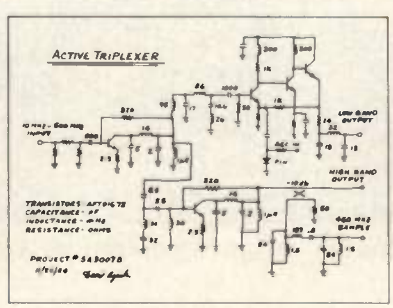
D. A log axis can be used for displaying very broad frequency ranges. This feed back amplifier operates over nearly a decade bandwidth.



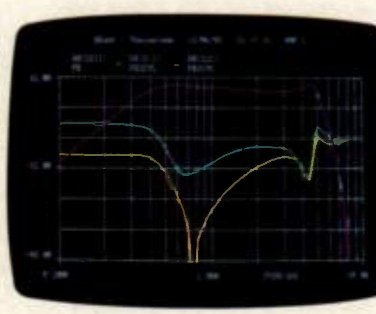
A



B



C



D

EEsof®

INFO/CARD 25

See us at the RF Technology Expo, Booths #434–438 & 533-537.

5795 Lindero Canyon Rd., Westlake Village, CA 91362 (818) 991-7530

The Computer Data Disk

Software-Based Catalog Offers Fast Device Selection.

By Norman E. Dye
Motorola Semiconductor Products Sector,
and Ed Prestwood
Cybersoft, Inc.

Traditionally, RF device selection has involved paging through hard copy selector guides and data books until a suitable device was found. Now the revolution in electronic data processing has resulted in the industry's first high-speed computerized approach to choosing RF parts. The process is not only faster, but also leads to a more optimum selection.

The new approach is called the "Motorola DATA DISK: Discrete Semiconductor Version." It is a high-speed IBM-compatible floppy-resident database containing technical information for more than 624 RF devices, more than 6,600 parameters and over 2,300 cross references for RF devices including RF bipolar transistors, RF MOSFETs and RF amplifiers. It also contains parametric data for power transistors, rectifiers, zeners, optoelectronic devices, sensors, thyristors and small signal devices — Motorola's entire discrete product offering of more than 6,500 devices. All this is available in five languages!

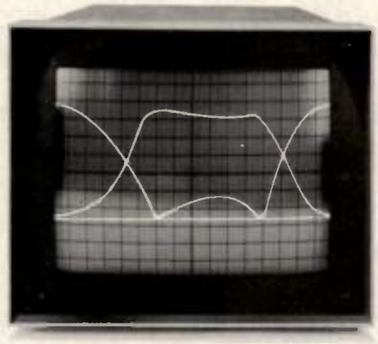
This disk contains information on over 624 RF devices.

Hard copy selector guides list device parameters by frequency, voltage, current, package and other characteristics, but not always in a manner that best reflects the needs of the user. The DATA DISK overcomes this drawback by allowing the user to specify not only what parameters are important, but also the order of priority.

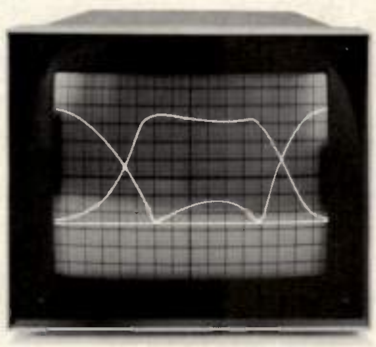
All that's needed to use the DATA DISK is an IBM compatible PC with at least 384K RAM. The only instructions required are printed on the disk sleeve: "Boot your computer, insert this disk, type 'M' then press 'Enter'." After loading, the user can select the language (English, French, German, Italian or Spanish), the screen colors (including monochrome) and the product line of interest (RF Devices, Optoelectronics, Thyristors, Sensors, etc.). The program highlights each selection and remembers the settings for the next use of the DATA DISK.

To select RF Devices, simply press the letter next to the selection labeled: "RF Devices." A menu will appear listing further subsections of RF such as Bipolar Transistors, FETs, Amplifiers, Diodes, etc. When the appropriate topic is chosen, another screen appears which asks for "Part Number Search," "Parametric Search" or "Search Help." Included on each screen are "smart" message lines that use progressive disclosure technique to explain what can be done from the current screen.

Users can obtain device information for any device or cross reference in the database by entering its part number, then pressing "Enter" to start the search. The DATA DISK searches the entire database whenever a part number search is instigated, examining over 30,000 entries in under a second. If a device is chosen that Motorola doesn't manufacture (such as RF2147) the program searches the cross reference to find the Motorola equivalent (MRF475) and then displays the parametric information for the MRF475 along



Their $14,000 sweep.



Wavetek's $7,000 sweep.

If all you need is a sweep generator that tests below 2500 MHz, Wavetek thinks that's all you should have to buy.

But other sweep generators cover frequency ranges many communication bands don't use. And they require plug-in modules and bulky, costly mainframes.

So you end up spending thousands more for frequency range capability you don't need.

Exactly what you want.

At Wavetek, our sweep generators get back to the basics. Simple, honest, reliable, sensible.

Each sweep covers a discrete frequency range in the sub-microwave area. Just what you need for a specific application.

Our 2002B's broad range of 1 to 2500 MHz makes it perfect for testing radar systems, communication equipment and components. In the lab, the field or the plant. Harmonic markers at 1, 10, 50 and 100 MHz are standard.

Our 2001 has become *the* instrument for people working in VHF, UHF and Extended Range UHF bands. Its range is 1 to 1400 MHz, in three bands: 1 to 500, 450 to 950 and 900 to 1400. Harmonic markers are standard.

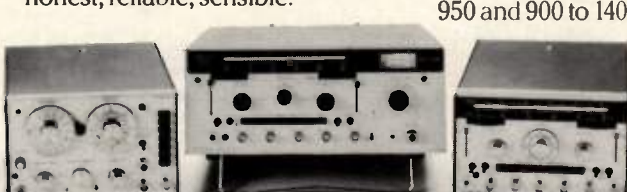
And our 1801C, with its 75 Ω output and 1 to 1000 MHz range, is ideal for CATV and broadband LAN applications. Its one wide band VCO eliminates the transients found in band switching instruments.

You buy only what you need.

By limiting our sweep generators to below 2500 MHz, Wavetek is able to design them to be simple but effective. And to build them for much less.

And do you really have an extra $7,000 to spend on something you don't need?

For more information and the name of your nearest distributor, call Wavetek at 1-800-428-4424. In Indiana call 317-788-9351.

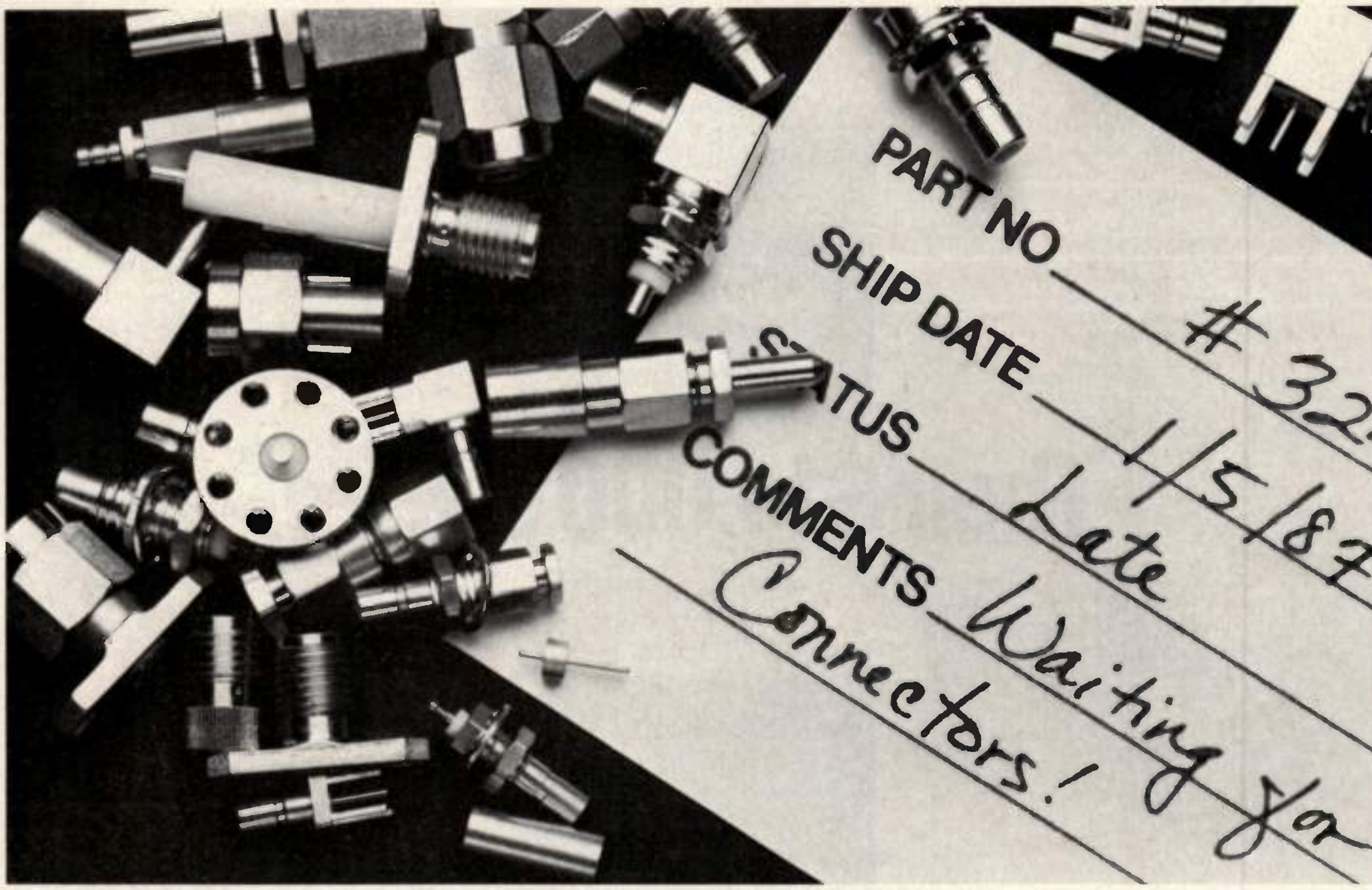


Model 1801C. $4,350. *Model 2002B. $6,900.* *Model 2001. $4,795.*

WAVETEK®

INFO/CARD 26

See us at the RF Technology Expo, Booths #346 & 348.



SMALL CONNECTORS CAN BE A BIG DEAL

AEP Subminiature Coaxial Connectors

Small connectors can kill a big system if they don't work or aren't there when you need them. AEP can help make sure this doesn't happen to you.

Connectors that work.

Our production standards exceed MIL-C-39012 requirements. 11% of our workforce is in quality control to make sure these standards are met. Need proof? We have shipped 144,000 cable assemblies (with AEP SMB connectors) for the ARC-164 military radio--NO REJECTIONS. We've also shipped almost 150,000 SMA and SMB connectors to a major radio manufacturer--NO REJECTIONS.

Connectors when you need them.

It's easy to get our parts quickly, thanks to our network of stocking distributors and four-week factory delivery of 92 standard items. If you need something unusual, we can generally deliver specials within twelve weeks.

The right connector for the job.

We make hundreds of varieties of SMA, SMB, and SMC connectors--many qualified to MIL-C-39012. Our 7000 series has unequalled performance in microminiature size. Do you need 75 ohm connectors? We make them. You can also save time, trouble, and money by letting us build flexible and semi-rigid cable assemblies for you.

If we sound like the kind of connector supplier you'd like to have, call or write for our 120 page catalogue.

We'll probably save you some money, too.

Applied Engineering Products
1475 Whalley Avenue
New Haven, CT 06525
(203)387-5282
Fax: 203/387-7832

INFO/CARD 66

See us at the RF Technology Expo, Booth #460.

with the following heading: "RF Bipolar Transistor: Direct Replacement for RF 2147."

The "Part Number Search" capability is convenient, but the "Parametric Search" capability is far more important, allowing users to select the parameters that are important to a specific application. Minimum or maximum values are entered as required, then "S" starts the search. One second later a listing of every device in the database that meets the specified requirements (and its associated parameters) is displayed in a table to allow comparison of up to 10 devices at a time. In all cases, as few or as many parameters can be selected for the search. The program displays the parameters in the same priority sequence as originally selected. All displayed data is sorted. The sort algorithm performs a multi-level sort across every selected parameter and lists the "best" device first, the "next best" second, etc.

"Parametric Search" also displays the number of devices found in any given selection process. If the number of devices is large, you can tighten the selection criteria or add additional parameters and then repeat the search process. One way to narrow a search is to select "Price" as a parameter to find parts that meet both technical and cost objectives. Note that the price information contained in the DATA DISK is the 100-up price used by distributors and is intended only as a relative indication of price. The DATA DISK provides alphabetical access to locations and phone numbers to over 300 worldwide Motorola sales offices and authorized distributors.

The next version of the DATA DISK, to be introduced in the second quarter of 1988, will include *all* 30,000-plus Motorola Semiconductor products (integrated circuits as well as discretes) on a single floppy disk. The company plans to update the DATA DISK at least once a year.

Copies of the Motorola DATA DISK are available for $2.00 each by requesting DK101/D REV 1 from the Motorola Semiconductor Literature Distribution Center, P.O. Box 20912, Phoenix, Ariz. 85036, or calling (602) 994-6561. The DATA DISK is also available to Motorola customers through their local Motorola Semiconductor Sales Office. For more information circle INFO/CARD #188.

A 60-Watt PEP Linear Amplifier

By Jose I. Cracovski
LANTEL

A 60 W P.E.P. linear amplifier with a gain of 40 dB and frequency range of 2-30 MHz employing RF Power FET's is described. The circuit employs a Class A driver and a Class B push-pull output stage. Power FET HF amplifiers are used over bipolars since they are easier to design, their performance is more predictable and they have better high order IMD. Reliability is favored mainly by the absence of second breakdown and much less susceptibility to thermal runaway. However, care must be taken not to exceed maximum ratings such as overvoltages. This problem may be considerably attenuated by proper design techniques.

The class A amplifier with feedback driver stage employs an MRF136 power FET (4) designated Q1 in Figure 1. Drive power is transferred to the output stage by means of T1, whose primary winding (3-4) receives about 1 W at a load impedance of 25 ohms. The latter value is dictated mainly by desired gain and device dissipation. Feedback voltage is delivered by winding 1-2 of T1 and applied to Q1's gate by means of a 180 ohm resistor. The characteristics of power

Values obtained by	f =2 MHz			f = 30 MHz		
	Av	Zi	G (dB)	Av	Zi	G (dB)
Equations (1), (2), (3)	9.9	60.3Ω	23.8	9.9	60.3	23.8
Computer Program	10.4	58.5Ω//65.5 pF	24.0	9.7	45.3Ω//58.2 pF	22.3
Measurement	9.6	63.5Ω//154 pF	23.7	10.3	42.6Ω//63.4 pF	22.6

Table 1. Comparison between measured and calculated results.

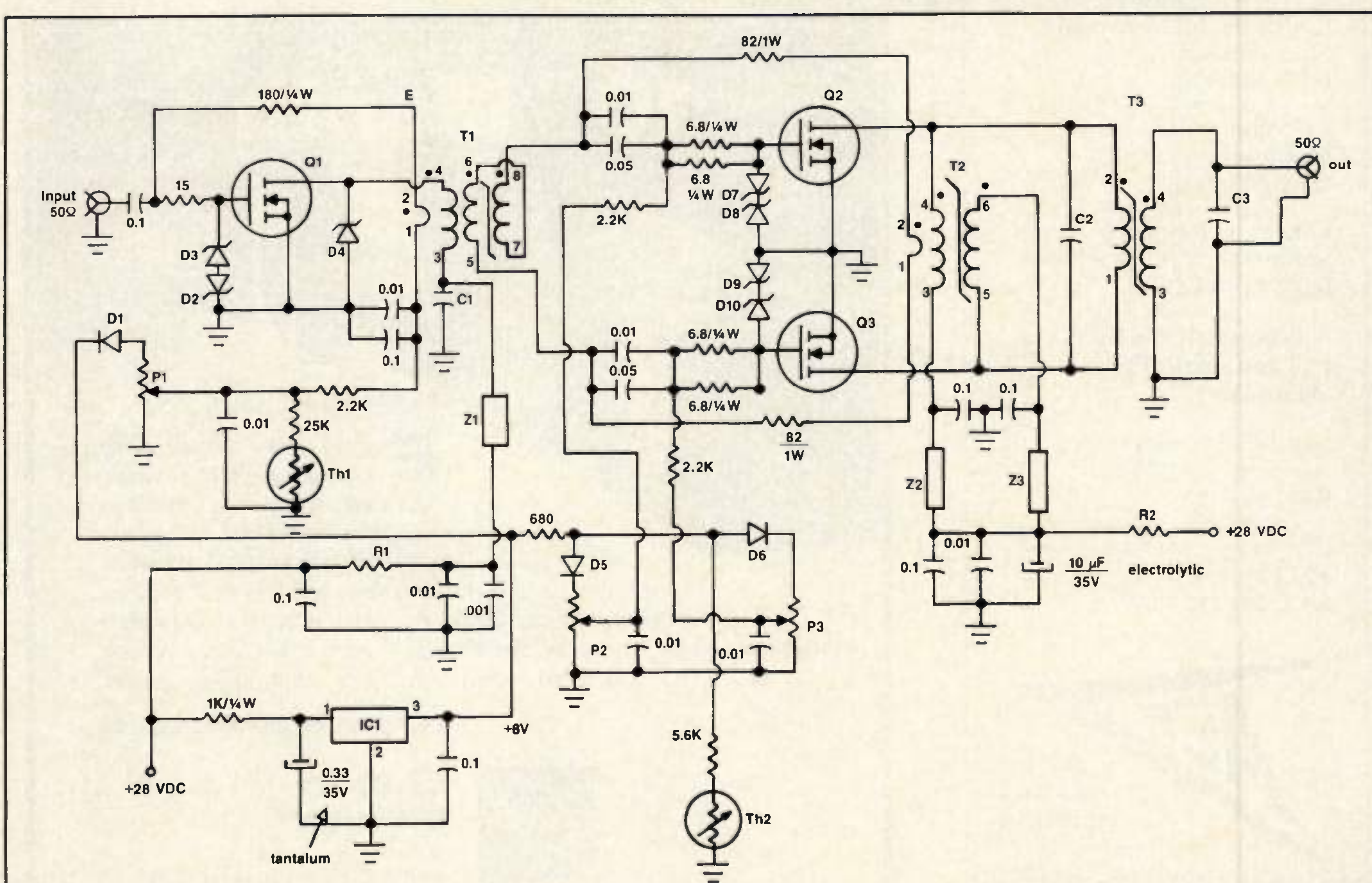


Figure 1. Schematic diagram of the amplifier.

Anzac Quality at Mini-Prices

Packaged Switches from stock . . . your choice $28.95

GaAs MMIC Matched SPST Switch
Model SW-209

Frequency Range	DC to 3 GHz
Insertion Loss	0.8 dB max
Isolation	45 dB min
Switching Speed	3 ns typ
Control Voltages	
V_{IN} Low/High	0/−5V
Input Power for 1 dB Compression	27 dBm typ
Dimensions	0.180″ × 0.180″ × 0.057″

GaAs MMIC SPDT Switch
Model SW-219

Frequency Range	DC to 3 GHz
Insertion Loss	0.7 dB max
Isolation	40 dB min
Switching Speed	2 ns typ
Control Voltages	
V_{IN} Low/High	0/−5V
Input Power for 1 dB Compression	25 dBm typ
Dimensions	0.180″ × 0.180″ × 0.057″

Performance at 500 MHz with 50-ohm impedance at all RF ports.

Both models available screened to MIL-STD 883C, Method 5008.4, Table VII, Class B Hybrids. Specify SW-209B or SW-219B when ordering. Pricing available upon request.

Anzac quality at mini-prices, what more is there to say?

INFO/CARD 29

Come see us at the RF Technology Expo '88, Booths #424, 426, 428, 430.

Adams Russell Electronics
©1987
ANZAC DIVISION

80 CAMBRIDGE ST., BURLINGTON, MA 01803, (617) 273-3333 TWX 710-332-0258 FAX (617) 273-1921 TELEX 200155

FET's allow the approximation of HF performance by assuming it as an ideal amplifier (infinite input impedance, zero output impedance and feedback capacitance). With this assumption, voltage amplification A_v, impedance Z_i and power gain G, can be roughly calculated by:

$$|A_v| = \frac{g_{fs}n^2R_r - n}{1+n^2\left(\frac{R_r}{R_L}\right)} \qquad (1)$$

$$|Z_i| = \frac{R_r}{1 + \frac{|A_v|}{n}} \qquad (2)$$

$$G = 10 \log \left(|A_v|^2 \times \frac{Z_i}{R_L}\right) \qquad (3)$$

Forward transconductance of the device is g_{fs}, n is the turns ratio between drain and feedback windings, R_r is the feedback resistor and R_L is the load resistance. For the driver Q1 in Figure 1, g_{fs} is 0.4 mhos, n is 5, R_r is 180 and R_L is 25. More accurate results were obtained by using S parameters provided by the manufacturer for the MRF136. This was carried out with a computer program in which the ideal values of the components were also entered (eg. T1's windings perfectly coupled, infinite inductance, pure capacitances, etc.) with D2, D3 and D4 excluded. The previously mentioned values are compared in Table 1 with those measured with a vector impedance meter and with windings 5-8 of T1 loaded with a 100 ohm resistor. Table 1 shows that equations (1), (2) and (3) can be a good starting point for the design. As expected, they are more accurate at the low end of the band.

Zeners D2, D3 and D4 prevent voltage spikes from contributing to exceed absolute maximum ratings. However, they don't alter the performance significantly (for example D2 and D3 add no more than 16 pF to the input). Z1, on the other hand, contributes to filter the DC supply. The 15 ohm resistor in series with the gate is for stabilization while drain current can be

f MHz	I_t Amp.	IMD,3rd –dB	IMD,5th –dB	IMD,7th –dB	IMD,9th –dB
1.5	3.6	24	34	41	49
5.0	3.6	30	36	44	52
10.0	3.6	31	38	48	51
20.8	3.5	30	42	49	51
30.0	3.5	24	40	46	56

Table 2. Intermodulation distortion.

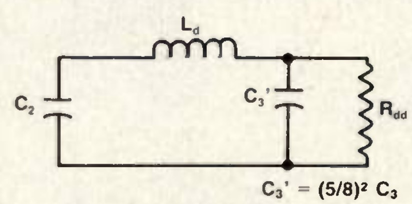
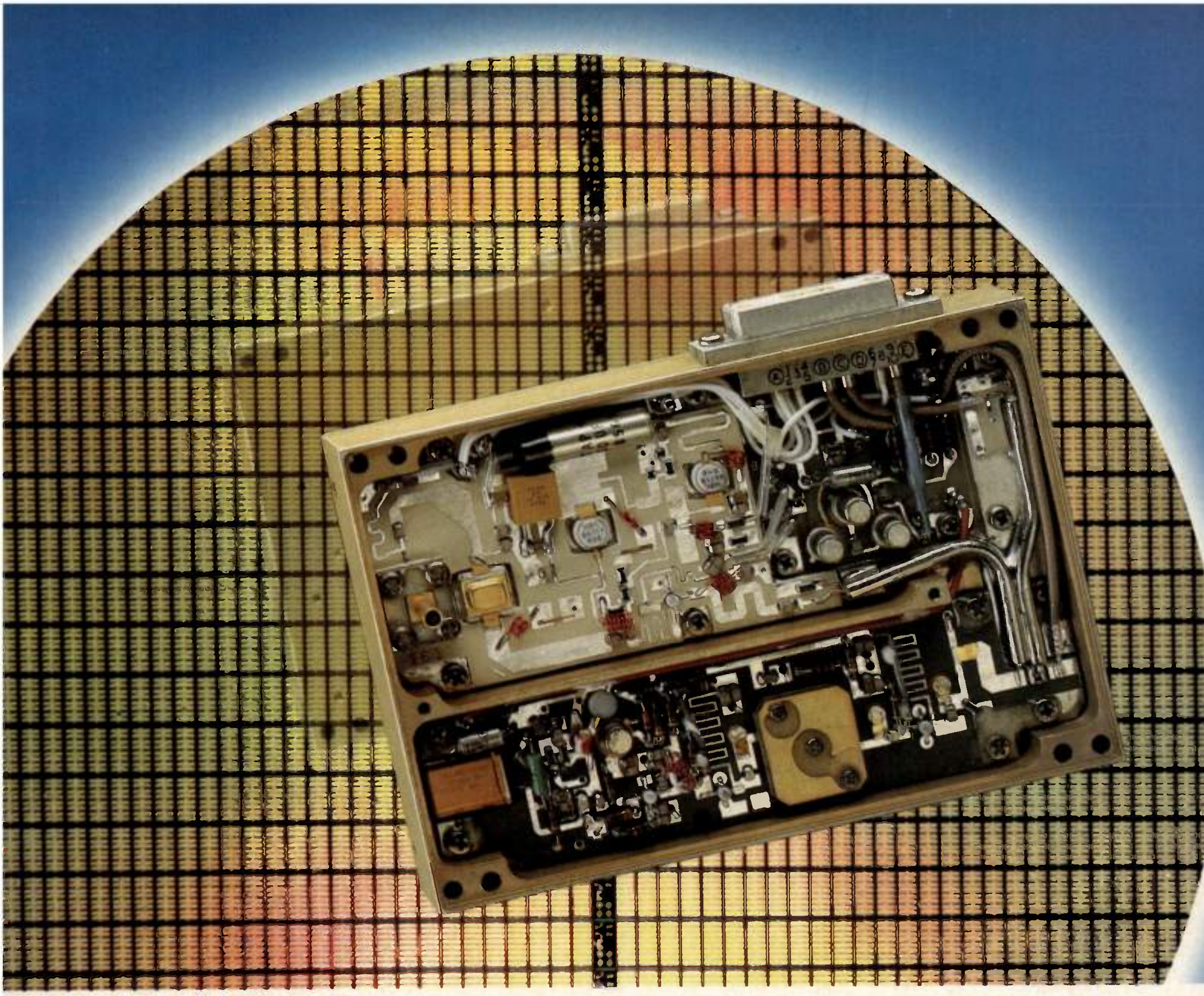


Figure 2. High frequency compensation for the amplifier.



The optimal solution . . .

Custom amplifiers and subsystems from the device experts — MSC

From hi-rel/military to high volume commercial applications, rely on amplifiers and subsystems from MSC to give you a competitive edge. With an in-house device capability, our amplifier and device engineers work together to design or optimize devices for specific performance characteristics . . . the optimal solution to your system design.

MSC has designed and manufactured pulsed/CW amplifiers and subsystems for avionics, radar, telecommunications, telemetry and ECM applications . . . with RF output powers from 1W-10KW and frequencies from UHF to 20 GHz. Consider these examples:

800W	3.1-3.4 GHz	Radar
1KW	1.2-1.4 GHz	Radar
1KW	960-1215 MHz	JTIDS
6KW	UHF	IFF

Building on a leadership position in a wide range of silicon and GaAs power transistors, MSC has been a major amplifier/subsystems manufacturer for more than 15 years. Our updated manufacturing facility is capable of high volume production and is equipped to meet the full range of high-rel device and amplifier/subsystems screening . . . as well as military quality/inspection requirements.

So put "the device experts" to work for your amplifier and subsystem requirements. For more information, circle the bingo number for our new brochure. Or call (201) 563-6300 for immediate assistance.

MICROWAVE SEMICONDUCTOR CORP.
A Siemens Company
100 School House Road, Somerset,
New Jersey 08873.

MSC . . . the experienced leader in advanced microwave technologies.

MSC

INFO/CARD 31

See us at the RF Technology Expo, Booths #544 & 546.

measured employing shunt R1.

Output Amplifier

The output amplifier employs two MRF138 power FET's operating in push-pull, class B, with feedback voltage applied to their gates via two 82 ohm resistors in a fashion similar to the driver stage. The drain current is supplied through T2, from which the feedback voltage is also derived (windings 1-2). T3 only takes care of transferring RF power to the load. Instead of a two transformer output scheme, it is possible to use only T3 with a center tap at it's primary for the DC supply since the resulting two halves would be reasonably coupled for even harmonic cancellation and for minimum DC flux. The scheme employed makes design changes easier and provides some performance improvements.

The required drain to drain load impedance is:

$$R_{dd} = \frac{2(V_{dd} - V_{ds})^2}{P_o} \tag{4}$$

Supply voltage V_{dd} is 28 V, saturation voltage for the MRF138 V_{ds} is 2.5 V, and P_o is 60 W. R_{dd} is then 21.68 ohms and a practical value of 19.5 ohms is selected.

The calculation of the input impedance of a feedback stage like this would be much more difficult than for the class A driver stage. However, in contrast to a bipolar push-pull circuit, where base to base impedance varies with the class of operation, the gate to gate impedance of common source FET circuits is always twice that from gate to ground(7). This makes it possible to estimate the input impedance with equations 1 and 2. The value for $R_1 = R_{dd}/4 = 4.88$ ohms; n=10 (turns ratio of winding 3-4 or 5-6 to 1/2 turn of winding 1-2 in T2); R_f=82 ohms; and g_{fs}=1.2 mhos (MRF138 at 2.5 A). Hence, Z_i=51.7 ohms and the gate to gate impedance is 103.5 ohms. The calculation of the above is only an example of how a design starting point can be obtained.

Using approximate measurement techniques, the MRF136 stage loaded with the MRF138 stage yielded an average input impedance of 55 ohms at 60 W CW for 2 MHz. This compares favorably with the value of 60.3 ohms obtained with equations (1) and (2). Measured voltage gain at 2 MHz CW was 85. This results in a 39 dB power gain at 55 ohms.

For maximum power output and better even harmonic cancellation, Q2 and Q3 should be a matched pair. According to reference 7, a 10 percent matching of g_{fs} is sufficient.

Compensation of the output transformer

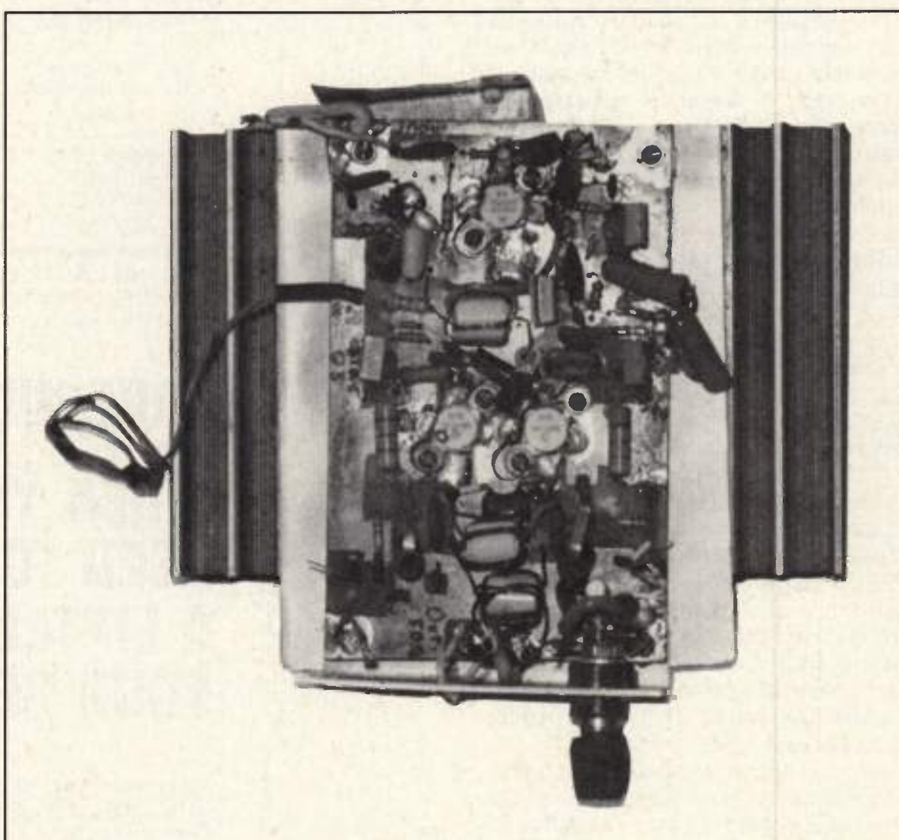
In the above discussion, the effect of the inductance of the windings in parallel with R_{dd} (3-4 + 5-6 of T2 and 1-2 of T3) was neglected. From the author's experience, this can be done if at the lowest frequency the reactance of the windings in parallel with R_{dd} is at least 10 times it's value.

With the cores employed, this reactance is a nominal 643 ohms at 2 MHz. If the resultant primary inductance can't be made bigger than $10R_{dd}$, it must be at least $4R_{dd}$. This allows R_{dd}, L_d, and the series compensation capacitors to form a constant K high-pass filter(8, 9).

It is also assumed that the windings on T3 are perfectly coupled, and that the leakage inductance has a significant value. To eliminate the effect of T3's leakage inductance, as seen from the primary, it is made to form part of a 3-pole low-pass Chebyshev filter along with compensation capacitors C_2 and C_3. This is demonstrated in Figure 2. The values of such capacitors can be calculated according to reference 8, but it should include the effect of the output capacitances of Q_2 and Q_3. Also, the influence of printed circuit tracks inductance should be taken into consideration. C_2 and C_3 are determined by looking at the amplifier's response with a spectrum analyzer and a tracking generator.

Bias Circuits

Bias circuits for FET's are simpler than for bipolars, as only one voltage source is needed. Main voltage is obtained with a 3-terminal 8 V regulator, IC1. Bias for Q1 is adjusted with P1 for a nominal drain current of 5000 mA. Although power FET's are much less susceptible to thermal runaway, it's value can increase with temperature. This is compensated for Q1 by thermistor Th1 placed as close as possible to Q1. Bias for Q2 and Q3 is established by adjusting P2 and P3 which are set for the same drain current for each device and a nominal value of 100 mA (200 mA total). Total drain current can be measured by means of R2. Th2 compensates the slightly positive temperature coefficient of Q2 and Q3 drain currents. D1, D5 and D6 prevent damage to drain supply gates and IC1 in case of drain to gate short in one of the devices. If bias voltage is removed during standby periods, a bias circuit with RC elements providing a time constant of 1 to 2 ms should be incorporated in the design.



View of amplifier board.

Assembly

The amplifier was assembled in a 2 7/8"× 4 21/32" double sided 1.0 oz. copper clad epoxy board (FR-4 material). The FETs were fastened to a 3"× 5" aluminum plate that is 80 mil thick. Care was taken to smoothen the surface beneath the transistors for optimum heat transfer. A heatsink (type MG4-10, R_{th} = 0.8°C/W) was fastened to the plate and Th1 and Th2 were pressed to the aluminum plate near the relevant FET's and then fixed. Silicon grease heat compound was applied where appropriate.

Performance

A two tone test of adequately combined and filtered signals separated by 1 kHz was performed at several frequencies. Intermodulation distortion (IMD) below one tone was measured along with total current consumption I_t and shown on Table 2. IMD from the 7th order on is equal or better than that for bipolars. Only the nominal value of quiescent current I_{DQ} for Q2 and Q3 was used. At all frequencies, the amplifier was stable with no parasitics observed.

Conclusion

This amplifier provides an example of an HF linear medium power amplifier suitable for SSB operation employing power FET's. More constant parameters with drain current and higher input impedance levels makes design of power FET amplifiers easier than using bipolars. rf

References

1. H. Granberg, "Power MOSFETs versus Bipolar Transistors" *RF Design*, Nov/Dec 1981
2. Roy Hejhall, "VHF MDS Power Applications", Motorola Application Note AN-878
3. Cracovski, J.I., "Applicacion de TECMOS de potencia en amplificadores de RF" *Revista Telegrafica Electronica* September 1985
4. Motorola RF Data Manual, 1983 edition.
5. Roy Hejhall, "RF Small Signal Design Using Two-Port Parameters", Motorola Application Note AN-215A
6. H. Granberg, "Linear Amplifiers for Mobile Operation" Motorola Application Note AN-762
7. H. Granberg, "Get 600 Watts from Four Power FETs", Motorola Engineering Bulletin EB-104
8. A. H. Hilbers, "Design of High-Frequency Wideband Power Transformers", Philips Electronics Application Bulletin, Vol. 32 No. 2
9. A. H. Hilbers, "High Frequency Wide-Band Power Transformers", Philips Electronics Applications Bulletin Vol. 30, No. 2
10. Cracovski, J.I., "Amplificador de banda ancha para BLU" *Revista Telegrafica Electronica*, September, 1977

About the Author

Jose I. Cracovski graduated in 1968 as an electronic engineer from the University of Buenos Aires, Argentina. He is currently affiliated with the Laboratorio Nacional de Comunicaciones (LANTEL). He can be reached at Arenales 1174, (1061) Buenos Aires, Argentina.

Parts List

Resistors are deposited carbon and unless otherwise noted their dissipation is 1/8 W and their values are in ohms, K=1,000. Unless otherwise noted, capacitors are disc ceramic rated at 50 V and their values are in uF.

C1 — 0.1 uF, 50 V mylar capacitor

C2 — 220 pF, 500 V, dipped mica capacitor. See text.

C3 — 100 pF, 500 V, dipped mica capacitor. See text.

D1, D5, D6 — 1N914, small signal silicon diode.

D2,D3,D7,D8,D9,D10 — Zener diode, 12 V, 1/2 W.

D4 — Zener diode, 60 V, 1 W.

IC1 — 8 V, regulator, MC78L08 or similar.

P1,2 — Trimpot, cermet, 10k

Q1 — MRF136, TMOS RF power transistor.

Q2,Q3 — MRF138, TMOS RF power transistor.

R1 — Shunt, three 1 ohm, 1/8W in parallel.

R2 — Shunt, constantan ribbon for a nominal 0.05 ohm

T1 — Windings 3-4; 5-6; and 7-8: 5 trifilar turns, 2.5 twists/inch of No. 26 enameled wire on FB-77-6301 Amidon Ferrite Bead (uo = 2,000; OD=0.375"; ID=0.194"; HT=0.41"). Winding 1-2: one loop of hook-up wire.

T2-Windings 3-4; 5-6: 5 bifilar turns 2.5 twists/inch of No 21 double insulated enameled wire bifilarly wound on FB-77-6301 Ferrite Bead. Winding 1-2: one loop of hook-up wire.

T3 — Winding 1-2: 5 turns of No 21 double insulated enameled wire, bifilarly wound with winding 3-4 which has 8 turns of the same wire. Both windings on FB-77-6301 Ferrite Bead.

Th1, Th2, NTC miniature resistor. 100k ohms at 25°C, 30k ohms at 50°C.

Predicting RF Output Power From Combined Power Amplifier Modules

By Roderick K. Blocksome
Rockwell International Corporation
Collins Defense Communications

A power level of a few hundred watts is presently the practical limit for a push-pull pair of RF transistors in a broadband linear power amplifier application. This type of amplifier is referred to as a module. When greater power levels are required, the outputs from two identical modules may be combined into a single output. For even greater power levels, many modules and multiple stages of power combining are required. For example, two groups of two modules each may be combined and the two combiner outputs combined in a third combiner for a single output. In similar manner, eight modules may be combined into a single output by using four combiners feeding two combiners feeding one combiner. This is referred to as three stages of combining.

Losses in wideband combiners are due to normal insertion loss and excess insertion loss. Normal insertion loss of combiners is characterized as mismatch loss and dissipation loss (heat loss in the magnetic core, winding dielectric, and winding resistance). These are not treated in this paper. Excess insertion loss is an additional loss to the output due to amplitude and or phase imbalance of the two input signals. Imbalance in amplitude and phase may result from two causes: (1) variations in the applied input signals and (2) less than perfect combiner construction.

A two input port combiner actually has two output ports. The output we are interested in is the *sum* port. The other port is the *difference* port and is terminated in the bridging resistor. Power lost to the output (sum port) because of excess insertion loss is delivered to the difference port and dissipated in the bridging resistor.

If two input sine wave signals were precisely in phase and of exactly the same amplitude, the combiner output (assuming an in-phase perfect combiner) would equal the sum of the two inputs less the combiner normal insertion loss. The bridging resistor would dissipate zero power and could be removed without any effect on the operation of the combiner in this example.

Combining of perfectly matched input signals is never achieved. Any difference in amplitude or phase or combination of both results in less than perfect combining. The question naturally becomes "How much difference in phase and amplitude can be tolerated for acceptable combining in a particular application?"

Reference 1 addresses this subject for narrow band applications. The expression for calculating the excess insertion loss and combiner output phase is applicable to wideband (multi- octave) hybrid combiners. First derive the expressions to find the excess insertion loss and the phase shift of the output relative to a reference input. The derivation of these expressions uses the same symbols as the referenced article but fills in missing details and adds clarifications so that the reader may readily understand the expressions and apply the technique to combiners with any number of inputs. The phase shift is necessary for calculating excess insertion loss in successive stages of combining.

Derivation of the expressions

A detailed derivation of the expressions for excess insertion loss and phase shift for a two-port combiner is given. Figure 1 is a schematic diagram of a two-port in-phase combiner. A and B designate the two input ports. The output port of summing port is designated by Σ and is connected to the load R_L. The difference port is designated by Δ and is terminated by R_B, the bridging resistor.

With only one input to the combiner, the input power divided equally between the R_B and R_L, thus:

$$P_{out} = \frac{P_{in}}{2}$$

$$\frac{\left(\frac{V_{out}}{\sqrt{2}}\right)^2}{R_L} = \frac{\left(\frac{V_{in}}{\sqrt{2}}\right)^2}{2R_L}$$

$$V_{out}^2 = \frac{V_{in}^2}{2}$$

$$V_{out} = \frac{V_{in}}{\sqrt{2}}$$

Note that V_{out} and V_{in} are peak voltages.

For an in-phase two-port combiner, the relationship can be

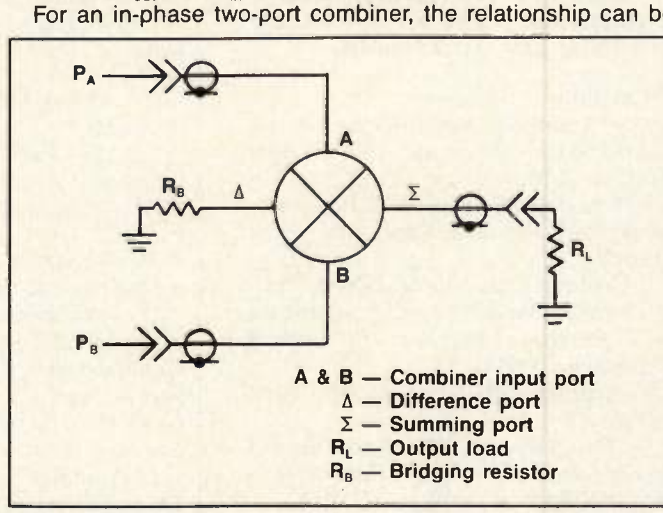


Figure 1. Two-port, in-phase combiner schematic.

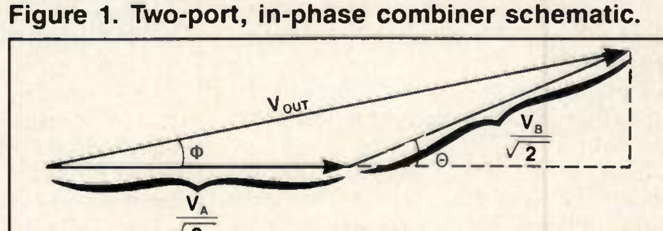


Figure 1A. Phasor diagram.

Paramixer.™

A Decisive Advantage In Winning The Wide-Band Dynamic Range Game. 135 dB Spurious-Free Dynamic Range.

At frequencies from HF to microwave, Paramixer™ Technology is a design architecture which realizes the highest dynamic range frequency converters available today.

Jamming Immunity (out-of-band dynamic range) of radar and communication receivers can be significantly enhanced even in the harshest environments with a Paramixer front end. The Paramixer frequency converter is capable of withstanding out-of-band interfering signals of up to one watt without suffering in-band desensitization. The unequalled second-order intercept performance of the Paramixer frequency converter can permit frequency hopping tuning speed to be maximized by eliminating the need for preselection filtering. Spur levels due to out-of-band jammers are reduced to levels presently attained by preselector designs.

Optimal in-band dynamic range can be attained by incorporating Paramixer technology throughout the RF chain. Triple-conversion architectures can be realized with more than 90-db in-band spurious-free dynamic range in a 1 MHz bandwidth.

Wide Frequency Coverage Applications—HF To Microwave. Paramixer technology can be used to realize low spurs and high dynamic range in designs for wide-band—

- Frequency Converters
- Translators
- RF-to-Digital Converters
- Exciters
- Synthesizers

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

Specifications For A Typical Paramixer Frequency Converter.

Input intercepts:	
Third-order	>+ 45 dBm
Second-order	>+ 82 dBm
Noise figure	<6.5 dB
LO power required	+ 17 to + 20 dBm
DC power required	<7 Watts

High-level Paramixer frequency converters have been designed to handle continuous signals at power levels *exceeding ten watts.* Gain a winning advantage in the wide-band dynamic range game—call us today for details.

Steinbrecher Corporation, 185 New Boston Street, Woburn, Massachusetts 01801, Telephone (617) 935-8460, Telex 948600.

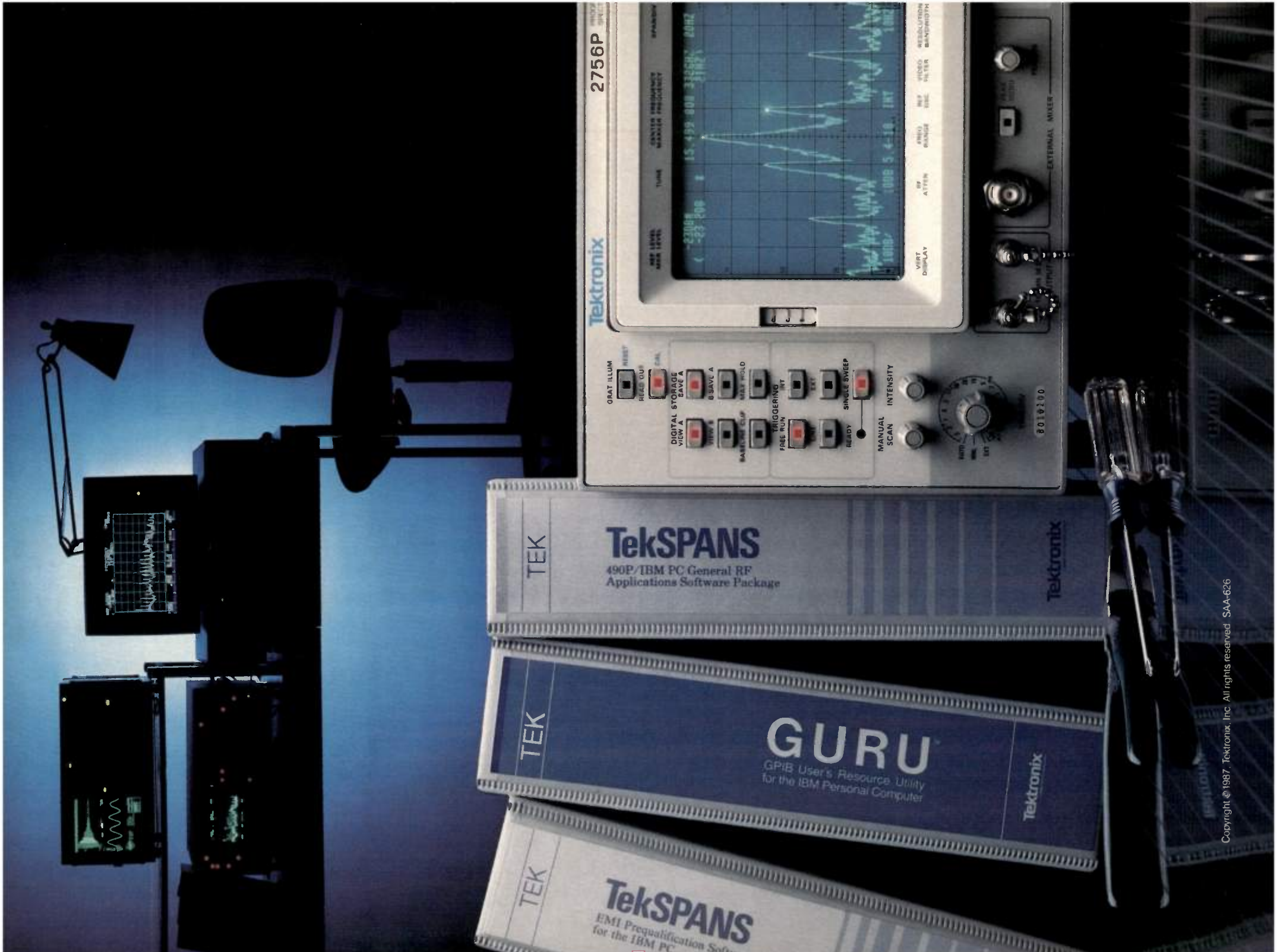
Steinbrecher

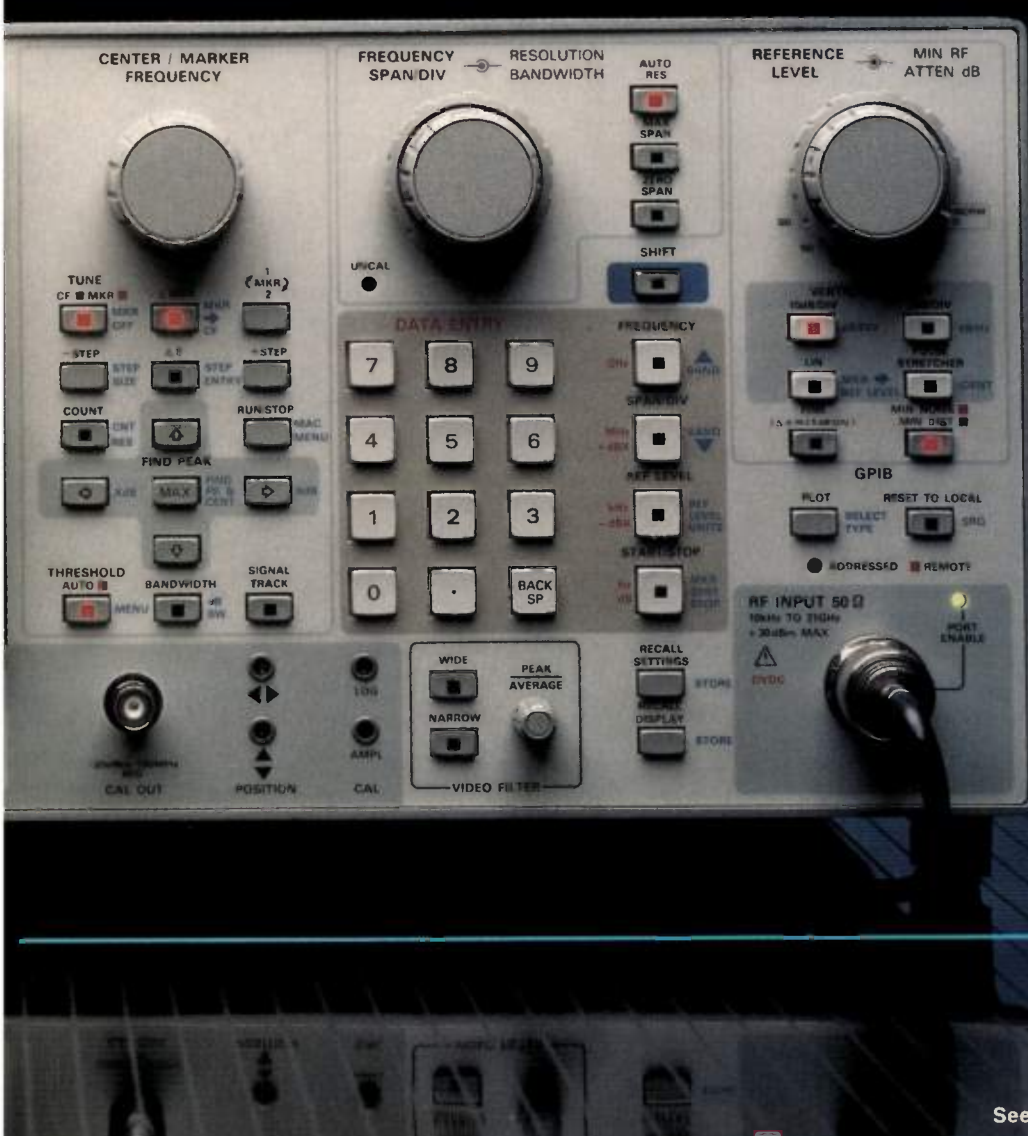
Providing a decisive advantage.

It is a Steinbrecher goal to provide our customers with a decisive advantage, gained through applied technology, superior engineering and high quality manufacturing.

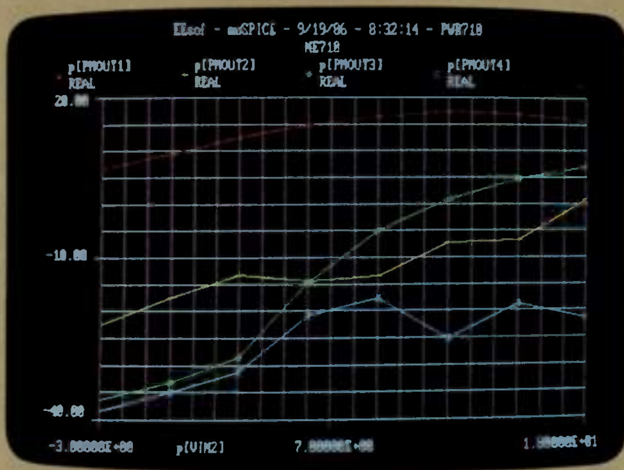
INFO/CARD 44

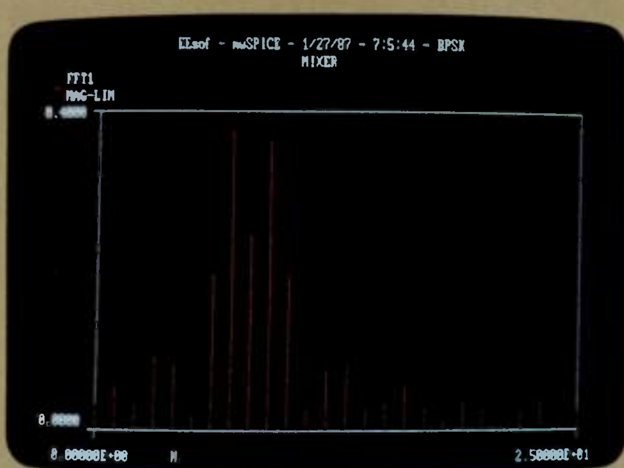
See us at the RF Technology Expo, Booth #656.

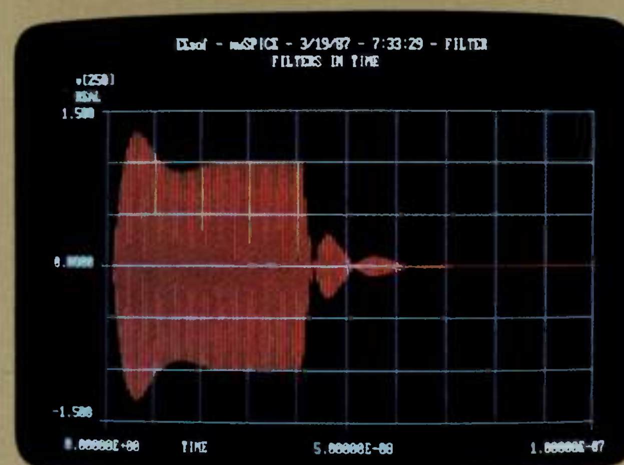

2756P
Tektronix
TEK
TekSPANS
490P/IBM PC General RF
Applications Software Package
Tektronix
TEK
GURU
GPIB User's Resource Utility
for the IBM Personal Computer
Tektronix
TEK
TekSPANS
EMI Prequalification
for the IBM PC


CENTER / MARKER FREQUENCY
FREQUENCY SPAN/DIV
RESOLUTION BANDWIDTH
AUTO RES
SPAN
SHIFT
REFERENCE LEVEL
MIN RF ATTEN dB
TUNE
STEP
COUNT
RUN/STOP
FIND PEAK
MAX
THRESHOLD AUTO
BANDWIDTH
SIGNAL TRACK
UNCAL
DATA ENTRY
FREQUENCY
SPAN/DIV
REF LEVEL
START/STOP
7
8
9
4
5
6
1
2
3
0
.
BACK SP
GPIB
PLOT
RESET TO LOCAL
ADDRESSED
REMOTE
RF INPUT 50 Ω
CAL OUT
POSITION
CAL
WIDE
NARROW
PEAK AVERAGE
VIDEO FILTER
RECALL SETTINGS

The evolution of microwave/RF nonlinear analysis— just became a revolution!







EEsof adds uniquely important features to its pioneering microwave SPICE™

EEsof sparked the evolution of SPICE as a nonlinear time-domain microwave design tool. Our latest version of mwSPICE provides revolutionary new capabilities.

Consider just the few examples reflected in the screens above. They derive from these new mwSPICE features.

1) Our new signal-power analysis capability: You can now do things like **(upper left screen)** look at the harmonics of a GaAs FET amplifier driven into compression, and **(upper right)** measure the signal power of a mixer at different frequencies— so you can compute conversion loss as a function of drive level.

2) A Fast Fourier Transform— *in the post processor!* Lets you **(lower left)** examine many varieties of transient analysis data interactively in a spectral display. No need for re-anaylsis because all the data you need is automatically stored.

3) New ability to synthesize driving functions lets you create unlimited modulated waveforms. For example, **(lower right)** a filter's response to pulse-modulated RF signal shows envelope distortion in time.

There's much more. We've enhanced analytic efficiency and improved convergence. You can now have virtually unlimited harmonic number in signal-power calculations. And you get many other important new features, too.

Find out about all of them. Call or write today: EEsof, Inc.,
5795 Lindero Canyon Rd., Westlake Village, CA 91362 (818) 991-7530
(TELEX: 384809 FAX: (818) 991-7109)

INFO/CARD 46

See us at the RF Technology Expo, Booths #434-438 & 533-537.

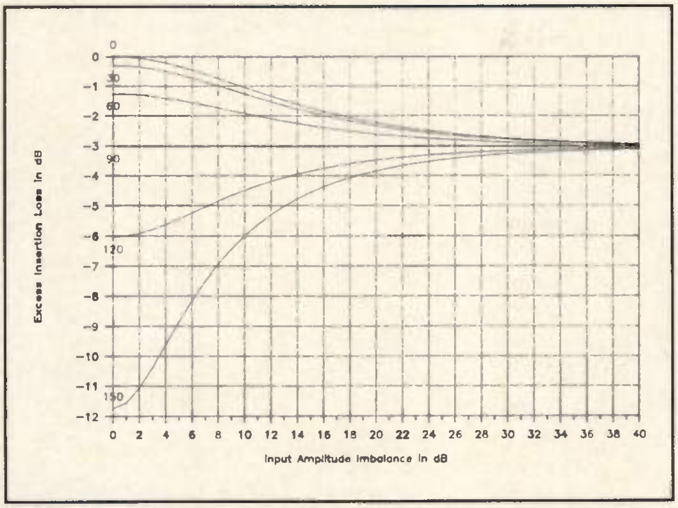
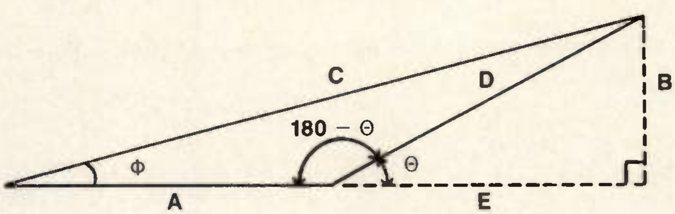


Figure 2. Excess insertion loss vs. amplitude imbalance for various phase differences.

represented between the input voltages and the output voltage (across the load R_L) by the phasor diagram in Figure 1A.

A general expression can now be derived for V_{out} in terms of V_A, V_B, and Θ, the phase difference between the two input signals. For multi-stage combining Φ, the difference between the combiner output signal and one of the input signals chosen as a reference (in this case V_A) is of interest. This expression requires trigonometric manipulation as follows:



$$C^2 = (A + E)^2 + B^2$$

$$C^2 = A^2 + 2AE + E^2 + B^2$$

Substituting: $B = D \sin \Theta$ and $E = D \cos \Theta$

$$C^2 = A^2 + 2AD \cos \Theta + D^2 \cos^2 \Theta + D^2 \sin^2 \Theta$$

$$C^2 = A^2 + 2AD \cos \Theta + D^2 (\cos^2 \Theta + \sin^2 \Theta)$$

Since $\cos^2 \Theta + \sin^2 \Theta = 1$

$$C^2 = A^2 + D^2 + 2AD \cos \Theta$$

Substituting the combiner voltages:

$$V_{out}^2 = \left(\frac{V_A}{\sqrt{2}}\right)^2 + \left(\frac{V_B}{\sqrt{2}}\right)^2 + 2\left(\frac{V_A}{\sqrt{2}}\right)\left(\frac{V_B}{\sqrt{2}}\right) \cos \Theta$$

$$V_{out}^2 = \frac{V_A^2}{2} + \frac{V_B^2}{2} + 2\frac{V_A V_B}{2} \cos\Theta$$

$$V_{out}^2 = \frac{1}{2}\left(V_A^2 + V_B^2 + 2 V_A V_B \cos \Theta\right)$$

The combiner output power is:

$$P_{out} = \frac{\left(\frac{V_{out}}{\sqrt{2}}\right)^2}{R_L} = \frac{V_{out}^2}{2 R_L}$$

$$P_{out} = \frac{\frac{1}{2}(V_A^2 + V_B^2 + 2V_A V_B \cos \Theta)}{2 R_L} \quad (1)$$

The total combiner input power is:

$$P_{in} = P_A + P_B = \frac{\left(\frac{V_A}{\sqrt{2}}\right)^2}{R_L} + \frac{\left(\frac{V_B}{\sqrt{2}}\right)^2}{R_L}$$

$$P_{in} = \frac{V_A^2 + V_B^2}{2 R_L} \quad (2)$$

The excess insertion loss is defined as:

$$\text{I.L.} = 10 \text{ Log}\left(\frac{P_{out}}{P_{in}}\right)$$

Substituting equation 1 and 2, we obtain:

$$\text{I.L.} = 10 \text{ Log}\left(\frac{\frac{V_A^2 + V_B^2 + 2 V_A V_B \cos \Theta}{4 R_L}}{\frac{V_A^2 + V_B^2}{2 R_L}}\right)$$

$$\text{I.L.} = 10 \text{ Log}\left(\frac{V_A^2 + V_B^2 + 2 V_A V_B \cos \Theta}{2 (V_A^2 + V_B^2)}\right)$$

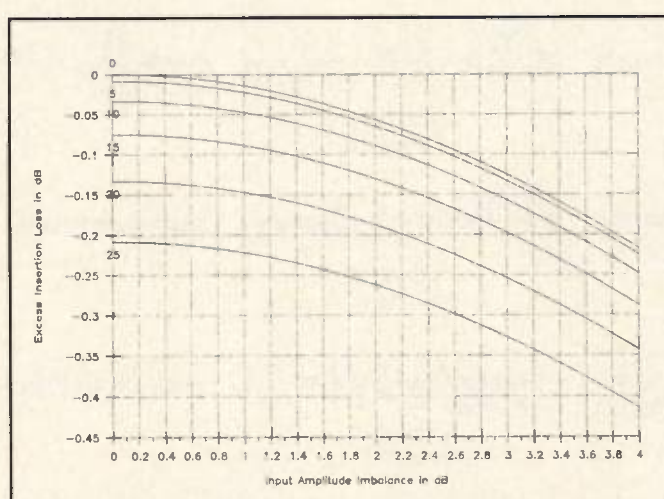


Figure 3. Excess insertion loss vs. amplitude imbalance for various input phase differences.

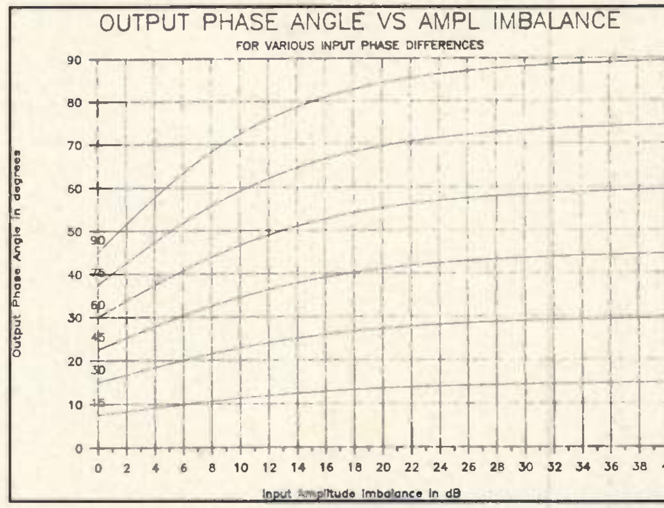


Figure 4. Output phase angle vs. amplitude imbalance for various input phase differences.

$$I.L. = 10 \text{ Log}\left[\tfrac{1}{2}\left(\frac{V_A^2 + V_B^2}{V_A^2 + V_B^2} + \frac{2\,V_A V_B \text{ Cos }\Theta}{V_A^2 + V_B^2}\right)\right]$$

$$I.L. = 10 \text{ Log}\left[\tfrac{1}{2}\left(1 + \frac{2\,V_A V_B \text{ Cos }\Theta}{V_A^2 + V_B^2}\right)\right] \qquad (3)$$

We now define the ratio of the individual input powers P_A and P_B as:

$$P_r = \frac{P_B}{P_A} = \frac{\left(\frac{V_B}{\sqrt{2}}\right)^2 / R_L}{\left(\frac{V_A}{\sqrt{2}}\right)^2 / R_L} = \frac{V_B^2}{V_A^2} \qquad (4)$$

We arbitrarily chose P_A as the largest amplitude input and designate it as the reference input. We now find V_B in terms of V_A and P_r from equation 4:

$$V_B = V_A \sqrt{P_r}$$

Substituting into equation 3, we obtain:

$$I.L. = 10 \text{ Log}\left[\tfrac{1}{2}\left(1 + \frac{2\,V_A \cdot V_A \cdot \sqrt{P_r} \text{ Cos }\Theta}{V_A^2 + V_A^2\,P_r}\right)\right]$$

$$I.L. = 10 \text{ Log}\left[\tfrac{1}{2} + \tfrac{1}{2}\left(\frac{2\,V_A^2 \sqrt{P_r} \text{ Cos }\Theta}{V_A^2\,(1 + P_r)}\right)\right]$$

$$I.L. = 10 \text{ Log}\left[0.5 + \frac{\sqrt{P_r} \text{ Cos }\Theta}{1 + P_r}\right] \qquad (5)$$

The phase Φ of the combiner output voltage with respect to V_A is found from the phasor diagram, but first the necessary trigonometry:

$$B = D \sin \Theta$$
$$E = D \cos \Theta$$

$$\tan \Phi = \frac{B}{A + E}$$

$$\tan \Phi = \frac{D \sin \Theta}{A + D \cos \Theta}$$

Substituting the combiner voltages:

$$\tan \Phi = \frac{\frac{V_B}{\sqrt{2}} \sin \Theta}{\frac{V_A}{\sqrt{2}} + \frac{V_B}{\sqrt{2}} \cos \Theta} = \frac{V_B \sin \Theta}{V_A + V_B \cos \Theta}$$

Next divide both numerator and denominator by V_A and substituting the ratio of the individual input powers:

$$\tan \Phi = \frac{\frac{V_B}{V_A} \sin \Theta}{\frac{V_A}{V_A} + \frac{V_B}{V_A} \cos \Theta} = \frac{\sqrt{P_r} \sin \Theta}{1 + \sqrt{P_r} \cos \Theta}$$

$$\tan \Phi = \left(\frac{\sin \Theta}{\frac{1}{\sqrt{P_r}} + \cos \Theta} \right)$$

$$\Phi = \tan^{-1} \frac{\sin \Theta}{\frac{1}{\sqrt{p_r}} + \cos \Theta} \qquad (6)$$

Sometimes it is convenient to work with the ratio of the input powers expressed in dB:

$$P_r\,(\mathrm{dB}) = 10 \log P_r$$

$$P_r = \log^{-1} \left(\frac{P_r(\mathrm{dB})}{10} \right) = 10^{\frac{P_r(\mathrm{dB})}{10}}$$

$$\sqrt{P_r} = 10^{\frac{P_r(\mathrm{dB})}{20}}$$

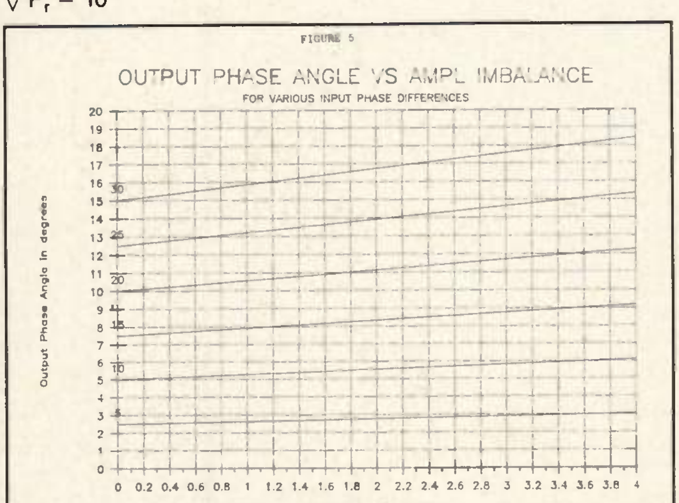


Figure 5. Output phase angle vs. amplitude imbalance for various input phase differences.

$$\frac{1}{\sqrt{P_r}} = 10^{\frac{-P_r(dB)}{20}}$$

Substituting into the expressions for excess insertion loss (equation 5) and the output phase angle (equation 6):

$$\text{I.L.} = 10 \text{ Log}\left[0.5 + \frac{10^{\frac{P_r(dB)}{20}} \text{ Cos } \Theta}{1 + 10^{\frac{P_r(dB)}{10}}}\right] \tag{7}$$

$$\Phi = \text{Tan}^{-1}\left[\frac{\text{Sin } \Theta}{10^{\frac{-P_r(dB)}{20}} + \text{Cos } \Theta}\right] \tag{8}$$

The total loss in a hybrid combiner is the sum of the excess insertion loss and the normal insertion loss which is composed of mismatch loss at the inputs and heat loss in the combiner.

A candidate combiner's insertion loss can be readily measured in the laboratory. The excess insertion loss can be calculated with a knowledge of the amplitude and phase imbalances to obtain the actual combined output power. If more than one stage of combining is used, the relative phase of the previous combiners output voltage is required to calculate the phase imbalance of the succeeding combiners.

Results

Figures 2 and 3 are plots of the excess insertion loss (equation 7) on two different scales. Figures 4 and 5 are plots of the combiner phase shift (equation 8) on two different scales. Figures 2 and 4 provide an overall understanding of the combiner behavior while Figures 3 and 5 are useful for designing combiner systems of power amplifier modules. These plots are valuable aids for determining acceptable amounts of phase and amplitude imbalance among multiple combined amplifier modules.

CAD of Multiple Combined Amplifiers

As the number of combined modules gets larger than four, the amount of calculation work becomes quite tedious. A computer spreadsheet program can be used to rapidly analyze large trees of combiners.

Such a program using Lotus 1-2-3-® and the equations derived earlier has been derived. The spreadsheet is most valuable when evaluating different amounts of phase and amplitude imbalance and their affect upon combiner output power and bridging resistor power. The amplitude imbalance can be taken to the extreme such as a module failure with the combiner results immediately available from the spreadsheet model.

An example of spreadsheet analysis is shown in Figure 6. It is set up for combining up to 16 modules using four stages of 2- port combiners. The matched loss in dB of each combiner is input as well as the individual module power output in watts and its phase relative to a chosen reference (module #1). The Lotus 1-2-3® spreadsheet then calculates four parameters at each two-port combiner which are:

1. Phase in degrees relative to a reference (module #1 in this case) of the combiner output signal.
2. The excess insertion loss in dB of the combiner due to phase and amplitude imbalance between the input signals.
3. The combiner output power in watts.
4. The power dissipated in the combiner bridging resistor.

The equations used in the spreadsheet are derived as follows (referring back to figure 1):

$$P_A + P_B = P_O + P_{BR} + P_L$$

Where: P_A & P_B = input power to the combiner ports A & B P_{BR} = power dissipated in the bridging resistor due to the excess insertion loss of the combiner.

P_O = combiner output power delivered to a matched load.

ANALYSIS OF MULTI-STAGE COMBINING OF AMPLIFIER MODULES	Input Variable Column	FIRST STAGE				SECOND STAGE				THIRD STAGE				FOURTH STAGE			
		PHASE DEGREES	EXCESS I.L.(DB)	OUTPUT POWER	BRIDGING POWER	PHASE DEGREES	EXCESS I.L.(DB)	OUTPUT POWER	BRIDGING POWER	PHASE DEGREES	EXCESS I.L.(DB)	OUTPUT POWER	BRIDGING POWER	PHASE DEGREES	EXCESS I.L.(DB)	OUTPUT POWER	BRIDGING POWER
#1 Power, Watts	280.00																
#1 Phase, Degrees REF	0.00																
1ST STAGE COMB. I.L., DB	-0.20	-1.52	-0.00	522.91	0.42												
#2 Power, Watts	268.00																
#2 Phase, Degrees	-3.00																
2ND STAGE COMB. I.L., DB	-0.20					-3.15	-0.43	572.82	58.99								
#3 Power, Watts	0.01																
#3 Phase, Degrees	-4.00																
1ST STAGE COMB. I.L., DB	-0.20	-3.99	-2.96	138.66	135.43												
#4 Power, Watts	287.00																
#4 Phase, Degrees	-3.00																
3RD STAGE COMB. I.L., DB	-0.20									-0.94	-0.10	1487.19	33.49				
#5 Power, Watts	287.00																
#5 Phase, Degrees	2.00																
1ST STAGE COMB. I.L., DB	-0.20	0.99	-0.00	534.55	0.25												
#6 Power, Watts	273.00																
#6 Phase, Degrees	0.00																
2ND STAGE COMB. I.L., DB	-0.20					2.01	-0.00	1019.53	0.32								
#7 Power, Watts	266.00																
#7 Phase, Degrees	4.00																
1ST STAGE COMB. I.L., DB	-0.20	3.02	-0.00	533.37	0.47												
#8 Power, Watts	293.00																
#8 Phase, Degrees	2.00																
4TH STAGE COMB. I.L., DB	-0.25													-0.67	-0.02	3218.28	14.07
#9 Power, Watts	272.00																
#9 Phase, Degrees	-5.00																
1ST STAGE COMB. I.L., DB	-0.20	-1.53	-0.02	525.16	1.99												
#10 Power, Watts	280.00																
#10 Phase, Degrees	2.00																
2ND STAGE COMB. I.L., DB	-0.20					-1.01	-0.00	1010.16	0.10								
#11 Power, Watts	270.00																
#11 Phase, Degrees	0.00																
1ST STAGE COMB. I.L., DB	-0.20	-0.49	-0.00	532.71	0.18												
#12 Power, Watts	288.00																
#12 Phase, Degrees	-1.00																
3RD STAGE COMB. I.L., DB	-0.20									-0.36	-0.00	1936.69	0.26				
#13 Power, Watts	268.00																
#13 Phase, Degrees	1.00																
1ST STAGE COMB. I.L., DB	-0.20	-0.96	-0.01	533.90	0.90												
#14 Power, Watts	292.00																
#14 Phase, Degrees	-3.00																
2ND STAGE COMB. I.L., DB	-0.20					0.30	-0.00	1018.07	0.49								
#15 Power, Watts	271.00																
#15 Phase, Degrees	5.00																
1ST STAGE COMB. I.L., DB	-0.20	1.56	-0.02	532.67	2.13												
#16 Power, Watts	289.00																
#16 Phase, Degrees	-2.00																

FIGURE 6 EXAMPLE OF MULTI-STAGE COMBINER ANALYSIS ON A SPREADSHEET

Figure 6. Example of multi-stage combiner analysis on a spreadsheet.

P_L = power lost as heat in the combiner as a result of the matched insertion loss.

I.L. = insertion loss (dB) of the combiner under matched conditions and no phase or amplitude imbalance on the two input signals.

X.I.L. = excess insertion loss (dB) due to amplitude and/or phase imbalance between the two input signals.

The power lost as heat in the combiner comes off the top:

$$P_L = P_A + P_B - \mathrm{Log}^{-1}\left[\frac{\mathrm{I.L.}}{10} + \mathrm{Log}\,(P_A + P_B)\right]$$

The power out of the combiner is found from the following:

$$P_O = \mathrm{Log}^{-1}\left\{\frac{\mathrm{X.I.L.}}{10} + \mathrm{Log}\left[\mathrm{Log}^{-1}\left(\frac{\mathrm{I.L.}}{10} + \mathrm{Log}\,(P_A + P_B)\right)\right]\right\}$$

Likewise the power in the bridging resistor:

$$P_{BR} = \mathrm{Log}^{-1}\left[\frac{\mathrm{I.L.}}{10} + \mathrm{Log}\,(P_A - P_B) \quad - P_O\right]$$

The phase of the various modules and combiner outputs are referenced to module #1, thus 0 is entered for it and all other signals are referenced to it. The phase angle of a combiner output is:

$$\Phi = \Theta_A - \mathrm{Tan}^{-1}\left[\frac{\mathrm{Sin}\,(\Theta_A - \Theta_B)}{\frac{1}{\sqrt{P_r}} + \mathrm{Cos}\,(\Theta_A - \Theta_B)}\right]$$

Where: Θ_A and Θ_B are the phase angles of the signals at port A & B and $P_R = P_A/P_B$

Remember that Lotus 1-2-3® requires all angles of trig functions to be in radians. Multiply an angle in degrees by Pi/180 to convert to radians. Divide an angle in radians by Pi/180 to convert back to degrees.

Figure 7 is an example of the Lotus 1-2-3® combiner three model. It is interesting to note the affect through the combiner tree of module #3 failure.

Summary

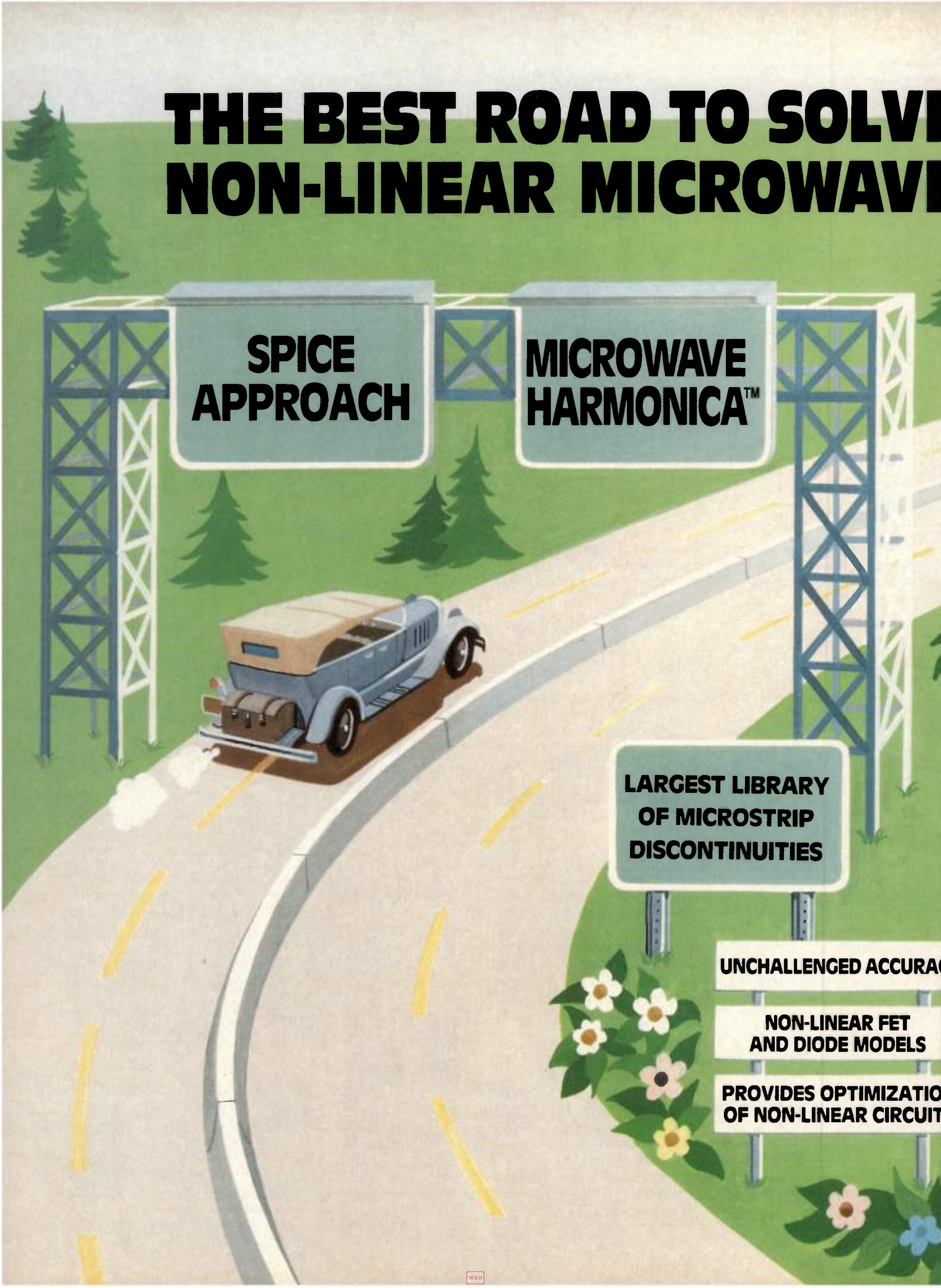
The equations modeling the behavior of two-port power combiners have been derived. The derivations are presented in detail so the reader may be assured of their accuracy and to enable one to similarly analyze combiners with an unusual number of input ports (i.e. 3-port or 7-port). Results are presented in graphical form to provide an intuitive understanding of combiner behavior. Finally a unique approach to computer aided design of large combining trees is presented using Lotus 1-2-3 spreadsheet software. rf

References

1. Earnest A. Franke, "Excess Insertion Loss at the Input Ports of a Combiner Hybrid", *RF Design*, Nov 1985, p. 43-48.
2. Roderick K. Blocksome, "Practical Wideband RF Power Transformers, Combiners, and Splitters", *Proceedings of RF Technology Expo 86*, p. 207-227.

About the Author

Roderick Blocksome is Manager of HF Power Amplifier Group at Rockwell International Corp., Collins Defense Communications, 855 35th St., NE, Cedar Rapids, IA 52498.


THE BEST ROAD TO SOLV
NON-LINEAR MICROWAV
SPICE APPROACH
MICROWAVE HARMONICA™
LARGEST LIBRARY OF MICROSTRIP DISCONTINUITIES
UNCHALLENGED ACCURAC
NON-LINEAR FET AND DIODE MODELS
PROVIDES OPTIMIZATIO
OF NON-LINEAR CIRCUIT

See us at the RF Technology Expo, Booths #410, 412, 509 & 511.

INFO/CARD 50

Wideband RF Power Amplifier

This Amplifier Operates Over A Wide Range Of Supply Voltages.

By H.O. Granberg
Motorola Semiconductor Products

A single amplifier covering frequencies from HF to VHF at a power output level of 300 watts would have been considered impossible or impractical a few years ago. This would still be true if not for the advances in power FET technology.

This article covers the design aspects of a 300 watt unit with a frequency range of 10 to 150 MHz.

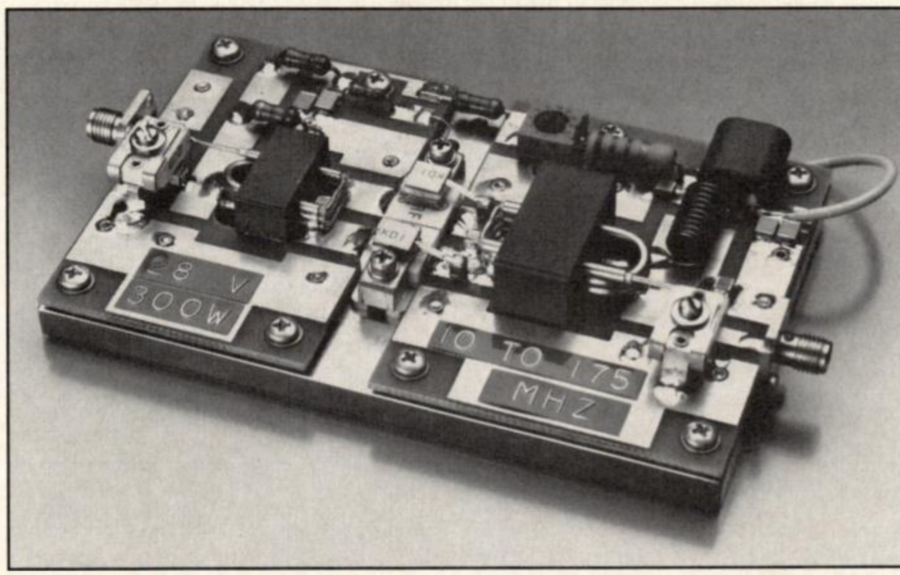


Figure 1. Overall view of the 300 watt, 10-150 MHz amplifier. Separate circuit boards are used for the input (left) and the output.

The MRF141G, used in this design, is housed in a special push-pull header commonly known as "Gemini" (twins), meaning that there are two identical transistors mounted next to each other on a common carrier or a flange. There are transistors (mainly FETs) available in the Gemini type packages rated from 20 watts to 300 watts. The lower power units can be used to frequencies of 1 GHz and higher, while the 100-150 watt units are designed to operate up to 500-600 MHz.

The advantages of a push-pull package such as the Gemini become apparent at higher frequencies, where the normal push-pull configuration with discrete devices would be impractical. In the push-pull circuit configuration the critical factor is the mutual inductance between the two push-pull halves, and not the device to ground inductance, as is the case in single ended designs. The Gemini or any other push-pull transistor housing permits the minimization of the mutual inductance to a level that approaches the ultimate in physical terms.

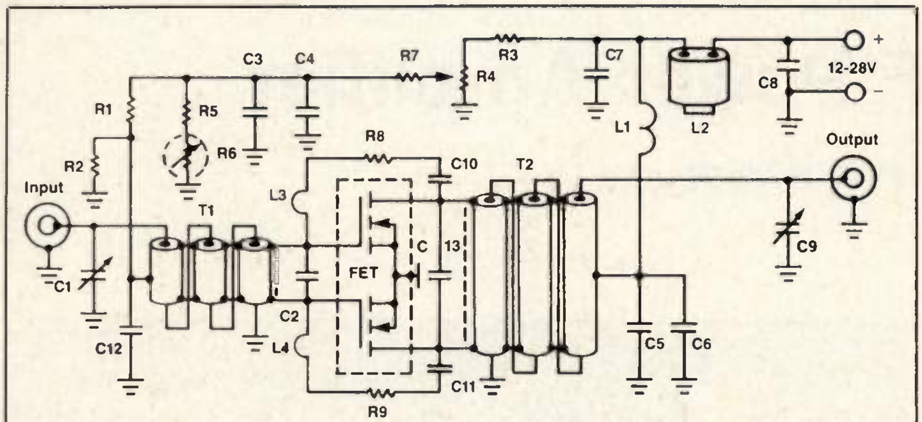
There are a couple of penalties we must pay for all this. One is a slightly higher cost when compared to two discrete units due to matching procedures involved and lower production yields resulting from double the possible reject rate. Another one is the reduced thermal characteristics. Twice as much dissipated power is concentrated virtually in the same area as in the case of a discrete design, leading to special cooling requirements.

About Power FETs

There have been designs of high power HF amplifiers using the T0-3 packages, and lower power versions with the T0-220 plastic units. With a given die geometry, a FET has approximately four times higher unity gain frequency than a bipolar transistor. This explains the fact that even the larger low frequency power FETs may have 10 dB or more power gain at 30 MHz, where a similar bipolar counterpart would be totally unusable. The difference is mostly in the figure of merit of the die itself, which is the ratio of feedback capacitance to the input capacitance or impedance. (This should not be confused with the more common base area/emitter periphery figure of merit die design formula.) With bipolar transistors the feedback capacitance (collector to base) is not usually specified, but it is 15-20 times higher than the drain to gate capacitance of a comparable FET, while the base/gate input impedances become about equal at increased frequencies. This feedback capacitance normally produces feedback within the device itself, whose exact phase angle depends on the capacitance values and other parameters.

In FETs designed specifically for RF, the die geometry is usually finer (larger ratio of the gate periphery to the channel area) than in the switching power FETs. This reduces the device capacitances automatically. Further reduction is achieved by splitting the die into a multiple of cells (groups of source sites and gate fingers) where the gates and sources are connected in groups of two or four by individual bonding wires to the common package terminals. For example, in the MRF141G one of the two die consists of 36 cells each having around 70 individual small FETs, making the total about 2,500.

In switching power FETs, the connections to the numerous source sites and gates are made with metal pattern on the die surface which allows the use of single large diameter bonding wires for the source and gate contacts. The increased metal area results in increased MOS capacitance and reflects to the device input (C_{ISS}), feedback (C_{RSS}) and output (C_{OSS}) capacitances. The transconductance of a MOSFET g_{fs} is a measure of its electrical size. Thus, a good indication of the high frequency performance can be obtained by comparing the capacitance values (especially C_{RSS}) of devices with



R1 — 1K/½W
R2 — 10K/½W
R3 — 330 Ohms/2W
R4 — 1K Trimpot
R5 — 6.8K/¼W
R6 — Thermistor, 10K at 25°C/2.5K at 75°C
R7 — 2K/½W
R8, R9 — EMC Technology Type 5310 or KDI Pyrofilm Type PPR 515-20-3 Power Resistors, 25 Ohms
C1, C9 — ARCO 402, 1.5-20pF Compression Mica or equivalent
C2 — 200pF Ceramic Chip
C3 — 0.1uF Ceramic Chip
C4, C5, C12 — 1000pF Ceramic Chip
C6, C7 — 0.01uF Ceramic Chip
C8 — 0.47uF Ceramic Chip or lower values in parallel for the value indicated
C13 — 300pF, 2x150pF or 100pF and 200pF Ceramic Chips in parallel

L1 — 10 Turns AWG #16 Enameled Wire, 5mm I.D.
L2 — Ferrite Beads over AWG #16 Wire, 1.5 uH total
L3, L4 — Lead Lengths of R8 and R9, 20mm total
FET — MRF141G
T1 — 9:1 RF Transformer. (15-25 Ohm, 1.2-1.6mm O.D. semi rigid coax.) Magnetic Core Required: Fair-Rite Products Corp. #9461012002/9361021002 E and I (2 ea.) Types, Respectively, or Equivalent.
T2 — 1:9 RF Transformer. (15-25 Ohm, 1.8-2.3mm O.D. semi rigid coax.) For Magnetic Core See Text.

Note: All chip capacitors of 0.01uF and less in value are ATC type 100 or equivalent.

Figure 2. Schematic of the amplifier.

similar transconductances.

Another fact to mention is the gate resistance. Most modern power FETs use a gate structure of polycrystal silicon, which can have a bulk resistance comparable to carbon. It is also used as a conductor between the metal pattern and each individual gate. In the RF power FETs, each gate is fed through a separate contact having a resistance of approximately 0.1 ohms. In the switching power FETs, the polycrystal silicon is applied in a sheet form in a separate layer, but the distance between the metallization and the farthest gate still results in at least 30-40 times higher gate resistance with a die of comparable size.

In high frequency applications the high gate resistance permits a part of the drain-source RF voltage or transients to be fed back to the gate through C_{RSS} in amplitudes that can rupture the gate-source oxide layer. The rupture will first occur in the far end of the die, away from the gate terminal. Since the gate resistance is internal to the FET die, external limiting or clamping circuits at the gate are of no help. The gate of a MOSFET is the most sensitive part of the device, which can be permanently damaged even by static charges during the handling. Although the larger FETs (100-150 W), due to their higher gate capacitance, are not as vulnerable as the smaller ones, proper precautions should be exercised.

Design and Construction

As discussed earlier, the common mode inductance in a push- pull circuit is not critical, and the ground path is only used for DC feed to the amplifier. The input and output impedance levels are established from gate to gate and drain to drain respectively. This allows the circuit board, which is made of the standard 1.6 mm G10 material, to be split into two sections. One carries the input matching network and part of the bias circuit, while the second section holds the output matching network, the bias set and the drain voltage feed and filtering circuitry. (See Figures 1 and 2). In addition to allowing wider design flexibility, this arrangement also simplifies the repair and maintenance of the unit, if required.

The two circuit boards including the space between them for the FET measures 115 × 75 mm. They are mounted on a copper plate with the same dimensions having a thickness of 6 mm. The input and output connectors (SMA) are mounted to the edges of the copper plate. They can also be placed at a remote location with coax connections to the amplifier utilizing any connectors that have good RF characteristics such as BNC.

Due to the large amount of heat concentrated in a small area in the form of dissipated power, it is important that the copper plate be employed as a heat spreader unless the heat sink itself is made of copper. The heat spreader can then be bolted to a piece of aluminum extrusion with thermal resistance of 1° C/W or less for normal intermittent operation without forced air cooling. The heat spreader and the extrusion surfaces should be flat without any burrs, and silicone thermal compound must be applied to the interface. The same practices should be followed in mounting the FET into the heat spreader. If the FET gate and drain leads are bent sharply up along the package sides, they will be aligned along

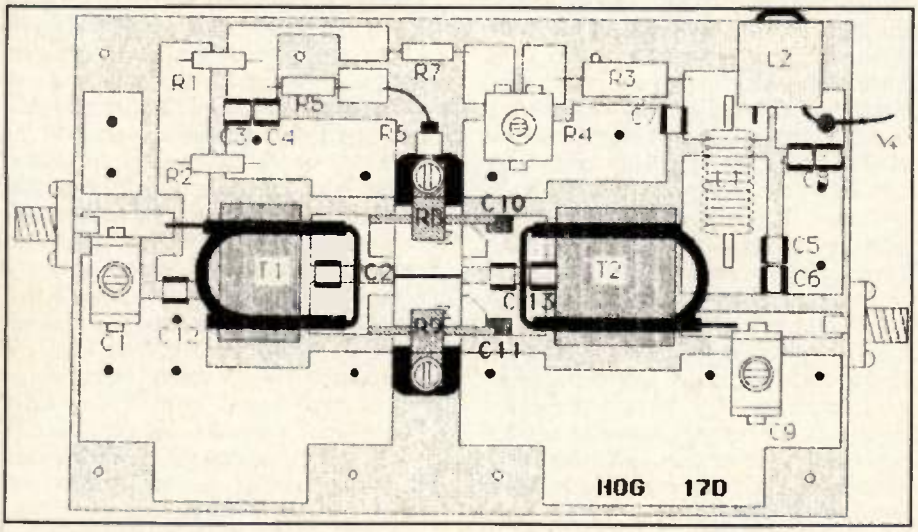


Figure 3. The component layout diagram. The only critical component locations are those of C2 and C13. They must be soldered in place (½ of C13) before the mounting of the input-output transformers.

the edges of the circuit boards. This makes the board spacing from the heat spreader less critical, which then can be anywhere from 1 to 3 mm. The FET lead lengths to the board connection points are variable by the same amount, but they have a minimal effect on the impedance matching and performance at these frequencies.

Details of the electrical design concepts of a similar amplifier are given in reference 1. The input-output transformers require a special low impedance semi-rigid coax cable making construction difficult in single quantities. The output transformer only requires a magnetic core if operation below 75 MHz is desired. In contrast, the input transformer always requires one regardless of the frequency of operation. In a push-pull FET amplifier design the gates of the two halves must be isolated by sufficient inductance or resistance (7,8). In order to prevent instabilities which will occur at the resonant frequency of the device capacitances, the internal wire bond inductances and the external inductances, sufficient isolation is required between the two gates which the magnetic core will provide. Without this, the two FETs of the push-pull circuit would see a parallel connection at some resonant frequency, which would result in serious instability problems.

The importance of the negative feedback (L3, L4-R8, R9-C10, C11) must be emphasized. Without it the power gain would exceed 30 dB at low frequencies, resulting in increased conditions for instabilities. The feedback is designed to lower the low frequency power gain close to the 150 MHz level it is at. L3 and L4, which consist of the lead lengths of R8 and R9 represent a reactance of 20 ohms each at 150 MHz. It also controls the frequency-amplitude slope. This in series with the 25 ohm resistor values lowers the power gain by one dB at 150 MHz but increases to as much as 15 dB at 10 MHz. C10 and C11 are only used for DC blocking and their values are not critical as long as their reactances are less than 10-15 percent of R8+R9. C10 and C11 are ceramic chip capacitor that are mounted vertically on the circuit board (Figure 1). Although unusual, it allows the feedback resistor leads to be soldered directly to the capacitor top terminals. This provides a much lower inductance path than the conventional mounting technique and saves board space. Since R8 and R9 must be able to dissipate up to 15 Watts each depending on the frequency of operation, they must be of a type that can be easily heat sunk. The type resistors designated

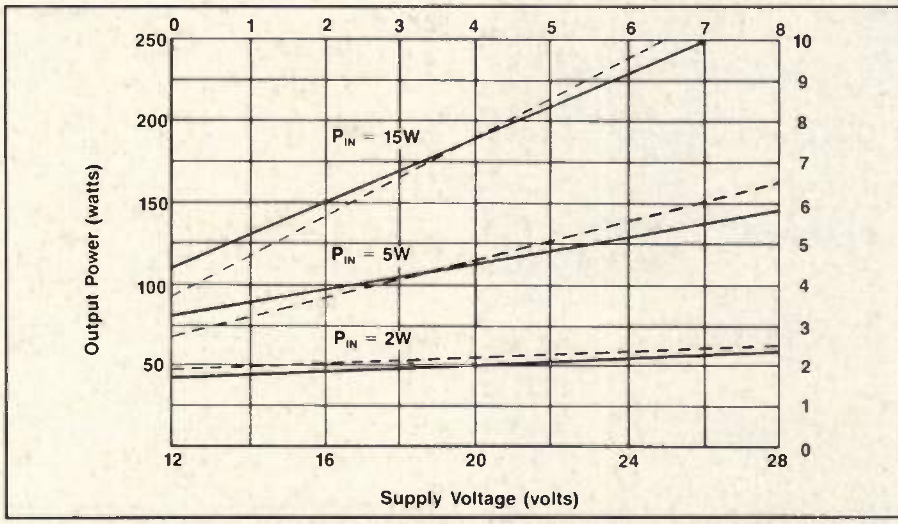


Figure 4. Amplifier power output versus the supply voltage at various input levels. Solid lines represent 150 MHz and dashed lines 10 MHz.

have mounting lugs which are terminally connected to the copper heat spreader through 5 mm high spacers.

These are mounted on top of the ends of the FET flange, allowing the use of common screws for fastening the resistors and the FET. The spacers must be of material with low terminal resistance like aluminum, brass or copper, and must have a larger surface area than thin wall tubing. A couple of stacked brass nuts, one size larger than the mounting screws is a good solution. Although not very professional it works rather well. If the unit is used for other than intermittent modes of operation such as voice communication, a thermistor (R6) can be used for bias stabilization. Without it the drain idle current will approximately triple if the FET case temperature is doubled, and would result in decreased efficiency. The thermistor can be attached to a solder lug, which is fastened with one of the resistor-FET mounting screws.

The input and output impedance matching is achieved with unique wide-

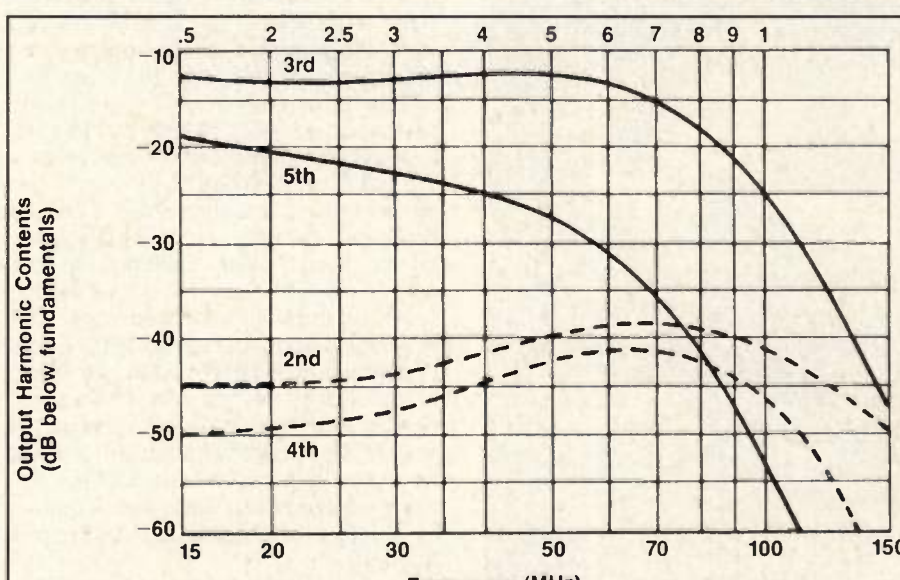


Figure 5. Output harmonic contents versus frequency. (V_{DS} = 28V, P_{OUT} = 300W.) The benefit of the push-pull configuration can be seen in the suppressed even order products. The data does not change considerably with varying the supply voltage or power output.

Low Frequency end MHz	u_1	Manufacturer and type #	Drain Eff. at 300 W, 75-100 MHz
75	1	No magnetic core	62-66%
25	20	Micrometals 101-2	59-63%
15	35	Micrometals 101-8	54-59%
7.5	125	Fair-Rite Prod. Corp. 9461014002/9361020002	46-52%
2	850	Fair-Rite Prod. Corp. 9443014002/9343020002	36-43%

Table 1. Effect of the output transformer magnetic core material on amplifier bandwidth and efficiency.

band transformers described in References 1 and 2. Some of their advantages are: DC isolation between the primary and the secondary, automatic balanced to unbalanced function and compact size in comparison to the power handling capability. Their principle is the same as in ordinary low frequency transformers, except that tight coupling between the windings is achieved through the use of low impedance transmission line, in this case semi-rigid coax cable. The low impedance side always has one turn and consists of parallel connected segments of the coax outer conductor. The inner conductor forms the high impedance winding, where the segments are connected in series.

This arrangement only permits impedance ratios with integers such as 1:4, 9, 16. The magnetic cores employed are the old E and I types. They can be inserted around the transformer after the windings are made up and mounted to the board. Rectangular openings in the boards are required to allow the I section to be laid against the heat spreader with thermal compound interface. The E and I cores are then cemented together and to the edges of the board openings. Special heat conductive epoxy would be preferable, but not mandatory. If there is no air flow on top of the amplifier, the output transformer can reach temperatures in excess of 100°C in continuous operation.

As a rule, the high frequency losses in magnetic material such as ferrite or powdered iron, are more or less directly related to its permeability, and appear as heat generated within the core. Since this part of the RF energy is not delivered to the output terminal, and the drain current is equal in each case, the result is lowered overall efficiency.

From the above we can conclude that the magnetic core material should be selected according to the lowest desired frequency of operation. For example, from 2 to 150 MHz, initial permeability (u_i) of over 600 and cross sectional area of about 1 cm² would be required. Ferrites in this category have Curie temperatures of 130-140°C, above which temperature they become paramagnetic and causes serious malfunctions in the operation of at lower frequencies. In such case special cooling structures would be required (See Table 1).

The amplifier described was originally designed for operation from a constant 28 volt power supply, for which reason regulation of the gate bias voltage was omitted. If the supply voltage is varied by more than 2 volts, the bias will have to be reset by R4 for a nominal 400-500 mA drain idle current. This can be avoided by connecting a 6.8-8.2 V zener diode (1N5921A-1N5923A) from the junction of R3 and R4 to ground. The idle current can then be set once, and would not change considerably from a supply of 12 to 28 V. The V_{DS} feed circuitry consists of the standard high and low frequency filtering to prevent any RF from feeding back to the power supply. C5, C6, L1 and C7 handle the high frequency end, while the low frequencies are taken care of by the L2-C8 combination.

Performance

With the 1:9 impedance ratio output transformer employed, the optimum power output at 12 and 28 V supplies would be only 50 and 265 watts respectively.

$$P_o = \frac{2V^2_{DS} - V_{DS_{ON}}}{50/9}$$

At these power levels the IM distortion is better than −30 dB at all frequencies, the worst case being at 50-100 MHz. From Figure 4 it can be seen that higher output levels are possible with increased drive power, but the amplifier will be close to saturation and can be only used for nonlinear applications such as FM or CW. For the best IMD, the idle current should be 500-800 mA total, but disregarding the linearity, it can be as low as 100-200 mA. Lower idle current will result in loss of power gain by 0.5-1.0 dB, while increasing the efficiency.

The stability of any RF power amplifier (especially solid state) under mismatched load conditions is always a concern. The power MOSFETs have been proven superior in this respect to the BJTs, although the stability is also circuit dependent to a great extend. The stability of the amplifier described here has been tested against load mismatches using a simulator of 30:1 at all phase angles and a 3 dB power attenuator to the amplifier output, which results in approximately 3:1 VSWR. Unconditional stability was shown at a combination of any power output level and supply voltage at 10, 50 and 150 MHz. Stability into a 3:1 mismatched load is almost considered a standard specification in the industry, meaning that the harmonic filter-antenna combination (if applicable) should have its input VSWR equal or lower. Normally 2:1 is easy to achieve over a fraction of an octave bandwidth, unless the filters are improperly designed. Figure 5 shows that at 150 MHz and beyond the output harmonics are well suppressed to start with, but a filter is still required to meet the FCC regulations. More elaborate filtering is necessary at lower frequencies, where the 3rd harmonic is only 12-13 dB below the fundamental. For most industrial applications, however, harmonic filtering may not be necessary. Although data is not shown, the amplifier can be used up to 175 MHz with a power gain of 10-11 dB. C1 should be adjusted for lowest input VSWR and C9 for the peak power output at the highest desired frequency of operation.

As the MRF 141G basically operates from a 28 V supply, lowering the voltage down to 20 or below would make the unit almost indestructible against load mismatches in case of an open coax or broken antenna. Figure 4 shows that the power output is still almost 200 watts at 20 V and 150 watts at 16 V. The ruggedness criterion does not apply against possible transients to the input from the signal source and assumes that the FET is properly mounted to the heat sink. A normal guideline is that a transistor should have its break down voltage (BV_{dss}) 2-25 times the operating voltage. The break down voltage is set by choosing the starting material (silicon) with proper resistivity or doping. If the break down voltage is too low, the output voltage swing may exceed it and cause an avalanche. If it is too high, the transistor will saturate at a low power level, but it will be harder to blow up since the device is less likely to exceed its dissipation limits. For the same reason, devices made for 50 V operation are often used at 30-40 V and at reduced power levels in applications like laser drivers and magnetic resonance imaging, where they must momentarily withstand a large output load mismatch. The circuit boards and other components for this design are available from Communication Concepts, Inc., 121 Brown Street, Dayton, OH 45402. rf

References

1. H.O. Granberg, "Building Push-Pull, Multioctave, VHF Power Amplifiers," *Microwaves & RF*, November 1987.
2. H.O. Granberg, "New MOSFETs Simplify High Power RF Amplifier Design," *RF Design*, October 1986.
3. Bill Olson, "Solid State Construction Practices, Parts 1-3," *QEX*, A.R.R.L. January-March, 1987.
4. H.O. Granberg, "Good RF Construction Practices and Techniques," *RF Design*, September-October, 1980 and Motorola, Inc. Reprint AR164.
5. Motorola Semiconductor Products, Inc., "RF Power MOSFETs," Publication AR165S.
6. Edwin S. Oxner, "Controlling Oscillation in Parallel Power MOSFETs," Siliconix Technical Article TA83-2, September 1983.
7. David Giandomenico, et. al., "Analysis and Prevention of Power MOSFET Anomalous Oscillation," *Proceedings of Powercon II*, Power Concepts, Inc. 1984.
8. Motorola Semiconductor Products, Inc. "RF Device Data," Publication DL110, Rev. 2.
9. EMC Technology, Inc. "Microwave Components," Publication 386-15, 1986.

About the Author

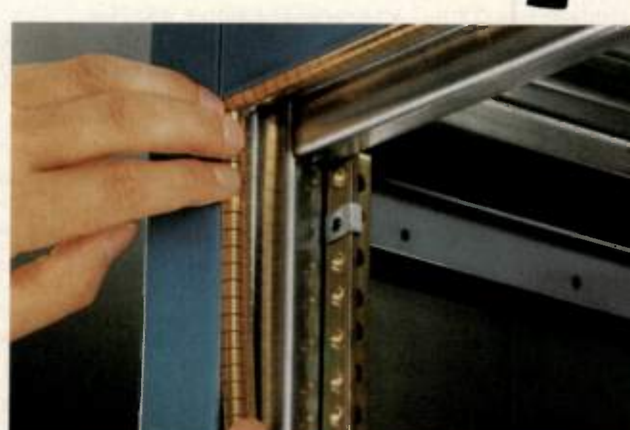
Helge Granberg is a member of the technical staff at Motorola Semiconductor Products, Inc., P.O. Box 20912, M/S B320, Phoenix, AZ 85036. He can be reached at (602) 244-4373.

Solve Your Control

For more than 40 years, Instrument Specialties has been recognized as the leader in providing products to control electronic interference. Our precision manufacturing techniques, applied to the fabrication of electronic gaskets from beryllium copper, bring out all of the inherent advantages of this unique alloy.

Lightweight, with excellent thermal and electrical conductivity, beryllium copper strips offer higher shielding effectiveness than other products made for this purpose. They are usable at lower contact forces, do not take a "set", can't flake or break into small (conductive) pieces, and are not affected by solvents. And, because of their wiping action, surface oxidation is automatically cleaned when an enclosure is opened or closed.

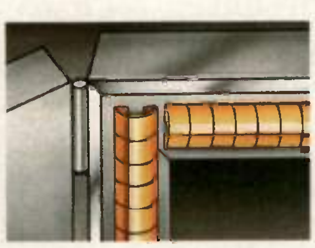
All Instrument Specialties shielding strips can be attached quickly and easily to the surface desired. Some carry a self-adhesive strip for this purpose. Others clip-on and are friction-held; many can be supplied with barbs that bite and grab, preventing slippage. Still others are supplied with holes for riveting.



This Sticky Fingers® design uses a self-adhesive tape to attach instantly. The upper part of the strip slides into the folded tab when enclosure doors are closed, preventing accidental damage to "fingers."

Interference Problems!

The Symmetrical Slotted Series of Instrument Specialties shielding strips employs a pierced track for mounting with nylon push rivets. The shielding strip compresses with bi-directional engagement.



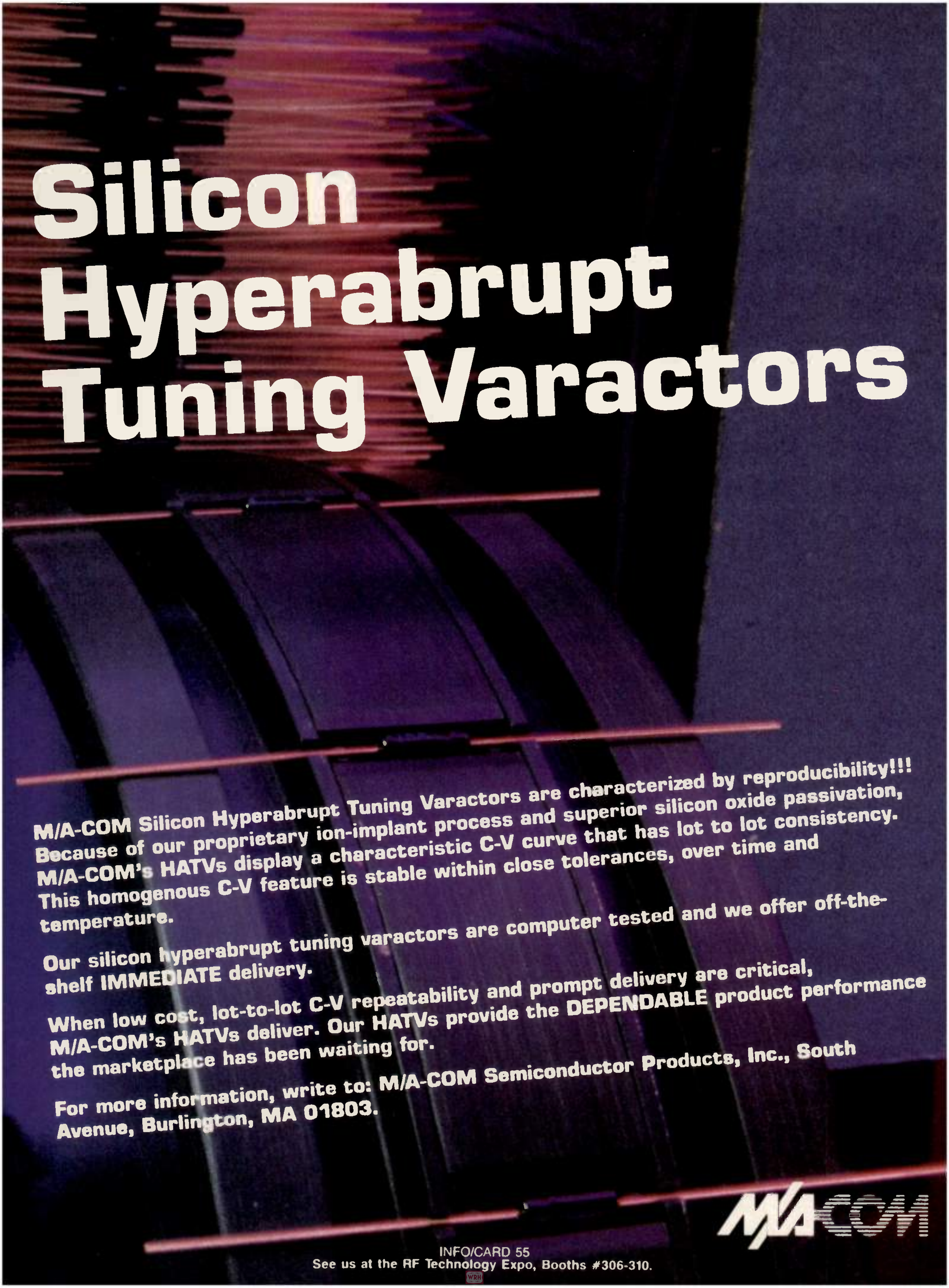
The Symmetrical Slotted Shielding (S³) series is perfect for sliding drawers and door enclosures, where frequent opening and closing occurs.

FREE! Twenty-four page guidebook describes all you need to know to select the proper interference control products for your application(s). Includes technical information, design formulae, plus product illustrations and complete specifications. Write Dept. RF-42, and ask for "Catalog E3-78," or circle the Reader Service Number. (If interested in Precision Stampings, also ask for Catalog 16.)

INSTRUMENT SPECIALTIES CO., INC.
DELAWARE WATER GAP, PA 18327-0136
Telephone: 717-424-8510
TWX: 510-671-4526 • FAX: 717-424-6213

Specialists in interference control since 1944

INFO/CARD 54
See us at the RF Technology Expo, Booth #549.


Silicon
Hyperabrupt
Tuning Varactors
M/A-COM Silicon Hyperabrupt Tuning Varactors are characterized by reproducibility!!!
Because of our proprietary ion-implant process and superior silicon oxide passivation, M/A-COM's HATVs display a characteristic C-V curve that has lot to lot consistency. This homogenous C-V feature is stable within close tolerances, over time and temperature.
Our silicon hyperabrupt tuning varactors are computer tested and we offer off-the-shelf IMMEDIATE delivery.
When low cost, lot-to-lot C-V repeatability and prompt delivery are critical, M/A-COM's HATVs deliver. Our HATVs provide the DEPENDABLE product performance the marketplace has been waiting for.
For more information, write to: M/A-COM Semiconductor Products, Inc., South Avenue, Burlington, MA 01803.
M/A-COM
INFO/CARD 55
See us at the RF Technology Expo, Booths #306-310.

Distortion in Nonlinear Circuits

Approximation Can Calculate Distortion Magnitude.

By Andrzej B. Przedpelski
A.R.F. Products, Inc.

Any circuit with a nonlinear transfer characteristic introduces harmonic and intermodulation distortion in its output. The magnitude of this distortion can be calculated when the transfer characteristic is known.

A nonlinear circuit, causing distortion of the input signal, produces additional frequencies not present in the original signal. This is usually an undesirable phenomenon, and in critical circuits, it becomes necessary to determine the magnitude of the problem.

The magnitude of the distortion is a function of input signal level and the characteristic of the circuit nonlinearity. A useful method, especially in RF circuit design, is to determine the relative magnitude of the different spurious frequencies in the output for a given signal level input. This calculation is made on a broadband basis (no selectivity), and selectivity can then be added to reduce the levels of the undesired outputs.

The first step is to determine the nonlinearity characteristic. If an output/input curve for the desired operating conditions is not available, it has to be measured. A typical transfer characteristic with a nominal gain of 20 dB is shown in Figure 1. To facilitate calculations, the curve has been normalized to obtain values of x in the range $0 \leqslant x \leqslant +1$. This normalization has no effect on the calculation. The effect of saturation is evident for inputs higher than 0.9.

The next step is to describe this curve mathematically. The suggested method is the Chebyshev odd approximation, which seems to give good results (1) and uses only the odd powers of x in the series:

$$y = C_1X + C_3X^3 + C_5X^5 \tag{1}$$

The equation expressing the transfer curve of Figure 1, using the above method is:

$$y = 10.246X - 0.2308X^3 + 2.1237X^5 \tag{2}$$

where y is the output signal and x is the input. The input signal can be represented as:

$$X = B + A\cos(F) \tag{3}$$

where F = frequency

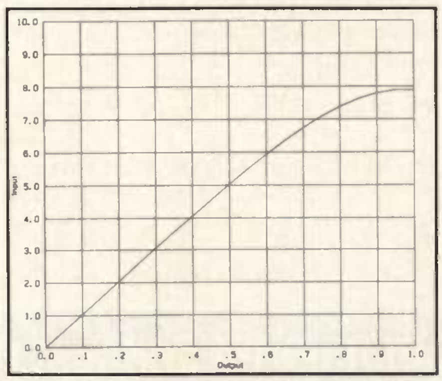


Figure 1. Nonlinear transfer function.

B = bias (operating point)
A = signal amplitude

A pure sinusoidal input signal is assumed to determine the relationship of the spurious output frequencies to the desired output signal.

By substituting (3) into (2), using trigonometric identities, and sorting out the terms, the expression for the output signal can be obtained:

$$y = K_0 + K_1\cos(F) + K_2\cos(2F) + K_3\cos(3F) + K_4\cos(4F) + K_5\cos(5F) \tag{4}$$

where K_2, K_3, K_4 and K_5 are the amplitudes of the harmonic frequencies and K_1 is the amplitude of the fundamental signal. K_0 is an indication of the shift of the operating point caused by the distortion.

The program in Table I calculates the value of the gain at the fundamental frequency, and the relative amplitudes of the

```
10 !   TABLE I  -   HARMONICS
20 !          A. PRZEDPELSKI  -  1 AUG 1984
30 !          A.R.F. PRODUCTS, INC.
40 !          BOULDER, CO
50 ! ****************  TRANFER FUNCTION FORM  ********************************
60 ! Y = C1*X + C3*X^3
70 ! ******************  ENTER CHEB COEFFICIENTS  ***************************
80 C1=1.0246*10
90 C3=-(.02308*10)
100 C5=-(.21237*10)
110 ! ******************  ENTER SIGNAL DATA  ********************************
120 B=.5 !            OPERATING POINT (BIAS)
130 A=.25 !           PEAK INPUT SIGNAL AMPLITUDE (NORMALIZED)
140 ! ***************  CALCULATE THE OUTPUT AMPLITUDES  ***********************
150 SHORT K0
160 K0=C1*B+C3*(B^3+1.5*A^2*B)+C5*(B^5+5*A^2*B^3+15/8*A^4*B)
170 K1=C1*A+C3*(3*A*B^2+.75*A^3)+C5*(5*A*B^4+15/2*A^3*B^2+5/8*A^5)
180 K2=C3*1.5*A^2*B+C5*(5*A^2*B^3+2.5*A^4*B)
190 K3=.25*C3*A^3+C5*(2.5*A^3*B^2+5/16*A^5)
200 K4=C5*(5/8)*A^4*B
210 K5=C5*A^5/16
220 PRINT "K0=";K0,"B=";B,"A=";A
230 PRINT
240 PRINT "FUND. GAIN=";20*LGT (ABS (K1/A));"dB"
250 ON ERROR GOSUB 340
260 PRINT "2nd HARM=";20*LGT (ABS (K2/K1));"dB"
270 PRINT "3rd HARM=";20*LGT (ABS (K3/K1));"dB"
280 PRINT "4th HARM=";20*LGT (ABS (K4/K1));"dB"
290 PRINT "5th HARM=";20*LGT (ABS (K5/K1));"dB"
300 PRINT
310 PRINT "NOTE: HARMONICS ARE REFERENCED TO FUNDAMENTAL OUTPUT"
320 END
330 ! OFF ERROR
340 PRINT "NONE"
350 RETURN
360 END
```

Table 1. This program calculates gain and amplitudes of the harmonics.

```
A                                                                C
K0= 4.9262          B= .5               A= .25                   K0= 4.6423          B= .5               A= .45

FUND. GAIN= 19.2230749411 dB                                     FUND. GAIN= 18.6020817462 dB
2nd HARM=-26.8290724206 dB                                       2nd HARM=-19.3538584227 dB
3rd HARM=-40.22009378 dB                                         3rd HARM=-28.8401222292 dB
4th HARM=-58.9078106462 dB                                       4th HARM=-42.970467145 dB
5th HARM=-84.9284105596 dB                                       5th HARM=-63.8856169562 dB

NOTE: HARMONICS ARE REFERENCED TO FUNDAMENTAL OUTPUT             NOTE: HARMONICS ARE REFERENCED TO FUNDAMENTAL OUTPUT

B                                                                D
K0= 4.8141          B= .5               A= .35                   K0= 4.5282          B= .5               A= .5

FUND. GAIN= 18.9685856886 dB                                     FUND. GAIN= 18.3684994864 dB
2nd HARM=-22.8590929316 dB                                       2nd HARM=-17.6836783258 dB
3rd HARM=-33.8813456726 dB                                       3rd HARM=-26.5978746302 dB
4th HARM=-49.885639253 dB                                        4th HARM=-39.9914354516 dB
5th HARM=-72.9836784528 dB                                       5th HARM=-59.9914354516 dB

NOTE: HARMONICS ARE REFERENCED TO FUNDAMENTAL OUTPUT             NOTE: HARMONICS ARE REFERENCED TO FUNDAMENTAL OUTPUT
```

Figure 2. Effect of drive level on harmonics (single-ended, Class A).

second, third, fourth and fifth harmonics.

Using this program, the effect of signal amplitude on distortion was calculated and is shown in Figure 2. The expected increase in harmonic content, with increase in signal level, is present.

Noting that the transfer function nonlinearity occurs at the positive peak of the signal, the distortion can be reduced by shifting the operating point down to avoid this curvature. This is illustrated in Figure 3. However, the peak negative input voltage should not swing below the origin.

The situation is much more complicated when two signals are present and IM distortion has also been evaluated. Using the same transfer function, shown in Equation (2) and the new input signal, the same process can be repeated.

$$X = B + A_1 \cos(F_1) + A_2 \cos(F_2) \qquad (5)$$

This time the harmonics and IM terms are grouped together. The solution is considerably more complex and is shown in lines 240 to 630 of the program in Table II. The coefficients T_3 through T_{23} are the amplitudes of the respective spurious frequencies in the output; T_1 and T_2 are the output amplitudes of the two frequencies F_1 and F_2. T_{24} is an indication of the operating point shift caused by distortion.

An example for two different values of input signal is shown in Figure 4. As expected, the amplitudes of similar terms, such as $4F_1-F_2$, $4F_2-F_1$, $4F_1+F_2$, $4F_2+F_1$, are the same, as long as the amplitudes of F_1 and F_2 are the same.

It is interesting to compare a single ended and a push-pull configuration, using the same nonlinearities. The transfer

```
10 !   TABLE II  -   5th ORDER HARMONICS AND IM PRODUCTS
20 !          A. PRZEDPELSKI   -   2 AUG 1984
30 !          A.R.F. PRODUCTS. INC.
40 !          BOULDER, CO
50 ! ****************  INSTRUCTIONS  ****************************************
60 !       y = C1 x + C3 x^3 + C5 x^5
70 !       y vs. x IS THE TRANSFER CURVE
80 !       x = B + A1 cos F1 + A2 cos F2
90 !       B IS THE DC OFFSET
100 !       A1 IS THE AMPLITUDE OF THE F1 SIGNAL
110 !      A2 IS THE AMPLITUDE OF THE F2 SIGNAL
120 !      F1 HIGHER FREQUENCY THAN F2
130 !      F1 LARGER AMPLITUDE THAN F2
140 !      OUTPUT LEVELS REFERENCED TO F1 OUTPUT AMPLITUDE
150 ! *************  ENTER CHEB COEFFICIENTS  ***************************
160 C1=1.0246*10
170 C3=-(.02308*10)
180 C5=-(.21237*10)
190 ! ********************  ENTER SIGNAL DATA  ***************************
200 B=0
210 A1=.3
220 A2=.5
230 ! ************************ CALCULATIONS  **********************************
240 G0=B^2+(A1^2+A2^2)/2
250 G1=2*A1*B
260 G2=2*A2*B
270 G3=A1^2/2
280 G4=A2^2/2
290 G5=A1*A2
300 D0=B^3+3*A1^2*B/2+3*A2^2*B/2
310 D1=3*A1*B^2+3*A1^3/4+3*A1*A2^2/2
320 D2=3*A2*B^2+3*A2^3/4+3*A1^2*A2/2
330 D3=3*A1^2*B/2
340 D4=3*A2^2*B/2
350 D5=A1^3/4
360 D6=A2^3/4
370 D7=3*A1*A2*B
380 D9=3*A1^2*A2/4
390 D11=3*A1*A2^2/4
400 T1=C1*A1+C3*D1+C5*(G0*D1+G1*D0+G1*D3/2+G2*D7+G3*D1/2+G3*D5/2+G4*D11+G5*D2+G5*D9)
410 T2=C1*A2+C3*D2+C5*(G0*D2+G2*D0+G2*D4/2+G1*D7+G4*D2/2+G4*D6/2+G3*D9+G5*D1+G5*D11)
420 T3=C3*D3+C5*(G0*D3+G3*D0+G1*D1/2+G1*D5/2+G2*D9+G5*D7)
430 T4=C3*D4+C5*(G0*D4+G4*D0+G1*D11+G2*D2/2+G2*D6/2+G5*D7)
440 T5=C3*D5+C5*(G0*D5+G1*D3/2+G3*D1/2+G5*D9)
450 T6=C3*D6+C5*(G0*D6+G2*D4/2+G4*D2/2+G5*D11)
460 T7=C5*(G1*D5/2+G3*D3/2)
470 T8=C5*(G2*D6/2+G4*D4/2)
480 T9=C5*G3*D5/2
490 T10=C5*G4*D6/2
500 T11=C3*D7+C5*(G0*D7+G5*D0+G1*D2/2+G1*D9/2+G2*D1/2+G2*D11/2+G3*D7/2+G4*D7/2+G5*D3/2+G5*D4/2)
510 T12=C3*D7+C5*(G0*D7+G5*D0+G1*D2/2+G2*D1/2+G2*D11/2+G3*D7/2+G4*D7/2+G1*D9/2+G5*D3/2+G5*D4/2)
520 T13=C3*D9+C5*(G0*D9+G1*D7/2+G2*D3/2+G3*D2/2+G4*D9/2+G5*D1/2+G5*D5/2+G5*D11/2)
530 T14=C3*D9+C5*(G0*D9+G1*D7/2+G2*D3/2+G3*D2/2+G4*D9/2+G5*D11/2+G5*D1/2+G5*D5/2)
540 T15=C3*D11+C5*(G0*D11+G1*D4/2+G2*D7/2+G3*D11/2+G4*D1/2+G5*D2/2+G5*D6/2+G5*D9/2)
550 T16=C3*D11+C5*(G0*D11+G1*D4/2+G2*D7/2+G3*D11/2+G4*D1/2+G5*D6/2+G5*D9/2+G5*D2/2)
560 T17=C5*(G1*D9/2+G2*D5/2+G3*D7/2+G5*D3/2)
570 T18=C5*(G1*D6/2+G2*D11/2+G4*D7/2+G5*D4/2)
580 T19=C5*(G1*D11/2+G2*D9/2+G3*D4/2+G4*D3/2+G5*D7/2)
590 T20=C5*(G3*D6/2+G4*D9/2+G5*D11/2)
600 T21=C5*(G3*D11/2+G4*D5/2+G5*D9/2)
610 T22=C5*(G3*D9/2+G5*D5/2)
620 T23=C5*(G4*D11/2+G5*D6/2)
630 T24=B+D0+G0*D0+G1*D1/2+G4*D4/2+G5*D7/2
640 PRINT "C1=";C1,"C3=";C3,"C5=";C5
650 PRINT "B=";B,"A1=";A1,"A2=";A2
660 PRINT
670 ON ERROR GOSUB 850
680 PRINT "F1= ";20*LGT (ABS (T1/A1));"dB",,"F2= ";20*LGT (ABS (T2/A2));"dB"
690 PRINT "2F1=";20*LGT (ABS (T3/T1));"dB",,"2F2=";20*LGT (ABS (T4/T1));"dB"
700 PRINT "3F1=";20*LGT (ABS (T5/T1));"dB",,"3F2=";20*LGT (ABS (T6/T1));"dB"
710 PRINT "4F1=";20*LGT (ABS (T7/T1));"dB",,"4F2=";20*LGT (ABS (T8/T1));"dB"
720 PRINT "5F1=";20*LGT (ABS (T9/T1));"dB",,"5F2=";20*LGT (ABS (T10/T1));"dB"
730 PRINT "F1-F2=  ";20*LGT (ABS (T11/T1));"dB","F1+F2=  ";20*LGT (ABS (T12/T1));"dB"
740 PRINT "2F1-F2= ";20*LGT (ABS (T13/T1));"dB","2F1+F2= ";20*LGT (ABS (T14/T1));"dB"
750 PRINT "2F2-F1= ";20*LGT (ABS (T15/T1));"dB","2F2+F1= ";20*LGT (ABS (T16/T1));"dB"
760 PRINT "3F1-F2= ";20*LGT (ABS (T17/T1));"dB","3F1+F2= ";20*LGT (ABS (T17/T1));"dB"
770 PRINT "3F2-F1= ";20*LGT (ABS (T18/T1));"dB","3F2+F1= ";20*LGT (ABS (T18/T1));"dB"
780 PRINT "2F1-2F2=";20*LGT (ABS (T19/T1));"dB","2F1+2F2=";20*LGT (ABS (T19/T1));"dB"
790 PRINT "3F2-2F1=";20*LGT (ABS (T20/T1));"dB","3F2+2F1=";20*LGT (ABS (T20/T1));"dB"
800 PRINT "3F1-2F2=";20*LGT (ABS (T21/T1));"dB","3F1+2F2=";20*LGT (ABS (T21/T1));"dB"
810 PRINT "4F1-F2= ";20*LGT (ABS (T22/T1));"dB","4F1+F2= ";20*LGT (ABS (T22/T1));"dB"
820 PRINT "4F2-F1= ";20*LGT (ABS (T23/T1));"dB","4F2+F1= ";20*LGT (ABS (T23/T1));"dB"
830 OFF ERROR
840 END
850 PRINT "NONE",,"NONE"
860 RETURN
870 END
```

Table 2. Fifth order harmonics and IM products can be obtained with this program.

```
A
K0= 4.5661          B= .49          A= .45

FUND. GAIN= 18.6937327554 dB
2nd HARM=-19.847945984 dB
3rd HARM=-29.237569525 dB
4th HARM=-43.2375966404 dB
5th HARM=-63.9772679654 dB

NOTE: HARMONICS ARE REFERENCED TO FUNDAMENTAL OUTP

B
K0= 4.41            B= .47          A= .45

FUND. GAIN= 18.8628981926 dB
2nd HARM=-20.836894163 dB
3rd HARM=-30.032357321 dB
4th HARM=-43.7687265196 dB
5th HARM=-64.1464334028 dB

NOTE: HARMONICS ARE REFERENCED TO FUNDAMENTAL OUTPUT

C
K0= 4.2495          B= .45          A= .45

FUND. GAIN= 19.0148364947 dB
2nd HARM=-21.829154136 dB
3rd HARM=-30.8293400178 dB
4th HARM=-44.2983717048 dB
5th HARM=-64.2983717048 dB

NOTE: HARMONICS ARE REFERENCED TO FUNDAMENTAL OUTPUT
```

Figure 3. Effect of operating point charge on harmonics.

```
A
C1= 10.246              C3=-.2308               C5=-2.1237
B= .5                   A1= .2                  A2= .2

F1=  18.9774511738 dB                    F2=  18.9774511738 dB
2F1=-27.267548508 dB                     2F2=-27.267548508 dB
3F1=-43.3122822844 dB                    3F2=-43.3122822844 dB
4F1=-64.4767876594 dB                    4F2=-64.4767876594 dB
5F1=-92.4355878328 dB                    5F2=-92.4355878328 dB
F1-F2=   -21.7397525578 dB               F1+F2=   -21.7397525578 dB
2F1-F2= -34.0268234492 dB                2F1+F2= -34.0268234492 dB
2F2-F1= -34.0268234492 dB                2F2+F1= -34.0268234492 dB
3F1-F2= -52.4355878328 dB                3F1+F2= -52.4355878328 dB
3F2-F1= -52.4355878328 dB                3F2+F1= -52.4355878328 dB
2F1-2F2=-48.9137626518 dB                2F1+2F2=-48.9137626518 dB
3F2-2F1=-72.4355878328 dB                3F2+2F1=-72.4355878328 dB
3F1-2F2=-72.4355878328 dB                3F1+2F2=-72.4355878328 dB
4F1-F2= -78.4561877462 dB                4F1+F2= -78.4561877462 dB
4F2-F1= -78.4561877462 dB                4F2+F1= -78.4561877462 dB

B
C1= 10.246              C3=-.2308               C5=-2.1237
B= .5                   A1= .1                  A2= .3

F1=  18.6699813383 dB                    F2=  19.0207952093 dB
2F1=-31.6506565452 dB                    2F2=-14.3886323601 dB
3F1=-54.423217354 dB                     3F2=-26.6887533054 dB
4F1=-82.2311175638 dB                    4F2=-44.0614171862 dB
5F1=-116.21051765 dB                     5F2=-68.4983921784 dB
F1-F2=   -17.5382582068 dB               F1+F2=   -17.5382582068 dB
2F1-F2= -35.986519302 dB                 2F1+F2= -35.986519302 dB
2F2-F1= -26.6496618172 dB                2F2+F1= -26.6496618172 dB
3F1-F2= -60.6474926428 dB                3F1+F2= -60.6474926428 dB
3F2-F1= -41.562642454 dB                 3F2+F1= -41.562642454 dB
2F1-2F2=-47.5832423672 dB                2F1+2F2=-47.5832423672 dB
3F2-2F1=-67.5832423672 dB                3F2+2F1=-67.5832423672 dB
3F1-2F2=-77.1256674616 dB                3F1+2F2=-77.1256674616 dB
4F1-F2= -92.6886924694 dB                4F1+F2= -92.6886924694 dB
4F2-F1= -64.0614171862 dB                4F2+F1= -64.0614171862 dB
```

Figure 4. Single-ended IM distortion.

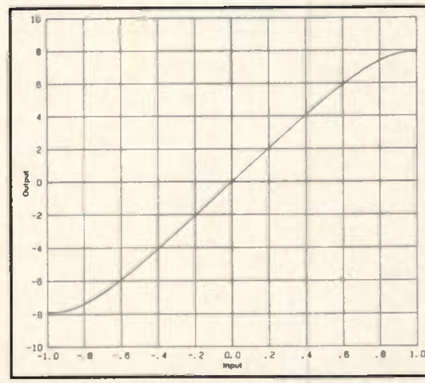


Figure 5. Symmetrical (push-pull) transfer function.

curve of such an idealized circuit is shown in Figure 5.

First, the program in Table I is used to obtain the harmonic content. Since twice the input swing is available, an input voltage twice the value of Figure 2 is used. The signal is centered at the origin (0,0).

The results are shown in Figure 6. As theory predicts, the even harmonics disappear. Because of the symmetry, the operating point does not shift. Since there are no discontinuities, the drive can be increased past the ±1 volt peak input.

The effect of unbalance can also be checked by shifting the operating point to reduce the symmetry. This is shown in Figure 7. As expected the even harmonics appear with even a small amount of unbalance, but are still smaller than the odd harmonics. The effect on odd harmonics is small.

Finally, IM distortion in the push-pull configuration can be calculated using the program of Table II. Again, with proper symmetry (B=0), the even order spuriouses disappear, as shown in Figure 8.

Figures 2 and 6 show that the gain at the fundamental frequency decreases with input level, since more power is produced at the spurious frequencies. This effect is shown in Figure 9 for equivalent conditions (twice the voltage swing in the push-pull configuration). The fundamental gain of the push-pull stage is somewhat higher, since the total distortion is lower.

The described method of determining the levels of spurious outputs caused by circuit nonlinearities, while somewhat simplified, shows the effects of input level changes, operating point, and symmetry. However, since an effort was made to keep the programs simple, some caution has to be exercised. In the single-ended configuration, the input signal should not swing below the origin (0,0). It can swing into the saturation region. In the push-pull configuration this limitation does not exist as long as the curve is monotonic. In calculating the inter-modulation distortion, the total maximum input voltage swing is the sum of the two peak voltages. This value has to be used while checking for signal swing in the single-ended configuration.

No attempt was made at checking sensitivity to the accuracy of the Chebyshev odd approximation. However, the first three terms seemed to be adequate to describe most of the common nonlinearities where some type of saturation (signal compression) is present. From there on, the analysis is rigorous. Unfortunately, there is no easy way to check the overall accuracy of this approach for small nonlinearities. As stated earlier, the analysis is based on the use of a broadband circuit with a constant resistive load.

The author wishes to thank Mr. James R. Jackson for the assistance in the tedious job of substituting equation (3)

DISCOVER THE POWER OF AVAILABILITY

THOMSON COMPONENTS   ACRIAN   MOTOROLA   Amperex   TRW

Now there is a one-stop source for all your RF needs — Richardson Electronics, Ltd. We are a franchised stocking distributor for the five most respected names in the industry — Acrian, Amperex/Philips, Motorola, Thomson-CSF and TRW. Their products are on our shelves and can be in your circuits the next day. So stop the endless search!

Richardson Electronics, Ltd. is your RF power source!

40W267 Keslinger Rd. • LaFox • IL • 60147 • 800/323-1770 • 312/232-6400 • FAX: 312/232-1071 • Telex: 283461 • EASTERN: 800/645-2322 • 800/221-0860 • SOUTHEASTERN: 800/348-5580 • NORTHEASTERN: 617/871-5162 • WESTERN: 800/348-5580 • CANADA: 800/387-2280 •
Other international inquiries contact the LaFox location.

INFO/CARD 58

GaAs MMIC Oscillators
— *Only from Pacific Monolithics*

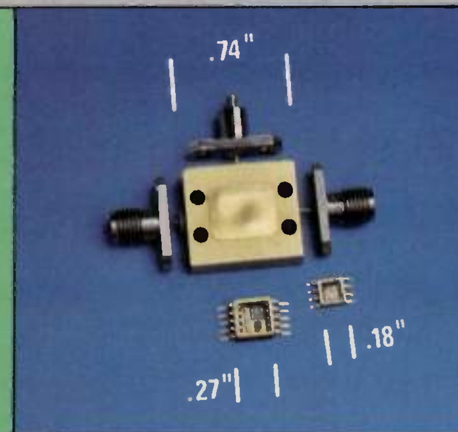
800 MHz to 18 GHz

Military and Commercial Applications

- ☑ *GaAs MMICs*
- ☑ *Reliability*
- ☑ *Repeatability*
- ☑ *Small Size*
- ☑ *Surface Mount Option*
- ☑ *Off-the-shelf and Affordable*
- ☑ *High Level of Integration*
- ☑ *On-Chip Buffers*

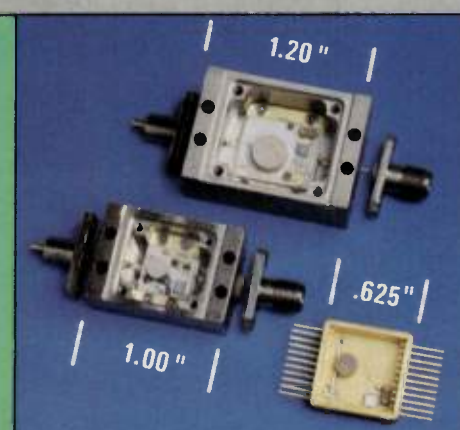
VCOs

Frequency range:
0.8 – 18.0 GHz
Power out: up to +25 dBm
Tuning: 20% standard
Load isolation: 40 dB
Ultra-broadband:
2.5 – 5.5 GHz



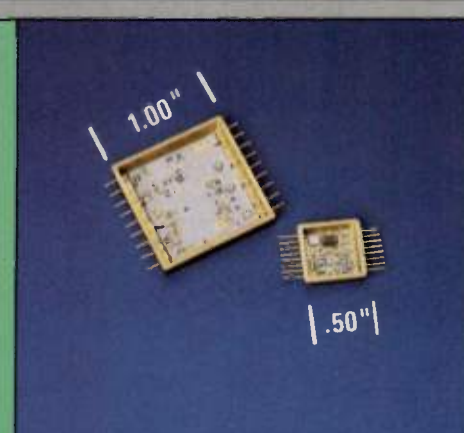
DROs

Frequency range:
3.5 – 18.0 GHz
Fixed or voltage tuned
(0.5% tuning)
Phase locked/MMIC phase
detector (±2ppm)
Temp compensated (±25ppm)
or oven controlled (±15ppm)



Oscillator Subsystems

Frequency range:
0.8 – 18.0 GHz
Multi-frequency band,
band selectable
Frequency synthesizer
Frequency converter with
local oscillator
Tailored to your
requirements



PACIFIC MONOLITHICS

245 Santa Ana Ct.
Sunnyvale, CA 94806-4512
(408) 732-8000
TWX: 510-600-3726
FAX: 408 732-3413

VCOs, INFO/CARD 118
DROs, INFO/CARD 119
Oscillator Subsystems, INFO/CARD 120

See us at the RF Technology Expo, Booth #301.

```
A
K0= 0                B= 0                A= .5

FUND. GAIN= 20.1034110978 dB
2nd HARM=NONE
3rd HARM=-45.1546286902 dB
4th HARM=NONE
5th HARM=-61.726347063 dB

NOTE: HARMONICS ARE REFERENCED TO FUNDAMENTAL OUTPUT

B
K0= 0                B= 0                A= .7

FUND. GAIN= 19.862102529 dB
2nd HARM=NONE
3rd HARM=-34.3966650038 dB
4th HARM=NONE
5th HARM=-49.79479564 dB

NOTE: HARMONICS ARE REFERENCED TO FUNDAMENTAL OUTPUT

C
K0= 0                B= 0                A= .9

FUND. GAIN= 19.3086808752 dB
2nd HARM=NONE
3rd HARM=-25.6448236976 dB
4th HARM=NONE
5th HARM=-40.5098164322 dB

NOTE: HARMONICS ARE REFERENCED TO FUNDAMENTAL OUTPUT

D
K0= 0                B= 0                A= 1

FUND. GAIN= 18.8357797856 dB
2nd HARM=NONE
3rd HARM=-21.672783806 dB
4th HARM=NONE
5th HARM=-36.3763160978 dB

NOTE: HARMONICS ARE REFERENCED TO FUNDAMENTAL OUTPUT

E
K0= 0                B= 0                A= 1.1

FUND. GAIN= 18.1624384791 dB
2nd HARM=NONE
3rd HARM=-17.8094521863 dB
4th HARM=NONE
5th HARM=-32.3915599786 dB

NOTE: HARMONICS ARE REFERENCED TO FUNDAMENTAL OUTPUT
```

Figure 6. Effect of drive level on harmonics (Class A, push-pull).

```
A
K0= .49517           B= .05              A= .5

FUND. GAIN= 20.0933182072 dB
2nd HARM=-47.5252394372 dB
3rd HARM=-44.6436865996 dB
4th HARM=-61.7162541724 dB
5th HARM=-61.7162541724 dB

NOTE: HARMONICS ARE REFERENCED TO FUNDAMENTAL OUTPUT

B
K0= .98815           B= .1               A= .5

FUND. GAIN= 20.062282213 dB
2nd HARM=-41.0759583188 dB
3rd HARM=-43.2630928556 dB
4th HARM=-55.664618265 dB
5th HARM=-61.6852181782 dB

NOTE: HARMONICS ARE REFERENCED TO FUNDAMENTAL OUTPUT

C
K0= 1.4767           B= .15              A= .5

FUND. GAIN= 20.0080044918 dB
2nd HARM=-36.8750739454 dB
3rd HARM=-41.3414940846 dB
4th HARM=-52.0885153628 dB
5th HARM=-61.6309404572 dB

NOTE: HARMONICS ARE REFERENCED TO FUNDAMENTAL OUTPUT
```

Figure 7. Effect of unbalance on harmonics.

```
A
C1= 10.246           C3=-.2308           C5=-2.1237
B= 0                 A1= .4              A2= .4

F1=  19.8449889891 dB                    F2=  19.8449889891 dB
2F1=NONE                                 NONE
3F1=-40.365815267 dB                     3F2=-40.365815267 dB
4F1=NONE                                 NONE
5F1=-69.220725995 dB                     5F2=-69.220725995 dB
F1-F2=  NONE                             NONE
2F1-F2= -33.9296018466 dB                2F1+F2= -33.9296018466 dB
2F2-F1= -33.9296018466 dB                2F2+F1= -33.9296018466 dB
3F1-F2= NONE                             NONE
3F2-F1= NONE                             NONE
2F1-2F2=NONE                             NONE
3F2-2F1=-49.220725995 dB                 3F2+2F1=-49.220725995 dB
3F1-2F2=-49.220725995 dB                 3F1+2F2=-49.220725995 dB
4F1-F2= -55.2413259082 dB                4F1+F2= -55.2413259082 dB
4F2-F1= -55.2413259082 dB                4F2+F1= -55.2413259082 dB

B
C1= 10.246           C3=-.2308           C5=-2.1237
B= 0                 A1= .3              A2= .5

F1=  19.7399658251 dB                    F2=  19.8926497706 dB
2F1=NONE                                 NONE
3F1=-42.8011462078 dB                    3F2=-34.0413866586 dB
4F1=NONE                                 NONE
5F1=-79.1108017596 dB                    5F2=-56.925926798 dB
F1-F2=  NONE                             NONE
2F1-F2= -33.2491687166 dB                2F1+F2= -33.2491687166 dB
2F2-F1= -30.2328581466 dB                2F2+F1= -30.2328581466 dB
3F1-F2= NONE                             NONE
3F2-F1= NONE                             NONE
2F1-2F2=NONE                             NONE
3F2-2F1=-45.7998767826 dB                3F2+2F1=-45.7998767826 dB
3F1-2F2=-50.236851775 dB                 3F1+2F2=-50.236851775 dB
4F1-F2= -60.6944266806 dB                4F1+F2= -60.6944266806 dB
4F2-F1= -47.3835017036 dB                4F2+F1= -47.3835017036 dB
```

Figure 8. Push-pull IM distortion.

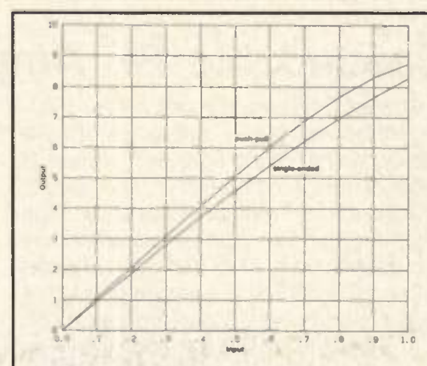


Figure 9. Fundamental frequency output vs. input level.

and (5) into equation (2).

Reference

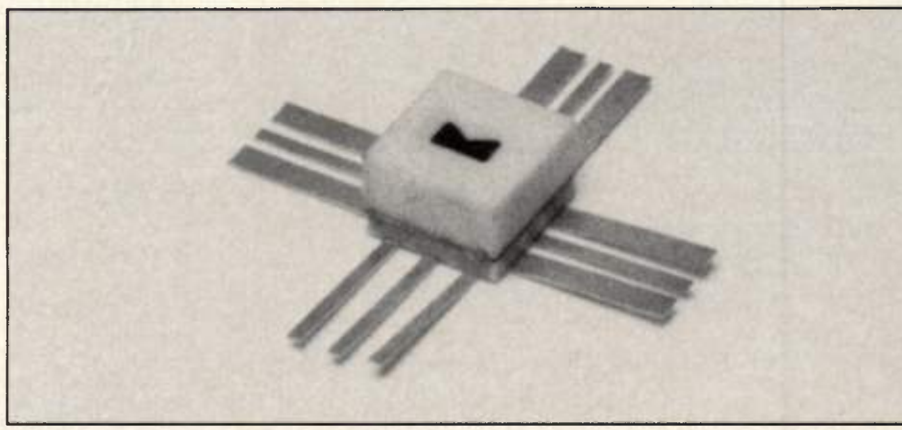
(1) Thomas R. Cuthbert, Jr., *Circuit Design Using Personal Computers*, John Wiley & Sons, New York, 1983.

About the Author

Andrzej B. Przedpelski is vice president, development of A.R.F. Products, Inc., 2559 75th St., Boulder, CO 80301. He serves as consulting editor to *RF Design*.

New Products Featured at RF Technology Expo 88

Merrimac Unveils SMD Power Dividers



These surface mount power dividers are designed for 50 ohm coplanar systems. The basic power divider is a hybrid junction with one of its ports internally terminated.

The PGD Series power dividers/combiners have RF bandwidths of 1 to 500 MHz. The PDG-02A-250 is a two way unit with minimum isolation of 20 dB, RF impedance of 50 ohms, 1.3:1 VSWR, typical insertion loss of 0.5 dB, and average input power into matched loads is 250 mW. Features for the PDG-03A-250 include minimum insertion loss of 15 dB, typical insertion loss of 1.0 dB, theoretical coupling of −4.8 dB, maximum amplitude balance of 0.3 dB and internal load dissipation of 35 mW.

Also from Merrimac are two directional couplers in a 0.25" square surface mount package. Available in 11 or 20 dB versions, these couplers cover the 10 to 1000 MHz range. The Kovar input leads are designed to be trimmed flush to the ceramic package or cut to the desired length as required for mounting. **Merrimac Industries, Inc., West Caldwell, NJ. Please circle INFO/CARD #186.**

Cascadable RF Amplifiers

Cougar Components introduces a variety of cascadable RF amplifiers in TO-8 packages with power outputs in excess of 100 mW from 5 to 2000 MHz. The Models AC1068 and AC1069 are dual stage high efficiency thin film cascadable amplifiers that operate from 10 to 1000 MHz. Typical gain is 24.5 dB with minimum gain of 24 dB on both models. Noise figure ranges from 5.0 dB to 5.5 dB depending on the model. Power output at the 1 dB compression point is +19.5 dBm for the 1068 and +22 dBm for the 1069. Typical intercept points are 32 dBm and 34 dBm respectively.

The AC382 amplifier covers from 10 to 250 MHz with 1 dB compression point output power of +21.5 dBm. The unit has typically 24 dB of small signal gain and a noise figure of 3.3 dB. Model AC379 has a typical noise figure of 5.0 dB while providing +20.5 dBm of output power at the 1 dB compression point over a 5 to 300 MHz frequency range. It has a typical gain of 14.0 dB. **Cougar Components, Sunnyvale, CA. INFO/CARD #201.**

Stripline Attenuators JFW Industries

The A-210 Series of 125 W stripline attenuators use beryllium oxide ceramic substrates and thick film resistor inks to achieve good transfer of heat from the film area thru the substrate to the heat sink. The films used exhibit a positive temperature coefficient which prevents thermal runaway problems. From DC to 3 GHz, the VSWR for a 50 ohm attenuator ranges from 1.15:1 to 1.25:1 depending on frequency. At a 1 to 10 dB loss and frequency range of DC to 1 GHz, the accuracy is ±0.3 dB. The accuracy becomes ±0.4 dB when the range becomes 1 to 2 GHz.

The T-210 Series of 125 W terminations use the same construction. The typical TCR for these devices is measured at 125 ppm/°C. The average power rating for a standard 50 ohm termination is 125 W and the peak is measured at 1000 W. The films used in these terminations exhibit a positive temperature coefficient which prevents thermal runaway problems. The leads for both devices listed are gold plated beryllium copper. **JFW Industries, Inc., Indianapolis, IN. Please circle INFO/CARD #185.**

Synthesized Signal Generator
Hewlett-Packard

HP introduces the HP 8657A 1040 MHz synthesized signal generator designed for in-channel receiver testing. Its phase noise is measured at –130 dBc at 500 MHz. For in-channel measurements such as distortion sensitivity, and hum and noise, the HP 8675A has less than 4 Hz residual FM. At 1 GHz, the specified single sideband phase noise is –126 dBc. For testing next generation radios with squelch and phase locked loops, the instrument offers DC FM under 10 Hz/hr. drift. **Hewlett-Packard Company, Palo Alto, CA. INFO/CARD #184.**

Low Power Prescalar
California Eastern Labs

CEL introduces low power prescalars from NEC. The UPB587G is a divide by 2, 4, 8 low power consumption (16.5 mW) silicon device. It operates from a 3 V supply at 5.5 mA from 0.05 to 1.0 GHz. Also being introduced is the NE320 hetero junction FET with 1.2 dB typical NF, and a minimum associated gain of 9.5 dB. **California Eastern Laboratories, Inc., Santa Clara, CA. INFO/CARD #183.**

RF Amplifiers
Amplifier Research

Model 1000L is a broadband RF amplifier that provides 1000 W CW from 10 kHz to 220 MHz. Model 250L has an output of 250 W CW over the same frequency range. **Amplifier Research, Souderton, PA. INFO/CARD #182.**

Linear Power Amplifiers
TRW RF Devices

TRW unveils integrated UHF power amplifiers with power outputs of 5, 10, 25, or 50 W. All models are CW Class A with 800 to 1000 MHz frequency response, 8 dB noise figure and 24 dB to 54 dB minimum gain. 12 W Class C RF transistors with frequency ranges of 2.3 to 2.7 GHz are being introduced. Typical gain of 6.8 dB with greater than 40 percent efficiency over the entire bandwidth is featured. **TRW RF Devices, Lawndale, CA. Please circle INFO/CARD #181.**

RF to Digital Converter
Steinbrecher

The Accuverter™ RF to digital converter converts an RF signal to 16-bit digital data with 30 kHz analysis bandwidth and RF input frequency options from 2 MHz to 100 MHz. **Steinbrecher Corp., Woburn, MA. INFO/CARD #179.**

Low Phase Noise VTOs
Gamma Microwave

The G2300 Series VTOs covers the 1 to 18 GHz range in 1/2 octave bands. It uses bipolar oscillator transistors to provide good phase noise performance. Fast settling of the device is achieved through the use of Si abrupt and hyperabrupt tuning diodes. **Gamma Microwave, Los Gatos, CA. INFO/CARD #174.**

RF/Microwave Connectors
AMP Inc.

AMP Microwave introduces crimp SMA, blind mate, TNC, BNC and various other connectors. **AMP Incorporated, Harrisburg, PA. INFO/CARD #173.**

Micro Inductance Meter
Micoil

This inductance meter measures inductors from 1 nH to 200 mH with an accuracy of 0.2 percent. The meter has optional four point probes that allow testing in-

circuit inductances of microstrip and hybrid micro inductors. It is priced at $3150. The LCD display provides eight scaled ranges from 20 nH to 200 mH full scale. **Micoil Corp., Conway, AR. Please circle INFO/CARD #180.**

RF Pulse Amplifier
American Microwave Technology

Model 3205 delivers 250 W linear power from 6 to 220 MHz with pulse widths over 250 ms. The pulse droop is less than three percent and blanking (turned off) is faster than 5 us. Protection includes over pulse/duty cycle, VSWR and thermal. **American Microwave Technology, Inc., Fullerton, CA. Please circle INFO/CARD #172.**

Oven Controlled Oscillator
Piezo Technology

The Model XO1137 has a $\pm 1 \times 10^{-8}$ stability from –55°C to +95°C. Other features include maximum power consumption of 1.6 W, phase noise of –153 dBc/Hz at 10 kHz offset and $\pm 1 \times 10^{-7}$/year aging. **Piezo Technology, Inc., Orlando, FL. INFO/CARD #171.**

HF Probe Cards
Inter-Logic Systems

Inter-Logic unveils a line of high frequency probe cards suitable for wafer and chip probing of GaAs devices and high speed silicon semiconductors. They may be used in existing probe stations. **Inter-Logic Systems Company, Inc., Garden Grove, CA. INFO/CARD #170.**

Signal Generator
Marconi Instruments

Marconi introduces the Model 2022C with a frequency range of 10 kHz to 1 GHz and output level of +13 dBm. Applications include use as a local oscillator for passive component testing and intermodulation measurements. It also features an auxiliary FM input socket to mix external and internal modulation which provides composite modulation capability for tests on receivers with sub-audible tones on digital signalling systems. **Marconi Instruments, Allendale, NJ. INFO/CARD #169.**

TO-8 Mixer
Watkins-Johnson

The M8TC is a TO-8 mixer packaged in a connectorized housing and operates between a LO and RF of 1 to 3400 MHz and IF of 1 to 2000 MHz with LO power of +10 dBm. High intercept is typically +18 dBm. Conversion loss for low, mid and high range is typically 6.0, 7.0 and 8.0 dB, respectively. **Watkins-Johnson Company, Palo Alto, CA. Please circle INFO/CARD #178.**

Filter-Amplifier Module
Integrated Microwave

IMC introduces a dual output 156-160 MHz filter-amplifier module that has 22 dB gain with 1 dB gain compression point greater than 0 dBm and power limiting ensures less than +15 dBm at the two RF output ports. The passband features 0.25 dB p-p amplitude ripple and 1.3:1 VSWR at both input and outputs. Passband noise figure is 6 dB max. **Integrated Microwave Corp., San Diego, CA. Pleas circle INFO/CARD #177.**

Power Transistor Packaging
Cabot Electronic Ceramics

The RF power transistor packaging from Cabot has efficient heat dissipation at RF and microwave frequencies. Hermetic and non-hermetic ceramic to metal packages are available. **Cabot Electronic Ceramics Inc., Greenville, RI. Please circle INFO/CARD #175.**

SPDT Switch
Dow-Key Microwave

Dow-Key unveils a coaxial SPDT switch that handles 140 W CW up to 10 GHz. It features SMA compatible connectors. **Dow-Key Microwave Corp., Carpinteria, CA. INFO/CARD #176.**

Synthesis Program
EEsof, Inc.

E-Syn™ 2.0 is used for designing lumped and distributed low-pass, high-pass, bandpass and bandstop microwave networks. It is also useful for synthesizing broadband matching circuits as well as filters, transformers, multiplexers, and singly terminated networks including Chebyshev, Butterworth, and elliptic (both equal-ripple and maximally flat) response characteristics. The program includes a distributed element synthesis capability and a response window added to both the lumped and distributed main screens for analyzing the specification window parameters. **EEsof, Inc., Westlake Village, CA. INFO/CARD #168.**

1/2 W Transistor
Amperex Electronic Corp.

The BFG195 has an h_{FE} of 40 and f_T of 7.5 GHz at 50 mA collector current. Noise figure is typically 1.8 dB at 800 MHz and the transistor has a gain of 12 dB at 2 GHz. In 100 piece quantities, the cost is $1.65 each. **Amperex Electronic Corp., Slatersville, RI. INFO/CARD #167.**

Microwave Switches
FL Jennings

TOC miniature microwave switches in TO5 packages are being introduced together with TOH miniature switches to 12 GHz in SMA and PC versions. **FL Jennings Div., FL Industries, Inc., San Jose, CA. INFO/CARD #166.**

Buried Shielding Laminates
Glasteel Industrial Laminates

Glasteel introduces the GST-MC3 buried shielding laminates where copper foil is sandwiched in-between woven fiberglass fabric material which has been impregnated with a polyester/epoxy resin system. **Glasteel Industrial Laminates, Duarte, CA. INFO/CARD #165.**

Low Noise Amplifiers
Optimax Inc.

Cascadable low noise amplifiers with typical noise figures of 1.2 dB and 1.3 dB are being introduced by Optimax. The frequency ranges are 2000 to 2400 MHz and 1200 to 1600 MHz respectively. **Optimax Inc., Hatfield, PA. INFO/CARD #164.**

Portable Spectrum Analyzer
Anritsu America

The MS2601A portable spectrum analyzer has a 10 kHz to 2.2 GHz frequency range with automatic calibration, 30 Hz resolution bandwidth and memory cards. **Anritsu America, Inc., Oakland, NJ. INFO/CARD #163.**

Power Sensor Calibrator
Bird Electronic Corp.

With the Model 4029 power sensor calibrator and a serial terminal or PC with serial port, the Bird 4420 Series power meters can be field calibrated to within ±3 percent of a known RF power standard. Functions include addition and deletion of individual calibration points, clearing of all calibration points and listing of calibration points for review. **Bird Electronic Corp., Solon, OH. INFO/CARD #162.**

uP Controlled Xtal Oscillator Hughes Aircraft

The HAC 3000 Series microprocessor controlled crystal oscillator (MCXO) combines crystal, CMOS and microprocessor technology. The standard MCXO has a frequency range of 3 to 20 MHz with output level of 0 to +3 dBm. The phase noise is −135 dBc at 10 kHz. **Hughes Aircraft Co., RF Products, Newport Beach, CA. INFO/CARD #161.**

Tuning Sticks American Technical Ceramics

The tuning stick is a device that makes on-board capacitor value selection easy. It consists of an ATC radial wire leaded capacitor with its specific value attached to a non-conductive stick. **American Technical Ceramics Corp., Huntington Station, NY. INFO/CARD #160.**

Broadband Power Amplifier Instruments for Industry

I.F.I. unveils the M5580 broadband 10 kHz to 1.0 GHz, 75 watt power amplifier. It may be changed from Band 1 (10 kHz to 500 MHz) to Band 2 (500 MHz to 1.0 GHz) by the toggle switch on the front panel. **Instruments for Industry, Inc., Ronkonkoma, NY. INFO/CARD #159.**

Wide Band Mixer Magnum Microwave Corp.

Model MM94ML/PL-1 covers 2 to 18 GHz on the RF and LO ports and 0.01 to 1.0 GHz on the IF port. The conversion loss is 8.0 dB and the LO/RF and LO/IF isolation are both typically 25 dB. VSWR of all ports is 2.5:1 typical and 3.0:1 maximum. The nominal LO power is +10 dBm and the 1 dB compression point is +4 dBm with the third order intercept point at +13 dBm. **Magnum Microwave Corp., Fremont, CA. INFO/CARD #158.**

Coax to Waveguide Adapter Assembly Huber + Suhner, Inc.

A coax to waveguide adapter assembly incorporating Sucoflex flexible microwave cable increases system reliability by offering a low VSWR, good insertion loss and phase characteristics. It is available for frequency ranges from 3.3 to 26.5 GHz. **Huber + Suhner Inc., Woburn, MA. INFO/CARD #157.**

Graphics Layout Package Compact Software

GaS Station is a PC based graphics layout package used in conjunction with simulation software to design GaAs MMICs, MM wave circuits and optoelectronic components. **Compact Software, Inc., Paterson, NJ. INFO/CARD #156.**

SAW Spectrum Analyzer Phonon Corp

The AS160-10-100(C) MC surface acoustic wave spectrum analyzer has a bandwidth of 10 MHz and resolution of 16 kHz. When supplied with multiple signal channels, it can provide high resolution (5 degrees) angular measurement. **Phonon Corp., Simsbury, CT. Please circle INFO/CARD #155.**

RF Variable Capacitors Polyflon Company

These non-magnetic RF variable capacitors have Q's greater than 5000 and feature PTFE construction. The capacitance range is from under 1 pF to 125 pF.

Polyflon Company, New Rochelle, NY. INFO/CARD #154.

GaAs MMIC VCOs
Pacific Monolithics

PM-OVO6XX-B(1 to 6 GHz) varactor tuned MMIC oscillators come with a MMIC buffer amplifier and a voltage regulator in a 0.270" square surface mountable package. PM-OVO6XX-A (2 to 6 GHz) features the same construction but measures 0.180" square. **Pacific Monolithics, Sunnyvale, CA. INFO/CARD #153.**

Frequency Synthesizer
Comstron Corp.

The FS 2000-18 frequency synthesizer is a microwave source that switches from 10 MHz to 18.4 GHz in less than 1 us with better than 4 Hz resolution and less than −52 dBc spurious content. **Comstron Corp., Melville, NY. INFO/CARD #152.**

ECL Clock Oscillator
Vectron Labs

DIP ECL clock oscillators (Series CO-430) are available at frequencies from 5 to 300 MHz. They are offered in either standard ECL and 100K ECL. Standard stability is ±25 ppm over the 0°C to 70°C temperature range. **Vectron Laboratories, Inc., Norwalk, CT. INFO/CARD #151.**

Receiver Performance Modelling Software
Webb Labs

CommView 1.0 allows receiver performance together with effects of AGC and modulation to be modelled. The user may enter excess broadband discrete noise for each stage. It is priced at $1495 and is tailored for IBM-PC/XT/AT and PS/2 machines. **Webb Laboratories, North Lake, WI. INFO/CARD #150.**

0 dB Conversion Loss Mixer
Synergy Microwave Corp.

This 0 dB conversion loss mixer is termination insensitive at the IF port with RF/LO/IF frequency range of 1 to 500 MHz. It costs $15 in 1000 piece quantities. **Synergy Microwave Corp., Paterson, NJ. INFO/CARD #149.**

Frequency Agile Filters
K & L Microwave

The Model 4HF-X225/X400-T/T frequency agile(hopping) filter utilizes 4 resonant sections and has a half dB bandwidth of 10 MHz with a typical 35 dB bandwidth of ±22 MHz. It measures 1.5" x 6" x 6". Also from K & L is the Model 100 2 X 16 switch matrix that is suited for general purpose switching and actuation of external devices from DC to 50 MHz.

A 6 band selectable channel multiplexer with a frequency range of 850 to 1450 MHz will be shown. **K & L Microwave, Inc., Salisbury, MD. Please circle INFO/CARD #148.**

Microwave Couplers
Aerowave, Inc.

The Series #02 coupler enhances sensitivity and stability of detected signal responses in network analyzers and reflectometer measurement systems for design configurations from 18 GHz to 325 GHz. **Aerowave Inc., Medford, MA. INFO/CARD #147.**

Power Amplifiers
Microwave Power

The LHJ-105 1 W power amplifiers have a frequency range of 6 to 18 GHz. Narrow band units are also available. **Microwave Power, Santa Clara, CA. Please circle INFO/CARD #146.**

Cable Assemblies
Storm Products Co.

Storm Products will be introducing flex microwave cable assemblies. **Storm Products Co., Hinsdale, IL. Please circle INFO/CARD #145.**

Miniature Bandpass Filters
Daden Associates

The frequency ranges for these bandpass filters can be specified from 10 to 3500 MHz. Standard configurations include PC board mounting, microstrip mounting and connectorized versions. Standard designs are based on a 0.05 dB Chebyshev response with other designs such as pseudo-elliptic available to maximize passband and stopband performance. **Daden Associates, Laguna Hills, California. INFO/CARD #144.**

Doppler Radar Filter Set
Microlab/FXR

BP-B93 is a set of five bandpass filters designed for use in doppler radar systems. Specifications include center frequencies of 200 to 300 MHz with a 3 dB bandwidth of 27 MHz and 7 pole Gaussian response. The filters have removable sub- miniature SMA connectors. **Microlab/FXR, Livingston, NJ. Please circle INFO/CARD #143.**

Microwave Sweeper
Integra Microwave Co.

Integra's Source-1 provides an analog sweep from 2 to 20 GHz and a leveled power output of 10 dBm, and harmonic rejection of better than 40 dBc. Mode selection includes F1-F2 sweep, Delta-F sweep, CW, and full band sweep. **Integra Microwave Co., Santa Clara, CA. Please circle INFO/CARD #142.**

Gunn Oscillators
Epsilon Lambda Electronics Corp.

These varactor tunable gunn oscillators provide 50 mW at 95 GHz over a tunable band of 500 MHz with linearity of 10 percent. **Epsilon Lambda Electronics Corp., Geneva, IL. INFO/CARD #141.**

S-Band Amplifier
Armatek

Armatek introduces an S-band amplifier with 43 dB gain, 1.35:1 VSWR and less than 0.7 dB noise figure. **Armatek, Richardson, TX. INFO/CARD #140.**

Gold Metalized FETs
SGS-Thomson Microelectronics

These FET devices have power levels from 5 W to 300 W at 28 V and from 15 W to 300 W at 50 V. Also being introduced is a 200 W gold metalized pulse power transistor. It is optimized for applications from the 1030 to 1090 MHz. **SGS-Thomson Microelectronics, Montgomeryville, PA. INFO/CARD #139.**

Microwave Amplifiers
Omega Microwave

Omega introduces amplifiers in miniature packages with frequency ranges from 6 to 18 GHz. **Omega Microwave, San Jose, CA. INFO/CARD #138.**

Programmable Spectrum Analyzer
Tektronix

The Tektronix 2754P has a frequency range of 50 kHz to 21 GHz with resolution bandwidth of 1 MHz to 1 kHz in decade steps. Features include frequency accuracy of 1×10^{-5}, direct keypad entry, direct plotter output, microwave preselection, and phaselock stability. It is priced at $19,900. **Tektronix, Inc., Beaverton, OR. INFO/CARD #137.**

Silicon Monolithic Amplifier
Motorola

Motorola is introducing a wideband (100 MHz to 1 GHz) silicon monolithic amplifier that is designed primarily for transmitter exciters. It has gain greater than 24 dB and power output range of 250 mW to 700 mW. The MHW2000 is a 50 ohm gain block offered in a TO-12 metal can package. The MHW2001 is the same die in a planar four-lead package, while the MHW2002 is the same die in a surface mount package (SO-8). Sample quantities are available for $28 each.

The MRF650 wideband power amplifier offers 50 watts of output power and is characterized from 400 to 512 MHz with a load mismatch of up to 20:1 at any angle. Pricing at the 100-up level is $23.90. MRF10120 is designed for pulsed applications such as JTIDS and Mode S. It delivers 120 W when used from 960 MHz to 1215 MHz, operates from a 36-volt supply and has a typical gain of over 9 dB. In 100+ quantities, it costs $361. **Motorola Inc., Semiconductor Products Sector, Phoenix, AZ. INFO/CARD #130.**

Connector Catalog
Applied Engineering Products

This catalog covers subminiature coaxial connectors which includes SMA, SMB, and SMC. A cross reference section together with assembly instructions is included. **Applied Engineering Products, New Haven, CT. INFO/CARD #136.**

SAW Oscillators
RF Monolithics

A companion receiver for the microtransmitter line has been developed using third generation SAW technology. Demonstration kits are available for both the transmitter and receiver devices. **RF Monolithics, Inc., Dallas, TX. Please circle INFO/CARD #135.**

Power Amplifiers
Epsco

The Model BMO250F040 miniature power amplifier delivers 40 W (min) of unsaturated power over a frequency band of 20 to 500 MHz. This Class AB linear amplifier has a typical gain of 47 dB. **Epsco, Inc., R.F. Division, Westlake Village, CA. INFO/CARD #134.**

ECL Oscillators
Oscillatek

Oscillatek introduces an expansion to their EM1100 Series, ECL compatible clock oscillator line. This expansion raises the upper frequency available in a 14-pin package to 350 MHz. Other features include a frequency stability of ±50 ppm absolute and power consumption of less than 200 mW. **Oscillatek, Olathe, KS. INFO/CARD #133.**

Passive Components
ARRA

ARRA is featuring a line of passive components such as attenuators, power dividers, phase shifters, 90 degree and 180 degree hybrids, and directional couplers. **ARRA, Inc., Bayshore, NY. Please circle INFO/CARD #132.**

UHF Isolators
Pamtech

High power UHF isolators with a bandwidth of 10 MHz and frequency range of 225 to 400 MHz will be unveiled. The isolation is 25 dB, insertion loss is 0.3 dB and VSWR is 1.5:1. Power is 50 W CW and 20 W reflected. **Pamtech, Camarillo, CA. INFO/CARD #131.**

VCO With Constant Tuning Rate

Synthesized Reactance Offers Linear Fine Tuning.

By Victor Koren
Tadiran (R & D)

In frequency synthesizers there is a need for an oscillator with two frequency controls: coarse and fine. Another requirement is constant tuning rate of the fine frequency control, not affected by the coarse tuning. The two common solutions are 1) to use a varactor for the fine frequency tune, and to switch different inductors, or 2) to use several oscillators for smaller frequency bands. The two approaches have problems since inductances in parallel do not add algebraicly, so it is not possible to get every value of inductance with few switched inductors, and switching between oscillators is cumbersome and expensive. In this paper the author shows a way that will allow the use of a varactor or switched capacitors as coarse tune control, and a special circuit to do the fine tuning.

The purpose of the circuit is to synthesize a variable reactance. The synthesis is done by taking a sample of the oscillator's tank circuit current, and injecting part of it back to the resonant circuit, as in Figure 1. Loading of the resonant circuit is avoided by using a high transformation ratio of the current transformer connected to a low input impedance amplifier and by using a high output impedance amplifier.

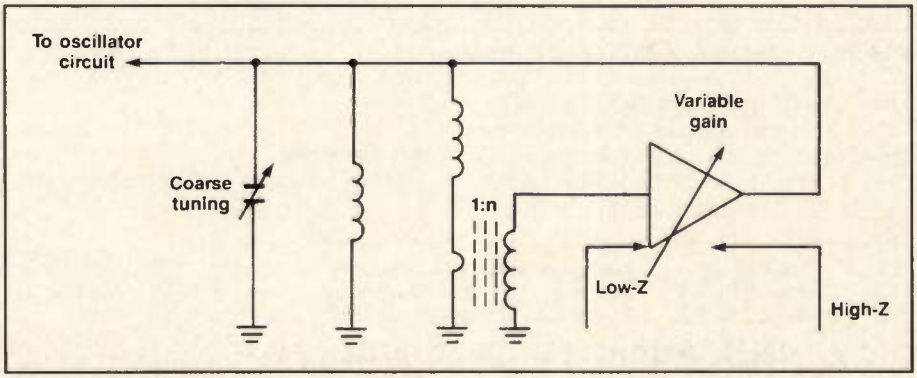


Figure 1. The basic block diagram.

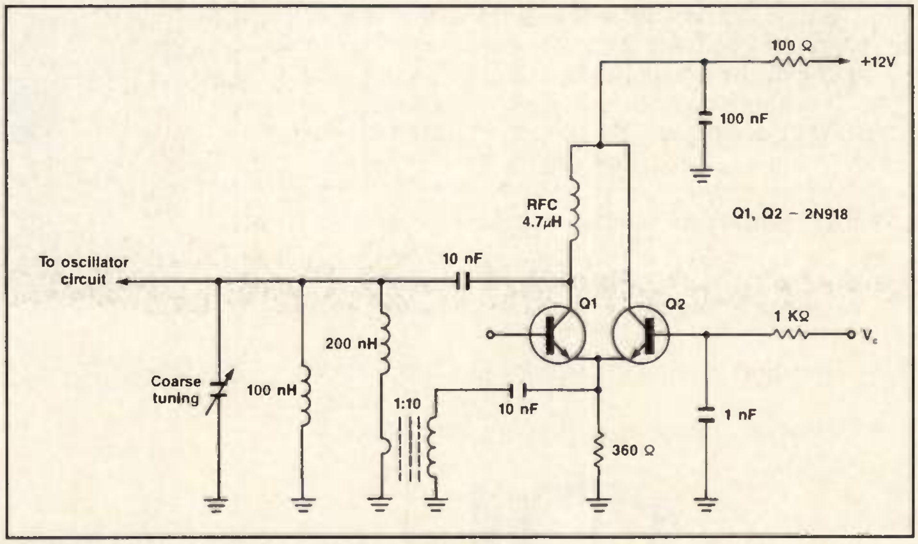


Figure 2. The complete circuit diagram.

Circuit Description

Sampling of the tank current is done by connecting a current transformer in series with part of the tank's inductance (see Figure 2). The sample current is connected to the emitters of a differential pair Q_1, Q_2. The current is divided between Q_1 and Q_2, depending on the control voltage V_c. The AC current that passes through Q_1 is injected back into the tank circuit. This current is in phase or anti-phase with the inductor current, so the tank sees the circuit as another reactance, inductive or capacitive, according to the direction that the current transformer is connected. The polarity of the VCO gain also changes according to the transformer polarity. The VCO gain is correlated to the differential gain of Q_1 and Q_2, so it can be changed by inserting resistors in series with the emitters, or by

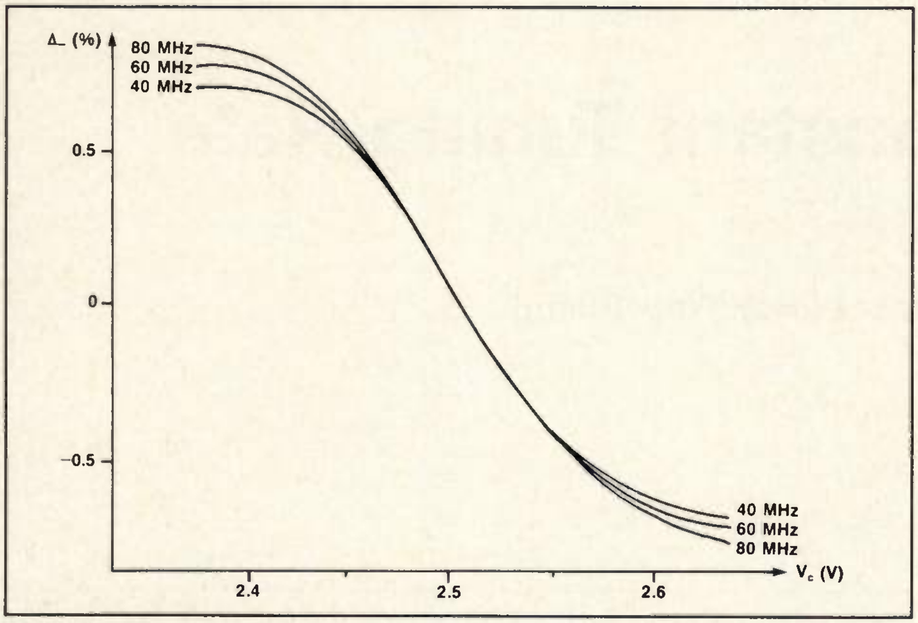


Figure 3. Measured frequency change.

changing Q_1 and Q_2 to FETs. The peak AC current into the amplifier has to be lower than the DC current into the emitters, to ensure linear operation of the circuit.

An Example

In Figure 2, the current sampling is in series with an inductive branch. A third of the tank current flows through this branch. The current transformer ratio is 1:10, so the sampled current is about 3 percent of the tank current. If all the sampled current is injected back to the tank, a change of 3 percent of the total inductance occurs with frequency change of about 1.5 percent.

Figure 3 shows the measured frequency change, percentage of F_o, vs. control voltage V_c, at three center frequencies of 40 MHz, 60 MHz and 80 MHz. The total frequency change is close to 1.5 percent. The measured oscillator voltage was about 1 V_{rms} across the tank circuit. At 40 MHz, the sampled current is the largest, and is about 2.8 mA peak and the DC operating current into the emitters is 5 mA. Hence, the circuit is in a linear operating point. rf

About the Author

Victor Koren is a project engineer at Tadiran, P.O. Box 267, Holon 58102, Israel. He holds a BScEE from Tel Aviv University.

Equal-Ripple LC Filter Synthesis

By Robert E. Kost
Control Data Corporation

A computer program that synthesizes low pass LC filters with equal-ripple passband and an arbitrary stopband attenuation specification is described. Chebyshev filters (equal-ripple passband and monotonically increasing stopband) and elliptic filters (equal-ripple passband and equal-ripple stopband) are special cases that can be designed with this synthesis program.

Possible uses of this program include reducing the stopband attenuation at high frequencies to reduce the passband phase shift (as compared to an elliptic filter which has a constant stopband specification) and specifying very high attenuation at specific frequencies to suppress parasitic oscillations.

The design begins with the passband ripple specification (or alternatively, the reflection coefficient) and the stopband attenuation requirements. The program has three parts: approximation, computation of the necessary immitance functions and the computation of the element values (realization).

The approximation (calculating the critical frequencies from attenuation requirements) portion of the program uses an iterative scheme described by Smith and Temes (1). This portion of the program adjusts the finite transmission zeros, if there are any, while constraining the passband to have equal-ripple attenuation characteristics. This is done to force all the minimum differences between the actual attenuation and the specified attenuation to be equal. This minimum difference is referred to as the *attenuation margin*. Any reduction in the filter order would result in a negative attenuation margin and the reduced order filter would not meet the required specification. It should be emphasized that equal-ripple filters are the most efficient in the sense of having the minimum number of elements for a specific attenuation requirement. The price paid for this efficiency is relative high phase distortion near the passband edge. Figure 1 illustrates the filter attenuation specification nomenclature.

The immitance functions are computed using a method outlined by Orchard and Temes (2). They use a transformed variable rather than the s-plane variable as is used in introductory discussions of filter synthesis. The reason for this transformation is that polynomials can be very ill-conditioned. That is, the roots of a poly-

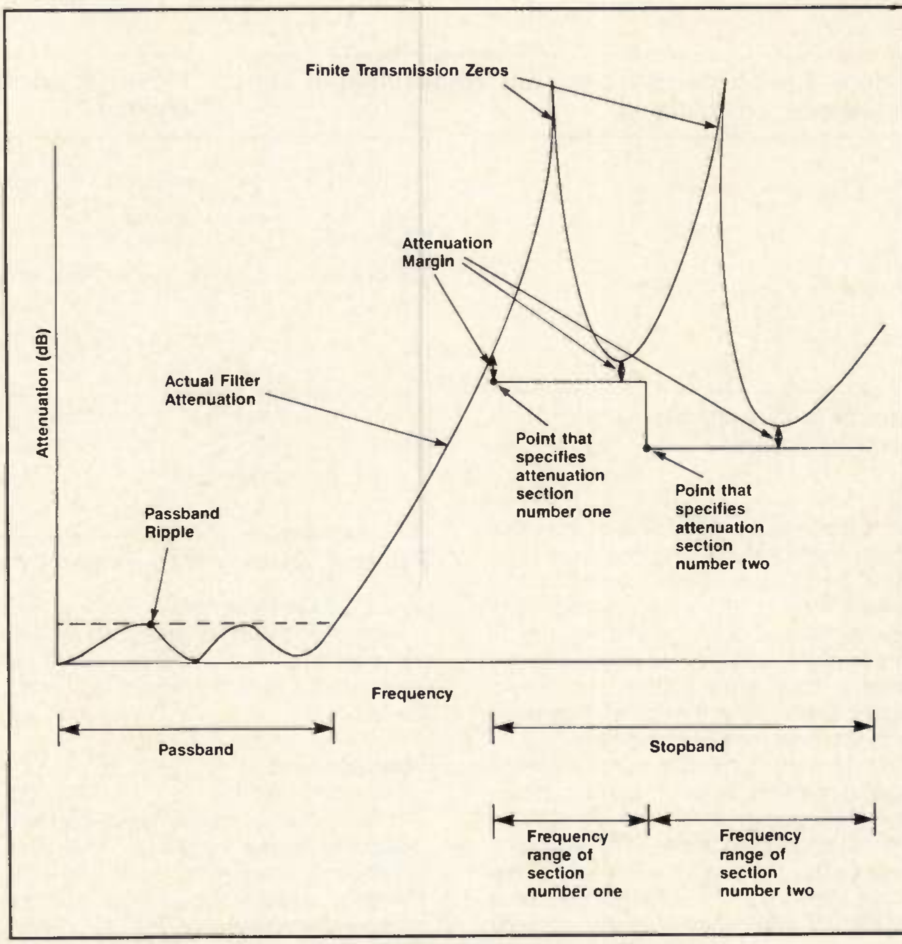


Figure 1. Nomenclature for the passband and stopband.

```
••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
:   L O W    P A S S    F I L T E R    S Y N T H E S I S   :
:                          - - - -                          :
:                   Equal Ripple Passband                   :
:               Piecewise Constant Stopband                 :
••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••

Divide the stopband attenuation requirements into piecewise constant sections.
The sections will be numbered sequentially with increasing frequency.

ENTER THE NUMBER OF PIECEWISE CONSTANT STOPBAND SECTIONS. - - - - - 1

Each section is defined by its lowest frequency (arbitrary units)
and its attenuation (dB).  The specific frequency units,
i.e. kilohertz or megahertz, will be entered later.

  ENTER THE LOWEST FREQUENCY AND ATTENUATION OF SECTION # 1  - - - - 5.0,30

ENTER THE BANDEDGE FREQUENCY - - - - - - - - - - - - - - - - - - - - 2.0
ENTER THE PASSBAND RIPPLE(dB) OR THE REFLECTION COEFFICIENT(%) - - - .25

ENTER THE INITIAL NUMBER OF TRANSMISSION ZEROS AT INFINITE FREQUENCY 1
```

Figure 2. The initial terminal display after passband and stopband specifications are entered.

```
The input frequency and attenuation specifications are:
Section #   1     5.000   30.00

The bandedge frequency is - - - - - - - - - - - - - - - - - -   2
The passband ripple is  - - - - - - - - - - - - - - - - - - -   .25 dB
The number of zeros at infinite frequency is  - - - - - - - -   1

The zero locations are:

   # 1   5.712617

The attenuation margin is     4.57 dB

ENTER <CR> TO COMPUTE NATURAL MODES
      T TO TERMINATE THE PROGRAM     ---------------------
```

Figure 3. The display after the approximation calculation is complete.

```
ENTER THE SEQUENCE OF ZERO REMOVAL  1


THE LOCATIONS OF THE NATURAL MODES IN THE SECOND QUADRANT AND THEIR
RESPECTIVES Q'S ARE:

         REAL              IMAGINARY             ZERO FREQ.             Q

      0.3440386            1.1016041            1.1540772              1.7
      0.8223233            0.0000000            0.8223233              0.5

NOTE: THESE LOCATIONS ARE NORMALIZED TO THE PASS BAND EDGE


ENTER 1 FOR SINGLY TERMINATED LC FILTER
      2 FOR DOUBLY TERMINATED LC FILTER
                                                            * * * * * * *  2
```

Figure 4. Display before termination instruction is entered.

Figure 5. Circuits along with their code numbers.

```
CODE #1 -- Shunt capacitor followed by a parallel combination of a
           capacitor and inductor in series (must be followed by code #2)
CODE #2 -- Shunt capacitor
CODE #3 -- Series inductor

ENTER THE CODES FOR THE FILTER STRUCTURE
1,2

WHAT IS THE INPUT IMPEDANCE (OHMS)
? 100

ENTER THE FREQUENCY UNITS
       R  -- RADIANS PER SECOND
       H  -- HEBTZ
       K  -- KILO-HERTZ
       M  -- MEGA-HERTZ
? m
```

Figure 6. Display with frequency entered.

nomial can be very sensitive to the value of the coefficients of the polynomial. Dalquist (3) gives a specific example of a relative error of 10^{10} of a polynomial coefficient that results in a relative error of .18 in one of the roots of that polynomial. As a result, there are examples of filter synthesis calculations that cannot be done with the precision of computers.

There are two solutions to this ill-conditioning problem. One is to perform a conformal mapping on the s-plane variable that is referred to above. This mapping causes the roots of polynomials to become widely separated and results in a significant improvement in the ill-conditioning of the polynomials. This is the approach used by Orchard and Temes and is used in this article.

Another solution is to avoid using polynomials altogether and do all the manipulation with factors of the polynomials. The combined use of these methods results in excellent ill-conditioning properties and is used, among other places, in a synthesis program called *S/FILSYN*. Only the transformed variable approach is used in the program that is described here. Since the transformed variable is used, this program can synthesize LC ladder filters up to the fifteenth order.

The realization portion of the program computes the element values from the immitances that were computed in the second part of the program. This procedure uses the transformed variable for the calculation of the element values, thereby, preserving the precision that was gained by using the more complicated approach to compute the immitances.

Use Of The Program

The program will be illustrated by several examples. The first example will be done in detail while the others will be abbreviated.

Example One

Passband ripple	.25 dB
Passband edge frequency	2.0 MHz
Stopband lower frequency	5.0 MHz
Stopband attenuation	30.0 dB
Source resistance	100 Ohms
Doubly terminated	

The number of stopband sections in this example is one (1) since the stopband is describable by a single frequency and attenuation (Figure 2). Therefore, the first entry appears as:

ENTER THE NUMBER OF PIECEWISE CONSTANT STOPBAND SECTIONS — 1

The next entry describes the lowest frequency and attenuation point of the stopband section. For this example this entry is 5.0 MHz and 30 dB. The frequency units of the first entry of the frequency-attenuation pair will be entered near the end of the program. The second entry is:

ENTER THE LOWEST FREQUENCY AND ATTENUATION OF SECTION #1 — 5.0,30

The following entry is the passband edge frequency which is 2.0 MHz. The same units for frequency are used here.

ENTER THE BANDEDGE FREQUENCY — 2.0

The passband ripple specification is entered at this point. This entry has units of percent or dB. If the entry is less that one, the units are interpreted as dB, otherwise the entry is read as percent. The relation between the two units is:

dB = −10 log (1 − (reflection coefficient(%)/100)^2)

Either an entry of .25 for the decibel units or 23.651 for the reflection coefficient in percent give the same results. For this example the next entry is:

ENTER THE PASSBAND RIPPLE (dB) OR THE REFLECTION COEFFICIENT % — .25

The number entered for the initial number of transmission zeros at infinite frequency plays a significant role in the final structure of the filter as it specifies the minimum order of the filter. Since the filter transfer function is a ratio of polynomials, the number of zeros at infinite frequency is the difference between the degree of the denominator polynomial and the numerator polynomial. Increasing the value of this entry reduces the number of finite transmission zeros since each finite transmission corresponds to a second

```
   CAP(FARADS)             IND(HENRIES)              ZERO FREQ.
C( 1)=.967715D-09              - - - -
C( 2)=.944023D-10        L( 2)=.822219D-05               5.713
C( 3)=.967715D-09              - - - -

LOAD IMPEDANCE =0.1000D+03 OHMS


A:\>
```

Figure 7. The final display.

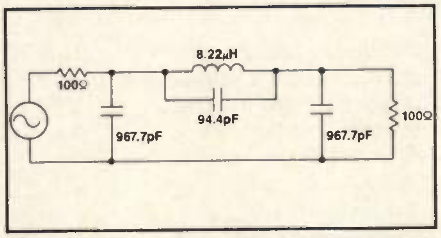


Figure 8. Third order filter from example 1.

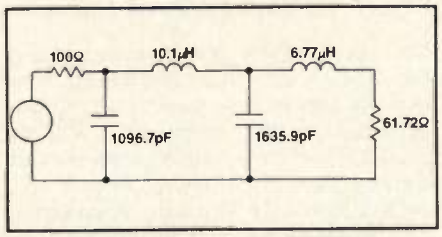


Figure 9. Filter from example 2.

order term in the numerator of the transfer function.

If a one is entered at this point, the number of zeros at infinite frequency in the final filter design cannot exceed two and the attenuation of filter in stopband will be adjusted by adding finite transmission zeros. The number of finite transmission zeros can be reduced by increasing this initial value. Any integer less than fifteen or greater than zero may be entered. The entry for this example is:

ENTER THE INITIAL NUMBER OF TRANSMISSION ZEROS AT INFINITE FREQUENCY 1.

Figure 2 shows the display after the passband and stopband specifications are entered and Figure 3 shows the completed approximation calculation.

The specification is met with a third order filter, which has a single finite transmission zero at 5.7126 MHz and the attenuation margin is 4.57 dB. The actual minimum attenuation in the stopband is therefore 34.57 dB. The synthesis program continues when the carriage return key is depressed.

The finite transmission zeros are realized as a parallel combination of an inductor and capacitor in a series branch of the filter. The resonant frequency of this pair will not allow signals at that frequency to pass thereby creating a transmission zero. A filter can have several different finite transmission zeros and they can appear in the filter in any order.

The next information to be entered involves the sequence in which the transmission zeros will appear in the filter. Filters with different element values can be designed by varying this sequence. The transmission zeros are numbered sequentially as shown in Figure 3. Since there is only a single zero in this example, which is labeled "#1," enter a single one (1) in response to the instruction calling for the sequence of transmission zeros. The entry is shown below:

ENTER THE SEQUENCE OF
ZERO REMOVAL 1

After the zero removal sequence has been entered, the terminal screen will appear as shown in Figure 4. The natural modes are computed and displayed along with the pole frequency (the distance from the s-plane origin to the pole location) and the pole "Q" (defined as the pole frequency divided by two times the real part of the pole location).

Either singly or doubly terminated filters may be designed. A doubly terminated filter will require a voltage source with some specified source resistance and it will require a resistor at the output of the filter. The value of this resistor is computed and displayed. If the singly terminated version is chosen, there will not be a resistor at the filter output and the filter will have to be connected to a circuit with high input impedance. For this example, the next entry is:

ENTER 1 FOR SINGLY TERMINATED
LC FILTER
2 FOR DOUBLY TERMINATED
LC FILTER — 2

The next phase of the synthesis requires the specification of the filter structure, the impedance of the source, and the units used for the frequency specification. Filter with normalized units may be designed by specifying radians per second for frequency units and one ohm for the source impedance. The code numbers used to construct the filter are shown in Figure 5.

Filter structure #1 is a shunt capacitor followed by a parallel combination of an inductor and capacitor in series. This type of filter section is used to create a finite transmission zero (the parallel inductor and capacitor) and a portion of a zero at infinite frequency (the shunt capacitor). Filter structure #2 creates a transmission zero at infinite frequency. This is roughly equivalent to the capacitor becoming a short at that frequency. Filter structure #3 is a series inductor. This section also creates a zero at infinite frequency. An example of using these structures to create a third order filter would be to have a structure sequence #2, #3, #2. This creates three zeros at infinite frequency and would corresponds to a transfer function where the numerator is a constant and the denominator is a third order polynomial. That particular kind of filter is referred to as a all pole filter since it has no finite transmission zeros. A third order filter with a single transmission zero is constructed with the structure sequence #1, #2. The parallel combination of the capacitor and the inductor create the finite transmission zero. The capacitors that precede and follow that pair create the transmission zero at infinite frequency. The entry for this example is:

ENTER THE CODES FOR THE
FILTER STRUCTURE 1,2

The source impedance of the generator driving the filter was specified as 100 ohms in the initial specification. The next entry will appear as follows:

WHAT IS THE SOURCE
IMPEDANCE (OHMS)
? 100

The frequency units for this example are MHz. Therefore the next entry will appear as:

ENTER THE FREQUENCY UNITS
R — RADIANS PER SECOND
H — HERTZ
K — KILO-HERTZ
M — MEGA-HERTZ
? M

The filter structure codes, the source impedance and the frequency units are entered as shown in Figure 6. The element values of the filter are shown in Figure 7. A schematic of the filter with the source and load resistors are shown in Figure 8.

Example Two

This example will have the same attenuation specification as the first example. However the synthesis will be done

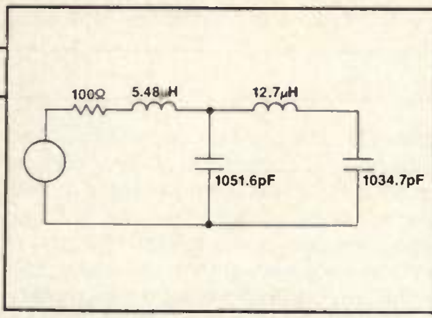


Figure 10. Filter from example 3.

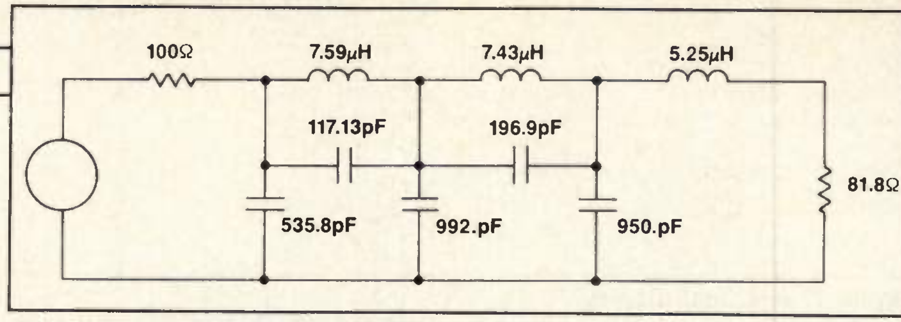


Figure 11. Schematic of example 4.

with four transmission zeros at infinite frequency. This will lead to an odd order filter without any finite transmission zeros. The data entered sequentially is:

number of stopband sections	1
attenuation specification	5.0,30
passband edge frequency	2.0
passband ripple	.25
zeros at infinite freq.	4
structure codes	2,3,2,3
doubly terminated	2
source resistance	100.
units for the frequency	M

The resulting filter has a 6.14 attenuation margin and has a structure shown in Figure 9.

Example Three

This example is the same as example two except that the filter is singly terminated. Use the structure code 3,2,3,2. Note that this filter must end with a shunt component. If the last component is a series element, current is unable to flow through it since a singly terminated filter is connected to a load of infinite impedance. This is equivalent to reducing the order of the filter by one and the filter structure would be inconsistent with the approximation.

Example Four

This example will require 70 dB attenuation at 5.34 MHz ±2% in addition to a 50 dB requirement for the rest of the stopband. The data to be entered sequentially is:

number of stopband sections	3
attenuation specification #1	4.0,50
attenuation specification #2	5.23,70
attenuation specification #3	5.45,50
passband edge frequency	2.50
reflection coefficient	10
zeros at infinite freq.	1
sequence of zeros	2,1
structure codes	1,1,2,3
doubly terminated	2
source resistance	100.
units for the frequency	M

The resulting filter has a 4.99 dB attenuation margin. The finite transmission zeros are 4.159 MHz and 5.337 MHz. The schematic is shown in Figure 11.

Example Five

This example illustrates an attenuation requirement that is reduced at high frequencies. This attenuation reduction results in a reduced order filter as compared

INFO/CARD 67

to one that has constant attenuation at stopband. Also, the sequence of finite transmission zeros in the filter is varied.

number of stopband sections	2
attenuation specification #1	1.5,60
attenuation specification #2	2.0,40
passband edge frequency	1.25
passband ripple	.10
zeros at infinite freq.	1
sequence of zeros	2,1,3
structure codes	1,1,1,2
doubly terminated	2
source resistance	100.
units for the frequency	M

The resulting filter is shown in Figure 12.

The same filter as in example number five is used except with the zero sequence changed to 1,2,3 as shown in Figure 13. The permutation of these three transmission zeros will give rise to six different filters. Half of these will be duplicates of others with the filter reversed. Therefore, there are three different realizations possible with this filter.

Circuit Analysis

After the filter synthesis is completed, it is important to analyze the filter to verify that the synthesis is done correctly. The approach taken by Wyatt (5) is ideal for ladder structures. The result of using the chain matrix to compute the attenuation of the filter designed in example four is shown in Figure 14. The scale used for the passband is different than the one used in the stopband to show the details of the passband.

Summary

A computer program that designs equal-ripple lowpass filters with flexible stopband requirements has been described. It is possible to specify the sequence that the transmission zeros occur in the filter. Thus it is conceivable to design all equal-ripple lowpass filter realization with this program.

The algorithms used for the approximation and realization make use of nonlinear optimization and a transformed variable is used to improve the numerical precision of the synthesis process. Several examples of filter synthesis are given.

The program was developed on an IBM personal computer under the DOS 2.0 operating system. An executable version is available on a flexible disk for $10 to cover the expenses of materials, handling and postage. Send request to Robert Kost, 4858 Colfax Avenue South, Minneapolis, MN, 55409.

References

1. Smith and Temes, "An Iterative Ap-

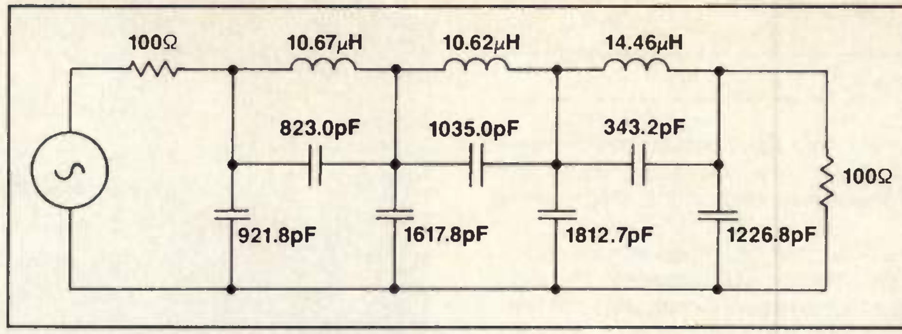


Figure 12. Filter from example 5.

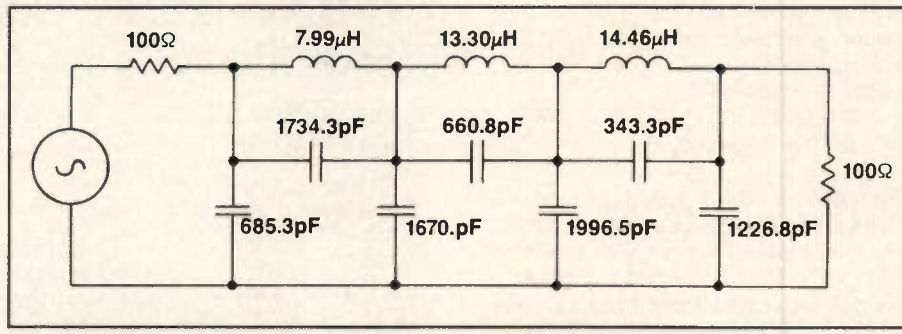


Figure 13. Example 5 with a transmission zero sequence of 1, 2, 3.

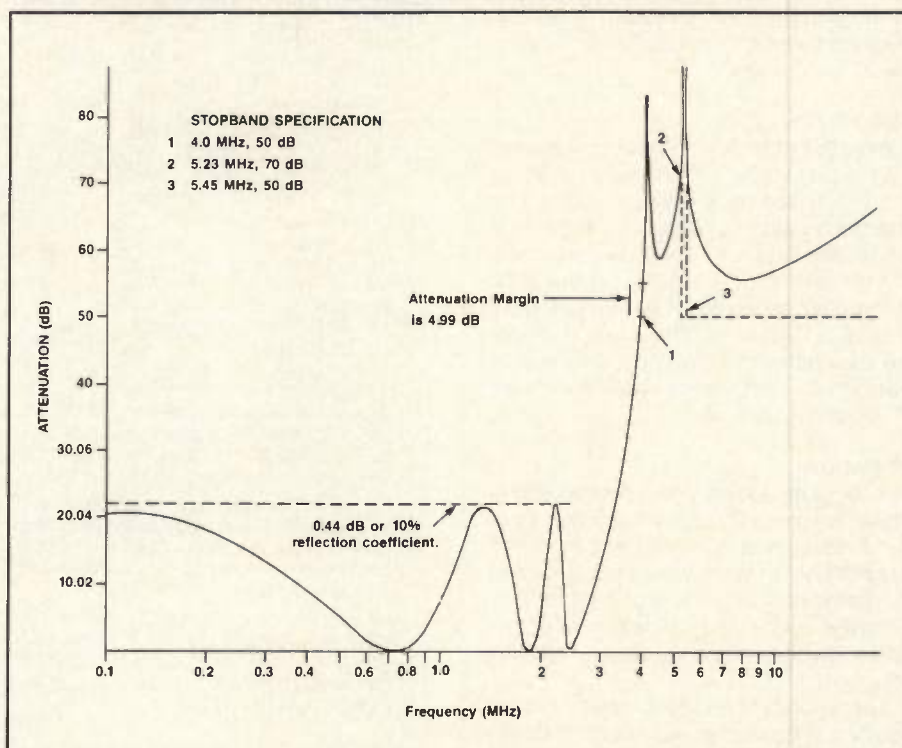


Figure 14. Response of filter in example 4.

proximation Technique For Automatic Filter Synthesis," *IEEE Trans. on Circuit Theory,* Vol. CT-12, pp. 107-112, March 1965.

2. Orchard and Temes, *IEEE Transactions on Circuit Theory,* Vol. CT-15, pp. 385-408, December 1968.

3. Dahlquist and Bjork, *Numerical Methods,* p. 246, Prentice Hall, 1974.

4. Temes and LaPatra, *Circuit Synthesis And Design,* pp. 123-193, McGraw Hill, 1977.

5. Wyatt, "A Ladder Program Analysis Program," *RF Design,* November 1986.

About the Author

Robert Kost is Manager of the Signal Processing Group at Magnetic Peripherals, Inc., Control Data Company, 7801 Computer Avenue South, Minneapolis, MN 55435. He holds a Ph.D. in Physics. His telephone number is (612) 830-6109.

Feedforward Compensation for Improved DC Performance

By Stan Goldman
Scientific Communications, Inc.

DC coupled video amplifiers with wide bandwidths, low DC offset voltages, and low noise figures are used in radar systems, test instruments, and phase noise measurement equipment. Unfortunately, wide bandwidth amplifiers have poor offset performance because of their low DC gain. This article discusses the use of feedforward compensation using a high DC gain low frequency amplifier to correct DC offsets of wide band amplifiers.

Many of the systems mentioned use A/D converters to detect and convert signals to digital words for processing by a computer. Video amplifiers are required between the system's receiver and A/D converter to amplify the received signal to an optimum conversion level for the A/D converter. A/D converters with increased speed and accuracy require a small DC bias offset in video amplifiers

	TRANSFORMATION	EQUATION
1	COMBINING BLOCKS IN CASCADE	$Y = (P_1P_2)X$
2	COMBINING BLOCKS IN PARALLEL; OR ELIMINATING A FORWARD LOOP	$Y = P_1X \pm P_2X$
3	REMOVING A BLOCK FROM A FORWARD PATH	$Y = P_1X \pm P_2X$
4	ELIMINATING A FEEDBACK LOOP	$Y = P_1(X \mp P_2Y)$
5	REMOVING A BLOCK FROM A FEEDBACK LOOP	$Y = P_1(X \mp P_2Y)$
6a	REARRANGING SUMMING POINTS	$Z = W \pm X \pm Y$
6b	REARRANGING SUMMING POINTS	$Z = W \pm X \pm Y$
7	MOVING A SUMMING POINT AHEAD OF A BLOCK	$Z = PX \pm Y$
8	MOVING A SUMMING POINT BEYOND A BLOCK	$Z = P[X \pm Y]$

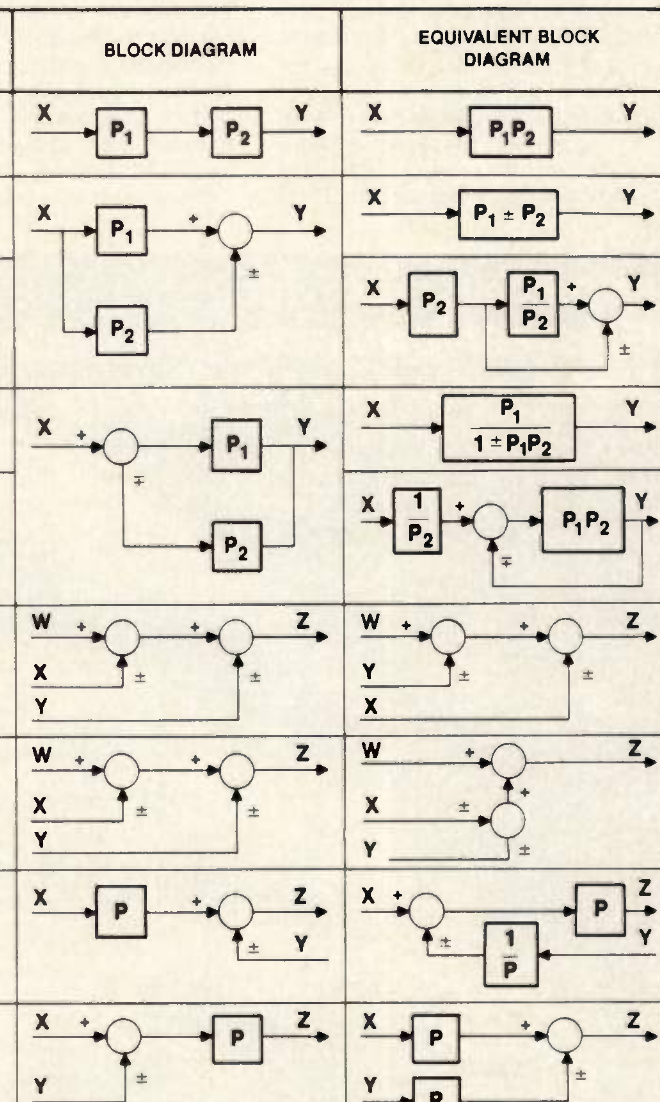


Figure 1. Block diagram transformation theorems that are used in the analysis.

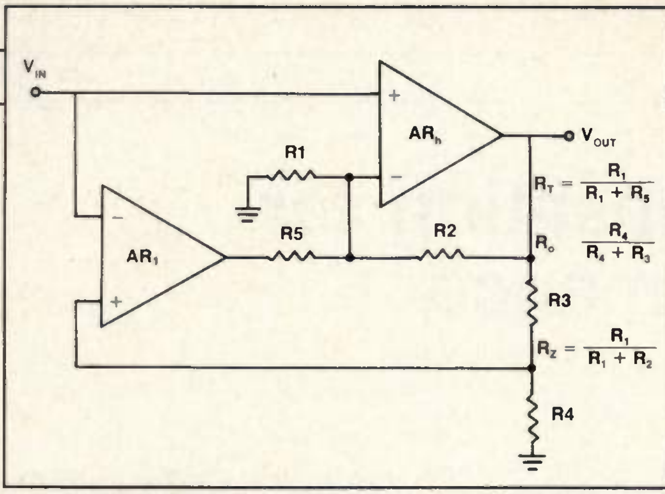


Figure 2. Schematic of feedforward compensation.

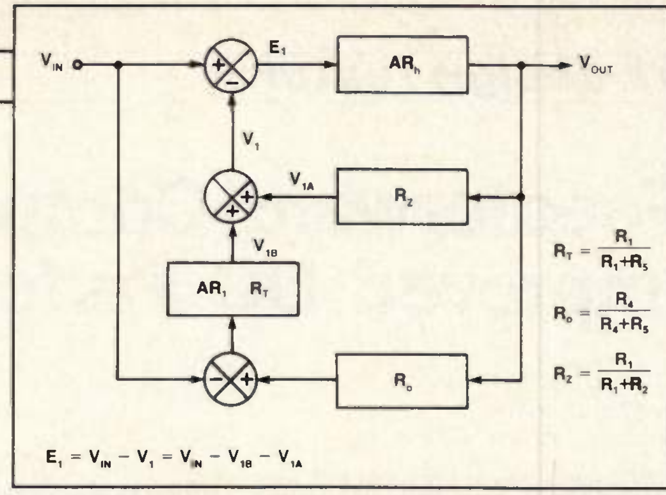


Figure 3. Block diagram of feedforward compensation.

while requiring large amplifier bandwidths to preserve the received signal. Proper phase detection in phase noise measurements require low DC offset performance from a video amplifier to preserve phase information.

To analyze the feedforward circuit configuration, block diagram transformation theorems are presented to reduce a complex circuit to a simple one. The block diagram transformations that are used in the following analysis are shown in Figure 1 with a complete list shown in Reference 2. A simplified video amplifier circuit is analyzed to show the improved DC performance using the high DC gain low frequency amplifier.

Figure 2 shows the schematic of the circuit to be analyzed, while Figure 3 shows the block diagram representation. Most techniques to analyze feedback circuits require the feedback loop to be broken so that the open loop transfer function can be calculated. Since it is unclear from Figure 3 as to where the loop should be broken, block diagram transformations are used. Figures 4 through 7 show the block transformation that occur after applying each transformation theorem. First the summing points are rearranged with the result shown in Figure 4. A summing point is moved beyond a block and summing points are rearranged (Figure 5). The equations at the bottom of Figure 5A and 5B are aids that reduce the confusion in rearranging summing points. A forward loop is eliminated and a summing point is moved ahead of a block as shown in Figure 6. The existence of a parallel feedback loop is now demonstrated in Figure 6. This was not apparent from looking at the original circuit. The parallel feedback

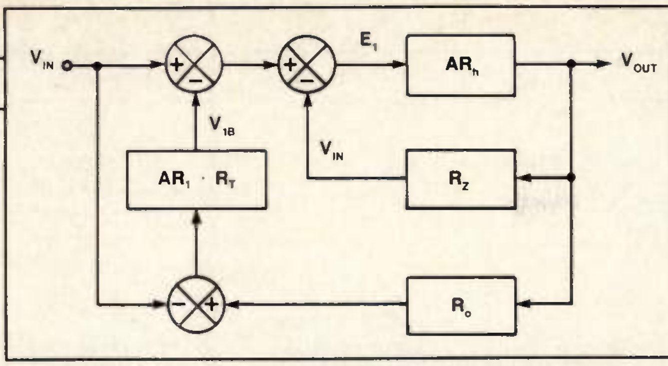


Figure 4. Results from using transformation 6B in Figure 1.

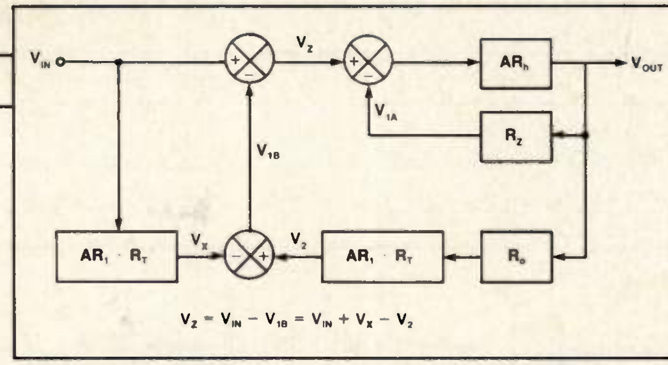


Figure 5A. Results after using transformation 8.

loop is eliminated and the results are shown in Figure 7.

The closed loop transfer function can be calculated from the control system theory shown in Equation 1 because the algebraic reduction technique has identified the forward transfer function and the feedback transfer function:

$$C/R(s) = G(s)/(1 \pm G(s) \cdot H(s))$$

where:

$-$ = positive feedback

$+$ = negative feedback

C/R(s) = closed-loop transfer function

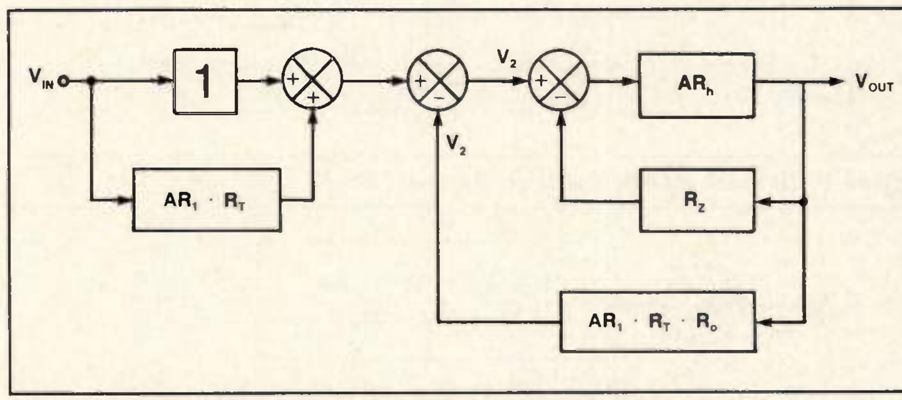


Figure 5B. results from rearranging summing points.

G(s) = forward transfer function

H(s) = feedback transfer function

G(s)·G(s) = open-loop transfer function

G(s)·H(s) = 1 and 0 degrees is the condition for oscillation for positive feedback and 1 and 180 degrees is the condition for oscillation for negative feedback.

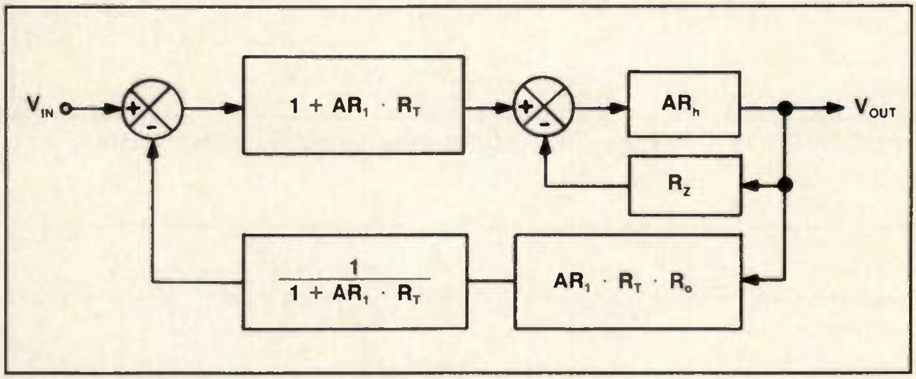


Figure 6. Block diagram showing parallel loops.

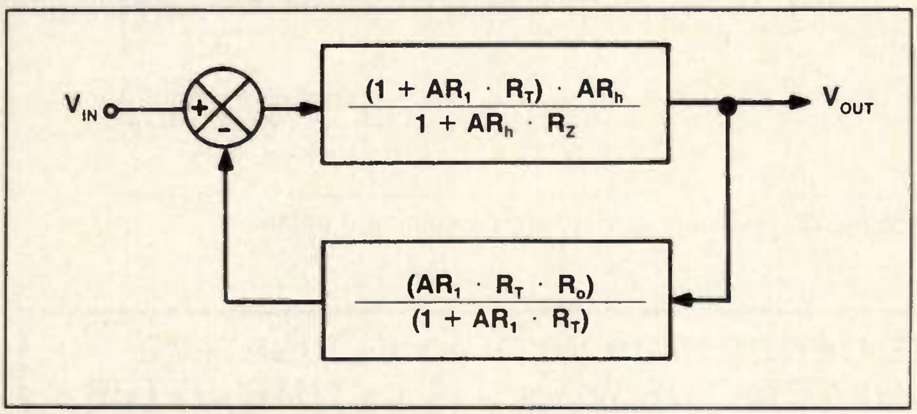


Figure 7. Results from eliminating parallel feedback loops.

$$\frac{\text{Output voltage}}{\text{Input voltage}}(s) = \frac{G(s)}{1+G(s)\cdot H(s)} \quad (1)$$

The forward transfer function and the feedback transfer function are substituted into Equation 1. This results in Equation 2, which is the closed loop transfer function for the parellel amplifier circuit.

$$\frac{V_{OUT}}{V_{IN}} = \frac{(1+AR_1 \cdot R_T)\cdot\left(\frac{AR_h}{1+AR_h \cdot R_Z}\right)}{1+\left(\frac{AR_h}{1+AR_h \cdot R_T}\right)\cdot(AR_1 \cdot R_T \cdot R_o)} \quad (2)$$

In order to calculate the actual response from Equation 2, the transfer characteristics of the operational amplifiers must be modeled. This was accomplished using Bode plot analysis and the operational amplifier's data sheets. The low frequency amplifier, Precision Monolithic's OP-02, had a 1 pole response, while the high frequency amplifier, Comlinear CLC-103, had a 3 pole response. Equation 3 is a mathematical model of the low frequency amplifier and Equation 4 is a mathematical model of the high frequency amplifier.

$$AR_1 = \frac{A_l}{1 + j\left(\frac{F}{F_1}\right)} \quad (3)$$

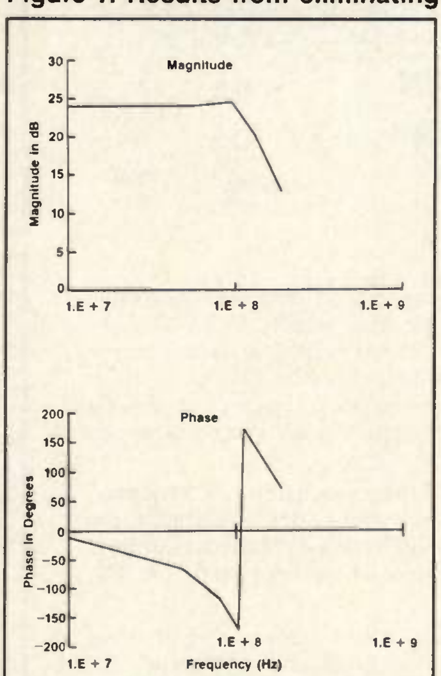


Figure 8. Measured magnitude and phase of video amplifier.

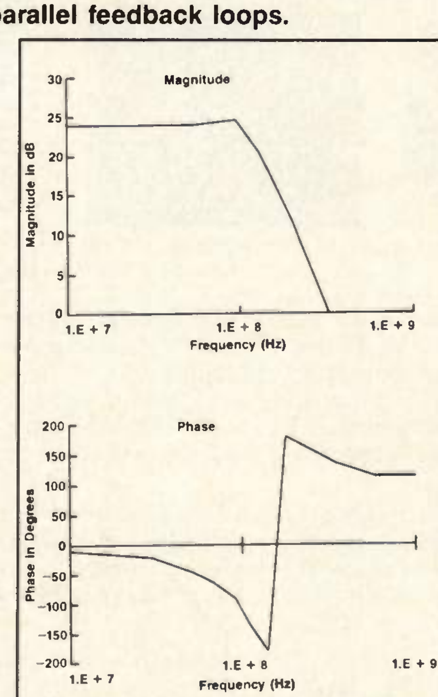


Figure 9. Computed magnitude and phase of video amplifier with no additional line length.

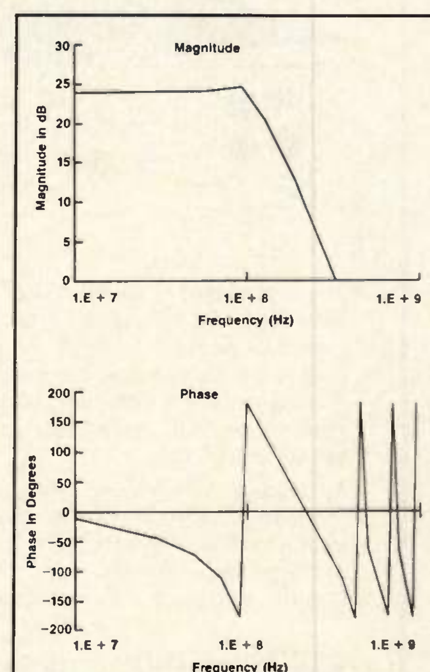


Figure 10. Computed magnitude and phase of video amplifier with 60 cm of additional line length.

$$AR_h = \frac{A_h\left(1 + j\left(\frac{F}{F_3}\right)\right)}{\left(1-\left(\frac{F}{F_2}\right)\right)^2 + j2D_M\left(\frac{F}{F_2}\right)} \quad (4)$$

where:

F = frequency variable

F_1 = corner frequency of the low frequency amplifier

F_2 = corner frequency of the 2 poles in the high frequency amplifier

D_M = damping factor

F_3 = corner frequency of the 3rd pole in the high frequency amplifier

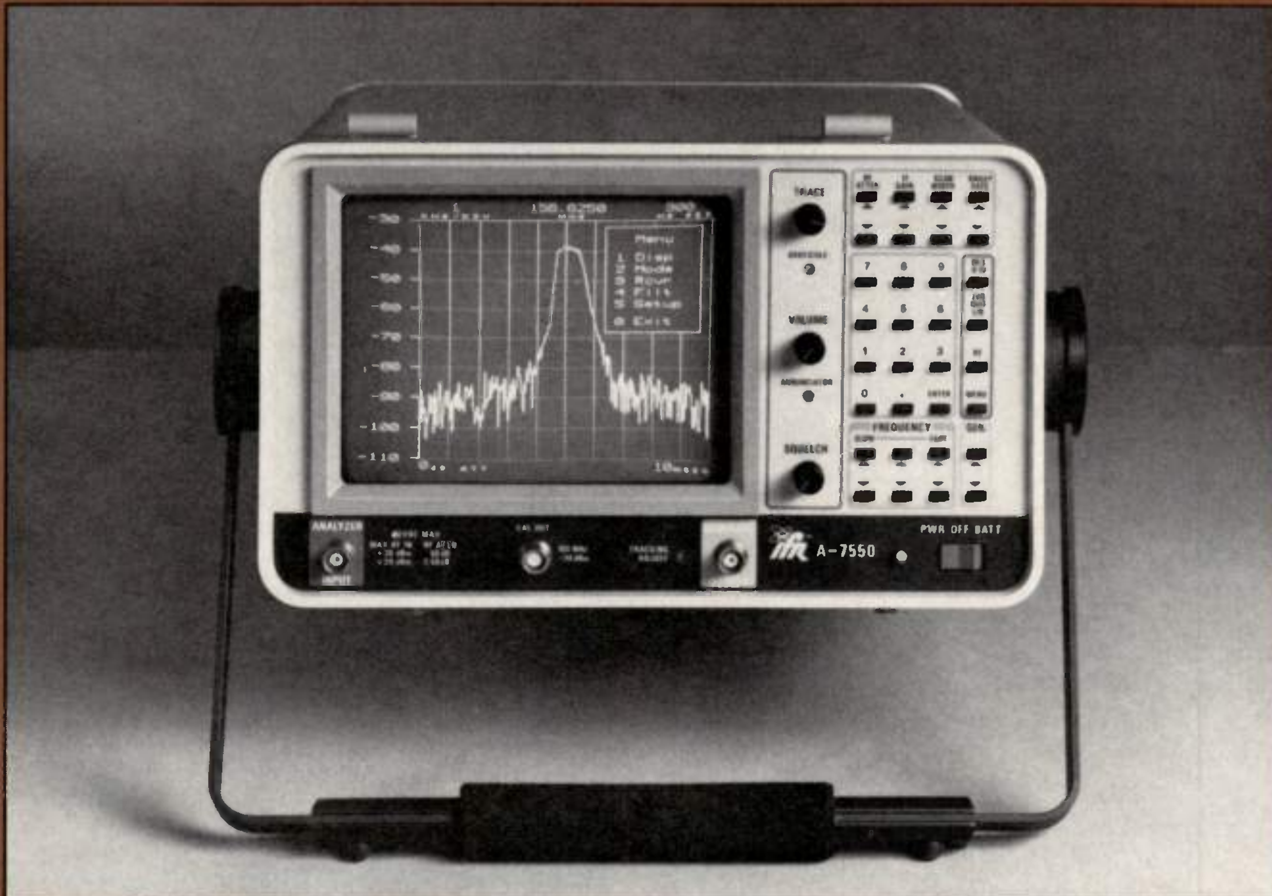
A_l = 1.786E6 = DC gain of the low frequency operational amplifier

A_h = 20 = DC gain of the high frequency operational amplifier

Comparison to Lab Analysis

A video amplifier was built and the circuit's electrical response was recorded. The measured magnitude and phase responses are shown in Figure 8. Evaluating Equations 2 through 4 on a computer resulted in the magnitude and phase responses that are shown in Figure 10. Notice the measured magnitude response agrees with the calculated magnitude response. However, there is a great discrepancy between the phase responses. The phase slope in the measured response is greater than the phase slope in the calculated response. This must be due to the line length in the test fixture that was used to test the amplifier. To eliminate the effects of the line length in the test fixture the insertion length on the network analyzer that was used to test the amplifier was changed so that the phase response for frequencies greater than 500 Hz were flat. With the insertion length of the network analyzer set to 60 cm, the amplifier's phase response on the network analyzer agreed with the calculated response. This meant the mathematical model of Equation 5 for line length had to be added to the theoretical model. The phase response of 60 cm of line length is added to Equations 2 through 4, and a phase response is computed that agrees with the measured response. The calculated phase response is shown in Figure 10.

$$\text{Phase} = \frac{2 \cdot L \cdot Pi}{c/F} \quad (5)$$



Runnerup Prize: The A-7550 Spectrum Analyzer from IFR, Inc. features 100 kHz to 1 GHz frequency coverage and microprocessor control that automatically selects and optimizes bandwidth, sweep rate, and slew rate of control functions. Single function keyboard entry and a menu driven display make operation easy and straightforward.

The runner-up prize is only slightly less grand than. . .

JUDGING CRITERIA

1. **Originality:** The purpose of the contest is to reward engineers for their unique design contributions. Each design will be evaluated according to its similarity to work by others, unusual application of a device or technique, and other judgments of its contribution to the advancement of the engineering craft.

2. **Engineering:** Engineering is the application of technology to solve a problem or meet a design goal. Entrants should clearly identify how their circuit was created in response to such a need. Judges will evaluate performance, practicality, reproducibility and economy.

3. **Documentation:** Communicating ideas to others is the business of *RF Design* and a necessary part of good engineering. Each entry will be judged on its description, analysis and graphical material. Each circuit should have a complete list of components, explanation of functions, and a summary of performance and test data.

ENTRY RULES

1. Entries shall be RF circuits containing no more than 6 single active devices (tubes or transistors), or 4 integrated circuits, or be passive circuits of comparable complexity.

2. The circuit must have an obvious RF function (as defined on page 6 of November 1987, *RF Design*) and operate in the below-3 GHz frequency range.

3. Circuits must be the original work of the entrant.

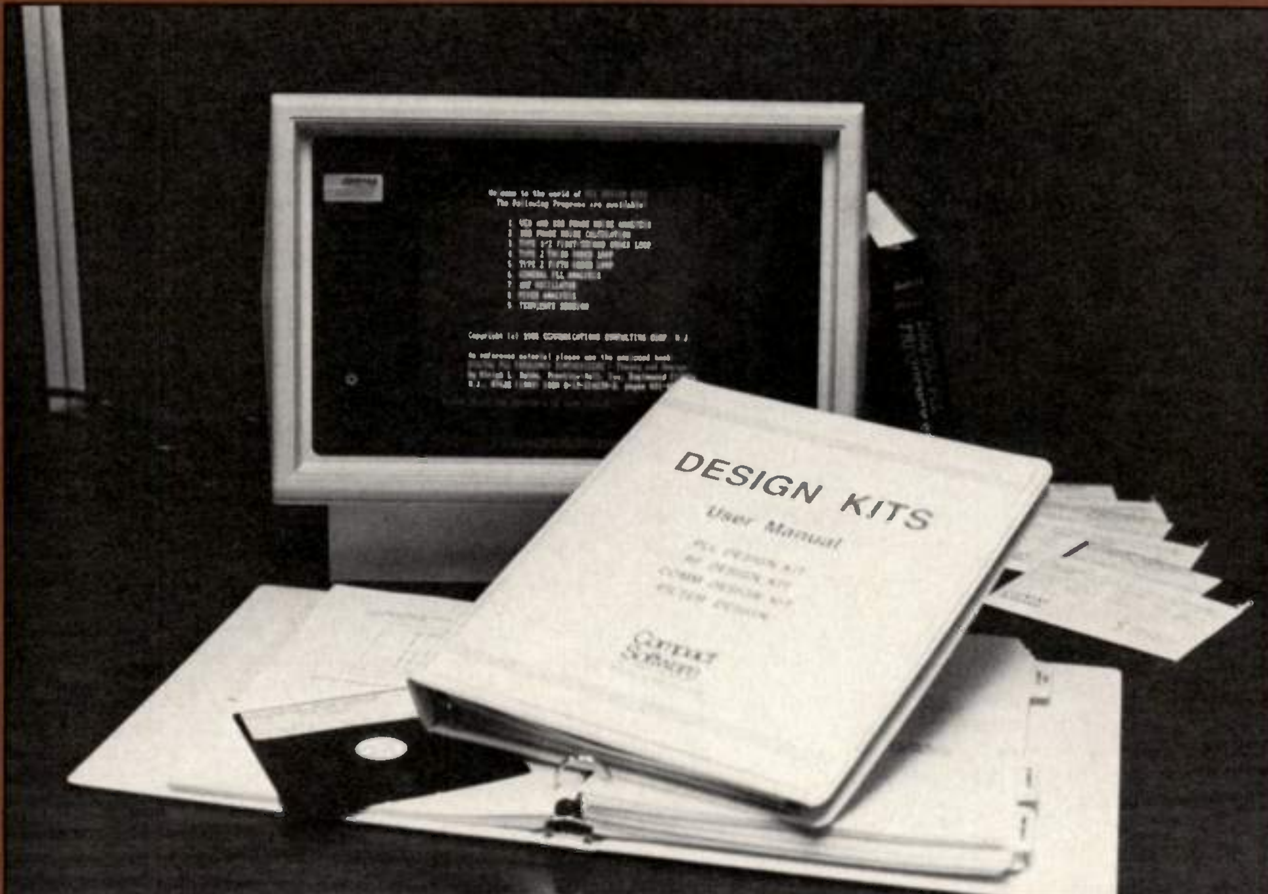
4. If developed as part of the entrant's employment, entries must have the employer's approval for submission.

5. Components used must be generally available, not obsolete or proprietary.

6. Submission of an entry implies permission for *RF Design* to publish the material. All prize winning designs will be published, plus additional entries of merit.

7. Winners shall assume responsibility for any taxes, duties or other assessments which result from the receipt of their prizes.

8. Deadline for entries: **March 31, 1988.**



Grand Prize: Compact Software's Design Kit Series, including the RF Design Kit® for system optimization, plus transformer and oscillator design; the Communications Design Kit® with digital system simulation, antenna evaluation, AGC synthesis and mixer analysis; the PLL Design Kit® for VCO design, plus stability, switching and non-linear analysis; and the Filter Design Kit® for LC, crystal, helical and interdigital filter design.

the grand prize in the 1988 RF Design Awards Contest!

Four honorable mention prizes will be awarded, each including two tuneable inductor designer's kits from Coilcraft: 108 "Slot Ten" inductors, 0.7-1143 uH, and 196 "Unicoil" inductors, 0.435-1.5 uH.

. . . and then there are four "honorable mention" prizes which are also quite grand.

Your chances of winning one of these six awards are better than one in twenty. . . and the grand prize winner will be the subject of our July 1988 cover as well. Those are the kind of odds that make it worth your while to pit your skills and ingenuity against the field. Now's the time to expose that ingenious circuit idea you've always wanted to show off to your engineering peers. Let the world know you're as good as you are!

MAIL YOUR ENTRY BY MARCH 31, 1988 TO GARY BREED, EDITOR . . .

rf design

6300 S. Syracuse Way
Suite 650
Englewood, CO 80111
(303) 220-0600

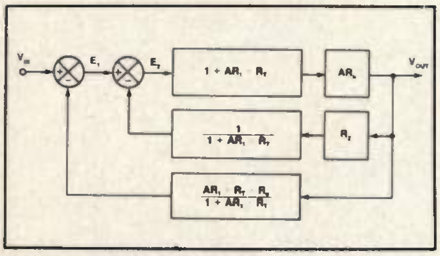


Figure 11. Figure 6 rearranged for error model analysis.

where: c = speed of light (cm/sec)

L = length of line (cm)

Error Function Derivation

Another advantage of having the simplified feedback configuration is that the error function can be evaluated and this helps determine the circuit's accuracy in following different input stimulus. The error function by control system theory is defined by Equation 6:

Error function =

$$\frac{E_1}{V_{in}} = \frac{1}{1 + G(s) \cdot H(s)} \qquad (6)$$

where:

V_{in} = input stimulus

E_1 = difference between the input and feedback voltages

Another form of the error function (Equation 6) shows the improvement effect of the low frequency amplifier on the high frequency amplifier's performance. Block transformation operations on Figure 6 must be performed to find this new error function. A summing point is moved ahead of a block in Figure 6 with the results shown in Figure 11. The outer loop error function (E_1/V_{in}) is shown in Equation 7, and the inside loop error function (E_2/E_1) is shown in Equation 8. The overall error function (E_2/V_{in}) Equation 9 is produced by multiplying Equation 7 by Equation 8:

$$\frac{E_1}{V_{IN}} = \frac{1}{1 + \dfrac{AR_h}{1+AR_h \cdot R_z}(AR_1 \cdot R_T \cdot R_o)} \qquad (7)$$

$$\frac{E_2}{E_1} = \frac{1}{1 + AR_h \cdot R_z} \qquad (8)$$

$$\frac{E_2}{V_{in}} = \frac{E_1}{V_{in}} \cdot \frac{E_2}{E_1} \qquad (9)$$

Equations 7 through 9 can be used to show the improved performance of the

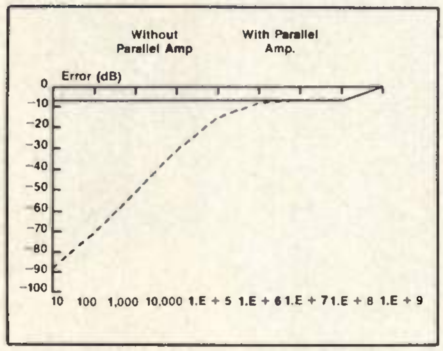


Figure 12A. The error function with and without parallel amplifier.

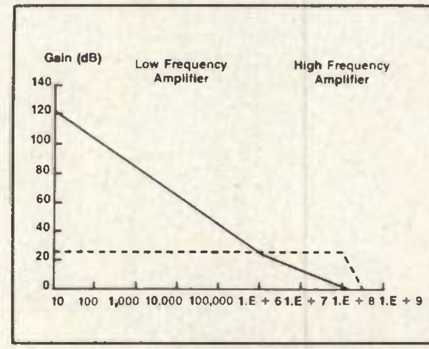


Figure 12B. Low and high frequency amplifier gain.

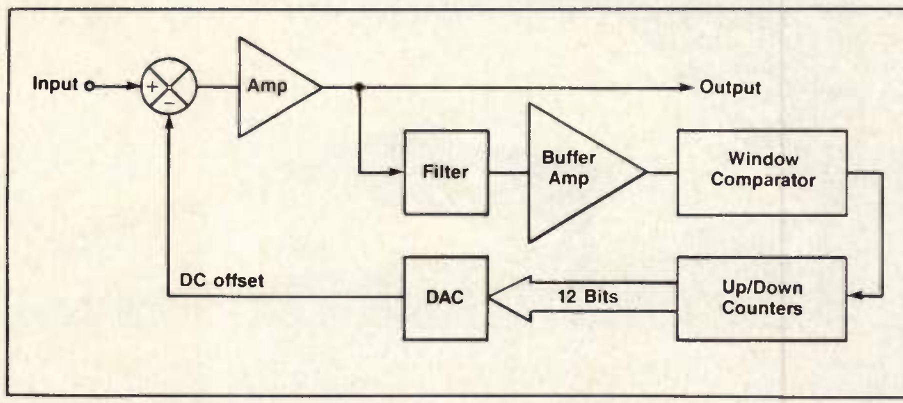


Figure 13. DC offset zeroing loop.

high frequency amplifier that can be achieved with the two parallel feedback loops. Equation 8 is the error function of the high frequency amplifier without the parallel amplifier. Equation 9 is the error function of the high and low frequency amplifier in parallel. Figure 12 shows the calculated values for equations 3, 4, 7 and 9. The top plot in Figure 12 shows the improved error function when the parallel low frequency amplifier loop is added. The bottom plot in Figure 12 shows the gain versus frequency responses for the low and high frequency amplifiers. Improvement in the error function starts at frequencies below 1 MHz, and by 10 Hz there is an improvement in the error function of 81 dB. A small error function means the output tracks the input. Figure 12 shows that the DC performance of the parallel loop is improved becaue the parallel loop produces an error value that is smaller than the error value for the high frequency amplifier by itself.

In many circuits the amplifier is not the only source of DC bias. For instance, when the video amplifier is used after a down conversion mixer, a DC offset occurs from the mixer bias level. In this case a DC zeroing loop is required to offset the mixer's bias. Figure 13 shows a configuration that will perform a zeroing function to solve this problem.

Block diagram transformations are useful in analyzing feedback or feedforward circuits. A circuit's performance can be further understood by analyzing the various block diagrams that result from the transformations. Using the block diagram transformations a high frequency video amplifier's DC performance was shown to improve by using a low frequency amplifier in a parallel loop. rf

References

1. "Fast Settling Wideband Operational Amplifiers (CLC 103AI, CLC103AM Data Sheet)," Comlinear Corporation, Loveland, Colorado, May 1982.

2. J.J. DiStefano III, A.R. Stubberud, and I.J. Williams, *Schaum's Outline of Theory and Problems of Feedback and Control Systems,* McGraw-Hill, New York, 1967.

About the Author

Stan Goldman is a senior engineer at Scientific Communications, Inc., 2908 National Drive, Garland, TX 75041. He can be reached at (214) 840-4900.

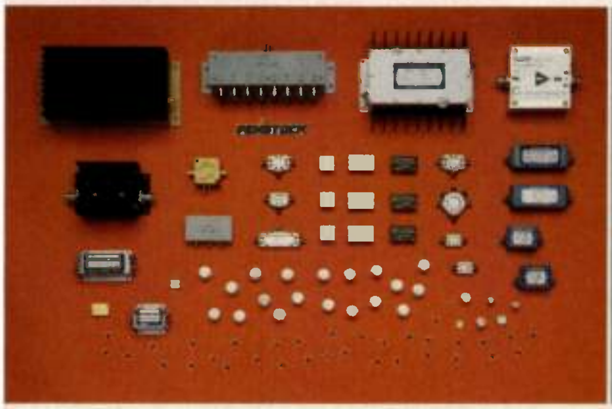
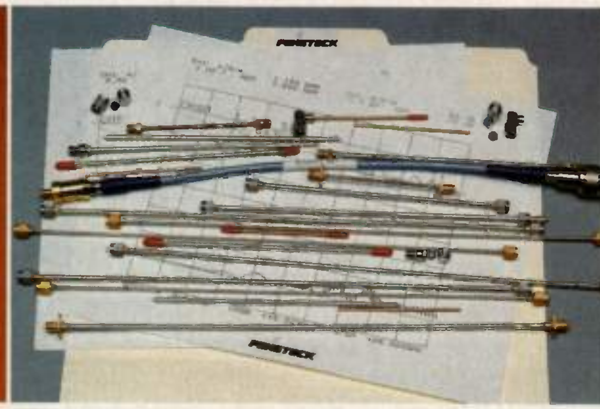
MICROWAVE/RF COMPONENTS

CONNECTORS DC — 50 GHz COMPONENTS DC — 18 GHz

(415) 948-6552 **PENSTOCK** (415) 948-6552

105 Fremont Avenue, Los Altos, CA 94022 FAX 415-948-0115

OVER 100,000 PARTS IN STOCK!

PARTS STORE

- ADAPTERS
- AMPLIFIERS
- ATTENUATORS
- BARRETTER MOUNTS
- CABLE ASSEMBLIES
- CIRCULATORS ISOLATORS
- CONNECTORS
- DIRECTIONAL COUPLERS
- FILTERS
- FLEX CABLE
- FREQUENCY DOUBLERS
- LIMITERS
- LOADS
- MIXERS
- MMIC COMPONENTS
- NOISE SUPPRESSORS
- OSCILLATORS
- PHASE DETECTORS
- POWER DIVIDERS
- POWER SPLITTERS/ COMBINERS
- SEMICONDUCTORS
- SEMI-RIGID CABLE
- SUB-ASSEMBLIES
- SUBSTRATES
- SWITCHES
- TERMINATIONS
- TRANSFORMERS
- TRANSISTORS

- AMPHENOL RF
- AVANTEK
- COMLINEAR
- EZ-FORM
- HUBER + SUHNER
- INMET
- MINI-CIRCUITS
- PALCO
- PENSTOCK ENGINEERING LABS
- WEINSCHEL

* * * * HANDY ORDER FORM FOR IMMEDIATE DELIVERY * * * *

AMPHENOL — LIMITED TIME
INSTRUMENTATION GRADE CONNECTORS TO 50 GHz (FOR AIRLINES)

Quantity — Total Ordered

_____ ea. 2.4 mm Male P/N 131-8001 . . . . . . $150.70 ea. _____
_____ ea. 2.4 mm Female P/N 131-8002 . . . $156.98 ea. _____
2.4 mm Female/K Connector Male
_____ ea. 131-8018 . . . . $235.74 ea. _____

AVANTEK — LOW PRICE
MMIC AMPLIFIERS

Quantity — Total Ordered

MSA-1023 High Output Power
_____ ea. + 27dBm@1GHz . . . . $45.00 ea. _____
MSA-0520 (metal hermetic pkg.)
_____ ea. DC-2.5GHz/8.5dB Gain @1GHz . . $35.50 ea. _____
MSA-0870 (metal hermetic pkg.)
_____ ea. DC-6GHz/23dB Gain@1GHz . . . . . $36.60 ea. _____
MSA-0635 (hermetic glass/ceramic pkg.)
_____ ea. DC-900MHz/19dB Gain@500MHz . . $7.00 ea. _____
MSA-0385 (plastic pkg.)
_____ ea. DC-2.5GHz/12dB Gain@1GHz . . . . $3.35 ea. _____
MSA-8685 Frequency Converter (plastic pkg.)
_____ ea. Applications from 0.1-2GHz . . . . . . $5.75 ea. _____

IN STOCK FROM PENSTOCK
CABLE ASSEMBLIES & ADAPTERS FOR LAB USE

Quantity — Total Ordered

Suhner 3' Armored Cable w/3.5 mm Connectors (male)
_____ ea. ea. end to 26.5GHz (SF104A) . . . . $459.65 ea. _____
Suhner 3.5 mm Male/"N" Female
_____ ea. Adapter . . . . $71.08 ea. _____
Weinschel SMA "Connector Saver" DC
_____ ea. 26.5GHz (SMA Male/Female) . . . . . $60.00 ea. _____
Suhner 7mm/N Female
_____ ea. DC-18GHz . . . . $90.00 ea. _____
Suhner 7mm/N Male
_____ ea. DC-18GHz . . . . $99.00 ea. _____

HUBER + SUHNER — FAST DELIVERY
INSTRUMENTATION GRADE CABLES

Quantity — Total Ordered

Suhner Extreemly Phase Stable 3' Cable
_____ ea. (104P) SMA Male to 18GHz . . . . . $206.77 ea. _____
_____ ea. Same as above 6' (104P) . . . . $262.45 ea. _____
Suhner HP8510 Cable Assemblies DC-26.5GHz
_____ ea. (104PB) . . . Call for Guaranteed Lowest Price _____

EZ-FORM — SUPER SAVINGS
MIL-C-17 APPROVED/TIN PLATED/SEMI-RIGID CABLE

Quantity — Total Ordered

_____ ft. EZ-Form .141 dia P/N 810043 . . . . $3.50/ft _____
_____ ft. EZ-Form .086 dia P/N 810175 . . . . $3.00/ft _____
Suhner Solderless SMA Male "C" Grip Connectors for .141 Cable P/N 11-SMA-50-3-60C
_____ ea. (no special tools required) . . . . $6.95 ea. _____

WEINSCHEL — SPECIAL
LAB & PRODUCTION FIXED ATTENUATORS

		Quantity				Total Ordered
2 Watt #3T-SMA (M/F) DC-12.4GHz	$40.00 ea.	3dB	6dB	10dB	20dB	
2 Watt #4T-SMA (M/F) DC-18GHz	$50.00 ea.	3dB	6dB	10dB	20dB	
5 Watt Model 1-"N" Connector (M/F) DC-12.4GHz	$50.00 ea.	3dB	6dB	10dB	20dB	
5 Watt Model 2-"N" Connector (M/F) DC-18GHz	$80.00 ea.	3dB	6dB	10dB	20dB	
2 Watt #3T-SMA (M/F) DC-12.4GHz	$50.00 ea.	2dB	4dB	5dB	30dB	
2 Watt #4T-SMA (M/F) DC-18GHz	$60.00 ea.	2dB	4dB	5dB	30dB	
5 Watt Model 1-"N" Connector (M/F) DC-12.4GHz	$60.00 ea.	1dB	2dB	4dB	30dB	
5 Watt Model 2-"N" Connector (M/F) DC-18GHz	$90.00 ea.	1dB	2dB	4dB	30dB	

SHIP TO:

NAME _____
TITLE _____
COMPANY _____
ADDRESS _____
CITY/STATE/ZIP _____
(_____) PHONE _____

☐ SEND FREE WALL CHART
☐ ENCLOSED IS $3.00. PLEASE SEND SPECS ON ITEMS LISTED ABOVE. (Free With Order)

METHOD OF PAYMENT

Add $5.00 Shipping and Handling (any size order).
California residents add 7% sales tax.

☐ Check or Money Order (no minimum)
(no currency please) AMOUNT ENCLOSED $_____

☐ MasterCard ☐ VISA
(MC/VISA add 5% service charge, minimum order $15.00)

☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐
Card Account Number

☐☐ - ☐☐ _____
month year customer signature
Expiration date and signature required.

VISA MasterCard

PENSTOCK MICROWAVE DISTRIBUTION
(415) 948-6552
105 Fremont Ave.
Los Altos, CA 94022
FAX 415-948-0115

One Antenna Kit with everything, to go please.

A complete line of kits with upper limits to 18GHz that satisfy FCC, VDE, and MIL-STD 461 specifications, and more.

Antenna kits that meet your specifications of high quality and frequency response, and that are also responsive to your demands of portability and easy use. A.H. Systems offers nine different kits that fill the bill. Each comes in a single, lightweight case. Just one kit can contain all the antennas, probes and cables to perform E-Field 1KHz-18GHz, H-Field 20Hz-50KHz and conducted 20Hz-100MHz testing. Antenna factor calibrations are provided with each antenna.

So order one to go, with everything, or one of our other tantalizing specials.

MODEL #	FREQ. RESP.	DESCRIPTION
SAS-200/510	300 - 1800 MHz	Log Periodic
SAS-200/511	1000 - 12000 MHz	Log Periodic
SAS-200/512	200 - 1800 MHz	Log Periodic
SAS-200/518	1000 - 18000 MHz	Log Periodic
SAS-200/530	150 - 550 MHz	Broadband Dipole
SAS-200/540	20 - 300 MHz	Biconical
SAS-200/541	20 - 300 MHz	Bicon'l Collapsible

MODEL #	FREQ. RESP.	DESCRIPTION
SAS-200/542	20 - 300 MHz	Biconical, Folding
SAS-200/550	.001 - 60 MHz	Active Monopole
SAS-200/560	per MIL-STD-461	Loop - Emission
SAS-200/561	per MIL-STD-461	Loop - Radiating
BCP-200/510	20 Hz - 1 MHz	LF Current Probe
BCP-200/511	100 KHz - 100 MHz	HF/VHF Crnt. Probe

Available now from your source for the finest EMI test equipment and accessories.

AH Systems
9710 Cozycroft Ave
Chatsworth, CA 91311
Tel: 818 998-0223
Telex: 182 640 WKVG

A.H. SYSTEMS

INFO/CARD 75

Optimizing 'On-Glass' Antenna Performance

By Marvin S. Grossman
The Antenna Specialists Co.

"On-Glass" antenna technology was documented with the issuance of U.S. Patent No. 4,238,799 on December 9, 1980. Since then, the advent of cellular mobile telephone has added enormous popularity to "on-glass" products; they are now available for all popular radio bands from 27 MHz citizen bands to 900 MHz cellular and trunking frequencies. However, auto manufacturers and makers of auto glass have not been idle. They continually develop new products which create challenges for antenna installers. RF interference occurs here due to the use of metal substances either on the surface or within the glass.

Until now, the only definitive glass test available has been a direct RF loss measurement, requiring relatively expensive and sophisticated test equipment. An alternative is a glass tester that allows capacitance-to-ground measurements to be correlated with RF loss, so correct on-glass installations may be predicted and alternative antenna types used when necessary.

Most cars are equipped with a rear window defogger option. This is usually a number of horizontal wires imbedded into, deposited on, or painted on the inside surface of the rear window. These wires, if positioned between the coupler and base, may absorb some of the signal going to and from the antenna. In those cases where the antenna base does not fit between the defogger wires, this effect may be minimized by straddling two wires rather than centering the base over a single wire. Other methods of defrosting include a fine wire mesh instead of parallel horizontal wires or a thin flash of silver over the inside window surface. Most aftermarket window tinting kits use metallized plastic sheeting which may also cause problems. These few exceptions provide a shield, effectively blocking the transfer of RF energy. An alternative roof or rear deck mount antenna should be considered in the above cases.

How does the installer determine if hidden characteristics of the prospective

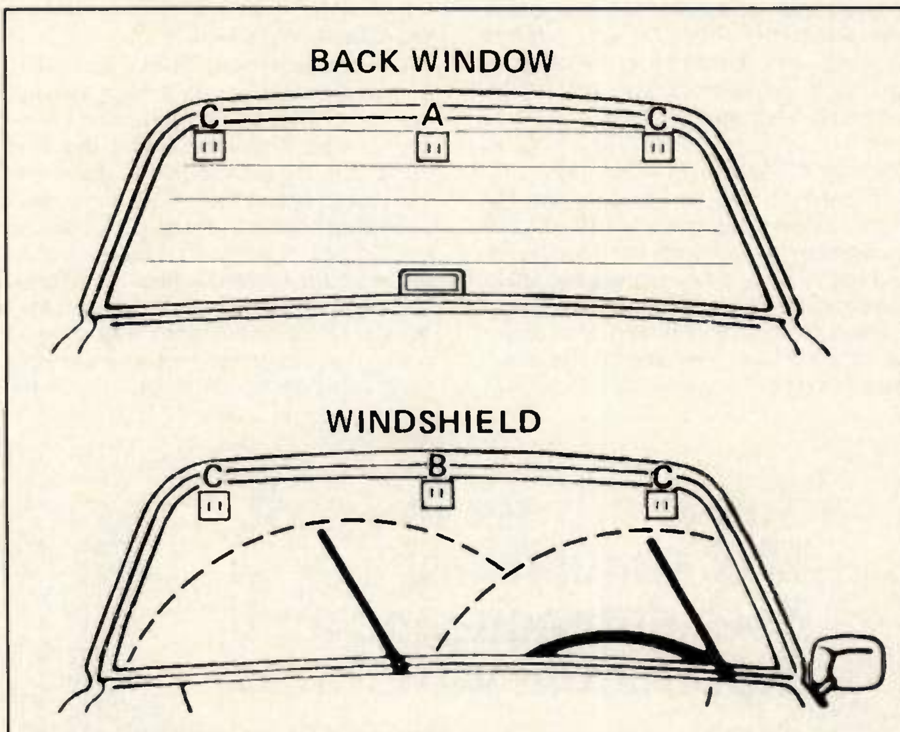


Figure 1. Typical mounting locations for 'on-glass' antennas.

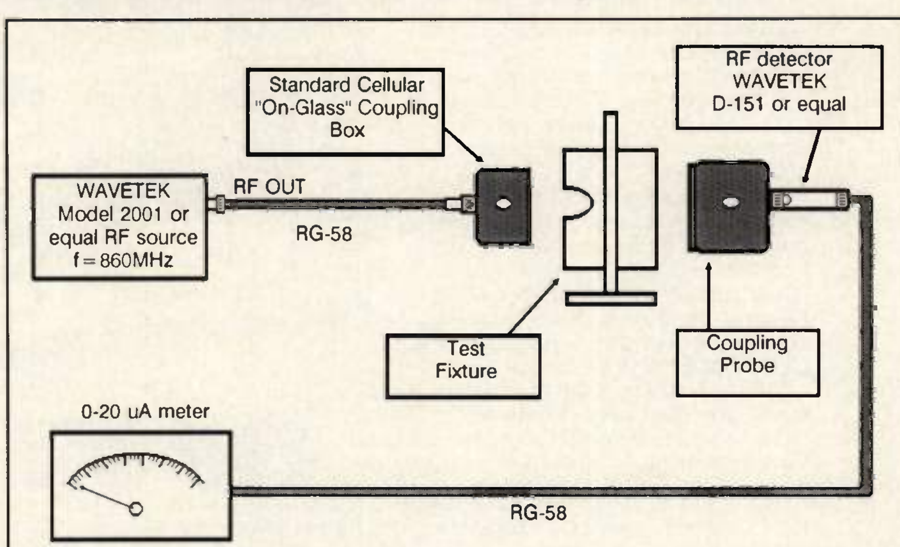


Figure 2. Typical test set-up for direct RF loss method.

mounting surface will allow adequate RF transmission? Test methods could be offered to give the installer a way to find the best spot on any piece of glass. This requires some analysis, leading to a decision of where to mount the antenna.

The most common mounting location (Figure 1) is the top center of the rear window (A) for rear-mounted radios, followed by the top center of the windshield, above the rear view mirror (B) for front-mounted radios. Better access for car wash removal may be gained by mounting it in the top corner of either window (C). Care must be taken to ensure that most of the whip (from the "curly-Q" up) extends above the roof line and that no defogger wires or similar devices pass through the mounting base area.

Testing a Mounting Location

In order to directly measure the RF transmission capabilities of the glass, it is necessary to generate the specific RF and apply it to one side of the glass while sampling the RF on the opposite side and displaying a meaningful reading on some sort of calibrated instrument. This time-consuming process is illustrated in Figure 2. A standard piece of clear automotive window glass is used to calibrate the set-up.

The coupling box and coupling probe must then be taken off the test fixture and placed on either side of the window that is to be tested. This usually requires two people since one must be on the inside and the other on the outside. Keeping the two coupling units exactly opposite each other, they will have to be placed in likely mounting locations until meter readings approach an acceptable value.

Checking an Existing 800 MHz On-Glass Installation

The equipment can be retrofitted onto an actual installation. To accomplish this, the outer whip and mount must be removed from the vehicle and the feed cable from the radio must be unscrewed from the coupling box. A cable can then be installed between the coupling box and the 800 MHz signal source. By placing the probe on the glass opposite the original coupling box, an actual RF reading may be taken through the glass. Examination of various automotive glass indicates that most common types compare favorably to standard glass.

If the insertion loss is more than desired, as in some cases where defogger wires are on the window surface, the installation may be repositioned for maximum meter reading to minimize the effect of the wires.

Glass Tester (Capacitance-to-Ground) Method

While performing field tests, a simpler less-expensive set-up was tested at the same time. In all cases, this alternative method traced nearly identically with the test that directly measured RF transfer. A device for performing the test can be obtained from the Antenna Specialists Co. as Model KAV-850 (Figure 3). The design uses the dielectric properties of automotive window glass to capacitively pass RF energy from an impedance-matching coupling box to a radiating element on the outside of the glass. Some windshields have visible barriers (like rear window defogger wires) and invisible barriers (like metal-film privacy tint) that may hinder this coupling mechanism.

The KAV-850 provides the antenna installer a fast but effective way of determin-

EMCO UPDATE

New Product Helps Maintain Test Site Integrity

Generator Provides Reference Standard

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

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

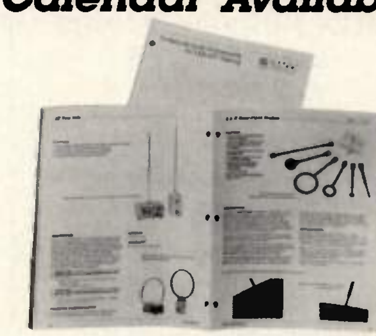
Now EMCO solves this problem with the introduction of the Model 4610 Royce Field Site Source. Site verification is now so simple it can be performed in just a few minutes at the start of each day.

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

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

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

New Catalog and Calendar Available

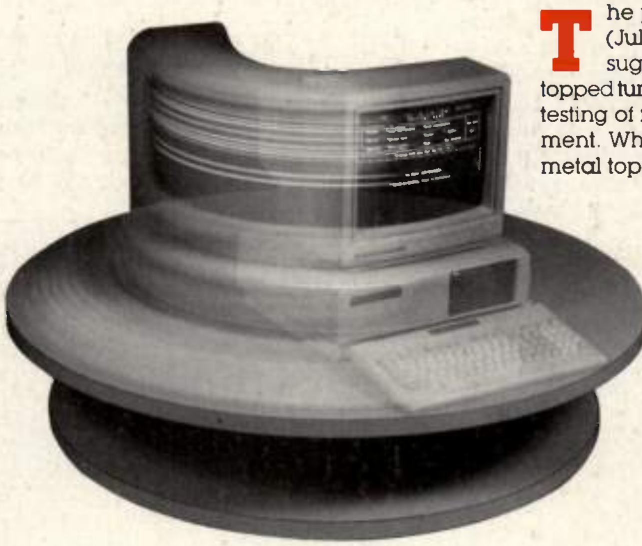


EMCO's new 80 page catalog is packed with helpful product info on more than 50 different antennas and accessories for EMI/RFI compliance testing. Send for your free catalog today and we'll also send you our 1988 calendar—it's a big 20" x 30" that includes helpful formulas and a product selection guide.

Call or write for your copy today.

Metal Topped Turntables Preferred by New FCC Standard

Nine Metal Turntable Models Available



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

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

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

First In Quality. First In Performance.

800-253-3761 or 512-835-4684 between 7:30 AM and 4:30 PM (CST)
Telex 797627 Fax 512-835-4729 P.O. Box 1546, Austin, Texas 78767

08151/89161 Fax 08151/16610 Munchner Str. 2 D-8137 Berg 1 West Germany

EMCO™
The Electro-Mechanics Company

INFO/CARD 76

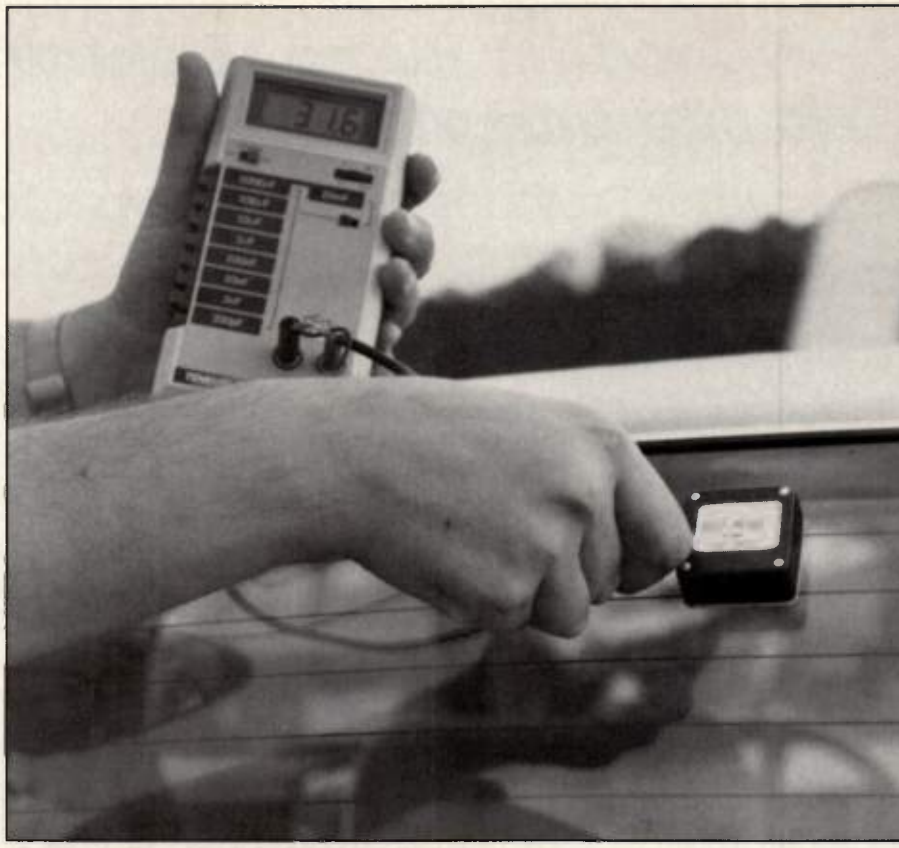


Figure 3. The Model KAV-8500 in use.

ing if a window has any of these hidden barriers as well as a means to find the best mounting position on the glass.

Testing Guidelines

The complete test set up for the capacitance-to-ground method requires a capacitance meter and the KAV-850. The capacitance meter should be set to a sensitive scale and calibrated to a round number by means of the nulling potentiometer (30 pF was used in field test). To ensure stability, the meter should be grounded to the vehicle body.

The capacitance is read with the coupling box of the KAV-850 against the glass at the desired location of antenna installation. Another reading is then taken with the coupling box off the glass. For the location to be acceptable, the difference in the two readings should not exceed 2 pF.

The test described helps the installer position an antenna in the best possible location conveniently. This method saves both time and labor related to the installation of antennas in vehicles equipped with defoggers and metallic films. rf

About the Author

Marvin Grossman is field applications manager at The Antenna Specialists Co., 30500 Bruce Industrial Parkway, Cleveland, OH 44139-3996.

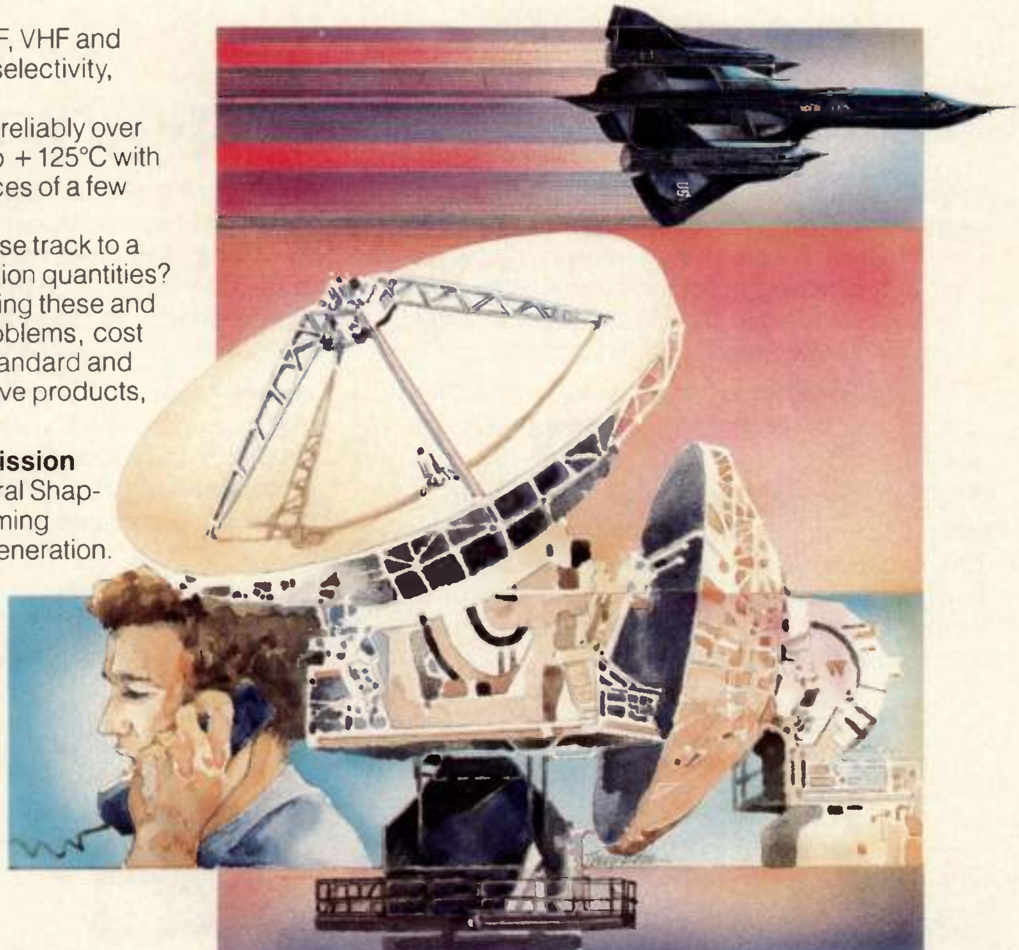
SAW Products-Solving Your Signal Processing Problems

Do your systems require RF, VHF and UHF filters with extreme selectivity, but space is very limited?

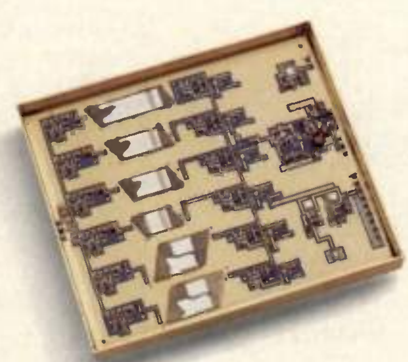
Must your system operate reliably over the full mil. range of $-55°C$ to $+125°C$ with frequency and delay tolerances of a few hundredths of a percent?

Do your filters need to phase track to a couple of degrees in production quantities?

Crystal Technology is solving these and other application specific problems, cost effectively with a full line of standard and custom Surface Acoustic Wave products, including:



- **Filters for digital transmission systems** that perform Spectral Shaping for minimizing ISI, and Timing Recovery filters for clock regeneration.
- **Filters for CATV and Satellite Receivers.** We manufacture VSB filters for systems M, BG, I, J and D/K as well as a complete line of Satellite Receiver filters at 70 and 610 MHz in all standard bandwidths.
- **Resonators and Oscillators** to solve your VHF and UHF frequency generation problems.
- **Delay lines** with fractional bandwidths greater than 50%.



- **Hybrid and P.C. Board Filter Modules,** including switchable filter banks, phase tracked filter sets ***a specialty of ours,*** channelized filter banks for communications and E.W. signal processing applications.
- **CHIRP Filters and Pulse Compression Sub-Systems** for radar, and Microscan receivers.

We are an experienced manufacturer of both commercial and mil-spec SAW products with a reputation for technical excellence and quality production. Our facilities are vertically integrated from crystal growth through components to modules.

Give us the opportunity to solve your signal processing problems. Call or write to: Crystal Technology, Inc., A Siemans Company, 1060 East Meadow Circle, Palo Alto, CA 94303, (415) 856-7911, Telex: 470103, FAX: (415)858-0944.

Crystal Technology, Inc.

See us at the RF Technology Expo, Booths #540 & 542.

INFO/CARD 95

Varian ...at the leading

Varian Eimac and Varian Microwave Tube Division...

KLYSTRONS

Beginning in the mid 70s Varian provided multi-megawatts of RF power for lower hybrid. This was achieved by combining half-megawatt klystrons at S band and quarter-megawatt klystrons at C band. This contributed significantly to the major United States effort in PLT and Alcator-C.

The reliability and long life of these tubes has led to their use by other facilities throughout the world.

Of significant importance is the advanced tube technology required to produce these products. This expertise is available for the design and production of tubes to meet your special requirements, whether they be plasma heating or particle accelerators.

VKS-8269/8270

VKC-7849 KLYSTRON

Operating Frequency (GHz)	CW Power (kW)	Typical Gain (dB)	Typical Efficiency (%)	Type Number
2.440–2.460	500	57	52	VKS-8269A
4.6	250	55	43	VKC-7849

For further information on Klystrons for lower hybrid heating call Varian Microwave Tube Division at (415) 424-5668.

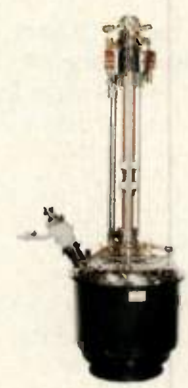
INFO/CARD 81

GYROTRONS

From a very modest beginning 12 years ago Varian has become the world leader in Gyrotron technology. CW tubes up to 200 kW are available in frequencies from 28 GHz to 140 GHz. Current design efforts will soon lead to one Megawatt devices at 140 GHz and even higher frequencies.

Varian's experience in developing and producing high power microwave sources has created the capability to produce tubes for a multitude of plasma heating applications, ion source development and materials processing research.

VGE-8060 60 GHz PULSED GYROTRON IN MAGNET



VGT-8014 140 GHz GYROTRON

OSCILLATORS

Frequency (GHz)	Type	Output Power Pulse/CW (kW)
8	VGH-8001	500/ —
28	VGA-8000	— /200
35	VGA-8003	— /200
53	VGE-8053	200/ —
53	VGE-8005A2	— /200
56	VGE-8005	— /200
60	VGE-8006	— /200
70	VGE-8007	— /200
106	VGB-8106A1	400/ —
140	VGT-8014	200/100
250	VGT-8025	25/ —

For further information on Gyrotron Oscillators and Amplifiers call Varian Microwave Tube Division at (415) 424-6984.

INFO/CARD 105

See us at the RF Technology Expo, Booth #411.

edge of fusion science.

active participants in TFTR, Doublett III, JET, JT-60, FTU, Heliotron, Culham, Wendelstein and other leading fusion energy experiments.

POWER GRID TUBES

Varian Eimac's half century of experience in developing state-of-the-art power grid tubes has brought them to the forefront in Multi Megawatt Amplifier Tetrodes and Switch/Regulator Tetrodes for ICRH and Accelerator Amplifiers; NBI, ECRH, and LHH Switch/Regulators.

X2242
2.5 MEGAWATT
AMPLIFIER TETRODE

4CPW 100K
100 KV
SWITCH/REGULATOR

TYPICAL AMPLIFIER TUBES

Type	Maximum CW Output (MW)	Maximum Frequency (MHz)
8973	1.5	200
8974	3.0	50
X2242	2.5	150

TYPICAL SWITCH/REGULATOR TUBES

Type	Voltage	Maximum Current	Anode Dissipation
4CPW 100K	110 KV	100A	100 kW
4CPW 300K	100 KV	150A	300 kW
4CPW 1000KA	150 KV	150A	1000 kW
4CPW 1000K	175 KV	100A	1000 kW

For further information on Power Grid Tubes call Varian Eimac at (415) 594-4006.

INFO/CARD 106

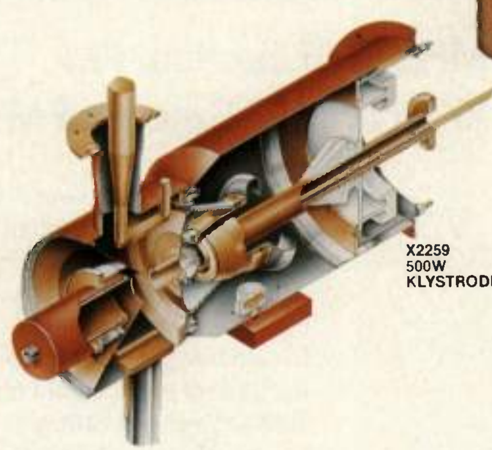
KLYSTRODES

Varian Eimac, long a leader in high power broadcast tube technology, has recently developed a series of high-power high-efficiency amplifiers for UHF-TV service based on the first new configuration of high-power electron tubes in over a decade.

This technology has led to the development of High Power UHF Amplifier Klystrodes for Accelerator and Fusion Service.

- RF Drive Pulsed
- High Efficiency
- Compact

X2254
KLYSTRODE
UHF AMPLIFIER



X2259
500W
KLYSTRODE CUTAWAY

KLYSTRODE POWER OUTPUT

Type	CW (kW)	Peak (kW)	Frequency
X2254	15	30	470–820 MHz
X2252	30	80	600–820 MHz
X2253	30	80	470–600 MHz
X2259	50	500	425 MHz
Dev.	500	500	425 MHz

For further information on Klystrodes call Varian Eimac at (415) 594-4000.

INFO/CARD 107

varian

VARIAN ELECTRON DEVICE GROUP / 611 Hansen Way / Palo Alto, CA 94304 / 415•493-4000

Milcom International Inc.

RF POWER AMPLIFIERS
FOR
MILITARY & AIRCRAFT COMMUNICATIONS

- **30-80 MHz VHF Tactical FM**
- **225-400 MHz UHF Satcom FM**
- **116-152 MHz VHF Aircraft AM**
- **225-400 MHz UHF Aircraft AM**

- ✔ **RF Power Output levels from 25 to 200 Watts**
- ✔ **RF Input Power from .25 to 20 Watts**
- ✔ **Manpack, Mobile and Fixed Installation Configurations**
- ✔ **Automatic amplifier bypass circuitry for transceiver operation**
- ✔ **Broad band circuitry, no tuning or adjustment required**
- ✔ **Amplifiers compatible with any Transmitter or Transceiver operating in the listed frequency ranges**
- ✔ **12 and 28 Volt models available**

These amplifiers are completely solid state RF power boosters designed for operation in the above listed VHF and UHF frequency ranges. They are intended for use with transceivers and transmitters such as the PRC 77, ARC 164, ARC 195, GRT 21/22, etc. These amplifiers will greatly extend normal communications range and will work equally well with older radios whose power output has degraded. The automatic amplifier bypass circuitry allows the amplifier to be connected directly to a transceiver without the need for an external antenna switching relay. Because of modular construction and simple test procedures the field maintenance requirements of these amplifiers are minimal, should they be required at all. For information on our standard product line or if you have a custom requirement please call or write us.

Milcom International Inc.

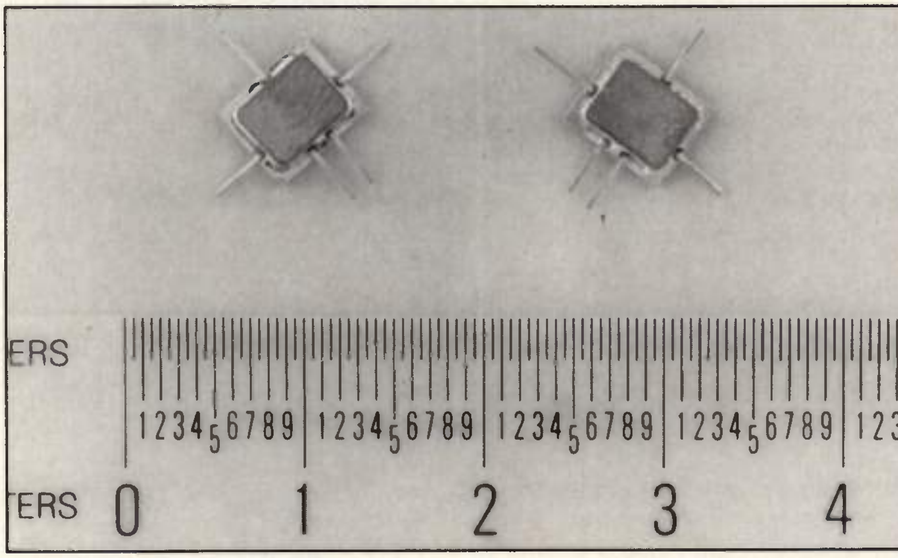
10891 CAPITAL AVENUE, GARDEN GROVE, CALIFORNIA 92643 • 714-554-1710

INFO/CARD 82

GaAs MMIC Switches From Tachonics

These GaAs MMIC switches provide an isolation of 50 dB at 1 GHz and 40 dB at 8 GHz and an insertion loss of 1 to 2 dB over the same range. Model TCSW-0500, a SPST switch, and Model TCSW-0600, a SPDT switch uses FETs as switching elements and feature low switching current, fast switching speed (subnanosecond) and low video breakthrough together with a high rate of spectral roll-off on switching noise.

The switches incorporate distributed FETs in shunt with high impedance transmission lines giving high isolation and low insertion loss at high frequencies. High isolation at low frequencies is aided by series FETs. Selectable internal loads on the switches allow them to be operated in either a reflective or matched mode. All ports remain matched to 50 ohms in both the ON and OFF states.

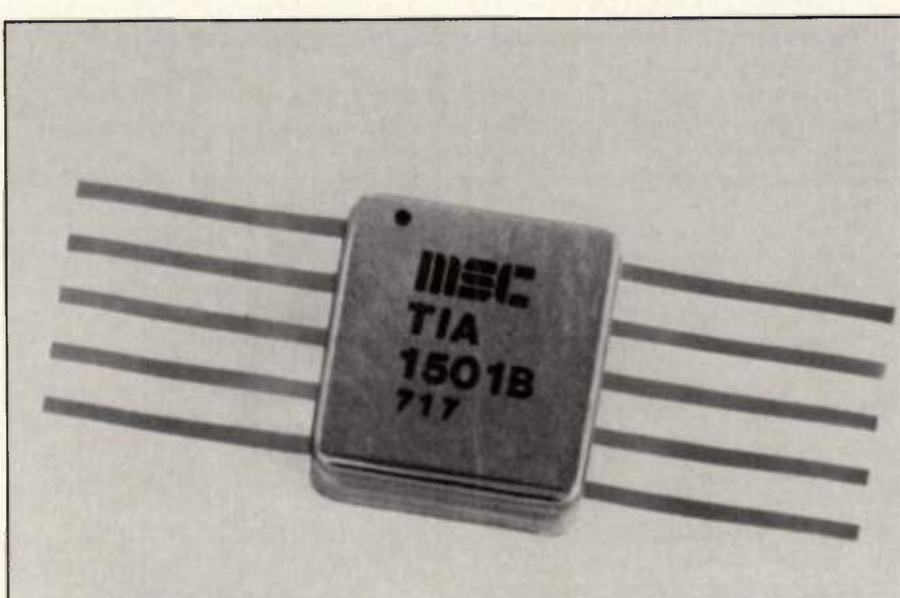


Both switches have a 1 dB insertion loss compression point of 32 dBm at 8 GHz and 27 dBm at 45 MHz and are rated for use from −65°C to +150°C. The switches are available as die or in hermetic ceramic packages (TC02) measuring 0.21"× 0.26"× 0.045". Two chips may be cascaded within other ceramic or metal packages to achieve even higher isolation. For example, two TCSW-0500 dies in a TCO2 ceramic package give typically 70 dB isolation at 2 GHz and, one packaged SPDT and two packaged SPST switches combined in a metal connectorized module have isolations of greater than 80 dB up to 6 GHz with a corresponding loss of less than 3 dB. **Tachonics Corporation, Plainsboro, NJ. Please circle INFO/CARD #220.**

MSC Introduces a Transimpedance Amplifier

The Model TIA 1501B GaAs transimpedance amplifier is a monolithic integrated circuit designed for use in direct detection, heterodyne and homodyne coherent lightwave receiver circuits. Accepting either a PIN or APD optical detector input, the amplifier has a flat frequency response with a typical bandwidth of 1.2 GHz (optical). A shunt gain control FET across the TIA input may be operated as a normal AGC or as a high frequency attenuator switch.

Temperature compensation over the operating temperature range of −55°C to +125°C can be accomplished with a mirror FET located adjacent to the feedback FET. The feedback FET is user adjustable — a feature that allows the user to optimize the transimpedance gain-bandwidth to specific applications. The TIA 1501B comes in a surface mount flat pack with 10 leads and costs $80 each in quantities of 100.



Also available from MSC is a test fixture designed to evaluate the TIA 1501B transimpedance amplifier in a fiber optic system. The SPT 111 simplifies rapid system prototyping by using a customized fiber compiled PIN or APD optical detector diode. The fixture includes a high frequency circuit board, RF-SMA connector, heat sink, device clamp assembly, and associated chip capacitor and resistor. It is priced at $500. **Microwave Semiconductor Corp., Somerset, NJ. Please circle INFO/CARD #219.**

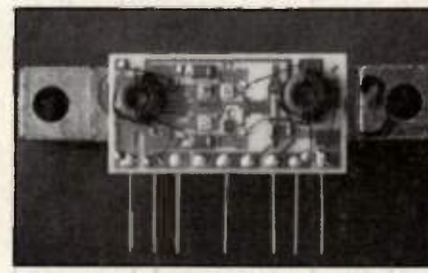
Multifunction Frequency Counters

Two multifunction frequency counters are being introduced by Mercer Electronics. The Model 9810 and Model 9800 provide period measurements, period averages and totalize functions. Both feature 8-digit displays with annunciators. The 9800, with a 10 Hz to 100 MHz range, is suited for general purpose applications and is priced at $255. The 9810 provides

a range of 10 Hz to 1 GHz and is suited for UHF radio communication systems. It costs $475. **Mercer Electronics, Elgin, IL. INFO/CARD #218.**

1-32 MHz Amplifier

The Model AR 1003250 high dynamic range low noise amplifier has a 3rd order intercept point of +51 dBm and noise figure of 5.0 dB (max). With two tones at



+10 dBm, 3rd order products are more than 82 dB down and gain across the 1 to 32 MHz band is 18 dB ±0.2 dB. Applications include receiver front ends, signal distribution and instrumentation products. **Advanced Milliwave Laboratories, Inc., Westlake Village, CA. INFO/CARD #217.**

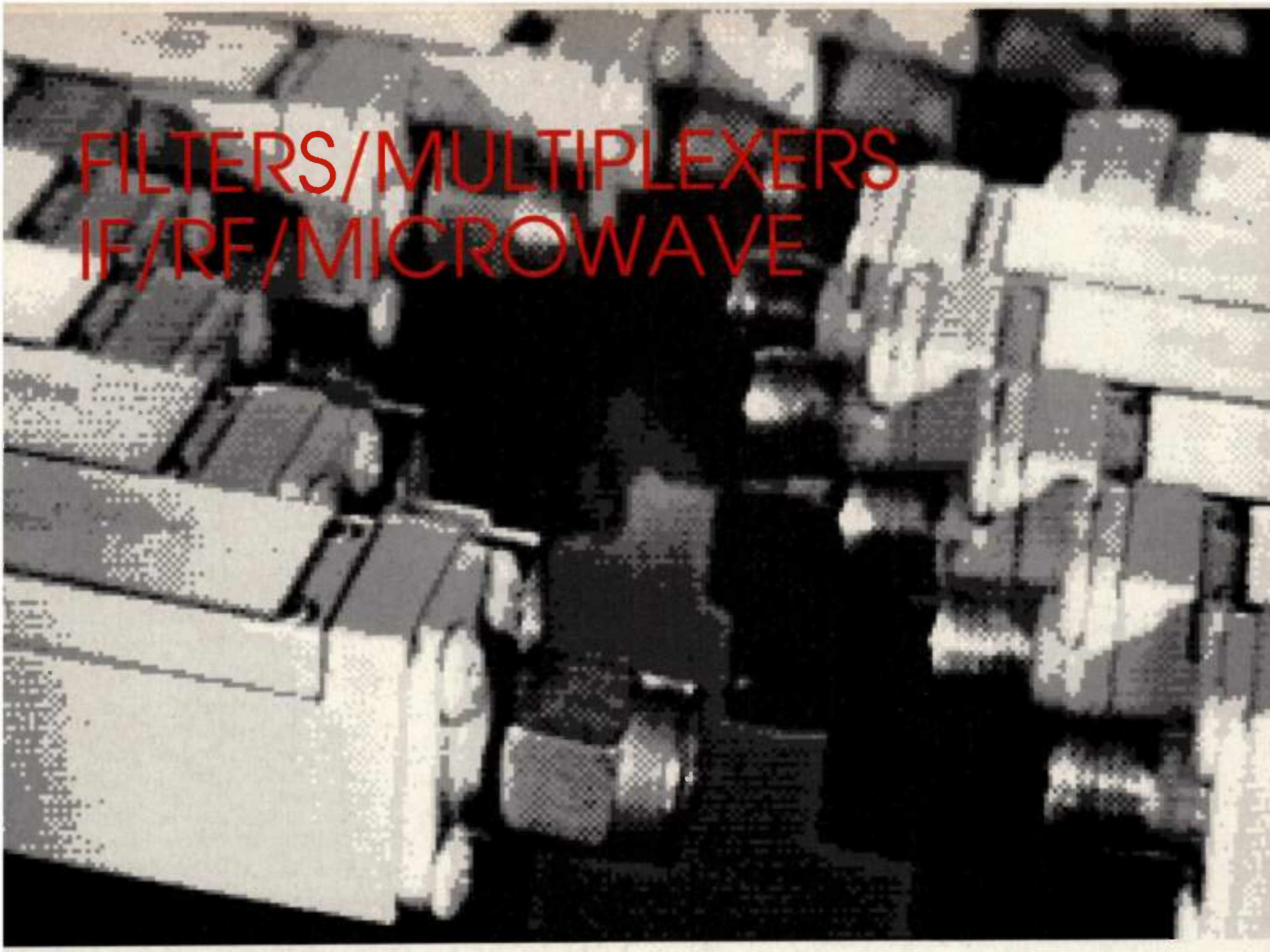
Low Cost DDS

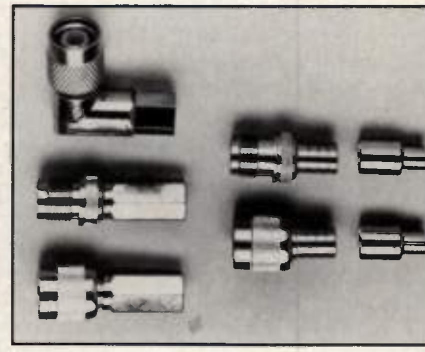
This 1 Hz resolution digital frequency synthesizer has an output of 1/2 $V_{p\text{-}p}$ into 75 ohms from 1 Hz to 6.5 MHz. A standard 12 key program is offered with the

microprocessor controller. The unit accepts as many as 32 keys and there is unused memory space for programming special features. The unit measures 8"× 6"× 3.25" and is priced at $429.95. **A & A Engineering, Anaheim, CA. INFO/CARD #216.**

TNC Connectors

A line of crimp-on and twist-on style field-installable connectors are available from Cambridge Products. Typical electrical characteristics include nominal impedance of 50 ohms, contact resistance of 0.2 milliohms for the output conductor and 1.5 milliohms for the center conductor. Dielectric resistance is 1500 V (rms), and the insulation resistance is 5000

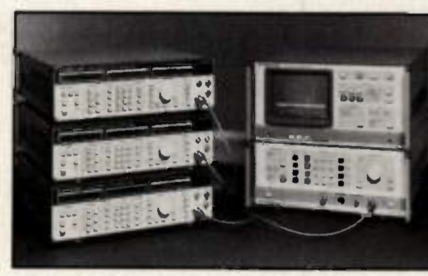

FILTERS/MULTIPLEXERS
IF/RF/MICROWAVE



megaohms (min). The maximum VSWR is 1.3 (max) at 4 GHz. Production quantities of the twist on TNC plugs are priced at $1.54 each and the crimp-ons are $1.29. **Cambridge Products Corp., Bloomfield, CT. INFO/CARD #215.**

RF Signal Generator

The signal generator SMH from Rohde & Schwarz generates digitally modulated signals required for testing radiotelephone networks for digital data and speech transmission. Its nominal frequency range of 100 kHz to 2000 MHz can be underranged down to 20 kHz and overranged up to 2080 MHz with a higher level of



tolerance. The synthesizer provides a frequency resolution of 1 Hz with a settling time of less than 15 ms. It delivers signals with controlled output levels from −137 to +13 dBm (overrange up to +16 dBm). The remote control interface IEC 625-1 (IEEE 488) permits listener, talker and service request functions. A 50 W overload protection circuit safeguards the SMH against externally applied RF signals and DC voltages. **Rohde & Schwarz, Munich, West Germany. INFO/CARD #214.**

30 MHz Calibrator

Boonton's 2520 RF calibrator provides a means of standardizing power meters, attenuators, amplifiers, detectors, and RF/microwave components. With a 30 MHz output traceable to NBS, the 2520 provides programmable levels from −70 dBm to +20 dBm with 0.1 dB resolution. Accuracy at 0 dBm is 0.055 dB. Output impedance is 50 ohms with VSWR less than

NEED BROAD-BAND COAXIAL RELAYS? FROM 2 TO 24 THROW, MATRIX HAS THE ANSWER

Our versatile 7000 series of coaxial relays have band-widths from DC up to 800 MHz. They're available from 2 to 24 throw. And by using our 9000 series cross-straps, switching matrices of any size can be configured.

Why have Matrix broad-band relays become the industry standard? Because we construct them of precision machined anodized aluminum alloy, all signal shield paths are silver plated, and basic switch elements are hermetically sealed in nitrogen filled gas envelopes with rhodium plated contacts to insure non-stick operation.

The end result is extremely low crosstalk, EMI and VSWR. Another plus, all switchpoints are individually field replaceable.

The units are plug compatible with Matrix 6100A and 1600 Series Logic Modules for compatibility with RS-232, RS-422 and IEEE-488 Interface busses as well as 16 bit parallel.

Non-blocking Matrix configuration may be easily assembled using our self-terminating relays and 5100A series power dividers. Built-in Video/RF amplifiers allow zero insertion loss designs.

So if you're looking for broad-band relays, it pays to deal with Matrix. After all, we've been designing state-of-the-art reed relay and semiconductor switching systems for over 18 years.

Our customers include government agencies, defense contractors, the TV industry, ATE and telecommunications companies—and more.

MATRIX
SYSTEMS CORPORATION

5177 NORTH DOUGLAS FIR ROAD
CALABASAS, CALIFORNIA 91302

Phone: 818-992-6776
TWX: 910-494-4975
FAX: 818-992-8521

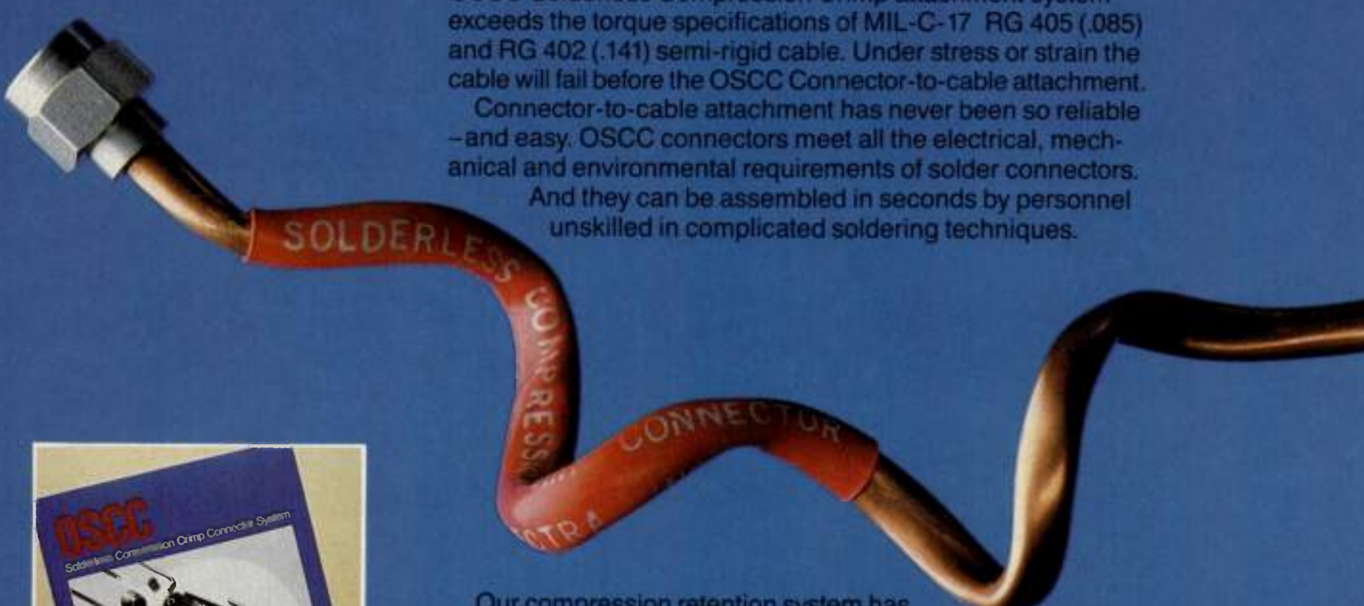
INFO/CARD 86

A New Twist On Performance.

The Crimp Connector Challenge.

M/A-COM Omni Spectra has met the challenge to produce a solderless connector that won't twist off your semi-rigid cable assembly. The cable-to-connector joint formed by our unique OSCC Solderless Compression Crimp attachment system exceeds the torque specifications of MIL-C-17 RG 405 (.085) and RG 402 (.141) semi-rigid cable. Under stress or strain the cable will fail before the OSCC Connector-to-cable attachment.

Connector-to-cable attachment has never been so reliable – and easy. OSCC connectors meet all the electrical, mechanical and environmental requirements of solder connectors. And they can be assembled in seconds by personnel unskilled in complicated soldering techniques.



Our compression retention system has been used with confidence in military airborne, shipboard and ground based systems, anywhere vibration and temperature stability are critical. You too could be using the easiest, most reliable connector assembly system available. Call today for our latest OSCC Solderless Compression Crimp Connector System catalog.

M/A-COM

Omni Spectra

21 Continental Boulevard, Merrimack, NH 03054 (603) 424-4111
50 Milford Road, Reading, Berkshire, Great Britain RG1 8LG (0734) 580833

INFO/CARD 87

See our OSCC Demo at the RF Technology Expo, Booths #306-310.

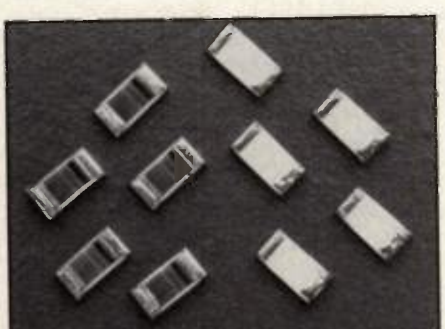
1.05. A 75 ohm adapter is provided and output level is automatically corrected for mismatch loss. The 2520 is priced at $2250. **Boonton Electronics Corp., Randolph, NJ. INFO/CARD #213.**

Wideband Op Amp

The AD9611 operational amplifier from Analog Devices has a small signal bandwidth of 280 MHz and full power bandwidth of 210 MHz. Settling time is 13 ns to 0.1 percent while the rise and fall times are 1.3 ns and 1.5 ns respectively. Current feedback is used instead of voltage feedback to provide dynamic performance that is relatively independent of gain settings. **Analog Devices, Inc., Norwood, MA. INFO/CARD #212.**

Flat Chip Resistors

Surface mountable precision resistor chips with resistance values from 50 ohms to 50 k ohms, and resistance tolerances to 0.1 percent are available from IRC. Temperature coefficients of resis-



tance are available to ±25 ppm/°C and power rating at 70°C is 125 W. Standard packaging is 8 mm tape and reel. In 1000 piece quantities, the resistors are $0.69 each. **IRC, Inc., Boone, NC. Please circle INFO/CARD #211.**

Wideband Video Multiplexer

The 8-channel DG538 video multiplexer from Siliconix has a 300 MHz bandwidth, cross talk of −97 dB at 5 MHz and provides TTL compatibility and address latch data readback to ease digital interface. It allows ± 5 V signal swings and is available in 28-pin plastic dual-in-line and J-lead surface-mount packages. In 100-piece quantities, the unit price ranges from $11.52 to $13.01. **Siliconix, Inc., Santa Clara, CA. INFO/CARD #210.**

Microwave Test Fixtures

Design Technique introduces the CPW (coplanar waveguide) microwave test fixture for test and evaluation of GaAs FETs and MMICs. The fixture features a sliding carrier loader that provides rapid insertion and removal of the test circuit. Included with the test fixture is a DC bias block which allows from 4 to 8 DC contacts to be made to isolated pads on the coplanar test circuit. As an option, up to 4 of the DC inputs can be specified to include integrated RF filters. A de-embedding package is also available for calibrating out the RF characteristics of the fixture. The price of the fixture starts at $2,640. **Design Technique International, Inc., Chatsworth, CA. INFO/CARD #209.**

Triaxial Connectors

The triaxial chassis jack from AVA provides an interconnection method for triaxial cables. It is suitable for use in low level, high sensitivity applications where a high transmission rate is desired. Mating is accomplished by means of a mechanically stable, 3-stud bayonet coupling. It features a nickel plated machined brass body, machined contact and teflon insulators. Both gold and silver platings are available. **AVA Electronics Corp., Drexel Hill, PA. INFO/CARD #208.**

RF Data Network

The Monicor System 200 complements existing data collection hardware by creating a wireless, portable, local area network. The system allows mixing and matching of various collection devices. It consists of the IC-210A master control unit and the IC-15 portable digital radio. The 210A provides network control and communication between a host computer and up to 250 different peripheral devices linked via the IC-15. An RS-232 link is required between the 210A and a host computer. The baud rate is user selectable up to 9600 baud and the RF data transmission rate is 2400 bits per second operating in the 450 MHz to 470 MHz band. The IC-15 is $1895 and the IC-210A is $2495. **Monicor Electronic Corp., Fort Lauderdale, FL. INFO/CARD #207.**

6 GHz Bandpass Filter

Model 5451 is a wideband interdigital bandpass filter with a 22 percent passband centered at 6 GHz. The 1 dB passband is from 5.27 to 6.78 GHz with 60 dB selectivity at 4.87 and 7.20 GHz. It measures 0.5"× 0.87"× 3.38" and has SMA connectors. The price of the filter is $375. **Microwave Filter Company, East Syracuse, NY. INFO/CARD #206.**

De-embedding Software

Design Technique announces the availability of the Elite 1.2 software de-embedding package designed for use with their family of microwave test fixtures. It works with the HP 8510 network analyzer to characterize GaAs FETs and MMICs. When used with Design Technique's test fixtures, the calibrated VSWR is typically 1.01:1 over the 45 MHz to 26.5 GHz range. The calibration kit consists of a cassette tape and a set of calibration standards. It is available for use with both the Design Technique CPW (coplanar waveguide) test fixture and microstrip test fixture. **Design Technique International, Inc., Chatsworth, CA. INFO/CARD #196.**

Public Domain Library Expands

The E.E. Public Domain Library has released disks 11 through 17. Also,disks 1, 3 and 9 have been updated. For more information on the new additions to this service, please circle the reader service number. **E.E. Public Domain Library, Plainview, N.Y. INFO/CARD #197.**

Distributed Low Pass Filter Programs

MSA introduces three filter programs. CXLPF designs distributed circuit lowpass filters in coaxial lines. The physical circuit is realized with round inner and outer conductors separated by a dielectric. SLLPF is for designing distributed circuit lowpass filters in stripline. The user specifies the low and high impedance levels. Length correction is applied for discontinuity compensation and proximity effects. MSLPF is a program that designs microstrip low pass filters. **Microwave Software Applications, Inc., Norcross, GA. INFO/CARD #198.**

RF Notes No. 4

RF Notes No. 4 (network analysis) assists in designing and analyzing R, L, C and transmission line networks up to 30 sections. Up to 14 sections of R, L and C elements may be entered in schematic diagram form or entered directly while output data is in tabular and graphical form. Graphics plot parameters are user selectable and the program is menu driven. It is priced at $179 plus shipping and handling. It runs on PC/MS DOS 2.1. **Etron RF Enterprises, Diamond Bar, CA. Please circle INFO/CARD #199.**

GPIB Test Program Generator

Wavetek San Diego has introduced a software application program called WaveTest™. It is an icon based programming environment that generates automatic test programs. Users can develop and edit test programs using flowcharts or modules as opposed to writing programs from scratch. Also included is an instrument library generator and an instrument database library with over 50 GPIB instruments from various manufacturers. With WaveTest's test program generator (TPG), the user links a series of instrument setups, program modules, operator prompt windows and formatting windows to create a test program. The TPG executes this as program code, handling internal timers, triggering and interrupts. Debugging features such as breakpoints, single step, trace variables and monitor GPIB transactions are included. Since instrument setups can be constants, variables or expressions, the user can dynamically control the instruments during program execution. This program runs on the IBM PC/AT and costs $3,990. **Wavetek San Diego, Inc., San Diego, CA. INFO/CARD #200.**

rf literature

RF/Microwave Filter Book

The *Filter Book* from Microwave Filter Company describes fundamental behavior of RF/Microwave filters from 1 MHz to 26 GHz and illustrates the form they can be expected to take. Filter types described are lowpass, highpass, bandpass, bandstop, bandsplitters, wide bandpass diplexers and triplexers, narrow bandpass diplexers and quadrature diplexers. Each category is broken down into three sections that describe the respective filters from 0 to 500 MHz, 500 to 1000 MHz, and 1000 MHz and up. Included is a two page glossary of filter terms and a section that illustrates the company's design, engineering, production and support facilities. **Microwave Filter Company, East Syracuse, NY. INFO/CARD #192.**

Analog Product Catalog

This catalog from Honeywell is broken down into 11 sections. The first section contains a selection guide, cross reference, identification codes, and ordering information. This is followed by sections on analog to digital converters, digital to analog converters, comparators, instrumentation amplifiers, special functions, evaluation boards, application information, quality assurance, package outlines and sales offices and representatives. **Honeywell, Inc., Signal Processing Technologies, Colorado Springs, CO. INFO/CARD #191.**

Digital Storage Oscilloscopes Brochure

Iwatsu Instruments has released a brochure that describes the DS-6612/6411 digital storage oscilloscopes. Keys on the control panel such as the storage, real time, index, set, cursor and set reference are outlined. Features like separate A/Ds per channel and full cursor measurement in both analog and digital are described. Drawings illustrate the features of the scopes including equivalent sampling of 60 MHz (DS-6612), absolute value measurement with ground as standard, 500 sec/div roll mode, GO/NO GO judgment function, waveform output function, averaging and peak channel hold functions, simultaneous 4-cursor display for convenience in measurement, pre-triggering function and save memory function. **Iwatsu Instruments, Carlstadt, NJ. INFO/CARD #190.**

Superconductivity Guide

Superconductivity: A Practical Guide for Decision Makers is a report designed to assist readers in understanding the significance of high temperature superconductivity (HTS) developments to their organizations and in translating that understanding into effective monitoring, research, and product development plans. Topics discussed include the practical significance of high temperature superconductivity, evaluating advances in HTS, understanding the HTS jargon, the current era of bulk and flexible HTS, and surface coating HTS. The report costs $595 and more information can be obtained by circling the reader service number. **Technology Futures, Inc., Austin, TX. INFO/CARD #189.**

EMI/RFI Technical Guide

Equipto Electronics has updated their EMI/RFI technical guide to include new standards information, recent test results, and information on additions to their line. Included is their double gasketing feature, leak proof handle and hinges, and standard accessories. **Equipto Electronics Corp., Aurora, IL. INFO/CARD #193.**

Product Selection Guide

This guide is designed to assist users in the selection of new and used instrumentation for rental, purchase or lease. Featured instruments include analyzers (logic, network, spectrum), environmental chambers, generators (signal, function, pulse, sweep), microwave equipment, oscilloscopes, and television/video instrumentation. Each product category includes summary specifications. **RAG Electronics, Inc., Canoga Park, CA. INFO/CARD #187.**

Note Describes Metal-Clad Laminates

This application note describes thick-metal cladding on RT/duriod[R] microwave laminates, provides processing tips and reviews possible applications. The thick metal cladding on RT/duriod® microwave thick and serves as a ground plane for stripline and microstrip circuit boards. Common thick metal options include aluminum, brass and copper. This note reviews advantages of this construction including heat sinking, connector and component mounting, minimization of thermal stress cracking of conductors and dimensional stability. **Rogers Corp., Chandler, AZ. INFO/CARD #194.**

Data Communications Brochure

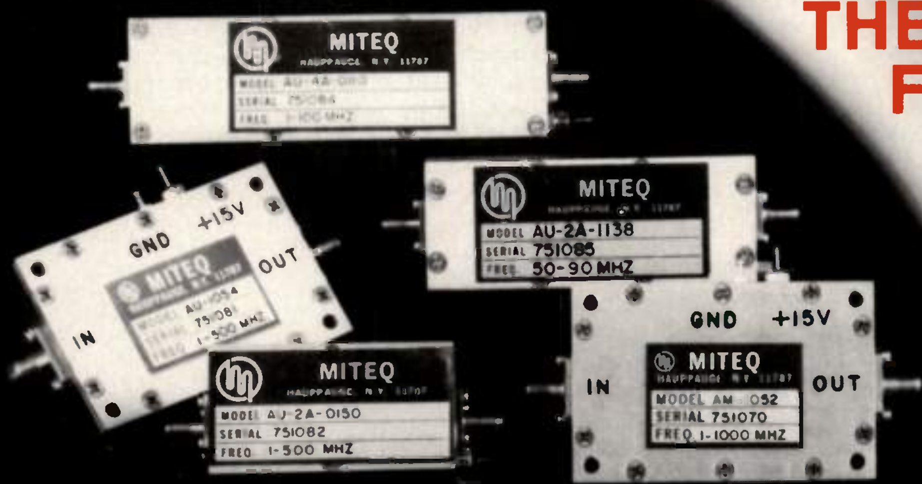
Data Communications in Automatic Identification Systems examines a model for data communications, various communication schemes between systems, methods of reducing transmission interference, the installation of equipment, a model for local area data communication networks, and the trends which data communication systems are beginning to take. The brochure costs $5. **AIM, Pittsburgh, PA. INFO/CARD #195.**

1988 Products Catalog

This catalog from Wiltron describes over 300 microwave measurements components, instruments, and systems in the DC to 60 GHz range. Featured products include vector network analyzers, scalar network analyzers, swept frequency synthesizers, sweep generators, and RF analyzers. It also gives specifications for precision measurement components, the

GUARANTEED 2 WEEK DELIVERY!

MITEQ...THE ULTIMATE IN LOW-NOISE WIDEBAND AMPLIFIER TECHNOLOGY IN THE 1-2000 MHz FREQUENCY RANGE



If low noise figure and wide bandwidth is the name of your game, if fast delivery will enhance your competitive standing, then go no further—MITEQ is your source.

Model Number	Frequency (MHz)	Gain (Min.) (dB)	Gain Var. (Max.) (±dB)	Noise Figure (Max.) (dB)	VSWR (Max.) Input	VSWR (Max.) Output	Dynamic Range 1 dB Gain Comp. Output (Min., dBm)	Nom. DC Power (+15V, mA)
AU-1054	1-500	29	0.5	1.6	2:1	2:1	+8	50
AU-1001	50-90	13	0.25	7.5	75Ω	75Ω	+15	65
AU-1189	1-100	30	0.5	1.3	2:1	2:1	+3	25
AM-1052	1-1000	25	0.75	2.0	2:1	2:1	+5	45
AU-3A-0110	1-100	45	0.5	1.3	2:1	2:1	+10	70
AM-3A-000515	5-1500	28	0.75	2.5	2:1	2:1	+5	65
AU-3A-0150	1-500	45	0.5	1.6	2:1	2:1	+10	70
AMMIC-1047	50-2000	35	1.0	2.5	2:1	2:1	+17	150
AMMIC-1022-100	50-2000	17	1.0	2.5	2:1	2:1	+6	50
AMMIC-1022-101	50-2000	17	1.0	5.0	2:1	2:1	+17	100
AM-3A-000110	1-1000	35	0.75	2.0	2:1	2:1	+10	75

Unsurpassed performance

- Guaranteed 2-week delivery—with most models delivered from stock
- Two-year warranty
- One day turn-around on repairs
- All models are reverse and over-voltage protected

Additional optional features:

- Integral power supply
- Integral bias tee for infrared mixer and diode biasing
- DC supply via output connector

This is only a fractional listing of available models. For more detailed information ask for our Amplifier Handbook, or give a call to Bill Pope—he is ready to serve you!

MITEQ

100 Davids Drive, Hauppauge, N.Y. 11788-2086
Tel. (516) 436-7400
TWX 510-226-3781
FAX 516-864-1586

K connector coaxial product line operating up to 46 GHz, and a line of 40 GHz fixed attenuators. Photographs and dimensional data complete the descriptions. **Wiltron Company, Morgan Hill, CA. INFO/CARD #228.**

Catalog and 1988 Calendar

Information on EMCO's line of antennas and accessories for EMI/RFI testing is provided in this catalog. In addition to product information, contained is FCC and VDE requirements, tables for the selection of equipment, and a list of formulas. A 20"× 30" 1988 calendar with information for test engineers is also being offered. **The Electro-Mechanics Company, Austin, TX. INFO/CARD #229.**

Directory of Superconductivity Research

This directory lists individuals from government agencies, academic institutions and businesses committed to researching, developing, marketing and funding the expanding scope of superconductors. Over 1000 individuals from 24 countries, each listed with their institutions, addresses, phone numbers and areas of research indexed by institution, location and area of research are included. More information can be obtained by circling the reader service number. **Pasha Publications Inc., Arlington, VA. INFO/CARD #230.**

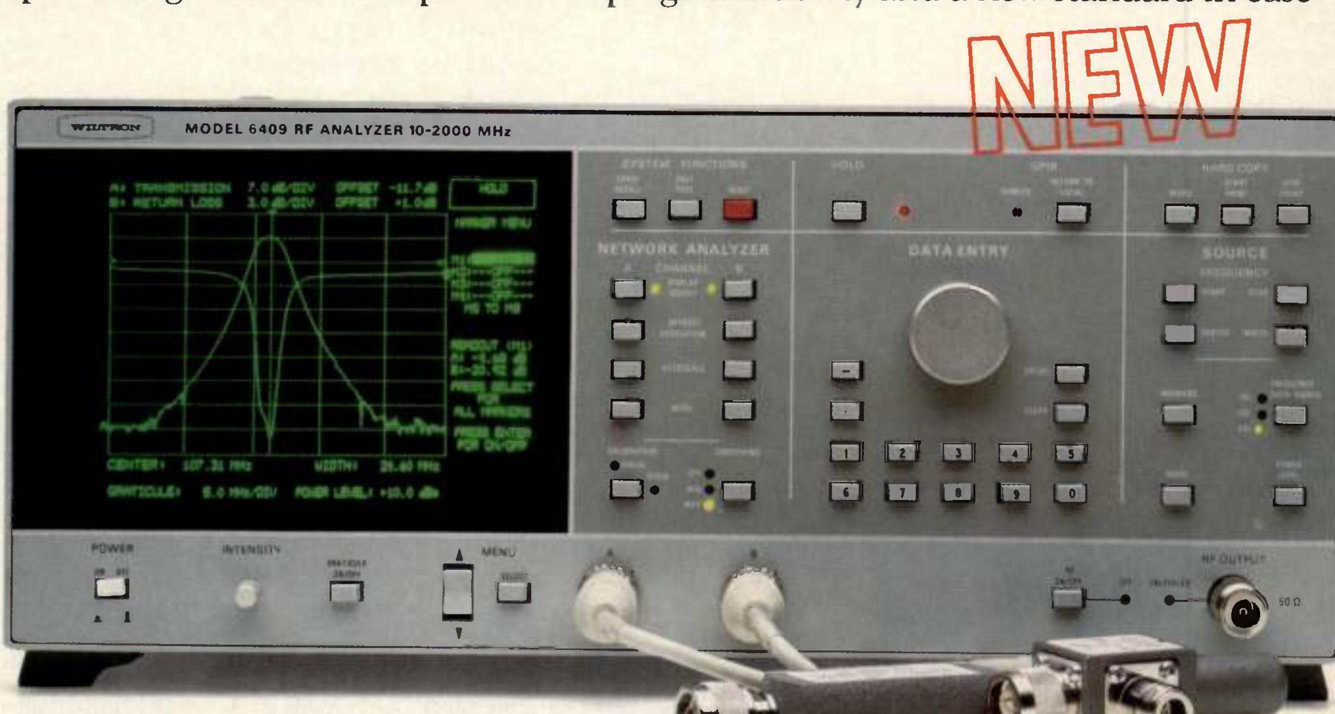
You don't g

With the NEW Wiltron RF Test System.

The new 1 to 2000 MHz Wiltron 6400 RF Analyzer. In a single, compact instrument, Wiltron brings you an affordable crystal-derived swept signal source, a scalar network analyzer, precision measurement components, and a display. Measure transmission, return loss, and absolute power.

It's a remarkable breakthrough. For far less than you would expect to pay, Wiltron gives you synthesizer-like performance over the entire 1 to 2000 MHz.

The 6400 has resolution and accuracy 10 times better than anything in its price range. It offers complete GPIB programmability and a new standard in ease



of operation. At twice the price, the 6400 would still be a bargain.

Our engineers gained exceptional stability and accuracy by "locking" the frequency to a crystal marker at the beginning of every sweep. Because frequency is always on the mark, you won't waste time looking for traces that have drifted off the screen. You'll have excellent repeatability of test data taken on very narrow bandwidth devices. Even if tests are made days apart.

et the drift.

Dynamic range is 71 dB (+16 to −55 dBm). Use the Wiltron 6400 for the most demanding applications including TV tuner, cellular radios, filters, amplifiers, diplexers and DBS. For a permanent record, test data are plotted in graphical or tabular format on an optional ink-jet printer.

The 6400 is a joy to use on the production line, in the laboratory, or out in the field.

Autoscaling can be used to automatically select the optimum display for your device. The display is fully annotated to ensure accurate, confusion-free interpretation of test data.

Specifications

Signal Source
Frequency Range:
  Model 6407: 1 to 1000 MHz
  Model 6409: 10 to 2000 MHz
Frequency Accuracy: ± 100 kHz
Frequency Resolution: 10 kHz
Leveled Output Power Range: +12 dBm to +0.1 dBm
  Optional attenuator: +10 dBm to −70 dBm
Harmonics: < −30 dBc
Nonharmonic spurious: < −40 dBc
Network Analyzer
Dynamic Range: +16 dBm to −55 dBm
Vertical Display Resolution: 0.003 dB maximum
Horizontal Display Resolution: 101, 201, or 401 points.
Normalization: 800 points, automatically interpolated for ranges less than full range.
Markers: up to 8.
SWR Autotesters
Directivity: 40 dB
Impedance: 50 or 75 ohms
Test Port Connector: Type N or BNC
RF Detectors
Impedance: 50 or 75 ohms
Test Port Connector: Type N or BNC

Test Data on Friday, 10:15 AM:
M1 Marker Frequency: 104.72 MHz
Passband Amplitude at M1 Marker: −4.82 dB

Test Data on Wednesday, 3:30 PM:
M1 Marker Frequency: 104.72 MHz
Passband Amplitude at M1 Marker: −4.86 dB

You get fast production test times since frequencies can be changed without recalibration. Go/no-go limit lines and up to eight markers, which can be set to test points of interest, make readings easier. Costly setup time is eliminated by storing up to nine front panel setups in memory.

In addition to the 6400's 17.8 cm (7 in.) display, there's a composite video output which will drive a larger screen. Production people love it. And with a weight of only 16 kg (35 lb), the 6400 can be carried to the most inaccessible repeater station.

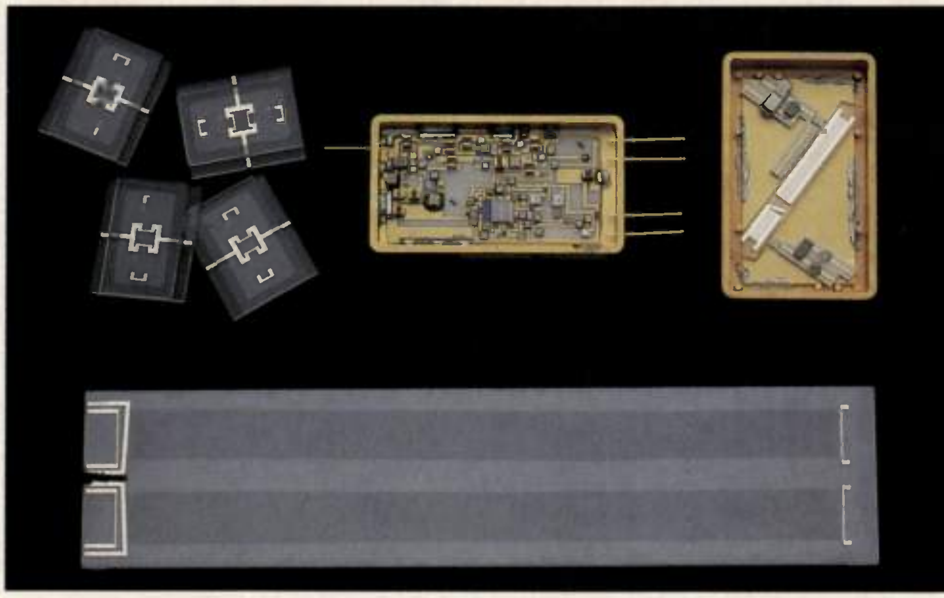
Now in a single instrument, you get everything you need to make fast, accurate RF measurements. And you don't get the drift.

For more information, contact Wiltron, 490 Jarvis Drive, Morgan Hill, CA 95037-2809. Tel: (408) 778-2000.

WILTRON

INFO/CARD 96

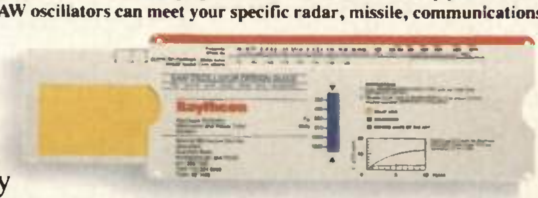
Raytheon SAW devices are in a class by themselves.



Here's their report card.

Product	Performance data
SAW stabilized oscillators	Frequencies from 200 MHz to 2 GHz. Resonator or delay line stabilized, voltage tuned or fixed frequency. Higher frequencies available from harmonic extraction.
SAW resonators	Unloaded Q as high as 20,000. All-quartz packaging provides superior aging characteristics.
Signal processing components and subsystems	
Dispersive and phase coded delay lines	Center frequencies from 20 to 2000 MHz, bandwidths from 0.1% to one octave.
SAW bandpass filters	Center frequencies from 20 to 2000 MHz, bandwidths from 0.01% to one octave.
Non-dispersive delay lines	Delays from 200 nsec to 100 μsec, center frequencies from 10 to 3500 MHz.

Send for this useful design guide slide-rule which will help you determine how Raytheon SAW oscillators can meet your specific radar, missile, communications and ECM needs.



Why are Raytheon SAW devices more advanced?

They feature broader bandwidths, higher frequency coverage, and a wide range of options.

What's more, Raytheon offers you the aid of engineering professionals with years of SAW experience.

That's how we can offer the right SAW device or subsystem for your specific application.

For more information, write Raytheon Company, Special Microwave Devices Operation, Bearfoot Road, Northborough, MA 01532.

Or call us at (617) 393-7300, extension 351.

Raytheon

INFO/CARD 97

See us at the RF Technology Expo, Booths #450-454.

rf literature *Continued*

Amplifier Application Note

Using the AD9610 Transimpedance Amplifier describes the use and application of this type of operational amplifier for high speed and high accuracy applications. Applications for the AD9610 include radar, line driving, digital radio, waveform analyzers, instrumentation/ATE, photodiode preamps, laser drivers, A/D/A conversion, and base-band communication systems. **Analog Devices, Inc., Norwood, MA. INFO/CARD #223.**

Instruments Rental Catalog

This catalog reflects inventories of general purpose test equipment. All equipment is NBS calibrated. Included is a complete manufacturer/model index to help the user locate specific models. **Continental Resources, Inc., Bedford, MA. INFO/CARD #224.**

Custom MMIC and Digital IC Brochure

Gallium Arsenide Custom and Semicustom Integrated Circuits describes the procedures for design and fabrication of custom MMICs and digital ICs available from Harris. The brochure details various program services and 1 micron and 0.5 micron fabrication processes. **Harris Microwave Semiconductor, Milpitas, CA. INFO/CARD #225.**

Measurement System Catalog

Narda introduces a microwave measurement system short form catalog. The 7000 Series is a microwave test station that performs standard measurements, power loss/gain, and VSWR/return loss measurements. The system functions as a signal generator, sweep generator, and DC voltmeter as well. **Narda Microwave Corporation, Hauppauge, NY. Please circle INFO/CARD #226.**

Brochure for Semiconductor Testing

Keithley has produced a brochure that describes how to use instruments in making measurements on semiconductors. The publication, a combination of tutorial and product descriptions, details measurement techniques in several specialized areas, including low level measurements, capacitance voltage (CV) tests, resistance and electromigration studies, and Hall Effect measurements. Also included is a discussion of automation semiconductor measurements through computer controlled instruments, switching matrices and fill turn-key systems. **Keithley Instruments, Inc., Cleveland, OH. Please circle INFO/CARD #227.**

Bliley

PEOPLE OFTEN BUY CRYSTALS FROM US BECAUSE THEY'RE TRYING TO MAKE THEIR OSCILLATORS AS TOTALLY RELIABLE AS WE MAKE OURS.

CONSIDER THAT.
LOOK AT OUR
NEW CATALOG.

Our vertical capabilities give you the assurance edge.

Quartz Crystals • Crystal Oscillators • Free Catalog

First Name in Frequency Control

BLILEY ELECTRIC COMPANY

2545 West Grandview Blvd.
P.O. Box 3428, Erie, PA 16508
(814) 838-3571 TWX 510-696-6886
FAX 814-833-2712

MADE IN USA

INFO/CARD 100

TECHNOLOGY FOR A NEW AGE

Go Beyond The Tip Of The Iceberg In Electronics Technology.

TRW's Electronic Systems Group has been a team leader in the U.S. Department of Defense's VHSIC program since 1980. And that's just the tip of the iceberg. Our engineers are also involved in the design of state-of-the-art satellite circuits, Millimeter Microwave technology, Wafer Scale Integration, Earth Terminal Communications, and next generation avionics technology. If you've already seen the tip of the iceberg, we invite you to explore the rest with us. Consider the following:

Electronic Systems Group

RF Electronics & Communications Laboratories

Communication subsystem design, microwave/millimeter wave circuit design, and electro-optics are among the most challenging and exciting growth areas in the space payload/aerospace industry. TRW's RF Electronics & Communications Laboratories in Redondo Beach are at the forefront of this growth, working directly with both military and civilian customers. These organizations are responsible for the design and development of all aspects of advanced communication hardware, from initial concept definition through final design and performance verification. They provide hardware for advanced spacecraft payloads and technology projects. Current openings include:

• **Project Managers**—Guide engineering teams developing complex hardware. These senior level positions require design and technical management experience.

• **Communication Engineers**—Design and develop communication payload units and subsystems. Involves requirements definition, unit/subsystem analysis, architectural and technology trades, studies and proposals, and leading hardware development efforts.

• **Section Heads**—Oversee the work of several developing engineers working on communication hardware. Provide technical direction and guidance to section personnel. Lead R&D activities, functional management, and proposals. BSEE/Physics, minimum 7 years experience.

• **Microwave & Millimeter Wave Circuit Designers**—Perform hands-on hardware development of innovative circuits and subsystems using GaAs MMICs and other III-V devices such as HEMTs and HBTs. Design and develop mixers, low noise and power amplifiers, VCOs, switches, modulators, and other communication circuits. 3+ years experience.

Please send resumes to: **TRW ESG, Brenda Anderson, R10/1757, Dept. RFD, One Space Park, Redondo Beach, CA 90278.**

Military Electronics & Avionics Division

Our Military Electronics and Avionics Division is engaged in the design and development of highly sophisticated digital and RF systems/subsystems for tactical defense and avionics. We're employing some of the latest new age technologies in VLSI/VHSIC, advanced digital and programmable signal processors, and software for application to EW, ESM, integrated CNI, data links, and ground processing systems. Join us as we engineer a new age of avionics technology. Consider the following:

San Diego Facility

• **Anechoic Chamber Supervisor**—At least 5-10 years experience in antenna range maintenance and testing. Should be capable of chamber equipment failure diagnosis and minor repairing. Experience with antenna pattern as well as scattering measurements is required. Knowledge of antenna automatic test equipment and computer language desirable. Should be willing to perform chamber planning and provide minimum supervision of junior technicians.

• **Antenna Engineers**—Requires at least 5-10 years experience in the analysis, design and development of antenna systems. Background with design, development, and hardware implementation of conformal antennas, radomes, and micro/stripline feed networks. Should be capable of electromagnetic analysis and antenna/platform radiation and scattering performance, and antenna system performance evaluation.

• **Communication System Engineers**—Provide system engineering for the development of advanced Communication, Navigation, Identification (CNI) systems, the next generation of military aircraft. Generate system requirements and specifications, perform design, analysis and algorithm and architecture development. Possess experience in modulation/demodulation theory, detection and estimation theory, coding theory, spread spectrum techniques, acquisition and tracking, digital signal processing, receiver system analysis.

• **Senior Communications Systems Engineers**—Define system requirements, perform configuration tradeoffs, allocate requirements to subsystems and analyze system performance for next generation integrated CNI avionic systems. Experience in modulation/demodulation, detection and estimation and coding theories, spread spectrum, acquisition and tracking and digital signal processing is required. Minimum BSEE/MS or PhD preferred and 12 years experience with existing military communication systems.

• **Microwave Receiver Designers**—Experienced in design of avionics receiver systems, subsystems and components. Responsible for receiver evolution from initial concept definition through final design, integration and performance verification. Key hardware technologies include synthesizers, monolithic microwave integrated circuits (MMIC) and microwave hybrids. BSEE required; MSEE preferred.

Please forward resumes to: **TRW MEAD, R. Angel, RC2/1351, Dept. RFD, One Rancho Carmel, San Diego, CA 92128.**

Because Anywhere Else Is Yesterday.

TRW's comprehensive employee compensation package includes professional amenities that are among the best in our industry. Tomorrow is taking shape at a company called TRW.

Equal Opportunity Employer
U.S. Citizenship Required For Most Positions
Agency Candidates Will Not Be Considered

TRW

A Company Called TRW

Advertiser Index

NEW — 112-Page Information and Product Catalog

Complete from Abrupt to Zener — 112-pages of designer data to make your life easier and your project trouble-free. Our new catalog will give you the needed information to complete even your toughest projects, by describing our broad base capabilities in silicon and gallium arsenide diodes.

Many of our high performance products are available as standard products or call us and discuss your special designs.

- **Silicon Abrupt Junction Tuning Varactors, 30V to 90 Volts**
- **FLTVAR — Frequency Linear Tuning Varactors**
- **VHF/UHF Hyperabrupt Tuning Varactors**
- **GaAs Tuning Varactors 15V to 60 Volts**
- **Power Generation — Multiplier Varactors**
- **Step Recovery Diodes**
- **Harmonic Generator Varactors**
- **Multi-Chip High Power Generator Varactors**
- **Noise Diodes**
- **Gunn Diodes**
- **Parametric Amplifier Varactors**
- **Control Devices — PIN and NIP Diodes**
- **UHF/VHF PIN Diodes**
- **Power RF Switching**
- **Small Signal RF Diodes**
- **HF Power PIN Diodes**
- **Limiter Diodes**
- **Chip Capacitors**

FREQUENCY SOURCES
SEMICONDUCTOR DIVISION
A SUBSIDIARY OF **LORAL** *CORPORATION*

16 Maple Road
Chelmsford, MA 01824
(617) 256-8101
TWX (710) 343-0404

INFO/CARD 108

See us at the RF Technology Expo, Booths #640-644.