RF design

engineering principles and practices

February 1992

Cover Story

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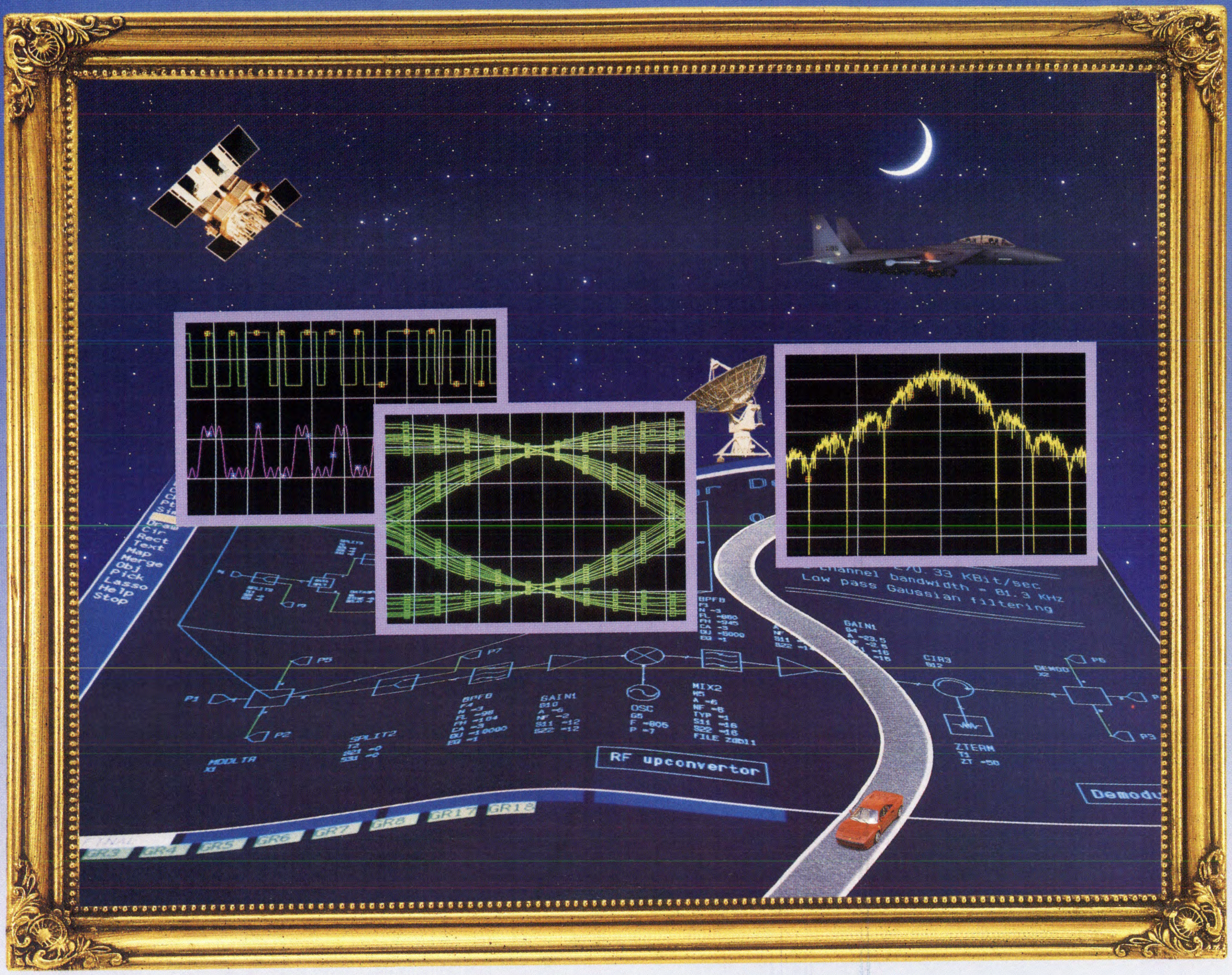

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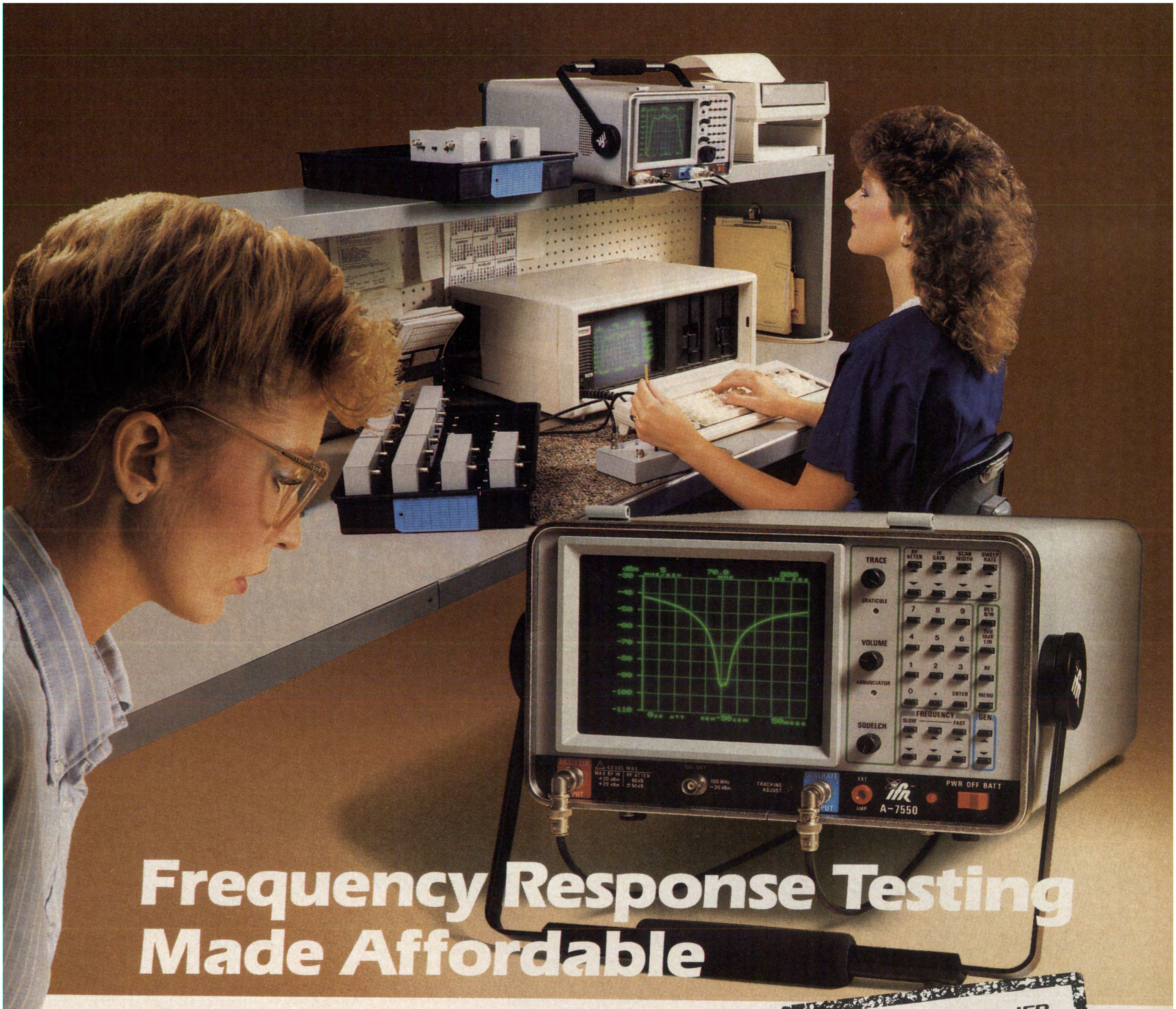

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P35-4101-0	0.5-3.5	9	4.5	22	Chip	Self-Biased
P35-4104-0	0.05-3.0	18	6.0	13	Chip	Low VSWRs
P35-4105-0	0.8-1.8	21	3.5	8	Chip	
P35-4110-0	1-6	7.5	4.6	20	Chip	
P35-4140-0	6-18	5.5	5.5	15	Chip	Pos. Gain Slope
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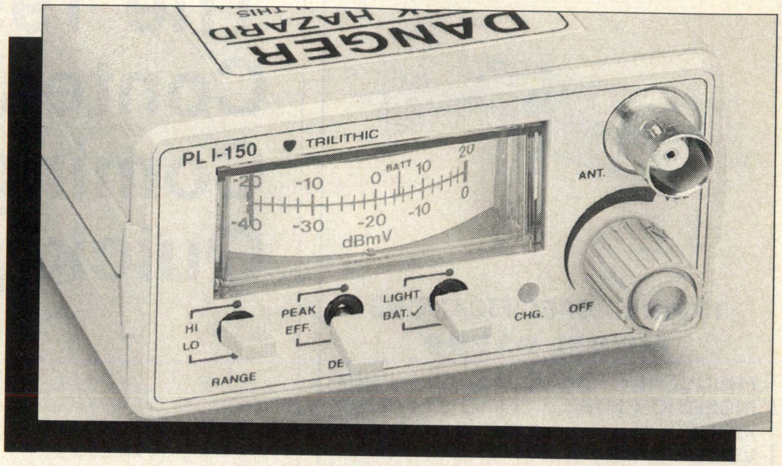
RF design

contents

February 1992



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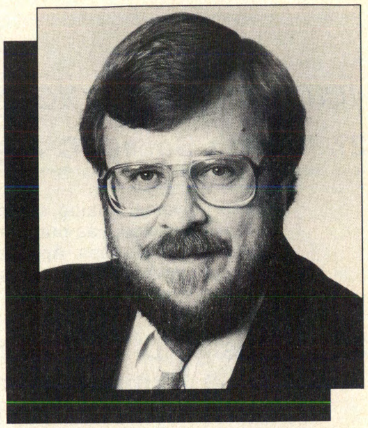
RF editorial

The 1992 Contest is Coming Up Quickly



By Gary A. Breed
Editor

Boy, time sure flies! It seems like just a few weeks ago that the judging was underway for the 1991 RF Design Awards Contest. The March 20th entry deadline for the 1992 edition will be here quickly. (For you previous contest participants, this is 10 days earlier than before — the judging has gotten more difficult, and we need a few more days to do it right.)

As you have probably noticed, we have outstanding Grand Prizes again this year. Hewlett-Packard is providing their HP 8711A Network Analyzer, to be awarded to the top Circuit Design Contest entry; and Eagleware has offered a complete package of design and analysis software, plus a fully-equipped '386 computer system for the winner of the PC Software Contest. With these prizes as motivation, we expect to see some outstanding engineering work in the collection of entries.

We have a nice collection of additional prizes, as well, starting with a repeat of last year's "T-shirt for everyone" idea. Everyone entering the contest will receive a special RF Design Awards T-shirt in appreciation of his or her participation. We hope to continue this tradition in future contests, creating a whole series of unique collector's items.

Twenty five Honorable Mention prizes will be awarded, consisting of several prototyping kits, handy collections of RF components for your lab shelf. Plus, any software entry selected for publication will get a one-year subscription to the RF Design Software Service. Even these consolation prizes are worth hundreds of dollars.

Of course, I'm telling you this to encourage your participation. My fellow judges, Consulting Editor Andy Przedpelski and 1991 winners Charles Wenzel and Mike Ellis, are waiting to be inundated with great design and software ideas! We know how much development work is going on in commercial and consumer RF applications, with new techniques being developed at a furious pace. These innovations could be potential winners. Don't give away any competitive secrets, but take a moment to think about some "new twist" you developed to improve an existing design method, or the most useful part of your "secret weapon" computer program.

Finally, I have to remind you that winning can be contagious! Our past winners definitely received more than just their prizes. They have also received recognition within their companies. Most have been given greater freedom to pursue new design ideas. Some even became the subject of promotional campaigns touting the quality of their company's engineering staff. Send us your winning circuit design or software idea. Make your boss look good for hiring you.

NCI synthesizers get your system flying...fast.

The airborne environment is a turbulent place for a synthesizer. Shock and vibration, rapid temperature cycling, and strict limits on power consumption, size, and weight combine to make operating here a real challenge.

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Output power (dBm)	+22 minimum
Output power variation (dB)	+/–2 or less
Output VSWR	Less than 1.2:1
Warm-up to full performance	Less than 1 min. at –40°C
Acquisition time (µs)	Less than 90
SSB integrated phase noise (deg. RMS)	Less than 2
Power consumption (W)	6.1 or less
Size (in.)	1.6 x 3 x 5.1
MTBF (hr.)	More than 10,000
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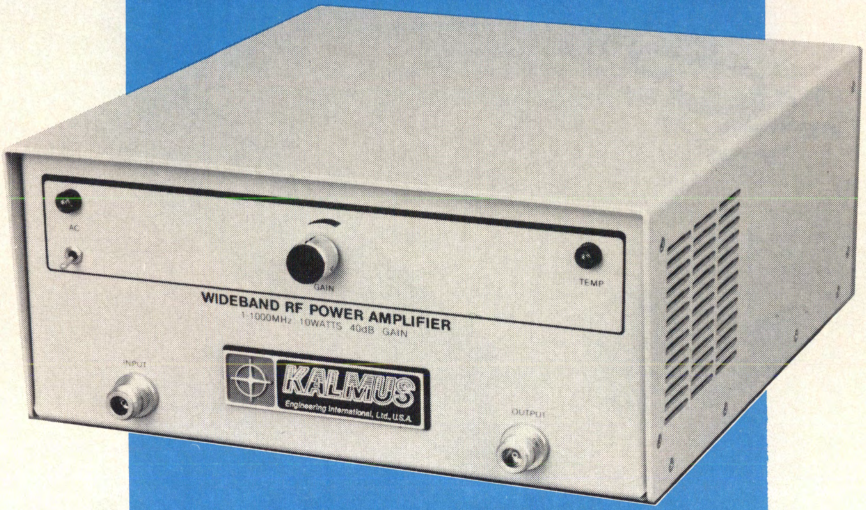

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410LC	10W CW	.006-400 MHz	43dB	30x35x13	4.5kg	100-240V	$ 4,600
710FC	10W CW	1-1000 MHz	40dB	30x35x13	7.3kg	100-240V	$ 6,695
727LC	10W CW	.006-1000 MHz	43dB	48x46x13	8.5kg	100-240V	$ 7,750
711FC	15W CW	400-1000 MHz	40dB	30x35x13	5.5kg	100-240V	$ 3,620
720FC	25W CW	400-1000 MHz	40dB	48x46x13	8.6kg	100-240V	$ 5,995
712FC	25W CW	200-1000 MHz	40dB	48x46x13	8.8kg	100-240V	$ 7,350
737LC	25W CW	.01-1000 MHz	45dB	48x46x13	10.5kg	100-240V	$ 9,995
747LC	50W CW	.01-1000 MHz	47dB	48x46x26	26.5kg	100-240V	$22,500
707FC	50W CW	450-1000 MHz	47dB	48x46x13	13.0kg	100-240V	$ 9,995
709FC	100W CW	500-1000 MHz	48dB	44x48x18	22.5kg	100-240V	$19,990
722FC	200W CW	500-1000 MHz	50dB	44x18x31	41.5kg	100-240V	$31,900

Note: Models 727LC, 737LC and 747LC consist of two bands with one common input and output connector, switched with coaxial transfer relay, manually, or by remote. Switching speed 5 milliseconds.

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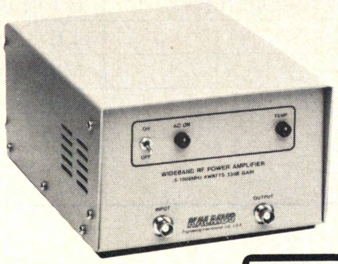

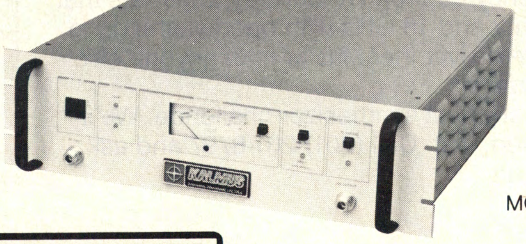

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INFO/CARD 6

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Coupler Confusion

Editor:

I found the *RF Design* article "Simple Bridge Circuit Mimics Ultra Broadband Couplers," November 1991, interesting and enlightening, but not original.

Werlatone Inc. pioneered the development of broadband RF couplers and power dividers using the ferrite loaded transmission line techniques to achieve the broadband high frequency equivalents of the bridge circuits.

The circuit and coupler described in the article were developed at Werlatone over 23 years ago. In 1969 we offered for sale three models, the DC14R, DC16R and the DC20R covering the 2-2000 MHz range. The DC16R is described by Mr. Dunsmore in the above referenced article.

The 20 dB coupler, Model DC20R, (now called the C2218) employs a ferrite loaded transmission line 1:1 transformer utilizing UT47 coax with a low loss/low perm ferrite on the hot end and the higher loss/higher perm ferrite on the ground end as described by Mr. Dunsmore.

In 1970 I was granted a patent for a lossless version of the wideband bridge type coupler, Patent # 3,550,042, and in 1972 Hoer of NBS was granted a coupler patent employing a combination of resistive and transformer techniques, Patent # 3,701,057.

Glenn C. Werlau
Werlatone, Inc.
Brewster, NY

Author's Reply

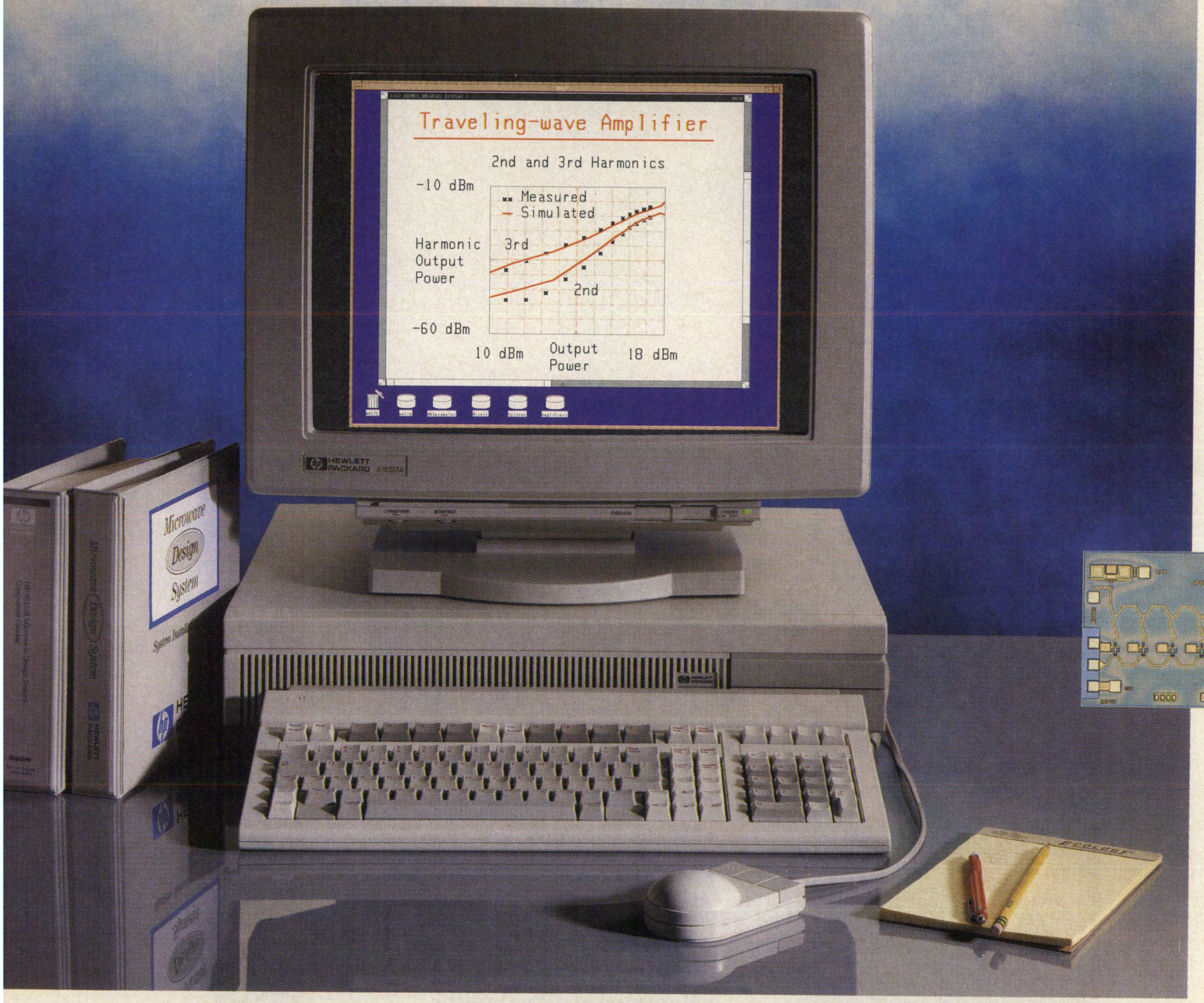
In submitting my entry to the design contest, I acknowledged that the general concept of a resistive (Wheatstone type) bridge was old. The concept of using a bridge as described dates back to before the mid 1960's, as has been indicated by this and other readers.

However, my new design, described beginning in the section headed "Coax Balun Structure," is believed to be an improvement. This improvement is based in the application of Surface Mount Technology (SMT) resistors in a microstrip printed circuit board (PCB), and maintaining a small size to generate good directivity over a very broad band, which could "be integrated in an RF PC board" without using connectors or packaging. This design demonstrates the application of RF PC board and SMT to higher frequencies, through careful modeling and construction techniques.

The pages I spent describing how a conventional bridge can have coupling and isolation was meant as a tutorial so that my improvement could be viewed in context, and did not intend to convey the impression that I had reinvented the bridge.

Joel Dunsmore
Hewlett-Packard Co.

HP's software shows you exactly what your GaAs FET circuits will do. Even when they go nonlinear.



Now nonlinear GaAs FET circuits like this 0.5-50 GHz amplifier can be accurately simulated using the new HP Root Model.

HP's Microwave Design System produces accurate nonlinear simulations.

The only way to get an accurate nonlinear simulation of a GaAs circuit is to use an accurate model. Now there is one—the HP Root Model. And it's part of the HP Microwave Design System (MDS).

Not only does the HP Root Model accurately simulate nonlinear GaAs FET circuit behavior, it accurately calculates linear behavior over bias as well.

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So if you'd like to see what will happen when your GaAs circuits go nonlinear, call your local HP sales office or one of the numbers listed below. And find out exactly what HP's Microwave Design System software can do.

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18-20 **International Mobile Communications Expo/Spring**
Las Vegas, NV
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23-27 **NEPCON West '92**
Anaheim Convention Center, Anaheim, CA
Information: Michael Critser, Conference Manager, Cahner's Exposition Group, 1350 East Touhy Ave., PO Box 5060, Des Plaines, IL 60019-9593. Tel: (708) 299-9311. Fax: (708) 635-1571.

25-27 **EMV '92**
Karlsruhe, Germany
Information: Messe & Kongreb GmbH, Postfach 10 32 61, D-7000, Stuttgart 10, Germany. Tel: (0711) 61946-0. Fax: (0711) 618079.

March

17-19 **Eighth Annual Review of Progress in Applied Electromagnetics**
Monterey, CA
Information: Perry Wheless, Dept. of Electrical Engineering, University of Alabama, PO Box 870286, Tuscaloosa, AL 35487. Tel: (205) 348-1757.

18-20 **RF Expo West 1992**
San Diego, CA
Information: Kristin Hohn, Cardiff Publishing Company, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel: (303) 220-0600, (800) 525-9154. Fax: (303) 773-9716.

April

12-16 **NAB '92**
Las Vegas, NV
Information: NAB, 1771 N Street, NW, Washington, DC. Tel: (202) 429-5350. Fax: (202) 429-5406.

21-24 **1992 Conference on GaAs Manufacturing Technology**
San Antonio, TX
Information: Mr. Larry Varnerin, Publicity Chairman. Tel: (215) 758-4061.

22-24 **EMC/ESD International**
Denver, CO
Information: Kristin Hohn, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel: (800) 525-9154. Fax: (303) 770-0253.

May

4-8 **InfoCom '92**
Florence, Italy
Information: Maurizio Decina/ Vittorio Trecordi, Consorzio Cefriel, Viale Sarca 202, 20126 Milan, Italy. Tel: (39-2) 66-100083. Fax: (39-2) 66-100448.

How to Implement the Deming Approach to Quality Improvement and Productivity
February 20-21, 1992, Denver, CO
Information: University of Colorado at Denver. Tel: (303) 756-8255. Fax: (800) 473-8348.

Global Positioning System: Principles and Practice
February 19-21, 1992, Washington, DC
Microwave High Power Tubes and Transmitters
February 24-28, 1992, San Diego, CA
VSAT Design, Analysis, and Applications for Data, Voice, and Video Environments
March 2-4, 1992, Washington, DC
Mobile Cellular Telecommunications Systems
March 9-11, 1992, Washington, DC
Radar Operation and Design: The Fundamentals
March 9-12, 1992, Washington, DC
Satellite Communications: System Planning, Design and Operation at Ku and Ka Bands
March 9-13, 1992, Washington, DC
Communication and Radar Systems: Applying Detection, Estimation, and Geolocation Techniques
March 11-13, 1992, Washington, DC
Modern Receiver Design
March 16-20, 1992, Washington, DC
April 6-10, 1992, London, England
Modern Radar System Analysis
March 16-20, 1992, Orlando, FL
April 6-10, 1992, London, England
Ionospheric Radio Propagation for System Planners
March 17-20, 1992, Washington, DC
Satellite Communications: System Planning, Design and Operation at Ku and Ka Bands
March 9-13, 1992, Washington, DC
Lightning Protection
March 19-21, 1992, Orlando, FL
Microwave Radio Systems
March 25-27, 1992, Washington, DC
Introduction to Radar ECM and ECCM Systems
March 25-27, 1992, Washington, DC
Broadband Communications Systems
April 6-10, 1992, Washington, DC
Introduction to Video Communications
April 13-16, 1992, Washington, DC
Cellular Radio Telephone Systems
April 15-17, 1992, Washington, DC
Analog/RF Fiber-Optic Communications
April 22-24, 1992, Washington, DC
Information: The George Washington University, Continuing Engineering Education, Merril A. Ferber. Tel: (202) 994-8522 or (800) 424-9773.

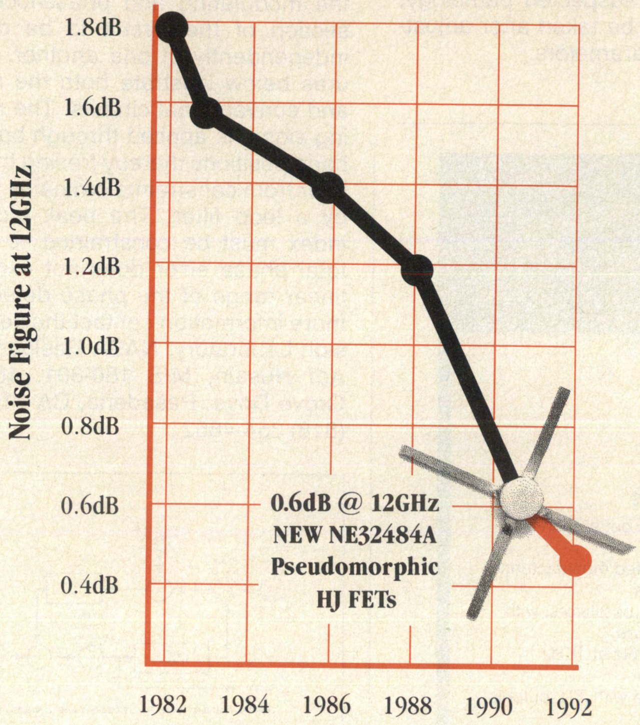
Antennas: Principles, Design and Measurement
March 11-14, 1992, St. Cloud, FL
Information: Kelly Brown, Southeastern Center for Electrical Engineering Education. Tel: (407) 892-6146.

Pulsed EMI
March 5-6, 1992, Boston, MA
April 15-16, 1992, Washington, DC
Information: Keytek. Tel: (508) 658-0880.

Radar Simplified
March 3-5, 1992, Northern CA
Radar Vulnerability to Jamming
March 3-5, 1992, Northern CA
Adaptive ECCM Processing for Radar
March 11-13, 1992, Northern CA
Impulse Radar
March 11-13, 1992, Northern CA
April 29-May 1, 1992, Washington, DC
ELINT Analysis
March 11-13, 1992, Northern CA
ELINT/EW Applications to Digital Signal Processing
March 11-13, 1992, Northern CA
ELINT Interception
March 16-18, 1992, Northern CA
Electromagnetic Propagation
March 16-18, 1992, Northern CA
Information: Research Associates of Syracuse, John Eckmair. Tel: (315) 455-7157.

Soldering, Cleaning and Surface Mounting
March 2-4, 1992, New York, NY
March 23-25, 1992, Mineapolis, MN
Surface Mounting and Fine Pitch Technology - Looking Beyond Principles and Practices
March 2-4, 1992, New York, NY
March 23-25, 1992, Mineapolis, MN
Information: NEPCON College of Manufacturing, Michael Critser. Tel: (708) 299-9311.

Snow Removal Devices



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Part No.	Freq (GHz)	NF (dB)	Ga (dB)
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NE42184A	12	0.9	10.5
NE76084	12	1.6	9.0
NE76038	4	0.8	13.0
NE76184A	4	0.8	12.0

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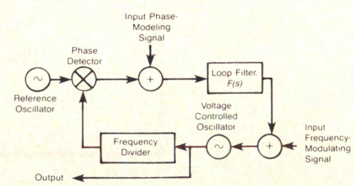
INFO/CARD 15

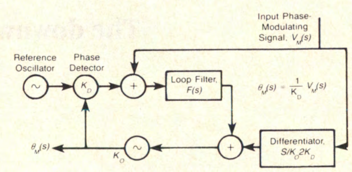
Real Time MRI Calculations

Researchers at SRI International have developed a high-performance computer graphics system that utilizes two sets of standard image data. Based on the data alone, the system can calculate and display new images that reflect any specified combination of imaging parameter values. The new system eliminates the need to subject a patient to repeated or prolonged Magnetic Resonance Imaging sessions when initial scans are inconclusive. In routine MRI diagnostic procedures, if standard scans fail to locate the suspected pathology, other scans must be taken after adjusting the imaging parameters.

Wideband Phase-Locked Angle Modulator — This circuit was first described in the December 1991 *Nasa Tech Briefs* and was developed at NASA's Jet Propulsion Laboratory. This modified circuit allows for the filters in the modulating and phase-locked-loop section of the circuit to be designed independently of one another. The figures below illustrate both the modified and conventional circuits. The modulating signal is applied through both baseband positions thereby freeing the modulator from constraints ordinarily imposed by a loop filter. The peak modulation index must be constrained so that the total phase error does not exceed the linear range of the phase detector. For more information contact the Jet Propulsion Laboratory, NASA Resident Office, Arif Husain, M/S 180-801, 4800 Oak Grove Drive, Pasadena, CA 91109. Tel: (818) 354-4862.

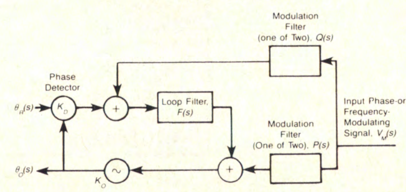


TYPICAL CONVENTIONAL PHASE-LOCKED ANGLE MODULATOR

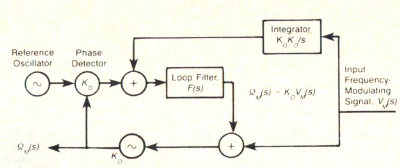


WIDEBAND PHASE MODULATOR

s = the Laplace-transform complex frequency
$\theta_R(s)$ = reference phase, rad
$\theta_O(s)$ = output phase, rad
$\theta_M(s)$ = output phase modulation, rad
$\Omega_M(s)$ = output frequency modulation, rad/s



MODIFIED PHASE-LOCKED ANGLE MODULATOR



WIDEBAND FREQUENCY MODULATOR

K_D = phase detector gain, volts/rad
K_O = gain constant of voltage-controlled oscillator, rad(s•V)
$F(s)$ = transfer function of loop filter
$P(s)$, $Q(s)$ = transfer functions of modulation filters
$V_{M(s)}$ = input modulating signal, volts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Cellular Service Trial Starts in Moscow — The first commercial cellular telephone service in Moscow recently began a limited trial. The service which initially has 100 customers will be expanded in early 1992 and have an ultimate capacity of 60,000 customers within five years. Moscow Cellular Communications was established in the Fall of 1991 under Russian legislation and the auspices of the Russian Ministry of Telecommunications and the Moscow Mayor's office. MCC is using a Nordic 450 MHz cellular system, which is widely used in Scandinavian countries. Initial construction costs are estimated at $7 million. Customers can place and receive calls to and from all other conventional and mobile telephones in Moscow and around the world.

Generic Radar Processor for Choosing Algorithms — Engineers at the Georgia Tech Research Institute have developed a Generic Doppler Processor that emulates most known Doppler processing methods in real time using just one piece of hardware. The processor does not require building new hardware and is re-programmable, offering the flexibility of software. Its inherent flexibility makes it useful in evaluating electronic countermeasures techniques. Among the options the processor offers is use of digital hardware to simulate a bank of analog filters, each tuned to a different frequency. The simulator uses an industrial PC chassis with one circuit board to drive the graphics display and ten additional boards to perform Doppler processing. A 386 CPU provides disk drive access and operator interface.

Technical Progress Bulletin Available — Measurement programs in semiconductor microelectronics, signals and systems, electrical systems, and electromagnetic interference are among those described in the *Technical Progress Bulletin*, available from NIST. The bulletin covers programs that provide national reference standards, measurement methods, supporting theory and data, and traceability to national standards. It features abstracts of papers and other published works arranged by topic. To receive the most recent issue or to be placed on the bulletin mailing list, write or call (stating professional affiliation or technical interest) EEEL, B358 Metrology Bldg., NIST, Gaithersburg, MD 20899. Tel: (301) 975-2220.

IEMT Call for Papers — A call for papers has been issued for the 1992 International Electronics Manufacturing Technology Symposium to be held September 28-30, 1992, in Baltimore, MD. Topics will address all phases of manufacturing including materials, fabrication, assembly, testing and quality systems. Special focus will be on integrating design and manufacturing, advanced packaging manufacturing, manufacturing operations improvement and analysis of manufacturing operations. A 250-word abstract describes the nature, scope, and significance of the proposed paper must be received by March 2, 1992. Abstracts may be sent to: Dr. Michael P. Cassidy, Program Chairman, AT&T, 3000 Skyline Dr., Mesquite, TX 75149.

INFO/CARD 19

RF expo

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WEDNESDAY 8:30 - 10:00 A.M.

SESSION A-1: Smith Chart Tutorial
The Smith Chart and Its Usage in RF Design • Neal C. Silence

SESSION A-2: Modern Design Methods
Designing for a Competitive Marketplace • (Speaker TBA)

WEDNESDAY 10:00 - 11:00 A.M.

RF EXPO WEST KEYNOTE ADDRESS
The Decade of the 1990s: Global 2000 • Robert Mayer Evans

WEDNESDAY 1:30 - 4:30 P.M.

SESSION B-1: Low Cost Design
Receiver Mixers and LOs • Jack Lepoff
Low Cost SMD Power Limiters • Raymond W. Waugh
Practical Variable Gain Amplifiers • Gary Franklin

SESSION B-2: Communications Systems
A Satellite Based Radio Tag System • Ian Dilworth
Own Jamming Excision — Changing the Way Communication Systems Are Jammed • Dennis K. Shiba
One Technique for Increasing Compression Ratio for Facsimile Picture Transmission Over Mobile Radio • Dr. Milorad Mirkovic, Branislav Pavic, Mihajlo Vujasinovic, Vladimir Tadic

SESSION B-3: Thermionic RF Power Devices
High Power RF Amplifiers (several papers) • Frank A. Miller, Chairman

SESSION B-4: Radar Systems
Space-Based Angle-Tracking Radar System • Valverde, Stilwell, Russo, Daniels, McKnight
RF Electronics Design for Space Flight Applications • A.A. Russo
Spurious Noise Prediction and Reduction in Direct Digital Synthesizers • C.C. DeBoy, C.R. Valverde, A.A. Russo
Electrical Performance of a GaAs DDS System for Space Applications • A.A. Russo
Signal Processing for a Space-Based Monopulse Radar • T.R. McKnight, C.R. Valverde
Thermal Distortion Analysis for Space-Based Monopulse Radar Antenna Array • A.R. Jablon, D.F. Persons

THURSDAY 8:30 - 11:30 A.M.

SESSION C-1: Power Amplifiers
The Design of RF Modules Intended for Combining High Power (Part 1 of Design of a 15 kW, Broadband VHF, Solid State Amplifier) • David N. Haupt
High Power VHF Power Dividing and Combining Techniques (Part 2 of Design of a 15 kW, Broadband VHF, Solid State Amplifier) • Hugh Gibbons
Monitoring, Control and Diagnostics of an RF Amplifier Over a Modem Link (Part 3 of Design of a 15 kW, Broadband VHF, Solid State Amplifier) • Paul Beaty

SESSON C-2: RF Components
RF Components for the 90s • Peter Hoffeins
Survey of Components for 900, 2400, and 5700 MHz Spread Spectrum • Al Ward
Various Mixer Types Used in Cellular Radios • Phyllis Austin-Lazarus

SESSION C-3: Filters
Tunable Bandpass Filters for VHF-UHF Receivers as a Preselector Applications • John Horvath
GaAs Technology Opens New Frontiers in Electronically Tunable Filters • David Peterson
High Power Filter for Broadcasting • Peter Niklaus

SESSION C-4: Antenna Design
Shaped Beam Microstrip Antennas Applied to Personal Communication Networks • John R. Sanford
Development of Microstrip Antennas • Marc Yacoubian
Miniature Narrowband Radiator for UHF Application • Ian Dilworth

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THURSDAY 1:30 - 4:30 P.M.

SION D-1: RF Design Awards Contest (Open Session)
oretical Basis for a Comprehensive Filter Design Program • Michael Ellis
Frequency Circulator/Isolator Uses No Ferrite or Magnet • Charles Wenzel

SION D-2: Modulation and Demodulation
ead Spectrum Cellular Communications • Steve Morley
v a QPSK Modulator Vector Error Relates to its Spurious Output • Phyllis Austin-Lazarus
ct IF to Digital Conversion Using New Monolithic RF Track and Holds • Allen Hill, Tom Gratzik

SION D-3: RF Integrated Circuits
gn of High Density, High Yield MMIC Devices for Low Cost Applications • Henrik Morkner
racterization of a Silicon Bipolar Process for RF ASIC Development • John Brewer
As MMIC Control Devices: Theory of Operation & Fabrication • Henrik Morkner

SION D-4: RF and Computers
ding a Network System for an Engineering/Manufacturing Company: Keeping Your Engineers Happy
Without Giving Away the Farm • Ken Wagers
deling Surface Mount Components • John Hirsekorn
ice Modeling and Harmonic Balance Simulation of RF/UHF High Power DMOS Transistor
mplifiers • Steve Hamilton and Octavius Pitzalis

FRIDAY 8:30 - 11:30 A.M.

SION E-1: Low Noise Amplifier Tutorial
gn of Low Noise RF and Microwave Amplifiers • Dick Webb

SION E-2: Frequency Synthesis
derless Phase Locked Loops • Dr. Scott Wetenkamp
gn Considerations for a Low Cost Wideband RF Synthesized Source • Chris Day
Monolithic 12-Bit 100MSPS Digital to Analog Converter For Frequency Synthesis Applications • Chris G.
tinez, John Brewer

SION E-3: RF Components
v Components for GSM, PCN, DECT, GPS, etc. Systems • Peter Hoffeins
Photistor: An Innovative, Optoelectronic RF Switch/Attenuator • Curtis W. Barrett
Design of a Monolithic Hybrid Integrated Circuit RF Package for Space Application • Brent Stoute

SION E-4: RF Systems
lict Temperature Rise in Reverse Biased PIN Diodes at High Power Levels • Mark C. Leifer, Ph.D.
Engineering Development of Low Cost GaAs Power Module for Cellular Telephones • Mark Easton
lysis of Dielectric Materials in Waveguide and Feedhorn • Tsang-Fu Chang

SPECIAL COURSES

ARCH 17, 18 AND 19

ndamentals of RF Circuit Design:
rt I — **March 17**

ndamentals of RF Circuit Design:
rt II — **March 18**

ter and Matching Network Design: L-C and
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Engineers	58%
Engineering Managers	16%
Engineering Service Professionals	6%
Owners or Officers	11%
Others (including reps, buyers, consultants)	9%

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New Printed Circuit Board Process — Printron, Inc. has developed a new process for manufacturing circuit boards that does not require the use of potentially toxic chemicals in the manufacturing process. The printing system, which is environmentally safe, utilizes atmospheric pressure to print metal slurries to form electronic pathways on a wide variety of substrate material including paper, plastics and ceramics. The two-step process can manufacture a circuit in approximately ten seconds, 50 times faster than current technology. Commercial release is targeted for late 1992.

New ADC IC Surpasses 14 Gigasamples/sec. — A new analog-to-digital convertor chip that acquires data at over 14 Gigasamples/second has been developed by Hypres, Inc. The device which operates at 4.2 Kelvin, is believed to be the world's fastest monolithic ADC. It is built from Josephson-junction devices fabricated using a 10 layer thin-film deposition process. In preliminary tests, the ADC sampled at 14.3 GS/s to digitize a 1 kHz sine wave. Input bandwidth tests indicate that the ADC can digitize 5 effective bits at 2.0 GHz, 4 effective bits at 4.0 GHz and 3 effective bits at 8 GHz for an estimated aperture time of 5 ps.

Sciteq Relocates — Sciteq Electronics, Inc. has moved. Their new address is: 9280 Sky Park Court, San Diego, CA 92123. Their telephone and fax numbers remain the same.

Cabot Ceramics Merged — Microelectronic Packaging Inc has merged Cabot Ceramics into its operations. Cabot Ceramics, now a wholly owned MPI subsidiary, will operate under the name Microelectronic Packaging America.

M/A-COM Consolidates Product Line — M/A-COM recently announced the consolidation and transfer of their RHG product line. As of January, the microwave mixers, mixer pre-amps and other frequency conversion products manufactured at the RHG facility will be transferred to M/A-COM's Control Components facility.

Daico Acquires Armatek Product Line — Daico Industries and Armatek recently disclosed that they have reached an agreement for Daico to acquire Armatek's GaAs MIC amplifier product line. The manufacture of Armatek's MIC amplifier product line will be phased into Daico's production facility over the next several months.

Teklogix and Infocap Announce Alliance — Teklogix and Infocap Systems have announced a strategic alliance to co-market RF data communications solutions for manufacturing, distribution, utility and office applications. Teklogix will supply hand-held and vehicle-mounted RF terminals, RF base stations, system network controllers and remote modules. Infocap will provide software products that are designed for managing inventory, work in process, time and attendance, labor reporting, warehouse functions and file tracking.

INFO/CARD 21

Space Applications — Grand Ideas and Tight Budgets

By Gary A. Breed
Editor

Electronics for space-based applications have slowed, but there is a realistic expectation that new and developing applications will sustain the current level of activity in this part of the RF industry.

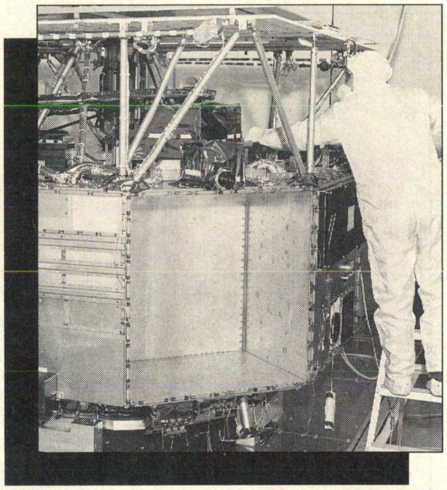
NASA Programs

In an article titled "Budget Explorers," the latest issue of Ball Aerospace's *Challenge* magazine describes NASA's Discovery program. The program plans to launch a series of spacecraft designed for useful exploration at the lowest possible cost. Larger programs like Voyager, Galileo, and the Hubble Space Telescope are unarguably valuable in the knowledge they provide about the universe, but Discovery missions are intended to provide more results-per-dollar through smaller, and more focused objectives. The first mission is not established, but could be a rendezvous with a near-earth asteroid.

Along with an ongoing Space Shuttle program and a subsistence-level Space Station program, NASA still has a substantial budget. However, the number of programs is not growing, and the cost of each is growing faster than the funding. NASA has just reported a reduction in the workforce dedicated to the Shuttle program, and RF suppliers providing ongoing support (such as TRW) have seen business slowing for the past few years. For companies supplying hardware for NASA programs, the best news is that both the President and Congress support a continuing space program, but with a "politically correct" share of Federal funding.

Space-Based Communications

Although research programs are being developed more slowly, there are some existing and proposed programs that are generating significant RF activity. The most obvious is the NAVSTAR/Global Positioning system, which now has sufficient number of spacecraft in place for nearly full-time coverage. The remaining members of the constellation will provide full time coverage, plus



spares.

There are two key areas of RF work for navigation products using GPS. The first is the basic L-Band receiver. With current technology, the tradeoffs between price and performance are still substantial. Considerable work on GaAs and silicon MMIC front-ends for GPS is taking place at companies like Pacific Monolithics, Avantek and others with experience and marketing plans directed toward large quantity customers.

Antenna designs, which must have a uniform hemispherical pattern, are another part of the receiver development. The need for compact, efficient and low-cost antennas has stimulated creativity among designers. New materials, printed conductors and flexible substrates have all been explored in the search for the best solution.

The other major design area is high performance timebase systems, both for calibration of GPS products, and as precision references slaved to the GPS transmitted timing data. Companies like Trak Microwave and Austron have made significant investments in the development of GPS-based products.

Commercial and consumer products based on GPS are being developed in a hurry, although few are on the market. Trimble Navigation has both professional and lower-cost GPS receivers, but they will be joined by numerous companies in the very near future as products for transportation, aviation, and sporting reach production.

Both Motorola and a Loral-QUALCOMM joint venture have planned new applications for space-based personal communications. Motorola's Iridium system and Loral QUALCOMM's Globalstar system would provide handheld communications via low earth orbit satellites anywhere on the earth. Although these proposals are still being studied by the FCC for frequency allocation, either would offer a substantial market for RF suppliers, as other types of personal communications are doing at present.

Other active space communications systems include INMARSAT for maritime communications, direct-broadcast satellite (DBS), and satellite digital radio. These are microwave-spectrum systems, but RF companies providing IF, modulation and demodulation components are beneficiaries of growth in the these systems.

Short-Term Outlook

As with most technology areas involving high cost systems, the market for space systems has suffered during the current recession. In the near-term, GPS-based products are expected to begin widespread use, and continued work on DBS, INMARSAT, VSAT, and other satellite systems will provide markets for RF products. NASA support of current programs is dropping, but the Space Station and new programs will keep activity at a modest level.

Internationally, the European Space Agency, Japan, India and the People's Republic of China are increasing their space capabilities. Some RF companies can expect to benefit from these programs, which principally involve communications satellites for telephone or television transmission. **RF**

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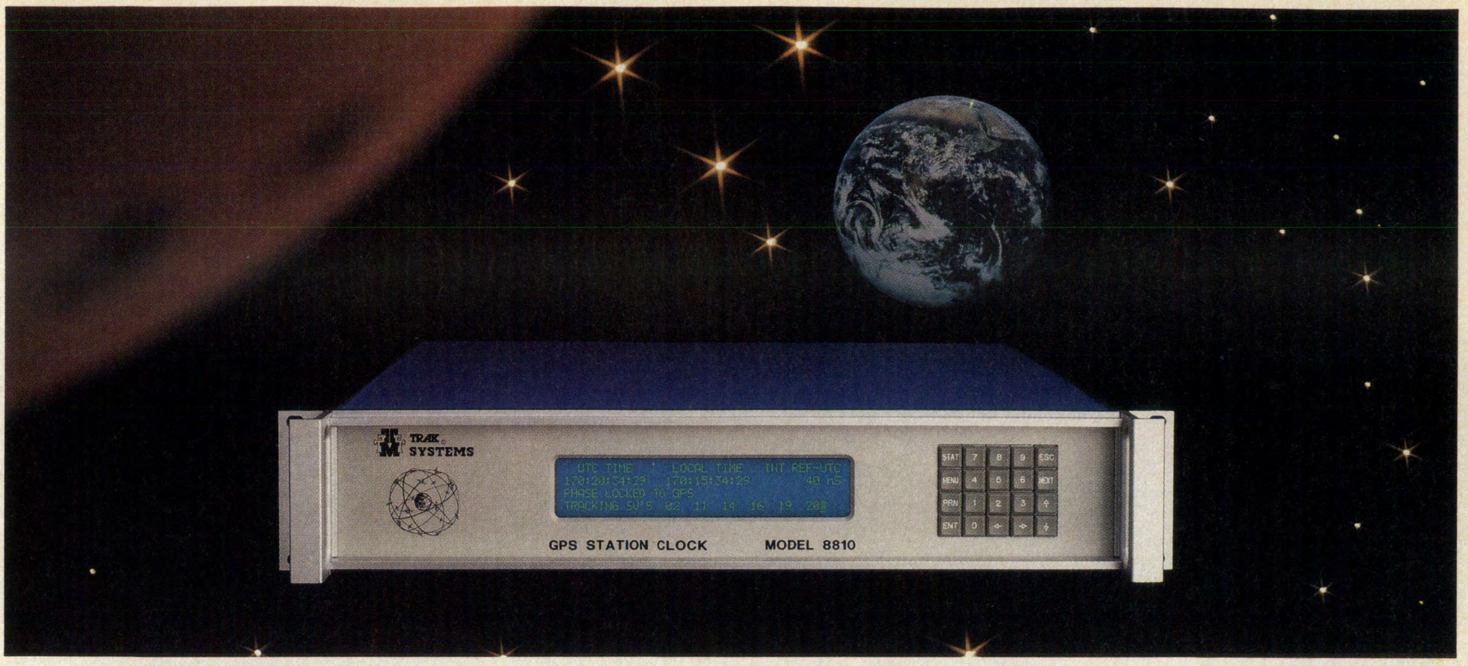

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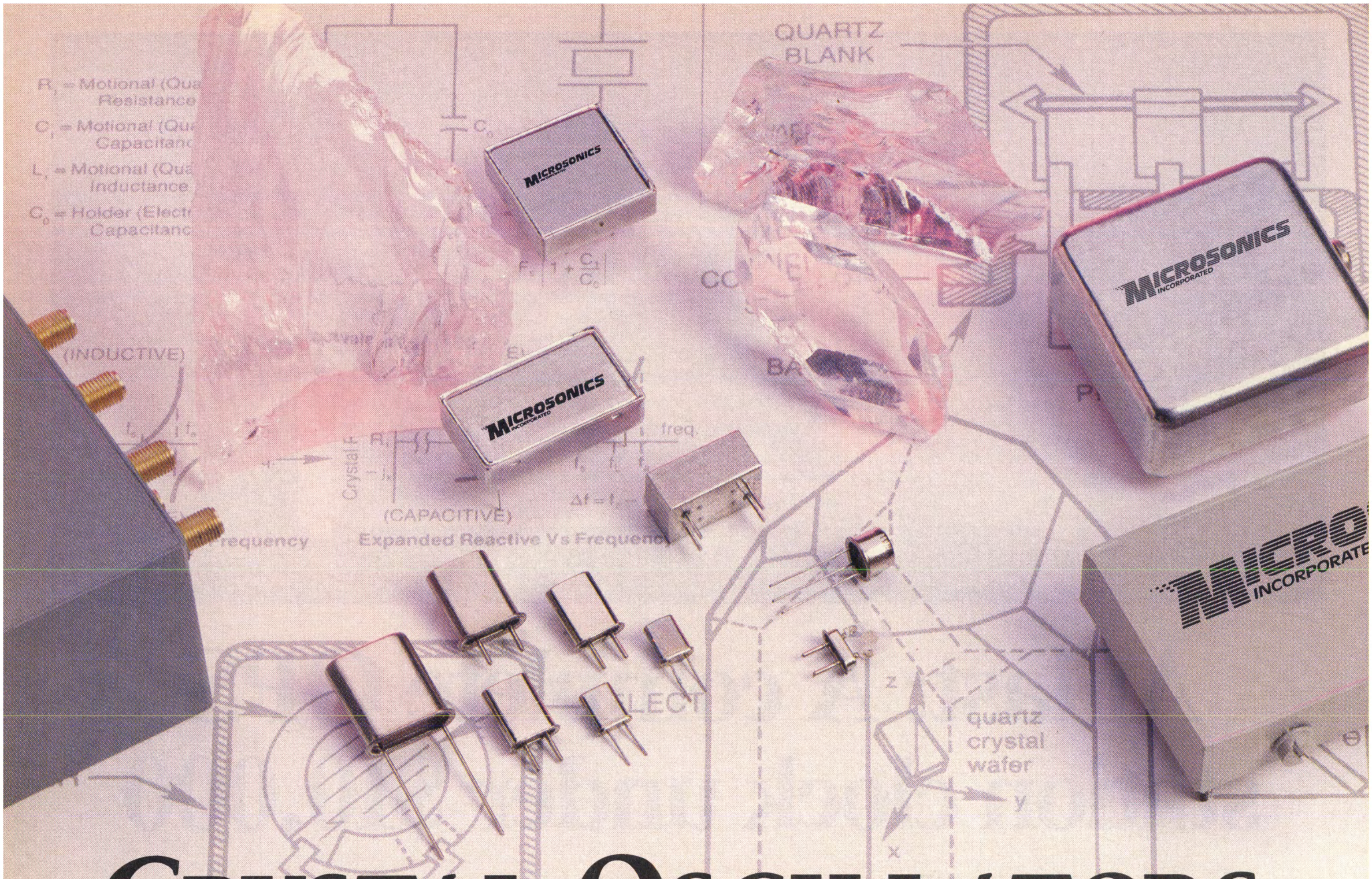
INFO/CARD 22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High Speed IC Applications Circuits

By Gary A. Breed
Editor

Here is a collection of applications circuits for high speed operational amplifiers, video amplifiers and buffers. These devices are seeing increasing use in RF, IF and video/baseband applications.

High speed "building block" integrated circuits have reached operating speeds comparable to RF only in the past three to five years. Their availability gives RF designers new options when designing amplification and signal processing circuitry. The predictability of a controlled-feedback op amp circuit, or the high input impedance and low output impedance of a unity-gain buffer can be extremely attractive in RF applications, as they have been for many years in lower frequency design.

Circuit Examples

Figure 1 shows the basic supply and bypassing scheme recommended for these wide bandwidth components. Bypassing from DC to 100s of MHz is a challenge. For RF bypassing, a 0.1 uF (typical) chip capacitor placed as close to the power supply pins as possible will assure maximum stability. A low series resistance (tantalum or similar type) electrolytic capacitor helps eliminate low frequency paths through the power bus. It may be necessary to include a series inductor in critical circuits to add another pole of high frequency rolloff, but it is not recommended that this be done routinely — resonances created by the addition of this component have the potential for stability problems.

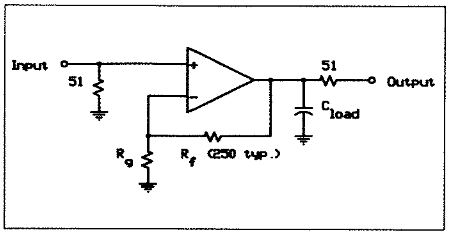

Figure 2. Basic non-inverting configuration for a current-feedback amplifier.

The circuit in Figure 2 is a generalized non-inverting amplifier using a current-feedback op amp. A double-ended supply is assumed. Depending on the actual load, C_{load} may represent a distributed element, or it may be a 3 to 10 pF capacitor added for high frequency peaking. The 250 ohm feedback resistor is a typical value, and will most often fall in the range of 100-1000 ohms. The combination of R_f and R_g establishes the gain at R_f/R_g.

The inverting configuration, shown in Figure 3 also shows biasing for a single supply. In this case, the source resistance R_s must be added to R_g (51 ohms) for gain calculations. If the input is driven from another op amp, R_s will be very small and can be disregarded in most cases. This circuit appears in the data sheet for the Linear Technology LT1229 dual current-feedback amplifier.

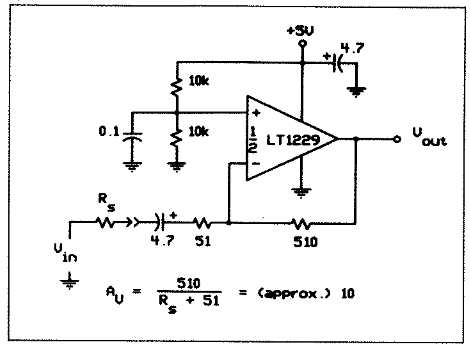

Figure 3. Inverting configuration, with single-supply biasing.

A useful RF application for these devices is a bandpass filter. The circuit in Figure 4 is a 40 MHz bandpass filter with a Q of 4 using the Comlinear CLC400 current-feedback amplifier. Adaptations of this basic circuit for tuning or control of Q are possible, which would be attractive in IF or instrumentation applications.

A bandstop, or notch filter is another application which takes advantage of an op amp's or buffer's low output and high input impedances. The circuit in

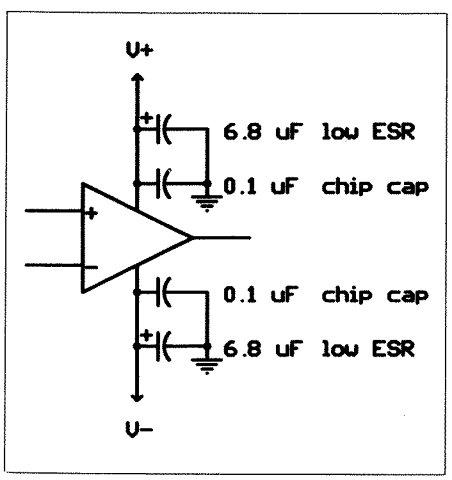

Figure 1. Power supply bypassing.

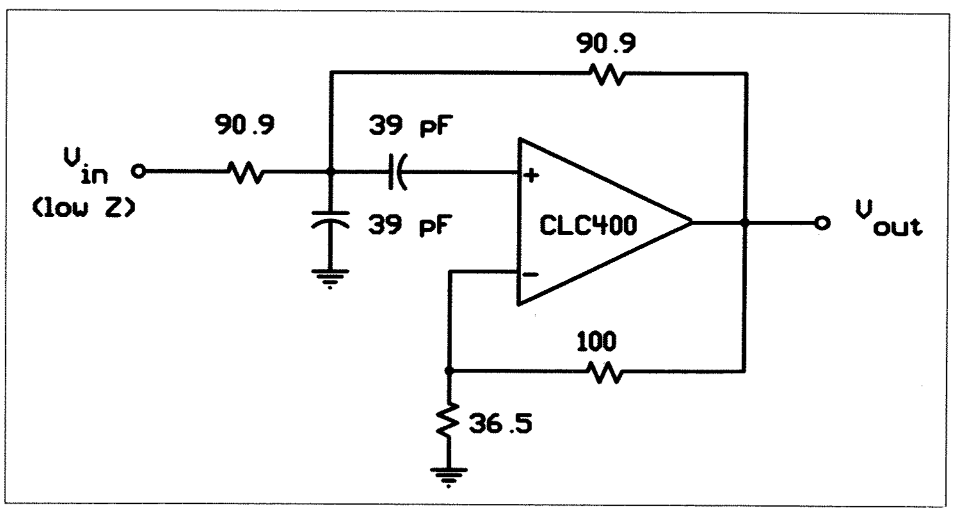

Figure 4. A 40 MHz active bandpass filter.

Figure 5 uses an Elantec EL2003 wideband unity gain buffer to implement a 4.4 MHz notch filter. Notch filters can be used for transmission zeros in more complex filter designs. Notch depth depends on the matching of the components.

Multiple-function ICs have also been implemented by several manufacturers Figure 6 shows an application for the MAX455 multiplexer/amplifier from Maxim Integrated Products. This circuit can be used as a video switcher, a data acquisition input switch, or as an RF switch with a minimum 25 MHz bandwidth. With 120 ns maximum switching time and typical 70 dB channel OFF isolation, multiplexing or modulation at MHz frequencies is possible.

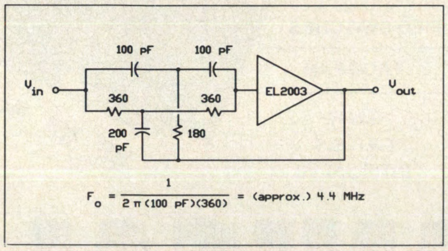

Figure 5. A bandstop filter with components which place the notch at 4.4 MHz.

The final example is Figure 7, a laser diode driver with 250 MHz bandwidth, using the Apex Microtechnology WB05 wideband buffer. The circuit has an input attenuator to improve the return loss of the input. The op amp stage sets the DC bias voltage and compensates for offset voltages. R1, R2 and C2 make up a lowpass filter in the feedback loop to the bias and offset compensation circuit. The high current capability of the WB05 and other manufacturers' buffers allows them to be used as easily implemented drivers for laser diodes, which require bias currents of 200 mA or more.

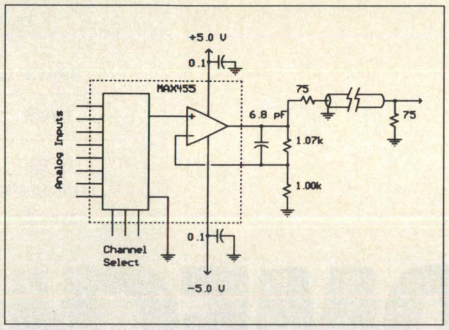

Figure 6. Multiplexer/switch IC with on-chip amplifier.

Design Hints

Layout and parasitics are the biggest problem an engineer will encounter when using these devices. It is essential that power supply decoupling, a good

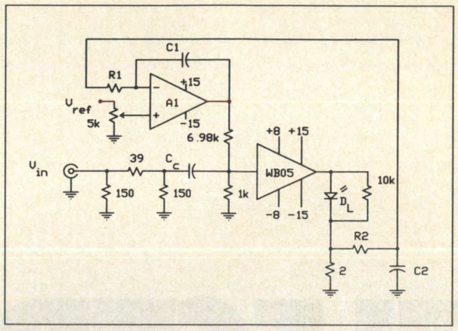

Figure 7. A laser diode drive circuit using a wideband, high-current buffer.

ground plane, and transmission line interconnections are maintained. Breadboard circuits are best accomplished using "dead bug" construction on a solid piece of copper-clad material, with components soldered in direct, point-to-point manner. When transferred to a printed circuit board, changes in interconnection length must be taken into account.

Component selection in the feedback and output circuits is also important. The feedback resistor R_f should be in the range of recommended values, and must be non-inductive. Avoid resistors that use a spiral cut in the metal film for resistance trimming, since they can have modest inductance. At the output, capacitive loading can be a problem, since it causes peaking at high frequencies. This can lead to oscillations as well as variations in frequency response. Techniques such as an output series resistor or more complex compensation may be required.

The experts in application of high speed ICs are the manufacturers. Since these are relatively new components, their applications engineers are still the primary source of information. These engineers developed the circuits included in this article. In addition to the companies already mentioned, Harris Semiconductor, National Semiconductor and Analog Devices make high speed components. Each company has a different emphasis in their products, so investigate all of them if you are considering these high speed "universal" components for your next design.

RF

The following companies offer high speed op amp, video amplifier and buffer components:

Analog Devices
One Technology Way
Norwood, MA 02062
(617) 329-4700

Apex Microtechnology Corp.
5980 N. Shannon Road
Tucson, AZ 85741
(602) 742-8600

Comlinear Corporation
4800 Wheaton Drive
Ft. Collins, CO 80525
(303) 226-0500

Elantec, Inc.
1996 Tarob Court
Milpitas, CA 95035
(408) 945-1323

Harris Semiconductor
P.O. Box 883
Melbourne, FL 32901
(407) 724-3739

Linear Technology
1630 McCarthy Blvd.
Milpitas, CA 95035
(408) 942-0810

Maxim Integrated Products
120 San Gabriel Drive
Sunnyvale, CA 94086
(408) 737-7600

National Semiconductor
2900 Semiconductor Dr.
Santa Clara, CA 95052
(408) 721-5000

Design of Low Noise, Wide Dynamic Range, GaAs Optical Preamps

By Robert Bayruns, Timothy Laverick, Norman Scheinberg and Daniel Stofman
Anadigics, Inc.

GaAs MESFET technology is ideal for use in lightwave receiver applications. FET devices have a fundamental advantage over BJT transistors in low noise applications because of their inherent high input impedance. Another advantage is that FETs are majority carrier devices and can be easily used as feedback elements in automatic gain control applications.

With this in mind, two different preamp designs are presented. The first obtains a 2 GHz bandwidth using a 5 kohm feedback resistor. The second, achieves a 200 MHz bandwidth and −38 dB sensitivity. An input overload level of 0 dBm (1 mA) is achieved by use of an on-chip AGC.

Low Noise Design

When designing an optical preamp, there is always a compromise to be reached between noise and bandwidth (Figure 1). A large value feedback resistor is desired since the mean squared noise of the feedback resistor is:

$$\overline{i_{FB}^2} = \frac{4kT\Delta f}{R_{FB}} \qquad (1)$$

However, with a large feedback resistor, the 3 dB bandwidth could suffer since:

$$f_{3dB} = \frac{1 + A}{2\pi R_{FB} C_T} \qquad (2)$$

where C_T is the total input capacitance ($C_{diode} + C_{stray} + C_{FET}$), and A is the open loop gain of the preamp. From Equation 2, a large voltage gain, A, is needed for low noise and wide bandwidth. For this reason, depletion type load devices are used almost exclusively in the input gain stage. But at high frequencies, the input gain stage can produce considerable noise, so a resistor load can be used instead. The input referred noise from the gain stage is:

$$\overline{i_{in}^2} = \frac{4kT\Gamma\omega^2 C_T^2 \Delta f}{g_{mi}} + \overline{I_{load}^2}\,\frac{\omega^2 C_T^2 \Delta f}{g_{mi}^2} \qquad (3)$$

Where g_{m1} is the transconductance of FETM1, $\Gamma = 1.7$ is a GaAs excess noise factor, and $\overline{I_{load}^2}$ is the mean squared noise current of the load device. For a 200 ohm load resistor, $\overline{I_{load}^2}$ is $8.3 \times 10^{-23} A^2/Hz$. For a 300 um FET, $\overline{I_{load}^2}$ has a value about an order of magnitude higher at $1.2 \times 10^{-21} A^2/Hz$.

Figure 2 shows the schematic of a new inductive load which provides both high gain and a lower noise than is possible in a resistive and a depletion load, respectively. The effective impedance of this load device of Figure 2 is:

$$Z_{ab} = r_{ds2}(1 + jg_m\omega L) + j\omega L \qquad (4)$$

For a 15 nH monolithic GaAs inductor, an increase in voltage gain of about two times is possible, which in turn, allows the use of a larger feedback resistor. The inductor also functions to degenerate the noise produced by the FET load.

At a frequency of 300 MHz with $g_{m2} = 42$ mS and L = 15 nH, $\overline{I_{load}^2}$ is half. At a frequency of 2 GHz, $\overline{I_{load}^2}$ is 7.8 ×

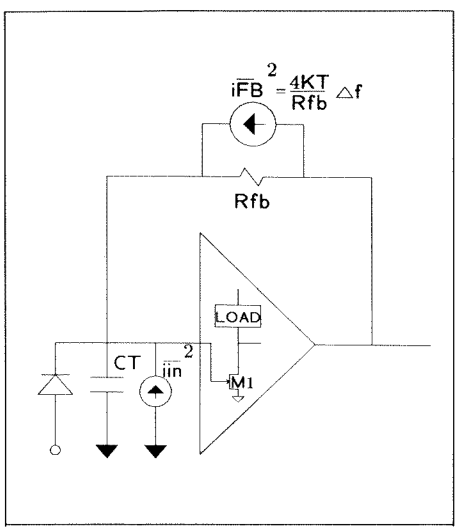

Figure 1. Equivalent circuit model of an optical preamplifier.

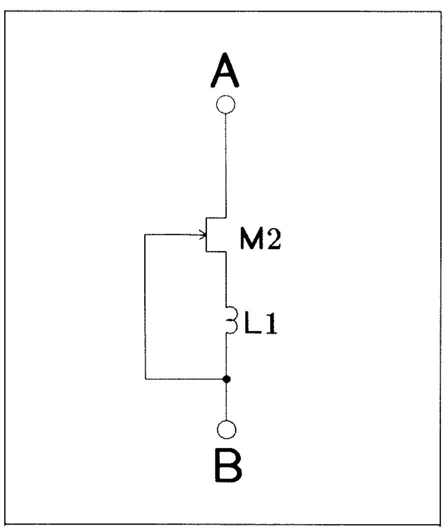

Figure 2. Schematic of an inductive load.

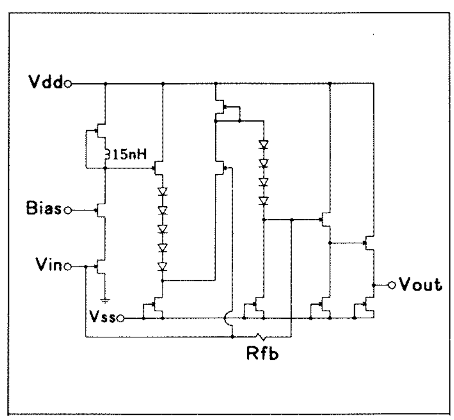

Figure 3. Schematic of transimpedance amplifier.

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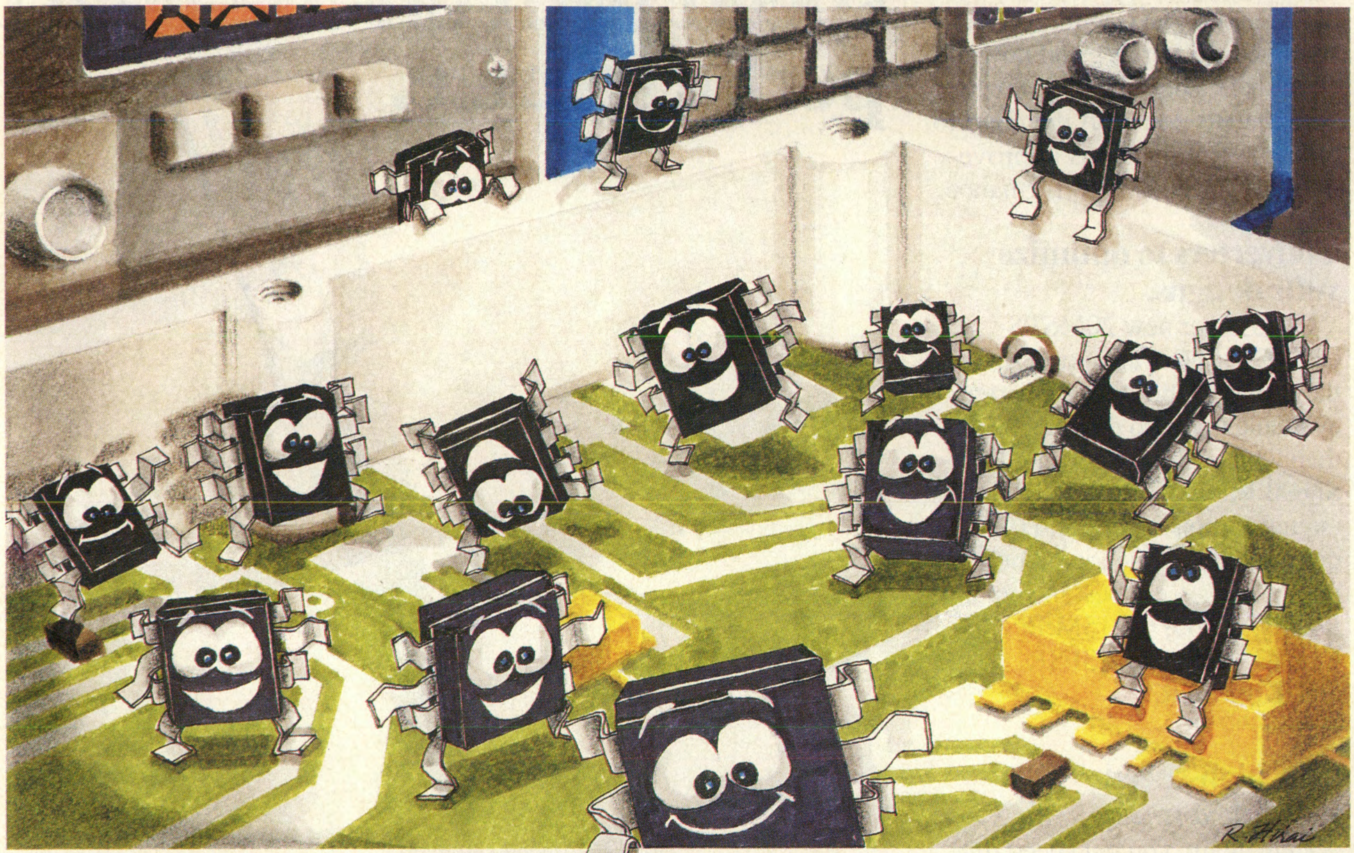

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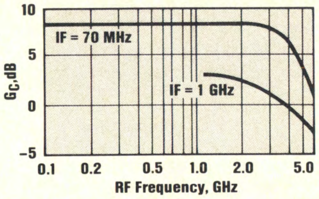

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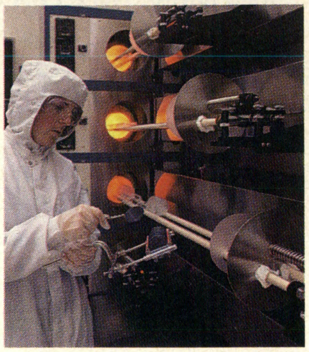

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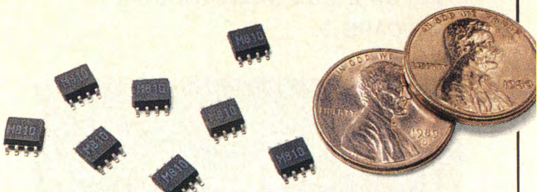

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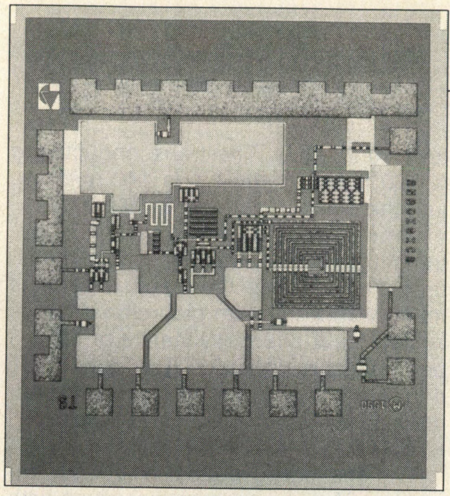

Figure 4. Chip micrograph of transimpedance amplifier.

$10^{-23} A^2/Hz$, which is less than M2 and a 200 ohm resistor.

2 GHz Preamplifier

Use of the inductor load circuit allows the design of a 2 GHz bandwidth preamplifier with a large feedback resistance of 5 kohm.

Figure 3 is a schematic of the 2 GHz transimpedance amplifier including the inductive load. This circuit has two gain stages; the first uses an inverting cascade stage, and the second is a non-inverting differential amplifier stage. The circuit is fabricated using D-mode technology with a 0.5 um gate length and

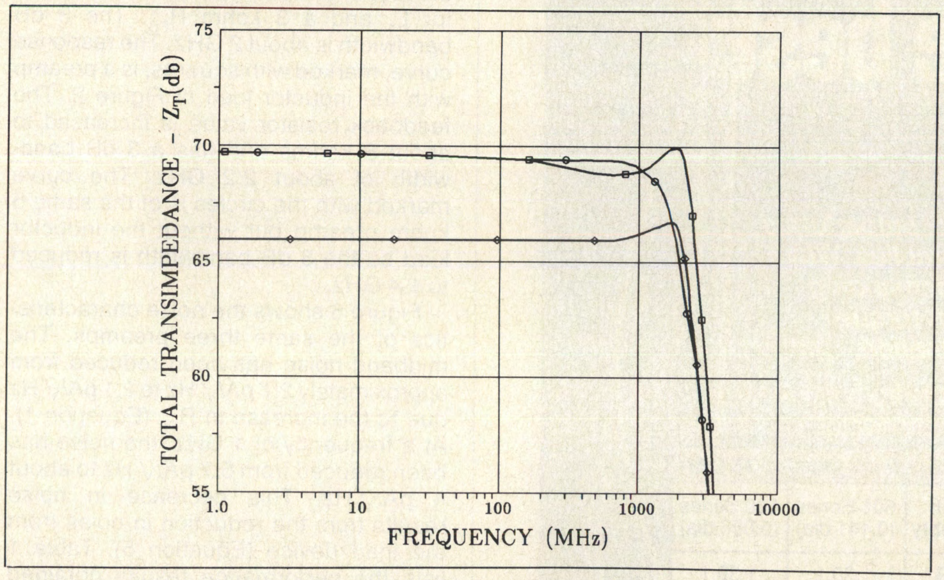

Figure 5. Measured optical frequency response.

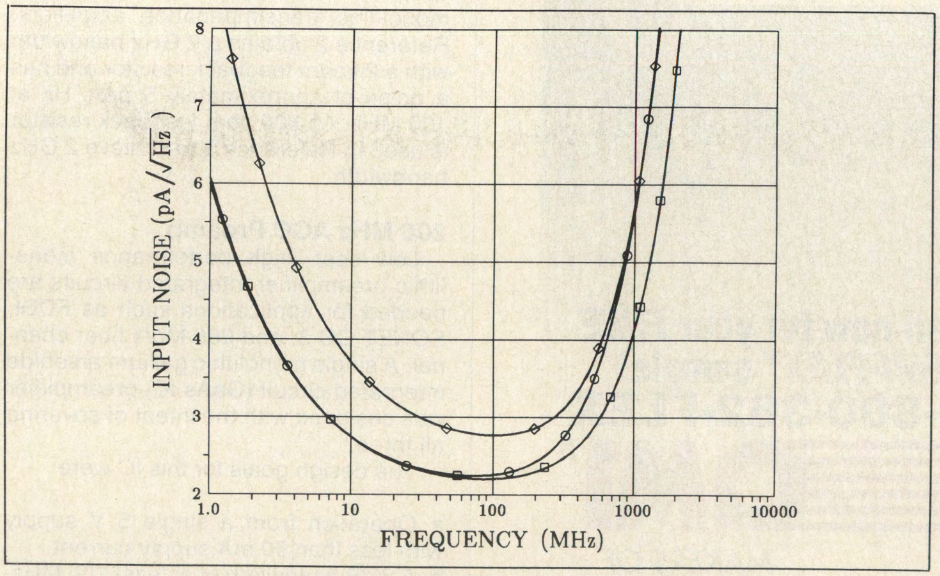

Figure 6. Noise characteristics of preamplifier circuits.

an f_T of 25 GHz. The transconductance is 170 mS/mm, the I_{dss} is 140 mA/mm, and the pinchoff voltage is −0.8 V.

Figure 4 shows a micrograph of the transimpedance amplifier which measures 2 mm^2. The feedback resistor is made with a thin film nichrome process which has a sheet resistance of 50 ± 5 percent ohms/square. The total FET periphery is about 2 mm. The current drain from V_{dd} is 100 mA and from V_{ss} is 75 mA.

The measured optical frequency response of three preamplifier chips with $C_{diode} + C_{stray}$ of 0.6 pF is shown in Figure 5. The curve with the diamonds shows the response of a preamp without inductor L_1 and a 3 kohm R_{FB}. The 3 dB bandwidth is about 2 GHz. The response curve, marked with squares, is a preamp with the inductor load of Figure 2. The feedback resistor value is increased to about 5 kohms and has a 3 dB bandwidth of about 2.2 GHz. The curve marked with the circles is of the same 5 kohm preamp but without the inductor load so the 3 dB bandwidth is reduced to 1.4 GHz.

Figure 6 shows the noise characteristics of the same three preamps. The midband noise has been reduced from approximately 2.7 pA/$\sqrt{Hz}$ to 2.1 pA/$\sqrt{Hz}$ due to the increase in R_{FB} (Equation 1). At a frequency of 1 GHz, the noise has been reduced from 5.7 pA/$\sqrt{Hz}$ to about 4 pA/$\sqrt{Hz}$. This decrease in noise results from the reduction in noise from the load device (Equation 5). Table 1 lists the performance results obtained with the preamplifier. These results compare favorably to recently reported monolithic transimpedance amplifiers. Reference 2 obtains a 2 GHz bandwidth with a 2 kohm feedback resistor and has a noise of approximately 5 pA/$\sqrt{Hz}$ at 100 MHz. An 800 ohm feedback resistor is used in Reference 3 to achieve 2 GHz bandwidth.

200 MHz AGC Preamp

Low cost, high performance monolithic preamplifier integrated circuits are needed for applications such as FDDI, SONET OC-3, and 266 Mb/s fiber channel. A single monolithic gallium arsenide integrated circuit (GaAs IC) preamplifier was designed with the intent of covering all three.

The design goals for this IC were:

- Operation from a single 5 V supply with less than 50 mA supply current.
- A 3 dB bandwidth of at least 200 MHz.
- Input optical overload of > −4 dBm

Parameter	Value
Chip Size	$2mm^2$
V_{dd}	+5 to +8V
I_{dd}	100 mA
V_{ss}	−3 to −5V
I_{ss}	75 mA
Transresistance	
$R_L = \infty$	5 kohms
$R_L = 50$	2.5 kohms
f_{3dB} ($C_{diode} + C_{stray}$ = 0.6 pF)	2.26 GHz
Input Referred Noise i_{in}	
10 - 600 MHz	<4.1pA/√Hz
1 GHz - 2 GHz	<8 pA/√Hz
Output Impedance	50 ohms

Table 1. Performance of a 2 GHz preamplifier.

(approx. 400 uA electrical)

• An optical sensitivity of < −35 dBm (10^{-9} BER) at 125 Mb/s and <−35 at 266 Mb/s.

Parameter	Value
Chip Size	$1mm^2$
Supply Voltage V_{dd}	+5V ± 10%
Supply Current I_{dd}	35 mA
+ f_{3dB}	230 MHz
Transresistance	
R_L = 50 ohms	
Pin = <−25 dBm	7 kohms
Pin = >−10 dBm	250 ohms
* Optical Sensitivity @ 10^{-9} BER	
B = 125 Mb/s	−36 dBm
B = 155 Mb/s	−37.5 dBm
B = 266 Mb/s	−35.5 dBm
Input Optical Overload	>0 dBm
Output Impedance	30 ohms
Output Swing	>0.3V p-p

+ C Diode = 0.4 pf

* Responsivity R = 0.9

* Noise Filter Bandwidth = 0.68 x B, 2^{15}−1 PRBS

Table 2. Performance results of 200 MHz GaAs preamplifier.

Input Overload	Feedback Resistor	F3dB	Sensitivity	B
0 dBm	60 kohm	60 MHz	−43 dBm	52 Mb/s
0 dBm	8 kohm	500 MHz	−33 dBm	622 Mb/s
0 dBm	3.3 kohm	1.2 GHz	−30 dBm	1.1 Gb/s

Table 3. Performance results from three lower power single supply circuits.

To obtain this sensitivity and dynamic range, a preamplifier with automatic AGC control is needed.

Figure 7 is the block diagram of the preamp IC shown connected to all external components. The inverting amplifier has an open loop gain of −35 and the bandwidth is 1.5 GHz. Using a photodiode with a capacitance of 0.4 pF allows a feedback resistor of 20 kohms.

The AGC circuit is accomplished with a feedback FET whose gate is fed the average value of the unbuffered output. As the average optical input level increases, a negative current flows out of the input and the gate of the FET is turned on with a positive DC voltage. It is important that the photodiode sink current out of the amplifier. This is because the source of the feedback FET should be connected to the virtual ground at the input to avoid pulse width distortion. The final output of the chip is a source follower buffer whose equivalent output impedance is 50 ohms.

The circuit was fabricated in Anadigics' low power GaAs MESFET process, which features an f_T of 17 GHz, a g_m of 160 mS/mm, a $g_m r_d$ of 30, and an Idss of 40 mA/mm. A precision nichrome resistor of 18 kohms used as the feedback resistor, is possible in this process. The tolerance on this resistor is better than ± 5 percent.

Figure 8 shows an eye diagram at the output of the preamp while operating at a bit rate of 266 Mb/s and a $2^{15}-1$ PRBS The upper trace shows the circuit operating at low input levels approximately 25 dBm. The lower trace shows the preamp operating with an optical input power of 0 dBm. The bandwidth at high optical levels is about 1 GHz since the feedback resistor changes from 18 kohms to about 500 ohms.

Table 2 lists the performance results obtained for the preamplifier thus far.

Other Bit Rate Preamplifiers

The amplifier of Figure 7 has an open loop gain of −35 and a 3 dB bandwidth of 1.5 GHz. By changing the feedback resistor value, we can design preamplifiers optimized for various different bit rates. Table 3 lists performance results obtained from three additional low power single supply circuits. *RF*

References

1. R. Bayruns, ''An Amplifier Having a Low Noise Active GaAs MESFET Load,'' U.S. Patent 07/554,802.
2. Y. Hatta, et. al., ''A GaAs IC Set for

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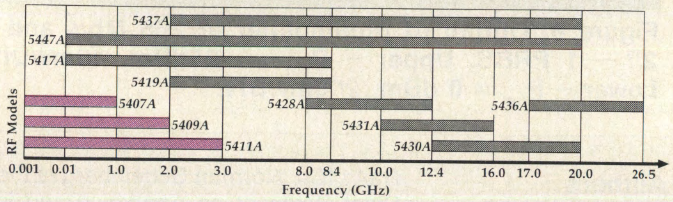

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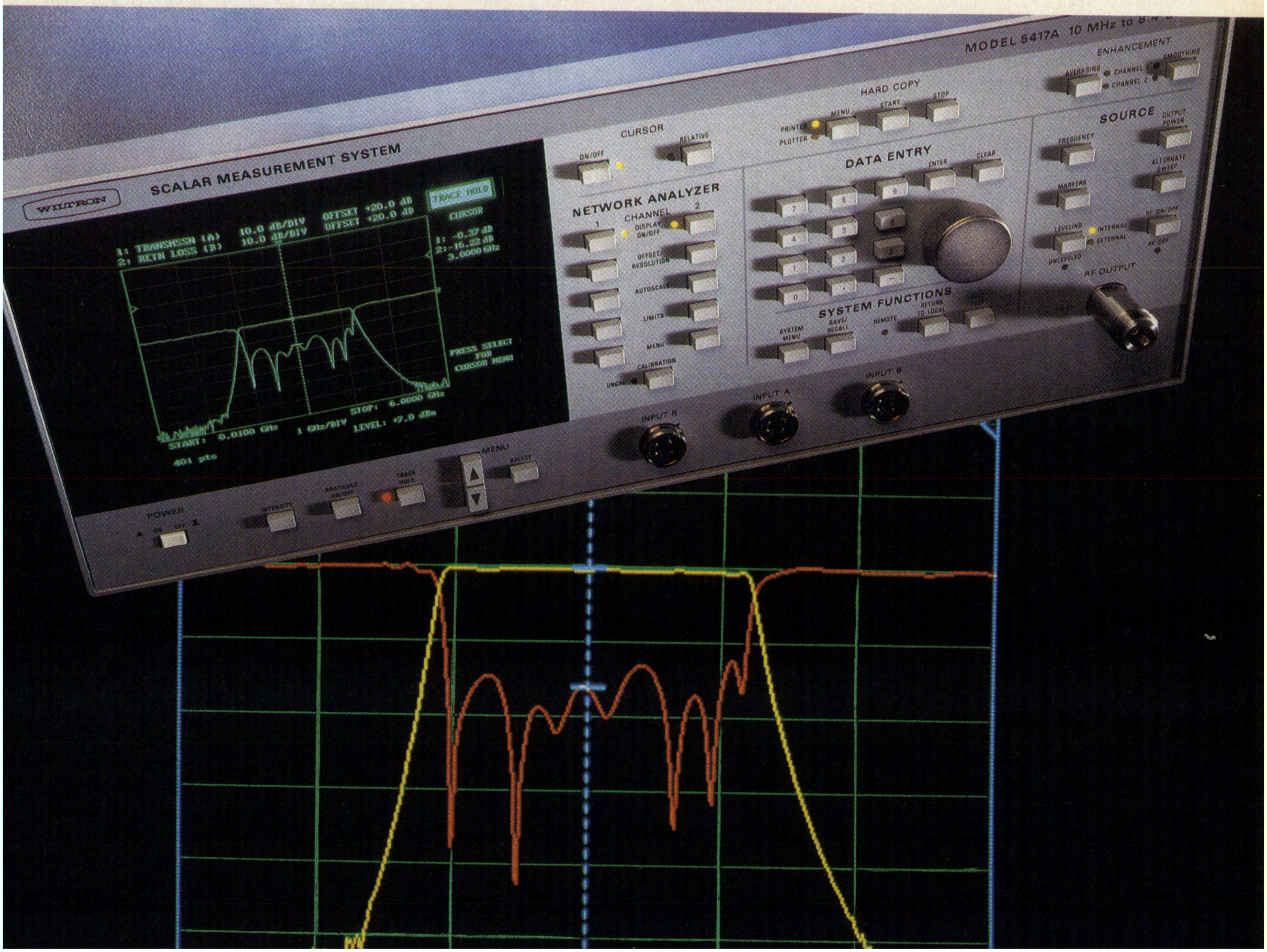


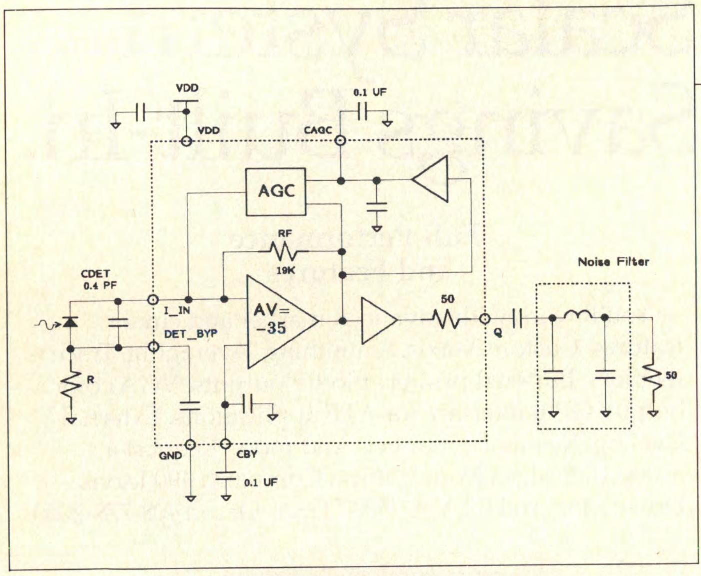


Figure 7. Block diagram of the Auto AGC GaAs preamplifier. External components are also shown.

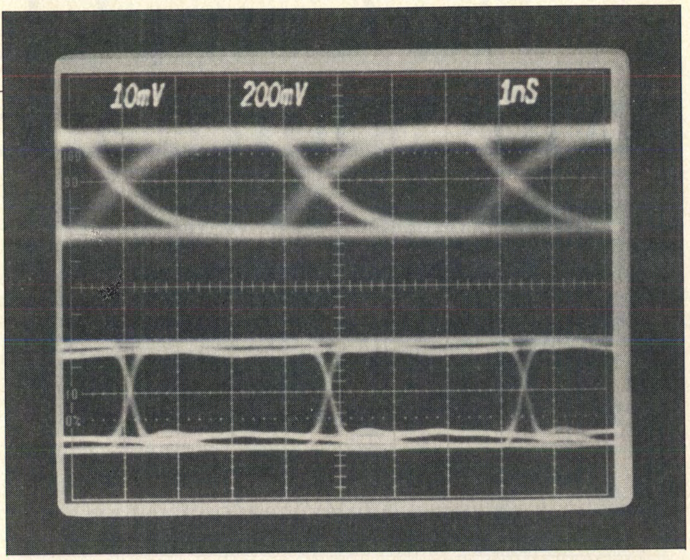


Figure 8. Output of preamplifier at 266 Mb/s and a $2^{15} - 1$ PRBS. Upper − P_{opt} = −25dBm, 10mV/DIV, Lower − P_{opt} = 0 dBm, 200mV/DIV.

Full Integration of 2.4 Gb/s Optical Transmission Systems," *IEEE GaAs IC Symposium Technical Digest*, pp. 15-18, 1988.

3. R. Minasian, "Optimum Design of a 4 Gbits/s GaAs MESFET Optical Preamplifier," *IEEE Journal of Lightwave Technology*, vol. LT-S, March 1987.

About the Authors

Robert Bayruns is the Director of RF and Digital Product Development. Tim Laverick is responsible for design, development and product engineering of fiber-optic and analog GaAs ICs. Norman Scheinberg is the Chief Scientist as Anadigics and is working on GaAs linear circuits. They can be reached at Anadigics, 35 Technology Drive, Box 4915, Warren, NJ 07059. Tel: (908) 668-5000.

Locating Power Line RF Interference

By James Harris
Trilithic, Inc.

Of all sources of radio interference, radio frequency interference (RFI) generated by AC power distribution systems is the most common and often the most difficult to track down. These systems are designed to be interference-free, but hardware defects and failures will inevitably occur, and a single defect can generate enough RF energy to disrupt VHF communications for miles. All such defects are repairable once the subject hardware is identified; not always a simple process.

Finding the power structures that generate RFI is both an art and a science, and proficiency improves only with practice. However, a methodical approach to RFI-hunting and use of the right instruments can shorten the learning process. This article describes a set of tools for RFI location and an efficient procedure for using them to locate RFI-generating power structures on the first attempt.

The Composition of Power RFI

RFI generated by power distribution systems takes the form of very short pulses or spikes. The pulses are sometimes less than 70 nanoseconds in duration and occur in bursts at one or both peaks of the AC sine wave. A given burst may contain from one to several hundred spikes. In part, the effect of a given RFI source on VHF communications is proportional to the number of spikes it generates in each burst. In TV applications, the threshold at which interference can be perceived varies as much as 8 dB, depending on the number of spikes per burst (See Table 1).

The power RFI spectrum is very broad, sometimes extending to hundreds of MHz. Amplitude decreases with increasing frequency in a regular, predictable way, the rate depending on the mechanism by which the interference was generated. Two mechanisms, corona discharge and microgap discharge, cause almost all power-related RFI. Both are associated with very high-voltage, or transmission power lines, and medium voltage distribution lines. Secondary lines, those carrying less than 1000 volts, are rarely a source of RFI, though they may conduct RFI generated by equipment connected to them.

Corona or brush discharge occurs at a point or along sharp edges of hardware in contact with high-voltage lines. The intense electrical field ionizes the air molecules near these points, and the resulting current generates the RFI energy. Corona discharge most commonly occurs on power structures operating at greater than 100 kV.

The amplitude of corona-generated RFI falls off very rapidly with increasing frequency. Although a problem for AM broadcasters and HF ham radio operators, corona only affects VHF communication systems if the point of radiation is very close to the receiving antenna.

Microgap discharge occurs when the field around the power line induces a charge on nearby hardware. If the charge is strong enough, very small sparks will jump between adjacent hardware, through layers of corrosion, or along cracks in insulators. These sparks, though small, generate considerable amounts of RF energy. Note that direct contact with the primary line is not necessary, so any loose pole hardware

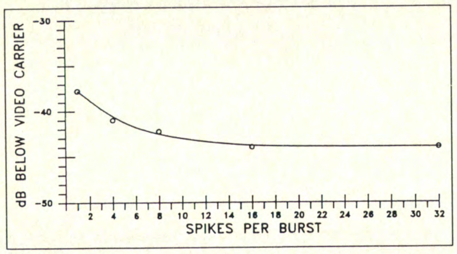
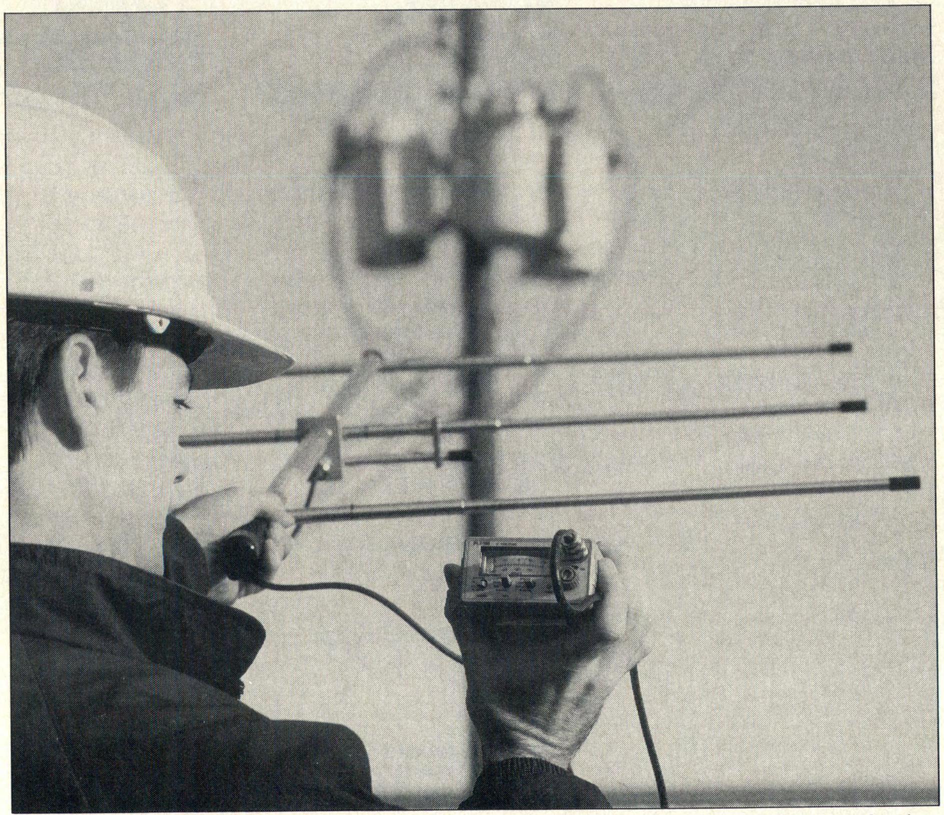
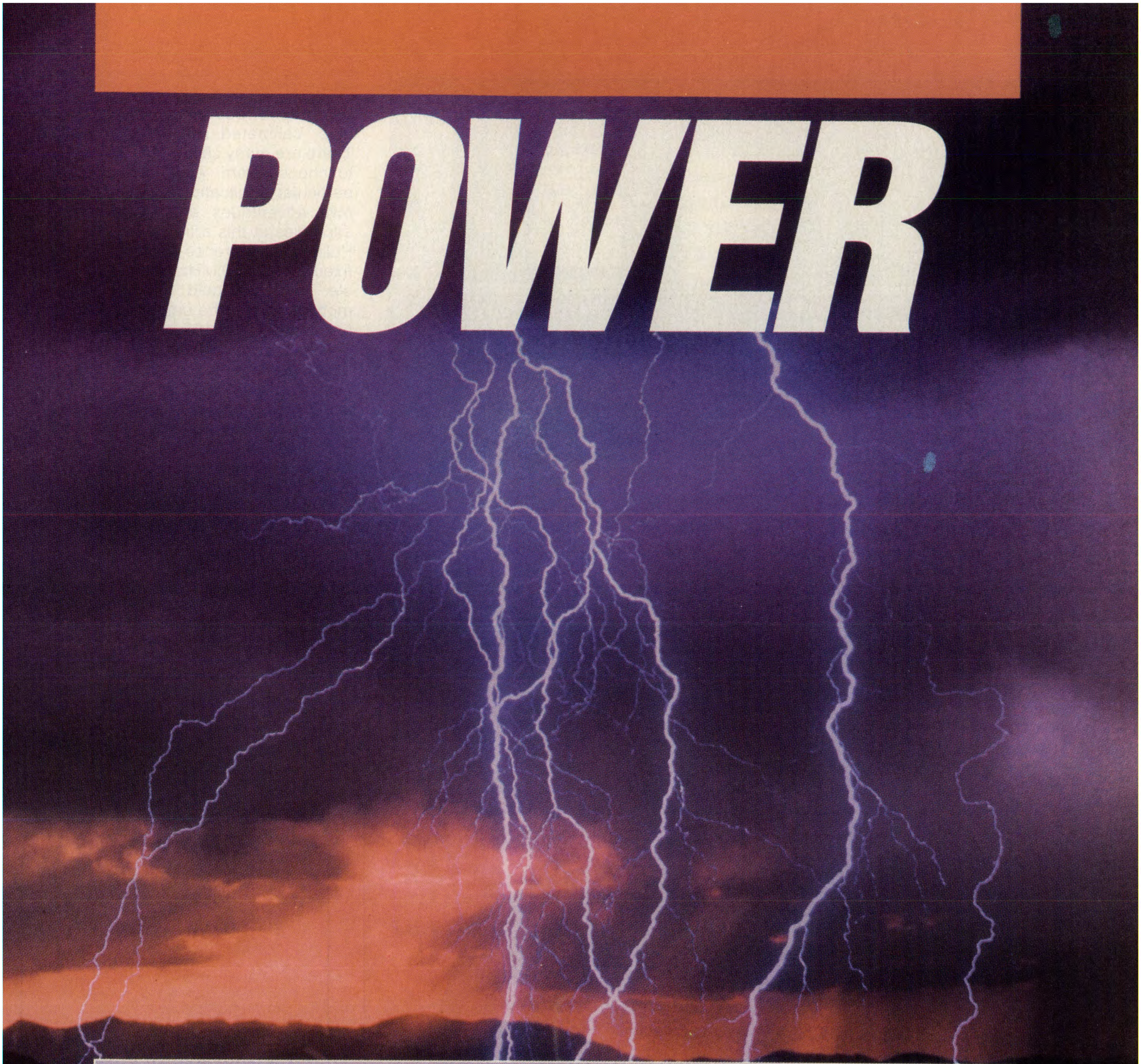
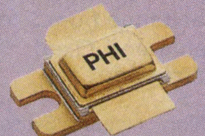


Table 1. Power line interference limit of detectability.



Engineer using Trilithic PLI-150 Interference Locator System to find a defective lightning arrestor that is generating VHF electrical noise. On foot measurements will usually track RFI sources to the nearest power pole.





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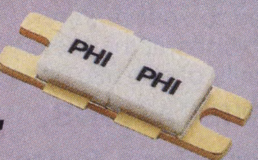

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PH2729-110M	2.7-2.9	110W	8.0dB	40%	100µS	10%
PH1214-220M	1.2-1.4	220W	8.0dB	53%	150µS	10%
PH1090-350L	1.03-1.09	350W	8.0dB	60%	250µS	10%

MOSFET Transistors

Part Number	Frequency MHz	Power Out	Gain	Efficiency	Operating Voltage
LF40100M	1000	100W	10.0dB	50%	40
CR2480M	960	80W	10.0dB	50%	26
UF28150J	500	150W	8.0dB	55%	28
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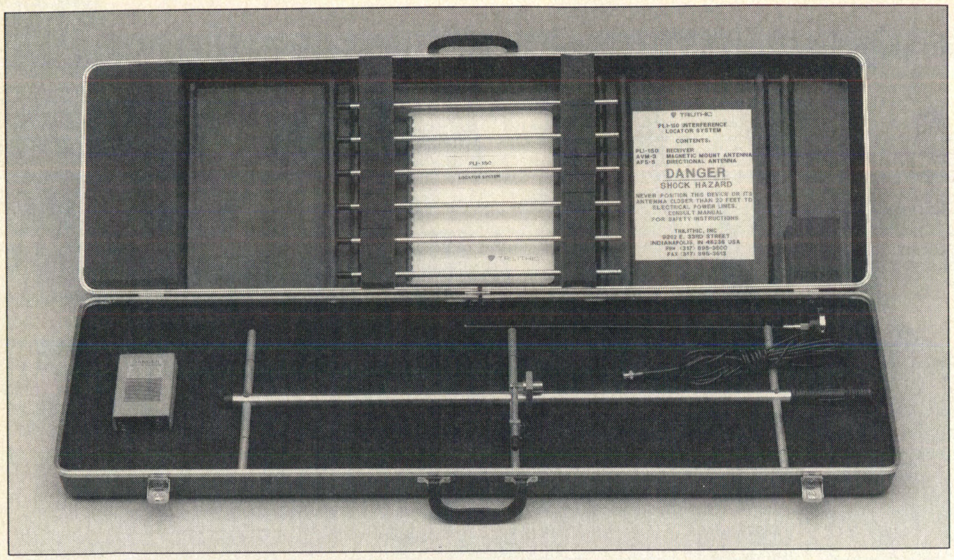

The PLI-150 kit is provided in a convenient carrying case.

(and occasionally, a rain gutter or chain link fence) near the line can be a site for microgap discharge.

Microgap-generated RFI can occur in transmission systems but is most often found in distribution systems. Statistically, the sheer volume of hardware used in distribution makes defects likely, and distribution lines are more often found near receiving sites. Also, the amplitude of microgap-generated RFI decreases with frequency at a much slower rate than RFI generated by corona discharge, so a microgap is likely to generate significant energy in the VHF spectrum. For all of these reasons, microgap discharge is the cause of most power-related VHF interference problems.

Finding Sources of Power RFI

The procedure laid out in the following paragraphs requires the use of a portable, calibrated RFI receiver system. There are many calibrated RFI receivers to choose from, each designed for a particular application and each with its own advantages and trade-offs. The examples in this article use the Trilithic PLI-150 Interference Locator System, a fixed-tuned, 150 MHz receiver with vehicle and hand-held antennas and a mobile mount. The unit of field strength used by the PLI-150, and in the examples in this article, is dBmV/meter. The dBmV scale is referenced to one millivolt, and was chosen because a dB scale simplifies calculations and because it is a widely used unit of measure in the CATV industry.

The steps in identifying power RFI sources are:

1) Estimate the field strength of the interference at the receiving site (base station, CATV headend, VHF amateur radio station, etc.).
2) Conduct a survey to locate and measure all RFI sources in a defined search area around the antenna.
3) Determine which of the located sources is strong enough, and at the right distance and angle, to cause perceivable RFI.

Step 1: Estimating RFI Strength at the Antenna

There are several ways to determine the level of RFI arriving at the antenna. The most direct way is simply to measure it. Unfortunately, this is not always practical. In video applications, for example, a weak signal can be disrupted by levels of RFI too small to be conveniently measured.

A less direct, but often more practical method, is to deduce the interference level from (S+N)/N estimates. For video applications this is especially attractive because data is available to correlate various levels of interference with effects on TV picture quality.

The simplest method of all is to determine not the actual (S+N)/N ratio, but the minimum (S+N)/N ratio that could cause perceptible interference. For example, power line interference becomes visible in a TV picture at about −40 dBc (dB below carrier). If the video carrier has an amplitude of 10 dBmV, the level of visible RFI must be at least −30 dBmV. The actual strength of the RFI might be greater, but if visible on the TV screen, it cannot be less. In this example, any RFI source found in the field that could produce interference at the receiving site greater than −30 dBmV, regardless of precise amplitude, would be of great interest.

Having determined the level of RFI at the antenna down lead by one of the methods above, the engineer must now convert down lead strength to field strength. The calculation takes the form:

[Field Strength (dBmV/meter)] = [Down lead Strength (dBmV)] −[Antenna Gain (dBd)] + [20log(.021Frequency)]

If the engineer is using a measurement system that operates on a frequency other than the frequency of interest, an additional correction is needed to account for the decrease in RFI intensity with increasing frequency:

[Correction Factor (dB)] = [20log(Measurement Frequency/Frequency of Interest)]

Example: Assume a receiving antenna gain of 7 dBd (antenna gain reference to a dipole), and a down lead RFI strength of −30 dBmV at 77.25 MHz (Channel 5):

[Field Strength (dBmV/meter)] = [−30dBmV] − [7 dB] + [20log(0.021 x

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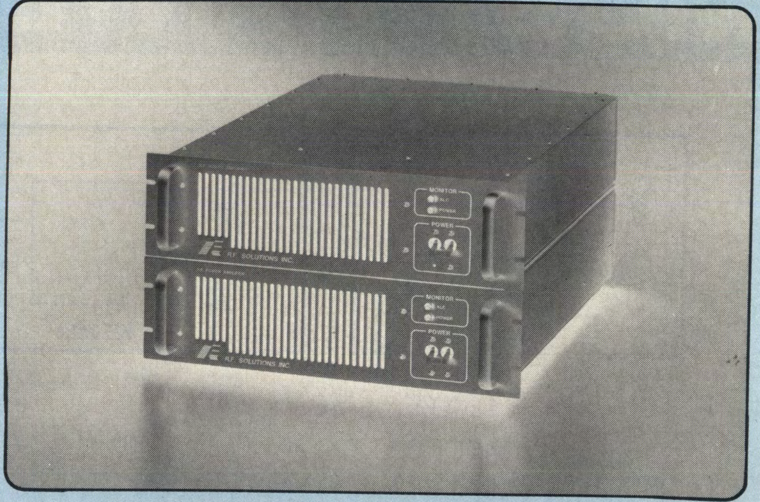

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INFO/CARD 44

77.25)] = [−30 dBmV] − [7 dB] + [4.2 dB] = −32.8 dBmV/meter

To determine the level that would be measured by an RFI receiver operating at 150 MHz:

[RFI at 150 MHz] = [−32.8 dBmV/meter] − [20log(150/77.25)] = [−32.8 dBmV/meter] − [5.8 dB] = −38.6 dBmV/meter

This value, which we will call the RFI threshold, will be used in Step 3 to evaluate RFI sources located in Step 2.

Step 2: Conducting a Field Search

When planning a field search, the engineer is confronted with two problems. First, the area that he must search will probably be quite large. A strong source can interfere with TV off-air reception from a distance of several miles. Clearly, it is not practical to cover such a large area on foot.

Secondly, any large search area is likely to contain dozens of power structures that radiate some amount of RF energy. Few of these will be relevant to the engineer's RFI problem. A large part of the engineer's task will be to differentiate between those few and the many sources that are not relevant.

The solution to both problems is to perform the search in two phases. The first phase is to survey the entire search area in a vehicle, using a mobile-mounted receiver and antenna, noting the location and approximate strength of all strong RFI sources and determining which sources warrant further examination. In the second phase of the search, the engineer returns on foot to these sources and makes accurate measurements using a portable RFI receiver and hand-held antenna.

There are two ways to organize an RFI search. One is to simply detect and measure every RFI source encountered and evaluate the data when the survey is completed. Although this approach will yield accurate results, most of the data will be quickly discarded during the post-survey evaluation.

Or, the engineer can plan a search using a map of the area. In preparing a search map, the engineer begins with the estimated strength of the RFI at the receiving site (the threshold derived in Step 1), allowing for the pattern of the receiving antenna. Using the formulas outlined in Step 3, he then calculates how strong an RFI source would have to be if found at various points in the search area, and marks these figures on the map for reference during the survey. During the search, he can refer to this map to evaluate sources as he finds them and take data only on those sources that are likely to contribute to the RFI problem.

Conducting a Vehicle Survey — Before beginning a vehicle survey, it is necessary to verify that there are no significant RFI sources in and around the receiving site. Observe the effect of turning off compressors, fluorescent lights and other auxiliary equipment in the immediate area. The engineer may also wish to sweep the area on foot, using the RFI receiver with a dipole or directional antenna.

For the vehicle survey, it is recommended that a calibrated, vehicle-mounted whip antenna be used with the receiver. The whip should be placed on the vehicle's roof at the point where ignition noise causes minimum interference. Since the whip is omnidirectional, RFI sources are located by noting peaks in RFI strength. The engineer should methodically follow the paths of all the primary power lines in the search area, noting the location and field strength for each source and the approximate distance between the whip antenna and the power lines. If he is using a map, he need only record the sources that approach the threshold level for that location. Sources more than 6 dB below the threshold can be ignored.

Occasionally two or more sources will be close enough to be received simultaneously. If the receiver has a loudspeaker, the individual sources can be differentiated by the sound each produces. It is unlikely that two sources that are close enough to overlap will sound the same.

If a source cannot be resolved to one or more clear-cut location, it may actually be several sources spaced very close together, or it may be a diffuse source caused by multiple defective insulators. It is sufficient to map out the general area and defer final judgement until measurements can be made with a directional antenna.

On-Foot Measurements — The vehicle survey will establish the approximate positions of one or more sources that may be strong enough to cause RFI problems. The engineer now uses the calibrated receiver with the directional antenna to determine the power and exact location of each of these sources. This phase is best conducted on foot.

Swinging the antenna up and down, and side-to-side, the engineer walks in the direction of increasing RFI strength. Rotating the antenna along its axis (so the tips of the elements point up and down) may improve pointing accuracy if the RF field is polarized. Once the precise location of the RFI source is known, its power should be measured at some convenient distance, and the location, field strength, and measurement distance should be recorded. Remember to subtract the gain of the directional antenna from the measurement data.

Step 3: Evaluating the Data

Received field strength depends on the strength of the source, its distance from the receiving site, and the characteristics of the receiving antenna. All of these factors must be considered when evaluating the RFI sources found in the field survey.

Attenuation caused by distance (path loss) increases at 20log(distance). Due to path loss, an RFI source 5000 feet from a receiving antenna must be 20 dB stronger than one 500 feet away to produce the same effect. Path loss also applies to field strength measurements, and a calibrated measurement requires that the distance between the measurement antenna and the source be known.

For simplicity, it is often convenient to express path loss to the receiving site and to the measurement antenna in the same formula:

[Path Loss] = [20log(distance to receiving site/distance to measurement antenna)]

If the pattern of the receiving antenna is omnidirectional, this formula is sufficient to evaluate the RFI sources found in Step 2. By subtracting the path loss from the measured strength for each source we can determine the RFI strength at the receiving site.

[RFI at the Receiving Site] = [Measured RFI strength at source] −[Path Loss]

If this calculation yields a value that is greater than the threshold level estimated in Step 1, the respective source is strong enough to cause perceptible RFI.

Example: Assume a source located 1000 feet from the receiving site with a strength of −6 dBmV/meter, measured from 50 feet away. At the receiving site this source would produce an RFI level of:

[Field Strength at the Receive Site (dBmV)] = [Field Strength measured 50 feet from the source] − [20log(1000/50)] = [−6 dBmV/meter] − [26 dB] = −32 dBmV/meter

If this is greater than the threshold value calculated in Step 1, the source is strong enough to cause problems.

If the antenna at the receiving site is not omnidirectional, the calculation should incorporate the attenuation caused by the antenna's directivity:

[RFI at the Receiving Site] = [Measured RFI strength at source] −[Path Loss] −[Antenna Directivity]

The directivity term can be calculated by estimating the angle of each source to the antenna's main lobe, then looking

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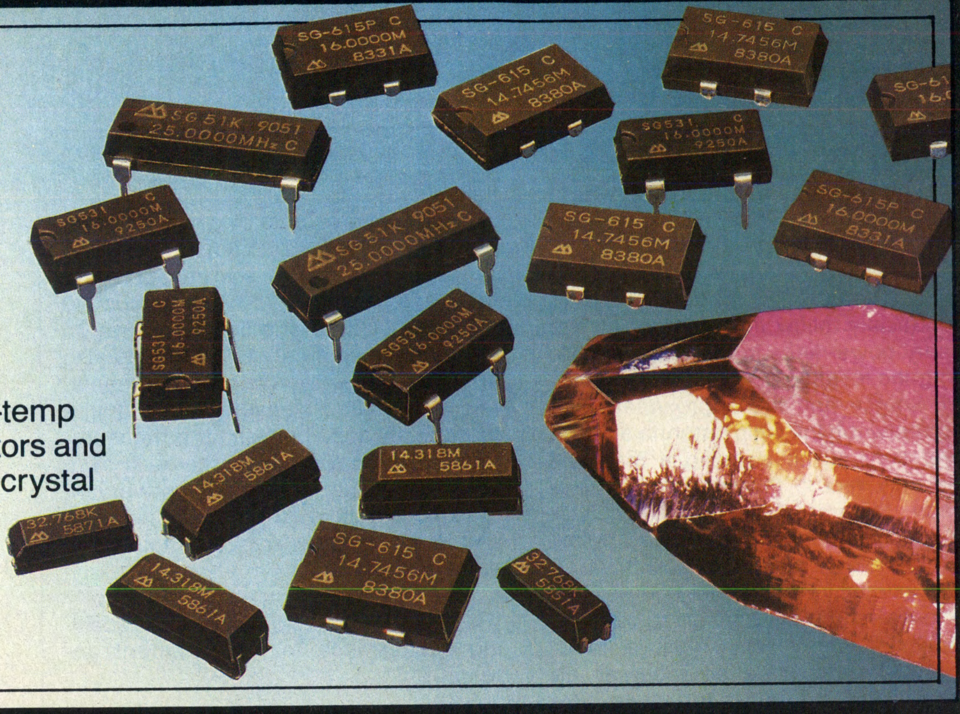

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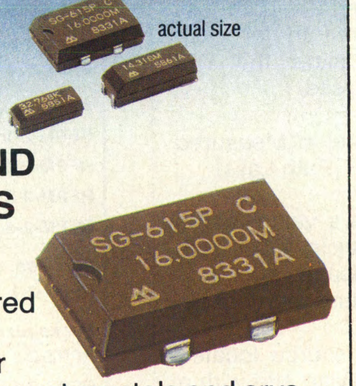

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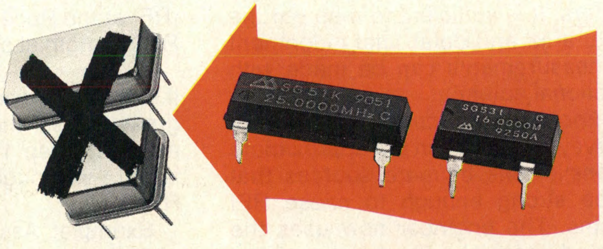

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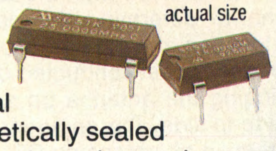

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[Field Strength at the Receive Site (dBmV)] = [Field Strength measured 50 feet from the source] – [20log(1000/50)] –[10 dB] = [–6 dBmV/meter] –[26 dB] –[10 dB] = –42 dBmV/meter

What to Do Next

When all of the relevant sources have been pinpointed, and the search data assembled and analyzed, report your findings to the power company. Power company troubleshooting crews can take over at this point, using ultrasonic sensors and other specialized short-range equipment to verify your conclusions and pin the interference problem down to a specific insulator or piece of hardware.

Conclusion

Finding power-related RFI sources is as much a technical art as it is a science. More variables influence the process than can be discussed in one article. However, results improve quickly with practice, especially if the engineer uses test equipment and search procedures that are designed for the task. In this article one such system has been described. For those interested in more information on RFI location, contact the IEEE or the American Radio Relay League, both of whom publish reference books on the subject, or contact the author.

For more information on the PLI-150 system, circle Info/Card 189. **RF**

About the Author

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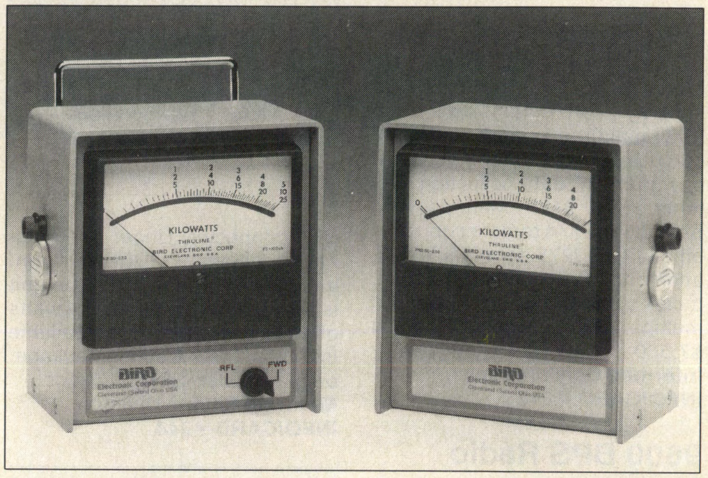
Bird Introduces High Power Directional Wattmeters

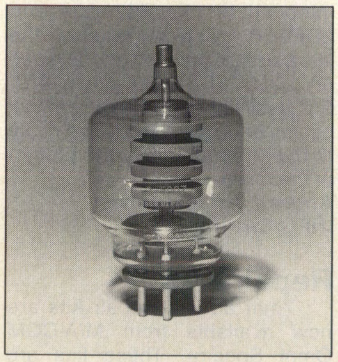
New ruggedized THRU-LINE® Directional Wattmeters for high power rigid line applications are announced by Bird Electronic Corporation. These improved units are available for 1-5/8, 3-1/8, 4-1/16 and 6-1/8 inch 50-ohm line sections, with either EIA flanged or unflanged connection. A 10-foot shielded cable connects the meter unit to the line section. Power levels offered cover 250 watts to 250 kW using a series of plug-in sampling elements for the various power and frequency ranges. One or two element configurations are offered for either manually reversible, remotely switched, or continuous dual-directional power monitoring. Accuracy is ±5 percent, enhanced with a new 4 × 4-1/2 inch mirrored-scale meter. The meter is also glass-faced rather than plastic to eliminate errors due to static buildup on the faceplate. The front lip of the case extends beyond the meter face, protecting it should the case fall on its front side. Multiple meter scales allow the metering unit to be used with different range elements, such as using a more sensitive reflected power element. The meter unit is available in single- and dual-meter configuration, in either stand-alone cases or a 19-inch rackmount.

Bird Electronic Corp.
INFO/CARD #250



Longer-Life 3-500Z Power Tubes

A new version of the Amperex 3-500Z power triode is being manufactured and distributed by Richardson Electronics, Ltd. These tubes, used in AM broadcast transmitter, amateur radio amplifier, and laser driver applications, are manufactured

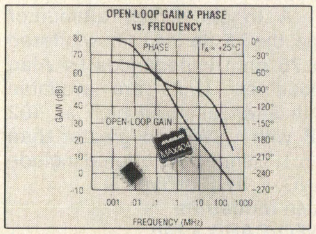


at Richardson's facility in Brive, France. The new 3-500Z model features a heavy graphite anode which improved the tube's handling of high level, intermittent overloads, a typical cause of reduced tube life. A zirconium-coated cathode also helps extend tube life. The improved ruggedness of the tube is reflected in a longer than normal warranty of 18 months or 3500 hours. The improved Amperex 3-500Z is available from stock.

Richardson Electronics, Ltd.
INFO/CARD #249

80 MHz Video Op Amp

The new MAX404 high speed operational amplifier is optimized for AC performance, output drive and stability while operating from ±5 volt supplies. This op amp features 500 V/us slew rate, an 80 MHz gain-bandwidth, 0.01 de-

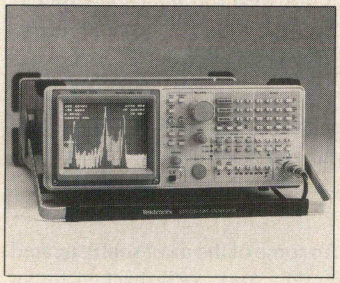


gree differential phase and 0.05 percent differential gain. The MAX404 is not a current feedback amplifier, and can be used in virtually all high speed op amp applications, with fully symmetrical differential input, 70 dB common-mode rejection ratio (CMRR) and 66 dB open-loop gain. Power bandwidth is greater than 65 dB in a gain of 2, 75 ohm cable driver circuit, assuring that PAL, NTSC and SECAM video is well within the device's slew rate capability. A ±3 volt output swing and 50 mA output current allows three 150 ohm loads to be driven. Pricing of the MAX404 starts at $2.21 in 1000s. DIP and SO packages,and commercial or extended temperature specifications are offered.

Maxim Integrated Products
INFO/CARD #248

Economical 1.8 GHz Spectrum Analyzer

Tektronix announces the 2711 Spectrum Analyzer, covering 9 kHz to 1.8 GHz for bench or field service applications. Positive-feel pushbuttons are functionally grouped for easy, logical operation. Sensitivity is up to −129 dBm, with 80 dB of display range, spans down to a narrow 10 kHz/div., and a selection of resolution bandwidth filters from 3 kHz to 5 MHz. Spectral activity can be viewed as a traditional analog display, or up to four digitally stored displays can be compared and measured. A built-in AM/FM demodulator with

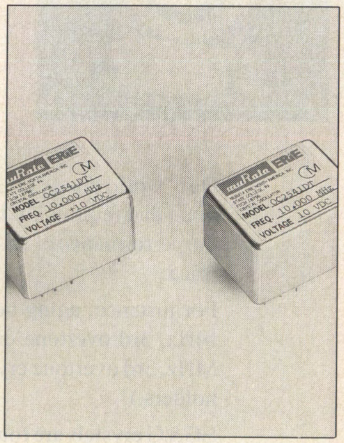


speaker and headphone outputs aids in signal identification and monitoring. The unit offers simple menu selection of automated carrier-to-noise, occupied bandwidth, normalized bandwidth, signal search and FM deviation. Price of the 2711 is $8,750.

Tektronix, Inc.
INFO/CARD #247

Low-Cost Miniature OCXOs

Murata-Erie North America introduces the OC2541DT, a low-cost miniature oven-controlled crystal oscillator utilizing an SC-cut crystal. This 10 MHz unit is specifically designed for local oscillator and reference oscillator applications in satellite communications systems, and is suitable for many other applications with high accuracy requirements. Typi-



cal specifications include a frequency stability of $\pm 2 \times 10^{-8}$ from 0 to +50C, and 1×10^{-7} per year aging. Operating current is 90 ma at 25C, with a 10 VDC supply. Dimensions of the oscillator are 1.08 × 1.41 × 1.0 inches. Typical pricing for 1000-piece quantities is $200 each.

Murata Erie North America
INFO/CARD #246

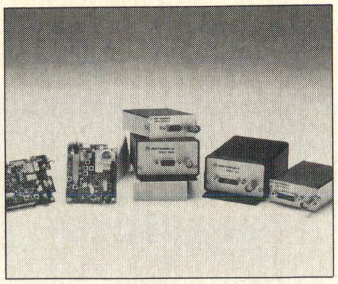
RF SUBSYSTEMS

RF Control Unit

Intermec announces the Model 9185 RF control unit to simplify connections between IBM mainframe and midrange computers and Intermec's spread-spectrum RF data collection systems. The 9185 features IBM SNA 3274/3174 remote controller emulation, 3278 terminal evaluation and 3287 printer emulation. It can support multiple hosts and multiple RF networks. Price is $7,580.
Intermec Corporation
INFO/CARD #245

9600 BPS Radio Modem

The RNet 9600 integrated radio modem operates at user selectable data rates of 9600, 4800, 2400 or 1200 BPS, and is offered in the 403-430 and 450-470 MHz UHF bands. Inputs are either TTL or RS-232 levels via a



DB9 connector. Under good signal conditions, its BER performance is better than 10^{-6}. The unit is available with either 2 or 4 watts of power. RNet 9600 is available in a 3.3 × 2.7 × 1.5 inch package, or in a smaller 'SLM' package.
Motorola Radius Division
INFO/CARD #244

SIGNAL PROCESSING

Cellular/GSM Circulators

High power circulators covering 820-960 MHz in 4 percent bands are available from Narda. Amplifier protection for systems of up to 100 watts CW is offered by these circulators when used with a customer-supplied load. Performance specifications include 0.4 dB insertion loss, 1.25:1 VSWR (max.) over a 0 to +70C temperature range.
Loral Microwave-Narda West
INFO/CARD #242

Low Cost Mixers

Synergy Microwave announces the SSM series of wideband mixers featuring true surface mount packaging and a very low cost for high volume production. The SSM-1 covers 0.5-500 MHz with 6.5 dB conversion loss with +7 dBm local oscillator power. The SSM-2 offers a 1000 MHz upper frequency limit with 7 dB conversion loss over the entire band. LO to RF isolation is typically 25 dB at 1000 MHz and 60 dB at 5 MHz. The mixers have a 0.4 sq. in. footprint and 0.22 inch height. Prices are $2.95 and $3.95 for the SSM-1 and SSM-2, respectively, in 10,000 quantities.
Synergy Microwave Corp.
INFO/CARD #241

Switched Attenuator

A toggle switch attenuator line, the TX Series, is now offered in 75 ohm impedances by Alan Industries. Units are available with attenuation as high as 102 dB with VSWR no greater than 1.5:1. Connectors offered include BNC, F, TNC or Type N.
Alan Industries
INFO/CARD #240

High-Intercept Mixer

The Anzac model ESMD-C2HX2 covers the 819-915 MHz band, with IF response of 20-100 MHz. A patented design provides a guaranteed third order intercept point of +26 dBm. Recommended LO power is +17 dBm. The unit is packaged for surface-mounting using automated assembly. Optimization for 200 MHz bandwidths from 100-1500 MHz is available at no extra charge. Price is $41.85 for 1-9 units.
M/A-COM Inc., Anzac Operation
INFO/CARD #239

SSB Modulator

TRM, Inc. announces the Model SSM 134-175, featuring low conversion loss and high sideband suppression for SSB modulation at a frequency of 75 ±1.625 MHz. Conversion loss is 8 dB maximum with signal input of +10 dBm and modulation input of 0 dBm. Carrier and sideband suppression is specified at −25 dBc minimum. The unit is packaged in a 1 inch square by 0.15 inch thick flatpack, offered in SMT, or with radial or axial leads.
TRM, Inc.
INFO/CARD #238

500-Watt Terminating Load

Model 1434 from Lucas Weinschel offers 500 watts power capability at less than 1.10:1 VSWR from DC-2.5 GHz. This 50 ohm load is rated for full power at 25C ambient, linearly derated to 50 watts at 125C. Peak power handling is 10 kW at 5 usec pulse width and 2.5 percent duty cycle. It is supplied with a Type N connector.
Lucas Weinschel Inc.
INFO/CARD #236

CABLES & CONNECTORS

Grounding Kits

Andrew Corp. introduces grounding kits for small diameter (1/4 and 3/8 inch) coaxial cables. Intended for the FSJ1-50A and LDF2-50 HELIAX® cables, the kits can also be used on RG types 6/U, 8/U, 11/U, 213/U and 214/U. For best lightning protection, all cables should be grounded close to the antenna and at the bottom of the tower.
Andrew Corporation
INFO/CARD #235

Repair Kits

7mm adapter repair kits are now available from M/A-COM Omni Spectra. These kits are designed to replace the jack or plug housing and center contact section of various connector types adapted to the Omni Spectra precision connector.
M/A-COM Omni Spectra
INFO/CARD #234

LC/LT Connectors

Large size LC and LT threaded coupling connectors for use with flexible coaxial cable are offered by Tru-Connector. The high-power connectors are fully gasketed, weatherproof, and

have a 50 ohm impedance over 0-1 GHz. Peak voltage ranges from 5,000 to 10,000, depending on the cable type.
Tru-Connector Corp.
INFO/CARD #233

SIGNAL SOURCES

0.3-2.0 GHz DTO

Model 2361 digitally-tuned oscillator from Radian Technology uses four sub-band DTOs selected for full 0.3 to 2.0 GHz coverage. Tuning and sub-band selection is via a 13-bit TTL input. Harmonics and spurious outputs are −60 dBc or better. Tuning speed is under 1 us to within 0.1 percent of frequency. The unit includes a 10 MHz bandwidth analog FM input.
Radian Technology, Inc.
INFO/CARD #232

DDS/PLL Synthesizer

QUALCOMM announces the Q0710-1 DDS-driven PLL synthesizer for 900-1600 MHz coverage in approximately 1 Hz steps. The unit features fast switching times and low spurious output. Pricing (1-9 units) is $1595, including a complete instruction manual.
QUALCOMM Inc.
INFO/CARD #231

ECL Clocks

The new E500 series of half-size ECL clock oscillators is announced by Connor-Winfield. Available frequencies cover 24-180 MHz, in standard 0 to 70C or industrial −40 to +85C temperature ranges. Frequency stabilities as good as 25 ppm are offered. Supply voltages may be −5.2, −4.5 or +5 volts. Prototype quantities of the E531 120 MHz unit are priced at $43.90.
Connor-Winfield Corp.
INFO/CARD #230

SMT Oscillator

Using HCMOS technology and an AT-strip crystal, the M-tron MM series covers 1.5-40 MHz in TTL/HCMOS, or 40.1-60 MHz in HCMOS. Tristate output is optional in either model. The MM oscillators are packaged in a ceramic SMT package with dimensions of .276 × .197 × .091 inches for applications where board space is at a premium.
M-tron Industries, Inc.
INFO/CARD #229

Airborne Synthesizers

NCI Systems introduces a new series of frequency synthesizers that can be tailored to MIL-E-5400T airborne applications. The NCS series are available for operation from 2-18 GHz with bandwidths to 300 MHz. Step size is 5 MHz. With +22 dBm output, power consumption is just 6.1 watts.
NCI Systems
INFO/CARD #228

AMPLIFIERS

RF Repeater

The PrismPlus™ from Decibel Products is a low cost repeater for cellular, trunking, ETACS, GSM and conventional applications. It handles up to 64 channels and covers up to 2 miles in diameter. Tow models are available, DBE34 with 2.5 watts, and DBE40 with 10 watts power output. Operation is from 110/220 VAC or 24 VDC.
Decibel Products
INFO/CARD #227

25 Watt VHF Amplifier

ENI announces the Model 325LA with 25 watts linear output from 250 kHz to 150 MHz for applications in transmitters, RFI/EMC testing, nuclear accelerators and general lab use. Nominal gain is 50 dB and it will handle a +13 dBm input signal for all output load conditions. A front panel meter monitors RF voltage and power. Price of the 325LA is $2,310.
ENI
INFO/CARD #226

Low Noise Amplifier

Veritech's VMA 18C-118 is a commercial quality low cost amplifier for the 17-19.4 GHz band, covered in 600 MHz segments. Specifications include 3.5 dB noise figure, 18 dB gain, and 2:1 VSWR. The amplifiers are unconditionally stable, and come packaged in a 1 × 1 × .22 inch housing.
Veritech Microwave, Inc.
INFO/CARD #225

300-watt amplifier

Model 300A100 from Amplifier Research covers 10 kHz to 100 MHz with 300 watts linear power output. Complete control and preamplification functions include automatic leveling threshold, detected RF input and output, pulse input capability, remote control capability and front-panel power metering. U.S. price is $19,000.
Amplifier Research
INFO/CARD #224

SEMICONDUCTORS

14-Bit 5.12 MHz ADC

Burr-Brown introduces the ADC614, a 5.12 MHz, 14-bit sampling analog-to-digital converter. The units wideband linearity allows true Nyquist spurious-free dynamic range of 88 dB below full scale. Analog bandwidth is 40 MHz. The ADC614 is a subranging ADC hybrid with pinouts consistent with Burr-Brown's 12-bit models ADC603 and ADC604. Pricing is $990 in 100s.
Burr-Brown
INFO/CARD #223

1/2 Watt Transistor

NEC's NE46134 is a surface-mount silicon bipolar transistor recommended for applications to 1.5 GHz, providing 1/2 watt output (1 dB compression) with a 12.5 V supply. Noise figure performance is 1.5 dB at 500 MHz and 2.0 dB at 1 GHz. In chip form (NE46100), the device may be used in amplifier applications to 3 GHz. Pricing is under a dollar in 1000s.
California Eastern Laboratories
INFO/CARD #222

Semiconductors targets Personal Communications Network (PCN) base station applications with 10 dB gain and 32 watts output, measured at 1.85 GHz. In Class AB linear service, two-tone IMD is −30 dBc or better at 15 watts output. Operating efficiency is 44 percent.
Philips Semiconductors
INFO/CARD #221

20 MSPS 12-Bit ADC

Comlinear Corporation introduces the CLC936, 1 12-bit 20 MSPS A/D converter. Key specifications include 74 dBc two-tone IMD performance, 64 dB signal-to-noise ratio, and 0.7 LSB differential non-linearity. The 15 MSPS CLC935 is also available, along with an evaluation board for either device. Pricing of the CLC936 is set at $750 in 100s.
Comlinear Corporation
INFO/CARD #220

DISCRETE COMPONENTS

Balun Transformers

A new line of low profile, surface mountable balun transformers is available from Toko America. Wound with parallel wire on a double ferrite core, a high degree of balance is maintained. Standard parts cover 1 MHz to 2 GHz with impedance ratios of 1:1 to 1:25.
Toko America, Inc.
INFO/CARD #219

Chip Capacitors

New MNOS chip capacitors with high Q and low insertion loss are announced by FEI Microwave. The F60 series provides a Q of 3000 at Ku-band, with typical 0.1 dB insertion loss. capacitance values range from 1.0 to 225 pF.
FEI Microwave, Inc.
INFO/CARD #218

Low ESR Capacitors

American Technical Ceramics announces the 180 Series 1.8 GHz capacitors. These devices feature rugged hermetic construction in a porcelain MLC configuration. The capacitance range is 0.5 to 100 pF. The devices are free of self-resonances through at least 1.8 GHz.
American Technical Ceramics
INFO/CARD #217

TEST EQUIPMENT

VXI Signal Generator

EIP Microwave introduces the 1141A VXIbus Synthesized Signal Generator Module, a 3-slot 'C' size unit covering 2-20 GHz with 1 Hz resolution. Presettable power output ranges from −90 to +10 dBm in 0.1 dB steps. Harmonics are −30 dBc or better, with spurious outputs down 65 dB or more. AM, pulse and wideband complex modulation are supported via external modulating signals.
EIP Microwave
INFO/CARD #216

Rental Instruments

IFR Systems announces a new rental program for selected test equipment, including spectrum analyzers, communications service monitors, options and accessories. Instruments can be rented for as little as 30 days, automatically renewed for as long as the equipment is needed. All rentals include a purchase option which allows 80 percent of the rental payments to be applied toward purchase.
IFR Systems, Inc.
INFO/CARD #215

Waveform Synthesizer

FlexStar announces the 7000 Waveform Synthesizer for computer and communications system testing. A high-speed complex analog waveform can be generated at 128 kByte pattern length and minimum step of 2 nanoseconds. Price of the 7000 is under $20,000.
FlexStar
INFO/CARD #214

VXI Power Meter

A new power meter, the Model 4052 from Racal-Dana, is introduced for VXIbus systems. The 4052 is equipped to measure from −70 dBm to 7 watts, and occupies a single C-size slot module. Three measurement channels can be included in the same module. The power meter is an ideal detector for a swept system using a signal generator, counter and directional coupler.
Racal-Dana Instruments
INFO/CARD #213

INFO/CARD 53

INFO/CARD 54

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NEW 2.4 to K
dc - 46 GHz

A Quick Microstrip Matching Program

By Toshihiko Takamizawa
Millimeter Wave Laboratory

This program was an entry in the 1991 RF Design Awards Software Contest. It is a good example of the kind of program engineers write to make the "first cut" in a design problem. This program computes simple series and shunt microstrip matching sections.

There are many sophisticated RF and microwave circuit design software programs on the market these days. These programs are very powerful, accurate, and have many functions. One such program is SANA, which I have been using on a PS/2 for a over year. I have found that I rarely use most of SANA's software functions with one exception; the design of matching networks using stripline circuitry.

The PC hardware required to run many commercial programs occupies a lot of space. In Japan, where space is at a premium, this is a problem. Time is also a consideration. Even though I may

```
Ok
RUN
INPUT FREQ.(GHz)
? 1.5
INPUT ABSOLUTE VALUE OF S11
? .964
INPUT ANGLE OF S11
? -42.1
INPUT ABSOLUTE VALUE OF S22
? .634
INPUT ANGLE OF S22
? -24.2
INPUT EFFECTIVE DIE. PERM.
? 2.08




1LIST   2RUN   3LOAD"  4SAVE"  5CONT  6,"LPT1 7TRON  8TROFF 9KEY 0SCREEN
```

Figure 1. Input data.

```
********** INPUT MATCHING NETWORK **********
********** WITH PARALLEL CAPACITY **********
INPUT OPEN STUB LENGTH  :  31.64392 mms
INPUT SHORT STUB LENGTH :  66.3127 mms
INPUT PHASE LINE LENGTH :  29.5302 mms

********** WITH PARALLEL INDUCTANCE ********
INPUT OPEN STUB LENGTH  :  37.69361 mms
INPUT SHORT STUB LENGTH :  3.02484 mms
INPUT PHASE LINE LENGTH :  23.59006 mms

********** OUTPUT MATCHING NETWORK *********
********** WITH PARALLEL CAPACITY **********
OUTPUT OPEN STUB LENGTH  :  22.58156 mms
OUTPUT SHORT STUB LENGTH :  57.25033 mms
OUTPUT PHASE LINE LENGTH :  39.76395 mms

********** WITH PARALLEL INDUCTANCE ********
OUTPUT OPEN STUB LENGTH  :  46.75598 mms
OUTPUT SHORT STUB LENGTH :  12.08721 mms
OUTPUT PHASE LINE LENGTH :  20.25154 mms
Ok

1LIST   2RUN   3LOAD"  4SAVE"  5CONT  6,"LPT1 7TRON  8TROFF 9KEY 0SCREEN
```

Figure 2. Output data.

```
10  REM  *********** QMAT ***********
20  REM
30  REM  COPYRIGHT BY T.TAKAMIZAWA
40  REM  MILLIMETERWAVE LABORATORY
50  REM                JUNE 5 1990
60  REM  STUB MATCHING CIRCUIT.
70  REM  THIS PROGRAM CALCULATES
80  REM  INPUT & OUTPUT PHASE LINE
90  REM  LENGTH AND STUB LENGTH.
100 REM  A CIRCUITRY TO BE CALCULATED IS
110 REM  PARALLEL CAP. BY OPEN & SHORT STUB,
120 REM  PARALLEL IND. BY OPEN & SHORT STUB.
125 REM  INPUT PARAMETERS:
130  REM  F=FREQ.(GHz)
140  REM  E=EFFECTIVE DIE. PERM.
150  REM  AB11=ABSOLUTE VALUE OF S11
160  REM  AG11=ANGLE OF S11
170  REM  AB22=ABSOLUTE VALUE OF S22
180  REM  AG22=ANGLE OF S22
190  PRINT "INPUT FREQ.(GHz)"
200  INPUT F
210  PRINT "INPUT ABSOLUTE VALUE OF S11"
220  INPUT AB11
230  PRINT "INPUT ANGLE OF S11"
240  INPUT AG11
250  PRINT "INPUT ABSOLUTE VALUE OF S22"
260  INPUT AB22
270  PRINT "INPUT ANGLE OF S22"
280  INPUT AG22
290  PRINT "INPUT EFFECTIVE DIE. PERM."
300  INPUT E
310  LET LG = 10 * (30 / (F * SQR (E)))
320  REM INPUT MATCHNG WITH PARALLEL C
330  LET AG = AG11
340  LET AB = AB11
350  GOSUB 800
360  PRINT "********** INPUT MATCHING NETWORK **********"
370  PRINT "********** WITH PARALLEL CAPACITY **********"
380  REM
390  PRINT "INPUT OPEN STUB LENGTH  : " LG * T1 / 360"mms"
395  PRINT "INPUT SHORT STUB LENGTH : " LG * T1 / 360 + LG / 4"mms"
400  PRINT "INPUT PHASE LINE LENGTH : " LG * T2 / 720"mms"
410  REM INPUT MATCHING WITH PARALLEL L
420  LET AG = AG11
430  LET AB = AB11
440  GOSUB 900
450  PRINT
460  PRINT "********** WITH PARALLEL INDUCTANCE ********"
470  REM
475  PRINT "INPUT OPEN STUB LENGTH  : " LG * T1 / 360 + LG / 4"mms"
480  PRINT "INPUT SHORT STUB LENGTH : " LG * T1 / 360"mms"
490  PRINT "INPUT PHASE LINE LENGTH : " LG * T2 / 720"mms"
500  REM OUTPUT MATCHNG WITH PARALLEL C
510  LET AG = AG22
520  LET AB = AB22
530  GOSUB 800
540  PRINT
560  PRINT "********** OUTPUT MATCHING NETWORK *********"
570  PRINT "********** WITH PARALLEL CAPACITY **********"
580  REM
590  PRINT "OUTPUT OPEN STUB LENGTH  : " LG * T1 / 360"mms"
595  PRINT "OUTPUT SHORT STUB LENGTH : " LG * T1 / 360 + LG / 4"mms"
600  PRINT "OUTPUT PHASE LINE LENGTH : " LG * T2 / 720"mms"
610  LET AG = AG22
620  LET AB = AB22
630  GOSUB 900
640  PRINT
650  PRINT "********** WITH PARALLEL INDUCTANCE ********"
660  REM
665  PRINT "OUTPUT OPEN STUB LENGTH  : " LG * T1 / 360 + LG / 4"mms"
670  PRINT "OUTPUT SHORT STUB LENGTH : " LG * T1 / 360"mms"
680  PRINT "OUTPUT PHASE LINE LENGTH : " LG * T2 / 720"mms"
690  END
800  LET AG = 0 - AG
810  LET B = (2 * AB) / SQR (1 - (AB * AB))
820  LET T1 = ATN (B)
830  LET T1 = T1 / 3.141592654# * 180
840  LET T2 = ATN (B / 2)
850  LET T2 = (0 - (T2 / 3.141592654# * 180)) - AG - 90
860  IF T2 > 0 THEN 890
870  LET T2 = ATN (B / 2)
880  LET T2 = (0 - (T2 / 3.141592654# * 180)) - AG - 90 + 360
890  RETURN
900  LET AG = 0 - AG
910  LET B = (2 * AB) / SQR (1 - (AB * AB))
920  LET T1 = ATN (1 / B)
930  LET T1 = T1 / 3.141592654# * 180
940  LET T2 = ATN ((0 - B) / 2)
950  LET T2 = (0 - (T2 / 3.141592654# * 180)) - AG + 90
960  IF T2 > 0 THEN 990
970  LET T2 = ATN ((0 - B) / 2)
980  LET T2 = (0 - (T2 / 3.141592654# * 180)) - AG + 90 + 360
990  RETURN
```

Figure 3. Program listing.

only need to do a short, simple task, I must still switch on the PC and wait for it to boot up.

These are the fundamental reasons behind the development of this simple program for calculation of a microstripline matching network. Of course, for the final design of circuitry, I still use SANA. But for doing a quick draft circuit, this program is very useful indeed. I can now design a matching network using a handheld PC, or even a pocket computer with BASIC, while in the car or on the train.

Program Description

This program is called QMAT (Quick MATch) and is written in BASIC. The method of calculation is based on the theoretical Smith Chart matching circuit design process. It traces manual circuit design procedures.

First, some parameters are entered at the prompt on the screen. They are frequency, magnitude and angle of S11 and S22, plus the effective dielectric constant of PCB material.

The program calculates the guide wavelength on the desired PCB material and the conjugate values of S11 and S22. It then calculates all the possible matching networks using microstripline techniques.

There are four types of circuits to be calculated: parallel capacitance for the input network, parallel inductance for the input network, parallel capacitance for the output network, and parallel inductance for the output network. All outputs are viewable on a single 640 x 200 dot screen display.

This program is meant as a quick reference program and not for designing finalized circuitry. Therefore, it will not handle S12 and S21 data. This means that the effects of S12 and S21 are not reflected in the output data. In the RF and lower microwave frequency region, the outputs are accurate enough for use in prototype design. Additionally, the program cannot calculate forward or backward gain and the stability factor. But this doesn't matter because if I needed that information I would use a commercial CAD program on my PC.

All output data has been verified by a commercial RF CAD program and shows reasonable accuracy. ***RF***

This program is available on disk from the RF Design Software Service. See ad on page 80 for ordering information.

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About the Author

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A Smith Chart-Based Impedance Matching Program

By Neal C. Silence
Microwave Engineering Consultant

The utilization of the Smith Chart to design matching circuits for a known impedance terminating a transmission line has been extensively documented. However, the mechanics of manipulating impedance or admittance data on the Smith Chart can be quite laborious. Particularly if one is using a dispersive transmission line. The use of programmable calculators and personnel computers in this process can enable the user of the Smith Chart to be more productive and subject to fewer errors. This RF Design Awards software entry was written for the engineer or technician to simplify the task of designing matching circuits in RF transmission lines.

This program is menu driven and provides both graphical and tabular presentations of the data in impedance or admittance form. Data can be transferred to and from disk files in an EESOF Touchstone format. However, only impedance and admittance data in a Real/Imaginary format is presently supported for this transfer. Both TEM and waveguide transmission lines are handled by this program through the entry of a cutoff frequency. The units of measure that are used within this program are: MHz for frequency, inches for length, ohms for impedance, Siemens for admittance, picofarads for capacitance, and nanohenrys for inductance.

This program was written using Microsoft QuickBASIC in order to take advantage of the many features offered by this relatively inexpensive package. This allows the engineer or technician the opportunity of modifying the program to fit a particular problem with a minimum of effort. For those who do not have or wish to use QuickBASIC, the stand alone executable version of the program can be used. This program will run on an IBM compatible computer, using MS-DOS. The computer should be equipped with an EGA or VGA adapter. The program will work with either a monochrome or color display. The stand alone program is executed by entering the following command from the MS-DOS prompt: ZMATCH [\E \V].

If one of the optional parameters in the brackets is used then the software will be configured as follows:

\E - EGA adapter and color display (640 × 350 resolution).
\V - VGA adapter and color display (640 × 480 resolution).

No parameter will default to an EGA or VGA adapter with a monochrome display (640 × 350 resolution).

If the program is being executed from QuickBasic, then the optional parameters are entered in the "Modify COMMAND$" dialog box that is accessed from the "RUN" menu.

The program starts with the display of an introductory screen which provides the usual information such as: program name and title, version number, etc. Pressing the ENTER key clears this screen and displays the main control menu. A copy of this menu is shown in Figure 1.

Selecting an appropriate number will cause that task to be executed. After completing the task, the program returns to the main menu. Data must be present for tasks 2 thru 8 to function. Data can be entered into the program by reading a data file or using task 9 to generate a fixed load. Most of the various tasks afforded by this menu are described below. The ones that are not described will be found to be self explanatory.

```
***** Impedance Matching Program *****

 0.  Exit Program.
 1.  Read a Data File
 2.  Plot a Smith Chart.
 3.  Change between Impedance and Admittance.
 4.  Change Reference Plane.
 5.  Add a Series or Shunt Element.
 6.  Change Zo.
 7.  List Current Values.
 8.  Save Current Values
 9.  Generate a Fixed Load Impedance
10.  List Files on a Directory.
Which?
```

Figure 1. The main control menu.

```
To add a series or shunt element
Select one of the following:

  1. Series Capacitance.
  2. Series Inductance.
  3. Series Resistance.
  4. Series Short circuited line.
  5. Series Open circuited line.
  6. Series Circuit from data file.
  7. Series Connection of a Series Resonant L-C circuit.
  8. Series Connection of a Parallel Resonant L-C circuit.

 11. Shunt Capacitance.
 12. Shunt Inductance.
 13. Shunt Resistance.
 14. Shunt Short circuited line.
 15. Shunt Open circuited line.
 16. Shunt Circuit from data file.
 17. Shunt Connection of a Series Resonant L-C circuit.
 18. Shunt Connection of a Parallel Resonant L-C circuit.

 20. Undo the last change.

  0. Return to previous menu.

Which?
```

Figure 2. Menu used to add a series or shunt element.

Task #1: Read a Data File

The format of the ASCII data file must be as follows:

! Title (optional)
# MHz (or GHz) Z (or Y) RI R [value] F_{co} [value]
F(1), RE(1), IM(1)
F(2), RE(2), IM(2)
F(i), RE(i), IM(i)

Comments:
MHz or GHz = Format used for frequency data.
Use Z for impedance data, or Y for admittance data.
RI indicates that the impedance or admittance data is supplied in a real and imaginary format (this is the only format accepted by this program).
The value after R is the characteristic impedance of the transmission line.
The value after F_{co} is the cut-off frequency of the transmission line.
F(i) = The frequency of the i'th data point.
RE(i) = The real part of the impedance or admittance.
IM(i) = The imaginary part of the impedance or admittance.
All impedance values are in Ohms, all admittance values are in Siemens, and all frequencies are in MHz or GHz. The full path name should be used when entering a file name (e.g. A:\DATA\ZDATA1.DAT).

Task #2: Plot a Smith Chart.

This task will provide a Smith Chart plot of the data as currently contained in the computer. The first data point is identified by a circle, and the last with a square. All data points are connected with straight lines. No drivers are provided to obtain a hard copy of this plot. However, a hard copy can usually be obtained by using the PRINT SCREEN key (please reference your computer's manuals for further information). Before the plot is made, the operator is prompted to supply an "ID". An ASCII string may be entered to identify the plotted data. This has been found to be helpful in keeping track of changes that have been made. This "ID" is placed in the upper right hand corner of the plot (it is also used as the second title in the data listing of task 7). A copy of a Smith Chart plot of the data generated in Example #2 (described below) is shown in Figure 11.

Task #5: Add a Series or Shunt Element

This task allows the addition of a series or shunt capacitance, inductance, resistance, short circuited line, open circuited line, or an arbitrary impedance/admittance from a data file. Negative values of R, L, or C are allowed so that adjustment or removal of previously entered values may be accomplished. The menu that is used for this task is shown in Figure 2.

After selecting the appropriate number for the desired operation, the operator will be prompted to enter the required data to complete this operation. After completing the selected operation, the program will return to the above menu.

Task #7: List Current Values

The capability of listing the current data values to the display or to the standard MS-DOS printer is provided by this task. A typical listing is shown in Figure 3.

Note: If a % sign appears in front of a number in any of the columns of the listing, this indicates that the number needs more space than has been assigned. Also the maximum VSWR that will be listed by this program has been coded to be 999.0.

Task #9: Generate a Real Fixed Load Impedance

A fixed load impedance with any real part in the range of 3.4×10^{-38} to $3.4 \times 10^{+38}$ can be created with this task. The imaginary part of this load impedance will be set to zero. An example of this task is shown in Figure 4.

Comments

Please note that a full path description must be entered as part of a file name if the file does not reside in the current drive and/or directory. A simple error handler is included in this program. Most of the error messages, such as "File not found" or "Disk Full", are self explanatory. Traps for the most obvious cases of arithmetic errors have been included in the program. If this type of error does occur, examining the data you are using along with the task you are executing will usually identify the problem. The message "ERROR XX No error message available" may occur for run time errors not listed in the error handler. This error may be encountered when the source code has been changed. The error code "XX" may be found on page 392 of the Microsoft QuickBASIC programming manual.

Matching the Output Impedance of a FET

The matching of the output impedance of a FET to a 50 ohm termination will be demonstrated. The S_{22} impedance data that will be used is shown in Figure 5. The objective will be to obtain a match at a frequency of 300 MHz using a simple L-C network as shown in Figure 6. One can readily calculate the values of inductance and capacitance needed to provide this match and then use the Smith Chart to see how this calculated result functions as a function of frequency. The calculated values for this FET at 300 MHz are 62.4 nH and 5.04 pF. Task 5 was used to add a shunt inductor and a series capacitor with these respective values, and the result is shown in Figures 7 and 9. The Smith Chart can also be used to determine the L and C values. The first step, as shown in Figure 8, is to obtain the admittance Y1 from the FET output impedance Z1. The next step is to add an inductive susceptance such that the resulting admittance Y2 can be inverted to an impedance Z2 that falls on the unity constant resistance circle of the chart. The addition of an appropriate value of capacitive reactance will then provide the desired impedance Z3.

Equations Used

The plotting of data and some of the procedures used by this program are based on the complex reflection coefficient. Since impedance or admittance is sometimes a more convenient data format to work with, a set of equations is needed to translate between these forms. The following set of equations are the ones that are used by this program.

SAMPLE DATA
TEST PLOT

REF = 0.000 inches. Zo = 50.0 Ohms
Fco = 0.0 MHz

Frequency	-- Reflection Coefficient --				-- Impedance --	
	AMP	Phase	Return Loss	VSWR	R	X
[MHz]	-	[Deg]	[dB]	--	[Ohms]	[Ohms]
1000.00	0.825	-157.2	1.7	10.40	5.00	-10.00
1025.00	0.678	156.5	3.4	5.21	10.00	10.00
1050.00	0.571	143.8	4.9	3.66	15.00	15.00
1075.00	0.571	79.8	4.9	3.66	30.00	50.00
1100.00	0.620	29.7	4.1	4.27	100.00	100.00
1125.00	0.600	0.0	4.4	4.00	200.00	0.00
1150.00	0.555	-29.9	5.1	3.49	100.00	-80.00
1175.00	0.352	-56.0	9.1	2.09	60.00	-40.00

Figure 3. A typical listing of impedance data.

FET S22 DATA

REF = 0.000 inches. Zo = 50.0 Ohms
Fco = 0.0 MHz.

Frequency	-- Reflection Coefficient --				-- Impedance --	
	AMP	Phase	Return Loss	VSWR	R	X
[MHz]	-	[Deg]	[dB]	--	[Ohms]	[Ohms]
250.00	0.690	-3.6	3.2	5.44	264.60	-44.20
260.00	0.689	-3.8	3.2	5.44	263.80	-45.80
270.00	0.689	-3.9	3.2	5.44	263.10	-47.40
280.00	0.689	-4.1	3.2	5.44	262.30	-49.00
290.00	0.689	-4.2	3.2	5.43	261.60	-50.60
300.00	0.689	-4.4	3.2	5.43	260.80	-52.20
310.00	0.689	-4.5	3.2	5.42	259.60	-53.90
320.00	0.688	-4.7	3.2	5.42	258.40	-55.60
330.00	0.688	-4.9	3.2	5.41	257.20	-57.40
340.00	0.688	-5.1	3.3	5.40	256.00	-59.10
350.00	0.687	-5.3	3.3	5.40	254.80	-60.80

Figure 5. FET output impedance data.

FET S22 DATA
With L-C Matching Network

REF = 0.000 inches. Zo = 50.0 Ohms
Fco = 0.0 MHz.

Frequency	-- Reflection Coefficient --				-- Impedance --	
	AMP	Phase	Return Loss	VSWR	R	X
[MHz]	-	[Deg]	[dB]	--	[Ohms]	[Ohms]
250.00	0.419	-90.5	7.6	2.44	34.87	-35.39
260.00	0.328	-96.7	9.7	1.98	37.68	-27.54
270.00	0.239	-102.6	12.4	1.63	40.59	-20.12
280.00	0.154	-108.0	16.2	1.36	43.60	-13.10
290.00	0.075	-113.3	22.5	1.16	46.70	-6.46
300.00	0.002	-120.2	54.7	1.00	49.91	-0.16
310.00	0.064	57.2	23.8	1.14	53.29	5.79
320.00	0.124	53.3	18.2	1.28	56.77	11.43
330.00	0.177	49.7	15.1	1.43	60.36	16.80
340.00	0.224	46.5	13.0	1.58	64.03	21.87
350.00	0.265	43.5	11.5	1.72	67.80	26.66

Figure 7. Output impedance of FET with L-C matching network.

```
Enter the number of frequency points? 10
Enter the Start, and Step Frequencies[MHz]? 1000,100
Enter Zo[Ohms]? 50
Enter the Cutoff Frequency[MHz]? 0
Enter Load Resistance? 75
Enter Title: Task 9 Example
```

Figure 4. Setting imaginary part of load impedance to zero.

These and other useful equations are may be found on page 72 of Reference 5.

Notation:
Γ = Complex Reflection Coefficient
Ρ = Magnitude of Γ
Θ = Phase angle of Γ (radians)
Z = Complex Impedance R = Real part of Z
X = Imaginary part of Z
Z_o = Characteristic Impedance of the transmission line $Z = R + jX$ $Y = G + jB$ $Y = 1/Z$

The complex reflection coefficient is obtained from the impedance by the following:

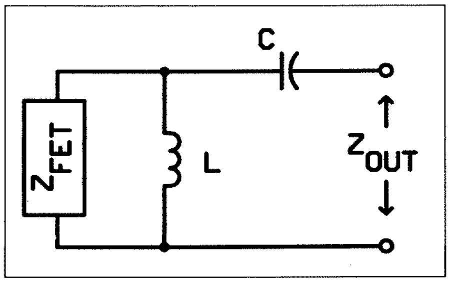

Figure 6. L-C matching network.

$$\Gamma = \varrho\, e^{j\theta} = \frac{Z - Z_o}{Z + Z_o} \tag{1}$$

$$\varrho = \sqrt{\frac{(R-1)^2 + X^2}{(R+1)^2 + X^2}} \tag{2}$$

$$\theta = \mathrm{Tan}^{-1}\left[\frac{2\,X}{(R^2 + X^2 - 1}\right] \tag{3}$$

The complex impedance is obtained from the reflection coefficient as follows:

$$R = \frac{1 - \varrho^2}{1 - 2\varrho \mathrm{Cos}\theta + \varrho^2} \tag{4}$$

$$X = \frac{2\varrho \mathrm{Sin}\theta}{1 - 2\varrho \mathrm{Cos}\theta + \varrho^2} \tag{5}$$

The input reflection coefficient of a transmission line of length 'l' that is terminated by a load whose reflection coefficient is Γ_{load} is given by:

$$\Gamma_{input} = \Gamma_{load} e^{-j2bl} \tag{6}$$

$$b = \frac{2\pi}{c}\sqrt{f^2 - f_{co}^2} \tag{7}$$

where:

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f = frequency of operation
f_{co} = cutoff frequency of the transmission line
c = velocity of propagation

Due to the way impedance and admittance are displayed on the Smith chart used by this program, the real and imaginary parts of admittance may be substituted in the above equations.

This program is available from the RF Design Software Service. See page 80 for ordering information. ***RF***

References

1. P.H. Smith, *Electronic Applications of the Smith Chart*, McGraw-Hill Book Company, New York, 1969. (Extensive references are included at the end of this book)

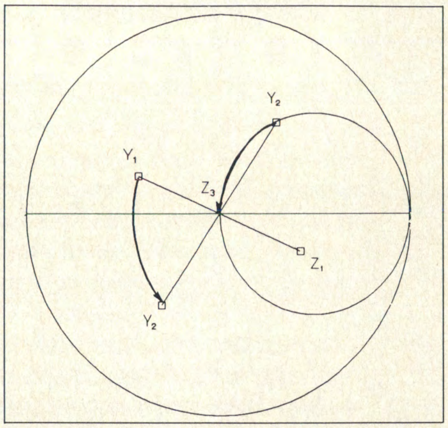

Figure 8. Smith Chart manipulations to obtain a match with a simple L-C network.

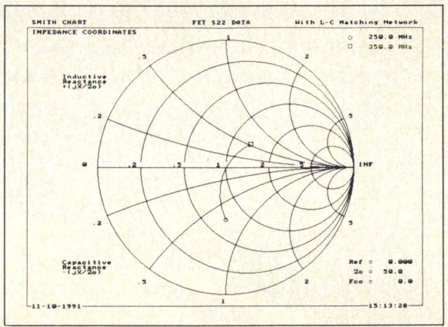

Figure 9. Copy of Smith Chart plot provided by the ZMATCH program.

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4. R.E. Collin, *Foundations for Microwave Engineering*, McGraw- Hill Book Company, New York, 1966, Chapter 5.
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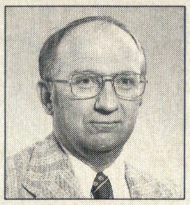
About the Author



Neal Silence is a microwave engineering consultant, specializing in support of the design, integration, and automated test of microwave subsystems. He can be reached at 12671 Squirrel Creek Road, Grass Valley, CA 95945. Tel: (916) 477-6659.

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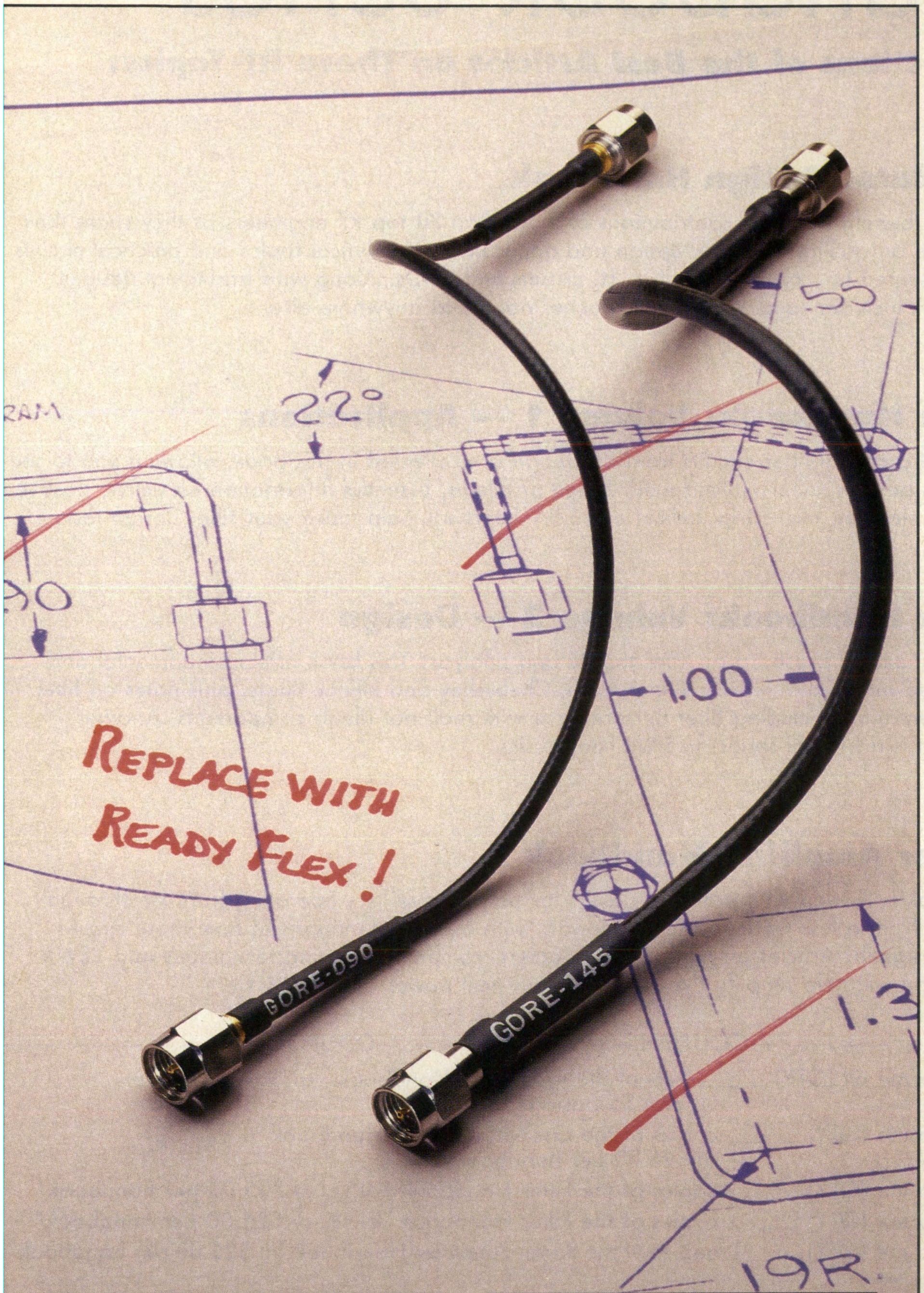

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INFO/CARD 62

A Wide-Range Oscillator

By Wayne Ryder
Data Broadcasting

Building an oscillator with a greater than 3 to 1 tuning range often results in amplitude variations, jumping frequency or ceasing oscillation as it is tuned. Further, many configurations offer only high output impedance. This RF Design Awards Contest entry describes an oscillator that overcomes these problems.

This oscillator has less than 20 percent amplitude change over its 3.5 to 60 MHz tuning range. The tuning rate is 2 to 3 volts for each 5 MHz over most of its range with no abrupt changes of amplitude, wave form or frequency. Output impedance is 50 ohms and the output level is 0.6 volts peak to peak. As shown in Figure 1, the circuit uses an ECL line receiver (MC10116), tuned by an RC network with a MVAM 125 as the variable element (1).

For a greater tuning range, six MVAM 125s can be connected in parallel. The oscillator will then tune from about 0.7 MHz to 19 MHz for a range of 27 to 1.

How It Works

At turn on, if the output is high, the input will be forced high through C1 causing the gate to latch up in the high state. It will remain there until C1 is charged by current through R1 and the input to the ECL line receiver reaches the threshold of the active region. At that time, the output will start to go low which will drive the input low through C1 resulting in positive feedback. This reinforcement will cause the output to change state very rapidly no matter how low the oscillation frequency. Once the output latches in the low state, it will remain until C1 is charged through R1 to the opposite polarity and the line receiver again enters the active region. Again it will rapidly latch to the positive state, thus beginning the cycle over again. The oscillation frequency can be calculated using the time constant R1C1 along with the output voltage swing, 0.8 volts, peak to peak, and the input threshold voltage, approximately 0.2 volts, peak to peak. *RF*

References

1. The MC10116 and the MVAM-125 are manufactured by Motorola.

About the Author

Wayne Ryder is a self-taught RF engineer. He has designed receivers, marine radio transceivers, modulators for cable companies, but has been active in all areas of design work. He can be reached at Data Broadcasting, 115 Hedge Road, Menlo Park, CA 94025. Tel: (415) 571-1800.

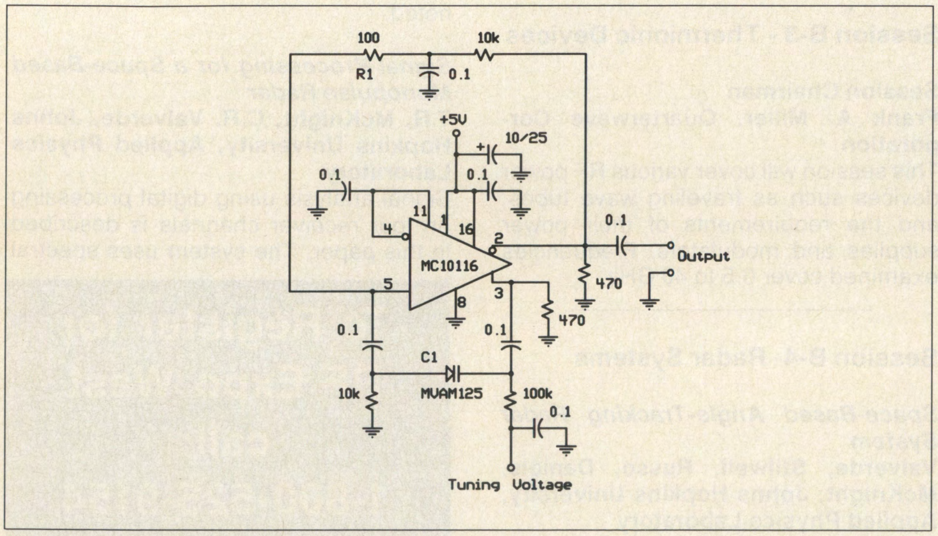


Figure 1. An oscillator with a 17 to 1 tuning range.

RF Expo West Features a Comprehensive Technical Program

Wednesday, March 18 8:30-10:00 a.m.

Session A-1 - Smith Chart Tutorial

The Smith Chart and Its Usage in RF Design
Neal C. Silence, Consultant
The theory behind the Smith chart, its capabilities, and its uses for impedance matching, circuit modeling and design are described in this tutorial presentation. Examples include a waveguide transition, FET output matching, PIN diode modeling and design of a matched PIN diode switch.

Session A-2 - Modern Design Methods

Designing for a Competitive Marketplace
Chairman: Gary Breed, RF Design
This session will include a presentation of the fundamental techniques required for low cost design, design-for-manufacturing, and short design cycles. A panel will discuss modern RF engineering methods and answer questions from the audience.

Wednesday, March 18 1:30-4:30 p.m.

Session B-1 - Low Cost Design

Receiver Mixers and LOs
Jack Lepoff, Hewlett-Packard Co.
A balanced mixer design using a dual Schottky diode in a SOT-23 package is presented. The cost of the entire mixer is under $1.00, and it is useful for DBS/VSAT frequencies.

Low Cost SMD Power Limiters
Raymond W. Waugh, Hewlett-Packard Co.
Many receivers are at risk of having their front ends burned out by high power RF and microwave stray signals. This paper presents practical design techniques for low cost power limiters operating at below 2 GHz. Measured data on prototype limiters is presented.

Practical Variable Gain Amplifiers
Gary Franklin, Hewlett-Packard Co.
This paper shows how PIN attenuator circuits can be combined with fixed gain silicon monolithic amplifiers to form low cost variable gain amplifiers.

Session B-2 - Communications Systems

Single Phase Unidirectional SAW Transversal Filters for Communication Systems
Bob Potter, Tyson Turner, Dr. Peter Wright, RF Monolithics
This paper describes a low loss filter implemented at 70 MHz for GSM applications. Losses as low as 5.5 dB and rejection of 50 dB have been achieved with this low cost technique.

Mixer Intermodulation Performance and Dynamic Range Enhancement
Elwood Brem, Locus, Inc.
A simple, elegant method to predict the location and amplitude of spurious mixer products. A new spur chart will be presented, and data on a new high dynamic range mixer will be illustrated.

Session B-3 - Thermionic Devices

Session Chairman
Frank A. Miller, Quarterwave Corporation
This session will cover various RF power devices such as traveling wave tubes, and the requirements of their power supplies and modulators. Frequencies examined cover 0.5 to 40 GHz.

Session B-4- Radar Systems

Space-Based Angle-Tracking Radar System
Valverde, Stilwell, Russo, Daniels, McKnight, Johns Hopkins University, Applied Physics Laboratory
This paper describes the S-Band Beacon Receiver radar system, a space-based system for tracking cooperative targets, such as 4-watt beacons at a distance of as much as 8000 km.

RF Electronics Design for Space Flight Applications
A.A. Russo, Johns Hopkins University, Applied Physics Laboratory
The design tradeoffs and criteria for selection of various parts of the beacon receiver are examined in this paper

Spurious Noise Prediction and Reduction in Direct Digital Synthesizers
C.C. DeBoy, C.R. Valverde, A.A. Russo, Johns Hopkins University, Applied Physics Laboratory
This paper examines DDS spurious signal generation resulting from phase and amplitude quantization in the sine ROM and DAC input, plus DAC nonlinearities, including glitches and second and third order intermodulation.

Electrical Performance of a GaAs DDS System for Space Applications
A.A. Russo, Johns Hopkins University, Applied Physics Laboratory
The design of a DDS system providing 35 Hz steps up to 240 MHz is summarized, along with test results on several DDS systems tested for this project. DDS-to-DDS repeatability test are also noted.

Signal Processing for a Space-Based Monopulse Radar
T.R. McKnight, C.R. Valverde, Johns Hopkins University, Applied Physics Laboratory
Signal analysis using digital processing on four receiver channels is described in this paper. The system uses spectral

analysis to perform narrow-band phase measurements of target radiation received on four spatially separated antennas.

Thermal Distortion Analysis for Space-Based Monopulse Radar Antenna Array
A.R. Jablon, D.F. Persons, Johns Hopkins University, Applied Physics Laboratory
This paper describes a method for predicting the beam pointing errors caused by thermal distortions. Distortion characteristics and final pointing error data are presented.

Thursday, March 19
8:30-11:30 a.m.

Session C-1 - Power Amplifiers

The Design of RF Modules Intended for Combining High Power
David N. Haupt, Erbtec Engineering
This paper describes device selection, impedance matching networks, bias stabilization techniques and cooling requirements in a high power amplifier system using multiple models.

High Power VHF Power Dividing and Combining Techniques
Hugh Gibbons, Erbtec Engineering
Two power dividing and combining schemes are described for low loss and high reliability, as used in a 15 kW NMR amplifier with 16 1200-watt amplifier modules.

Monitoring, Control and Diagnostics of an RF Amplifier Over a Modem Link
Paul Beaty, Erbtec Engineering
Diagnostic and monitoring software requires ongoing attention in order to provide useful feedback to the product design group. Data gathering via telephone modem is an option for field monitoring of an operating unit.

Session C-2 - RF Components I

RF Components for the 90s
Peter Hoffeins, Siemens Components, Inc.
A review of the current state of the art is presented for silicon RF transistors, RF diodes and GaAs MMIC components. Packaging and quality considerations are presented, along with applications for these devices.

Survey of Components for 900, 2400, and 5700 MHz Spread Spectrum
Al Ward, Avantek
This paper reviews current components available for amplification and control functions in low cost UHF and microwave applications, such as spread spectrum communications authorized under Part 15.

Various Mixer Types Used in Cellular Radios
Phyllis Austin-Lazarus, Hughes Network Systems
Four type of mixers are explored in this paper, covering characteristics beneficial to transmitter requirements in dual-mode cellular radios.

Session C-3 - Filters

Tunable Bandpass Filters for VHF-UHF Receivers as a Preselector Applications
John Horvath, Minaret Radio
This paper presents a tunable bandpass filter design for use as a preselector in VHF/UHF receivers. The prototype circuits are implemented using low cost SMT components.

GaAs Technology Opens New Frontiers in Electronically Tunable Filters
David Peterson, ITT Aerospace/Communications Div.
Narrowband preselector filters for high dynamic range receivers have been implemented using a bank of switched, binary weighted capacitors fabricated on a GaAs monolithic chip. The example filter tunes 30-88 MHz SINGCARS band.

Session C-4 - Antenna Design

Shaped Beam Microstrip Antennas Applied to Personal Communication Networks
John R. Sanford, Huber & Suhner AG
The pattern advantages of a shaped beam antenna over a conventional broadside antenna for PCN applications is discussed in this paper. Propagation models and measured data are presented in comparison to a dipole antenna.

Development of Microstrip Antennas
Marc Yacoubian, Micro Engineering
Design, fabrication, testing and implementation of microstrip patch antennas is the subject of this paper. Practical aspects of design and data on actual antennas is presented.

Analysis of Dielectric Materials in Waveguide and Feedhorn
Tsang-Fu Chang, KAIMEI Electronic Corp.
Theoretical analysis methods of an electromagnetic wave in a dielectric loaded waveguide are reviewed, then analysis of a wave in a dielectrically loaded feedhorn for operation at 10.95 and 12.75 GHz is analyzed.

Thursday, March 19
1:30-4:30 p.m.

Session D-1 - RF Design Awards Contest (Open Session)

Theoretical Basis for a Comprehensive Filter Design Program
Michael Ellis, U.S. Army Corps of Engineers
This 1991 RF Design Awards Software Contest winner is a collection of program modules for the synthesis and

analysis of filters. The author describes the program configuration and the models used for the various computations.

Low Frequency Circulator Uses No Ferrite or Magnet
Charles Wenzel, Wenzel Associates
This paper describes an active RF circulator which has DC to hundreds of MHz performance for isolation and measurement applications. This is the winning design in the 1991 RF Design Awards Circuit Design Contest.

Session D-2 - Modulation and Demodulation

Spread Spectrum Cellular Communications
Steve Morley, QUALCOMM Inc.
An overview of system requirements and performance benchmarks for cellular communications is presented, with explanations of how CDMA spread spectrum communications fits power, noise, and channel protection requirements.

How a QPSK Modulator Vector Error Relates to its Spurious Output
Phyllis Austin-Lazarus, Hughes Network Systems
This paper derives the relationship between the CTIA digital cellular radio modulator error specifications, the actual modulator phase and amplitude errors, and the output spectrum of the modulator.

Direct IF to Digital Conversion Using New Monolithic RF Track and Holds
Allen Hill and Tom Gratzik, Analog Devices
This paper describes the use of monolithic track and hold circuitry in direct IF to baseband conversion using low cost analog to digital converters. Conversion of 10 MHz to 70 MHz is described.

Session D-3 - RF Integrated Circuits

Design of High Density, High Yield MMIC Devices for Low Cost Applications
Henrik Morkner, Avantek, Inc.
This paper describes how to design low cost MMICs for best manufacturing yield by minimizing occupied real estate, and presents several products as examples.

Characterization of a Silicon Bipolar Process for RF ASIC Development
John Brewer, Tektronix Microelectronics
An ASIC process for custom semiconductor manufacturing has been characterized for RF devices fabricated with the process. Design aids and standard cell designs are offered, as well.

GaAs MMIC Control Devices: Theory of Operation & Fabrication

Henrik Morkner, Avantek, Inc.
GaAs FET MMIC control devices such as switches and attenuators are replacing mechanical and PIN diode devices. This paper describes the techniques required for manufacturing these devices, and how those methods differ from amplifier FET processing.

Session D-4 - RF and Computers

Building a Network System for an Engineering/Manufacturing Company: Keeping Your Engineers Happy Without Giving Away the Farm
Ken Wagers, Erbtec Engineering
This paper is a discussion of techniques used to create an easily maintained computer network, designed to allow necessary access for engineering productivity, with appropriate security where required.

Modeling Surface Mount Components
John Hirsekorn, Hewlett-Packard Co.
Development work for the improvement of models of common surface-mount components is reported, including inductors, capacitors and resistors.

Device Modeling and Harmonic Balance Simulation of RF/UHF High Power DMOS Transistor Amplifiers
Steve Hamilton and Octavius Pitzalis, EEsof, Inc.
A new power DMOSFET model for simulation of RF power amplifiers using harmonic balance techniques, and the model parameter extraction methodology are described in this paper. jOmega simulation of two DMOSFET amplifiers are presented as examples.

Friday, March 20
8:30-11:30 a.m.

Session E-1 - Low Noise Amplifier Tutorial

Design of Low Noise RF and Microwave Amplifiers (3-hour session)
Richard Webb, Webb Laboratories
This tutorial begins with a discussion of system noise contributions, followed by noise characteristics of RF and microwave small-signal amplifiers. The theory and practice of noise measurement is also discussed.

Session E-2 - Frequency Synthesis

Dividerless Phase Locked Loops
Dr. Scott Wetenkamp, Pacific Monolithics
This paper describes one technique for eliminating the divider noise in a phase locked loop synthesizer. New radar and telecommunications systems require performance such that divide-by-

Design Considerations for a Low Cost Wideband RF Synthesized Source
Chris Day, Hewlett-Packard Co.
Low cost design techniques for a wideband synthesized signal source are described in this paper. The technique was used in the design of the synthesizer in HP's newest low cost network analyzer.

A Monolithic 12-Bit 100MSPS Digital to Analog Converter For Frequency Synthesis Applications
Chris G. Martinez and John Brewer, Tektronix Microelectronics
The design and characterization of the TKDA30, a 100 MSPS DAC for frequency synthesis applications is described, including dynamic response and spurious performance.

Session E-3 - RF Components II

New Components for GSM, PCN, DECT, GPS, etc. Systems
Peter Hoffeins, Siemens Components, Inc.
Both discrete and MMIC components using both silicon and GaAs are reviewed for their application in 900-2.5 GHz systems. Low voltage performance, device efficiency, packaging and proposed component lineups for GSM and PCN are discussed.

The Photistor: An Innovative, Opto-electronic RF Switch/Attenuator
Curtis W. Barrett, SQ3R Consulting
A novel photoconductor is described which permits operation into the microwave region. Operation is controlled by fiberoptic cable in environments where conducting wires would disturb operation or measurements.

The Design of a Monolithic Hybrid Integrated Circuit RF Package for Space Application
Brent Stoute, Spar Aerospace Limited
A custom RF package is described, designed for use in satellite transponders operating a frequencies up to 15 GHz. Package effects include better than 25 dB return loss as less than 0.1 dB insertion loss.

Session E-4 - RF Systems

Predict Temperature Rise in Reverse Biased PIN Diodes at High Power Levels
Mark C. Leifer, Spectroscopy Imaging Systems Corp.
To ensure reliability, PIN diode switch designers must keep junction temperature low under all conditions. This paper presents a method of predicting high power performance based on low power measurements.

The Engineering Development of Low Cost GaAs Power Module for Cellular Telephones
Mark Easton, Avantek, Inc.
An RF power module suitable for the cellular telephone market is described, with initial performance results of 33.5 dBm power, 26 dB gain, and 55 percent power-added efficiency over 824-849 MHz. A second module with +35.5 dBm power and 13 db gain is also described.

System Design Study for Data Collection Using Geostationary Satellites
Ian Dilworth, University of Essex
System requirements and design of key components of a satellite-based data gathering system is described. The system monitors ocean fish migrations and movements, with tags that are released from fish, float to the surface and transmit to low-orbit satellites.

Attenuator Basics

By Gary A. Breed
Editor

Attenuators are common components in RF systems and test setups, but they are too often taken for granted. This tutorial note reviews the basic principles of resistive attenuators.

The common resistive attenuator is intended to perform a simple function — absorb a specified amount of power while presenting a defined impedance (ideally, purely resistive) at both input and output. Its function is that of a lossy voltage divider, with the relationships of its resistive elements presenting desired impedances at the input and output. While this is not an especially complex function, it represents three variables:

Z_{in} (input impedance)
Z_{out} (output impedance)
A (attenuation, numerical ratio of input to output power)
Note: Attenuation in dB = 10 log A

For resistive attenuators, there are two common topologies, the Tee and Pi, as shown in Figure 1. It can be shown (analysis not included here) that three elements are required to maintain control over all three variables. The particular topology is selected primarily to allow practical values of resistance; both Tee and Pi configurations are equivalent. Typically, low attenuation values will be easier to implement with a Tee network, with higher attenuation more practical using a Pi arrangement.

Computation of the element values for a Tee attenuator follows these formulae (1):

$$Z3 = \frac{2\sqrt{Z_{in} \cdot Z_{out} \cdot A}}{A - 1} \tag{1}$$

$$Z1 = Z_{in}\left(\frac{A+1}{A-1}\right) - Z3 \tag{2}$$

$$Z2 = Z_{out}\left(\frac{A+1}{A-1}\right) - Z3 \tag{3}$$

For Pi attenuators, the formulas are:

$$Z3 = \frac{2}{A-1}\sqrt{\frac{A}{Z_{in} \cdot Z_{out}}} \tag{4}$$

$$Z1 = \frac{1}{Z_{in}}\left(\frac{A+1}{A-1}\right) - Z3 \tag{5}$$

$$Z2 = \frac{1}{Z_{out}}\left(\frac{A+1}{A-1}\right) - Z3 \tag{6}$$

When using these equations, remember that A is a numerical value for attenuation, not a decibel notation.

Why Use Attenuators?

The signal level reduction provided by an attenuator can be used for many purposes, such as:

Matching signal levels. Keeping system components within specified operating ranges is often required. Common usage is to match levels between off-the-shelf components or assemblies which have different design signal levels.

Extending dynamic range. By adding attenuation at high signal levels, the range of instruments or circuits can be extended.

Calibrating signal levels. Comparison of an unknown signal to a known reference level can be done by adding calibrated attenuation to the stronger of the two until the levels are equal, then noting the difference.

Controlling impedances. Another property of resistive attenuators is that they are not directional. Attenuation is the same in both directions. This means that they can be used to improve an impedance match by increasing the return loss. For example, a 6 dB attenuator guarantees a worst-case 12 dB return loss if either port is open or shorted (6 dB loss, 100 percent reflection, another 6 dB loss back to the originating port).

When the additional loss introduced by the attenuator can be tolerated, an attenuator may be a reliable and inexpensive alternative to more complex impedance-controlling networks.

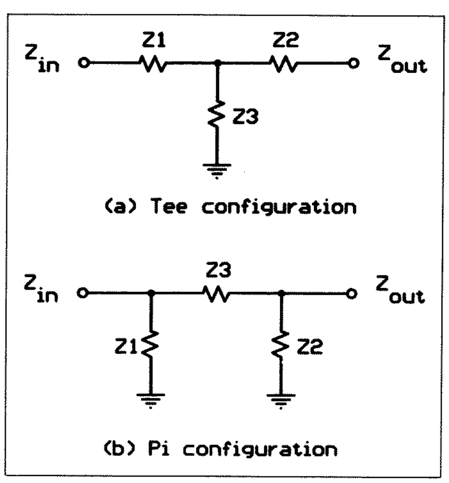


Figure 1. Basic Tee and Pi attenuator configurations.

Other Variations

Attenuators can be made variable to meet specific performance goals. Variable attenuators can have adjustable resistors in the three legs. In cases where precision is not required, a single element (usually Z3) can be made variable, and the attenuation can be varied over a modest range without too much variation in the impedance. For this kind of application, another topology, the bridged-tee is often used, adding an extra element to keep the impedance relatively constant over a wider range of attenuation.

Another common variable attenuator circuit uses PIN diodes, which act as voltage-variable resistors (2). To minimize component count and circuit complexity, these attenuators typically use a bridged-tee or similar configuration. At VHF and higher frequencies, PIN diode attenuators are very common.

It is possible to make variable attenuators using FETs as variable resistive elements (3). This implementation is often used in GaAs MMIC circuits.

Another common configuration is the step attenuator. A number of fixed attenuator sections are switched in and out of the circuit — large or small increments as required for the application.

References

1. D. Fink, D. Christiansen, Editors, *Electronics Engineers' Handbook*, Third Edition, McGraw-Hill, 1989, pp. 12-56, 12-57.
2. J. Lepoff, R. Waugh, "The PIN Diode - A Tutorial," *Proceedings*, RF Expo West 1991, pp. 1-13.
3. E. Oxner, *Designing With Field-Effect Transistors*, Second Edition, McGraw-Hill, 1990, pp. 243-246.

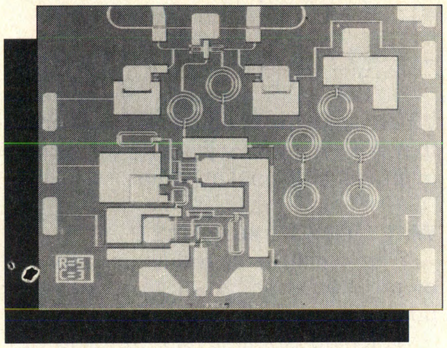
GaAs MMICs Buck the Trend

By Liane G. Pomfret
Associate Editor

In the past several years the GaAs MMIC industry has not exploded the way some analysts predicted, but it has maintained steady growth and is looking forward to even better growth through the nineties. The market focus has shifted from a military to a strongly commercial market, opening up new marketing possibilities.

Despite the excitement of the late 70s and early 80s, GaAs MMIC technology did not take off the way people thought it would. In the beginning, companies were jumping into the market without a great deal of forethought; consequently, the dropout and closure rate was unusually high. Companies that survived the early shake-ups have good people, a strong marketing plan, and the financial backing to keep them from closing or being bought out. There are still some changes occurring, most notably the recent TriQuint, GigaBit, Gazelle merger and Motorola's recent wafer fab startup, but these are indications of a healthy market. According to Louis Pengue a vice president of marketing at TriQuint, "The MMIC industry is the most stable part of the GaAs industry. . . and I think it has outstanding growth potential."

This growth is going to occur in the commercial sector. While military DoD spending is still occurring, it has been cut back and the large houses are now looking for other markets. M/A-COM, ITT Defense, TRW, Raytheon, Hughes and Texas Instruments are all offering high volume, commercial services. For them it is an alternative to shutting down their facilities and a way of justifying the expense of keeping them open. Steve Layton, manager of custom product sales at Pacific Monolithics comments, "I suspect we'll see a downsizing as those OEMs who now operate foundries have difficulty justifying the extremely high cost of operation." Tom Lantzsch, operations manager for Motorola's RF IC Operation describes the philosophy behind their new wafer fab, "We built a manufacturing facility based on a consumer market versus other wafer fabs which were built in the past to service the requirements of the military. The net result is we will be able to produce products with lower costs and in shorter cycle times."



Mobile communications has opened up more areas of new technology than the electronics industry has seen in years. Manufacturers of GaAs MMICs are finding out, like everyone else, that communications of any kind is a lucrative market. GaAs MMICs have found uses in all types of mobile communications: satellite, mobile phones, LANs, DBS, GPS, PCNs, and more. Their small size and low power consumption make them ideal for applications requiring portability or tight space constraints.

In the February 1989 issue of *RF Design*, a quote ran "Three years ago, a 3-inch wafer was priced at approximately $2000. This figure has dropped to a current price of about $100." The report goes on to mention that pricing will fall considerably over the next two years, something that has never happened and manufacturers do not expect to it happen in the foreseeable future.

When GaAs technology was first being developed, the exchange of information among engineers and companies was relatively open. That has since changed as companies have developed more proprietary processes and competition has become more intense. Development is still occurring, but information no longer flows as openly. The pace of new developments has decreased as well. As with any new technology, it has reached a point where improvements are no longer giant steps, but small increments i.e. dropping the price a bit, increasing the manufacturing volume, shrinking the chip, making it faster, decreasing the operating voltage, or offering a new type of circuit. Many of the manufacturers have focused on niche markets instead of aiming for blanket coverage.

In the same report in the February 1989 issue, the market was described as "a somewhat custom market." This focus has changed and now companies tend to focus on application specific products rather than custom products. According to Louis Pengue, "The type of parts we're doing are application specific, and not particularly customer specific. We're doing a general receiver chip for GPS use and we've talked with three or four companies about specifying that part." This type of approach to marketing and designing makes sense as evidenced by the number of GaAs MMIC firms doing it. It targets a larger audience, but offers many of the features found only in custom designs, because it focuses on just one application. One of the most unique factors in the GaAs MMIC industry is the niche orientation of many of the companies. Many of the commercial firms, such as Anadigics, TriQuint, Pacific Monolithics and Vitesse serve different parts of the market. According to Charlie Huang, executive vice president of Anadigics, "I do believe that the business that exists today is of good enough size to keep these companies in business, especially if you look at the fact that we each have our own proprietary markets for our products and don't necessarily compete with one another."

The market and technology are still relatively young, but it has become strong and continues to grow despite a fluctuating economy. The military market no longer wields the influence that it did several years ago, and the commercial communications market has become a driving force. New marketing strategies will make the difference to many GaAs MMIC manufacturers over the next few years. **RF**

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MicroSim Corporation
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Measurement Cards

Hewlett-Packard has introduced a new test card that allows selected HP 8590 series portable spectrum analyzers to perform CT2-CAI RF transmitter measurements. The card can be used for production test of CT2-CAI bases and handsets and for field service of cordless telephone networks. Measurement functions such as carrier power, carrier-off power, adjacent channel power, out-of-band power, spurious emissions, power vs. time, intermodulation and frequency deviation and error are included in the card. Price is $2010.
Hewlett-Packard Company
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Selection Guide and Spice Models

A new IBM-PC compatible disk contains over 1000 current component models, an industry cross reference section, sales office listings, a listing of applications literature, domestic prices, and ordering information for Burr-Brown's high performance, linear product line. New features include more than 70 Spice models for operational amplifiers, difference amplifiers and instrumentation amplifiers.
Burr-Brown Corporation
INFO/CARD #208

Rain Attenuation Program

The NASA Lewis Research Center Satellite Link Attenuation Model (SLAM) is a QuickBASIC computer program for evaluating the impact of rain attenuation on a communication link established between an Earth terminal and a geosynchronous satellite. The user needs to know the longitude of the satellite, the latitude and longitude of the earth terminal, the height of the terminal above sea level, yearly average rainfall at the terminal site and the operating frequency of the link.
Lewis Research Center
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RF literature

High Speed Databook

Elantec, Inc. has released their 1992 databook. The databook contains specifications and applications information as well as macromodels, advanced product information pages, and the handbook from their analog applications seminar.
Elantec, Inc.
INFO/CARD #200

Signal Processing Catalog

Synergy Microwave has released its 1992/93 signal processing product line catalog. The catalog features phase shifters, mixers, power dividers, filters, directional couplers, modulators, attenuators, transformers, and doubles in frequency ranges from DC to 5 GHz.
Synergy Microwave Corporation
INFO/CARD #199

Land Mobile Communications

A 224-page catalog from Decibel Products outlines their products for the land mobile communications market. Catalog 23 includes descriptions of base antennas, cables and connectors, cavities and filters, duplexers, transmitter combiners, receiver multicouplers, monitors, power amplifiers, and fiber optic signal distribution systems. Also included are sections on applications and engineering with systems design information.
Decibel Products
INFO/CARD #198

Wire, Cable and Tubing

Weico's new, 44-page catalog details their lines of cable, wire and tubing for the aerospace, communication, instrumentation and computer industries. Performance, temperature and electrical characteristics; physical descriptions are included.
Weico Wire & Cable Inc.
INFO/CARD #197

IC Selector Guide

Motorola has released a new selector guide for their linear and interface ICs. The guide includes new switching regulator control circuits, RF communications circuits, and surface mount devices in addition to their regular line of standard devices.
Motorola Inc.
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Ceramic Components Bulletin

An 8-page brochure from Duramic covers the properties and potential mechanical and electrical/electronic applications of precision

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"A Quick Microstrip Matching Program" by T. Takamizawa. QMAT program does quick evaluation of simple transmission line and stub matching circuits. (BASIC)
"A Smith Chart-Based Impedance Matching Program" by Neal Silence. Menu-driven program with tabular and Smith chart displays of impedance or admittance, allowing the user to add series or shunt elements to accomplish matching. (QuickBASIC, compiled and source code)

January Programs: RFD-0192
"A VCO Tuning Range Calculation Program" by Marshall Hollimon. VCOCALC program has curves for common varactors, computes and plots tuning range, handles parasitics and allows linearity analysis. (QuickBASIC, compiled and source code)
"A Program for Winding RF Coils" by David Raley. COILTURN program computes number of turns, self-resonance, reactance, and other parameters for single-layer air-wound inductors. (BASIC, compiled and source code)

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alumina parts and components. The brochure describes the alumina's high chemical resistance to acids and alkalies, its dimensional stability at high temperature, dielectric properties, its refractoriness, abrasion resistance and nuclear properties.
Morgan Matroc Inc., Duramic Division
INFO/CARD #195

Circuit Processing Brochure

Polyflon Company has released a new brochure detailing their microwave and RF circuit processing capabilities. The brochure covers their processing techniques, materials, CAD system, quality assurance, testing and product lines.
Crane Polyflon
INFO/CARD #194

Coaxial Connectors Catalog

Solitron's 226-page catalog contains a full range of RF and microwave connectors such as SMA, SSMA, high frequency SSMA, SMB, SMC, TNC, high frequency TNC and TY-N.
Solitron/Microwave
INFO/CARD #193

Blind Mate Connectors

An 18-page catalog from Huber and Suhner describes their new BMA blind mate connecter line. The connectors are used in applications requiring either rigid or floating configurations. The catalog describes adaptors, assembly tools and accessories as well.
Huber + Suhner, Inc.
INFO/CARD #192

Stock Catalog

A catalog of nearly 1,800 stock items are included in a new catalog from Potter & Brumfield. Included are electromechanical relays, solid state relays and time delay relays. Also listed are input/output modules, circuit breakers, sensors, sockets, mounting boards and accessories. A photograph and brief specifications are given for each series.
Potter & Brumfield
INFO/CARD #191

Data Sheets

Data sheets covering Anadigics' series of GaAs MMICs for use in Ku-Band direct broadcast satellite downconvertors for TV home receivers are now available. The data sheets cover the four ICs in the AKD12000 series and describe performance characteristics and applications.
Anadigics, Inc.
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RF design

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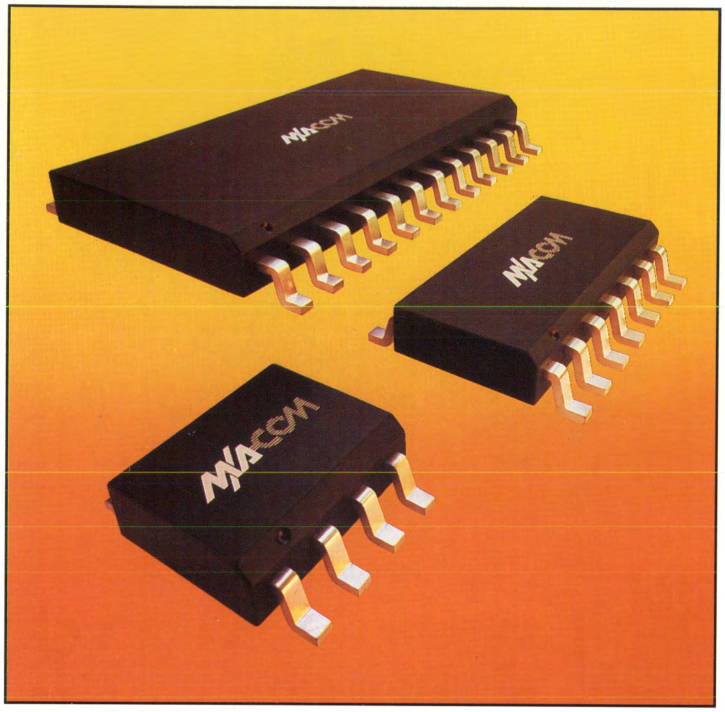

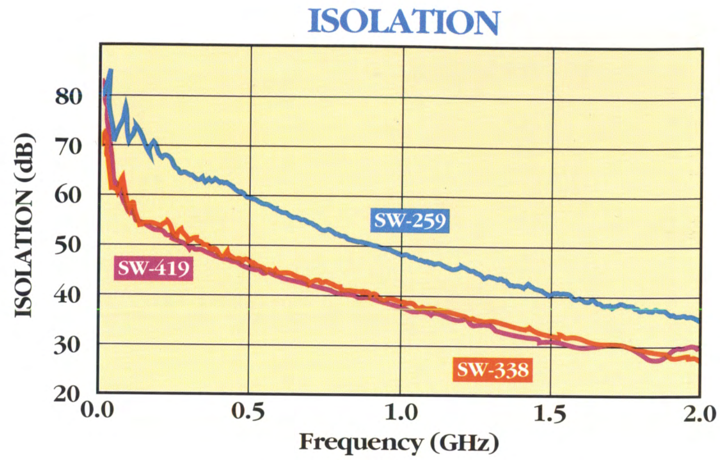

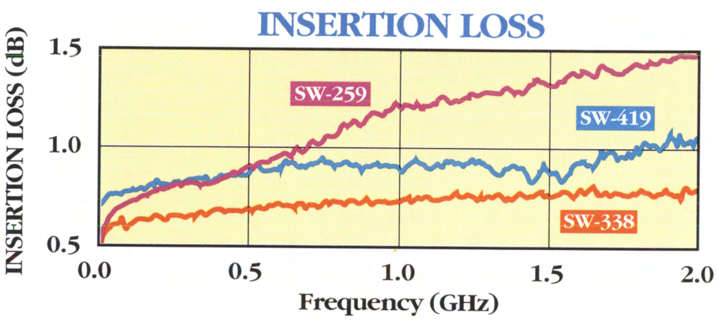

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SW-289	DPDT	0.5	36	1.1:1	46	SOIC, 14 lead
SW-338	SPDT Non-Reflective	0.7	40	1.2:1	46	SOIC, 8 lead
SW-339	SPDT Non-Reflective	0.7	36	1.2:1	46	SOIC, 8 lead
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